CARNEGIE INSTITUTION OF WASHINGTON

YEAR BOOK No. 46

July 1, 1946—June 30, 1947

With Administrative Reports through December 12, 1947

CARNEGIE INSTITUTION OF WASHINGTON
WASHINGTON, D. C.
1947

THI LORD BALTIMORE PRESS, BALTIMORE, MARYLAND

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PRESIDENT AND TRUSTEES

PRESIDENT

VANNEVAR BUSH

BOARD OF TRUSTEES

WALTER S. GIFFORD, *Chairman*
ELIHU ROOT, JR., *Vice-Chairman*
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HOMER L. FERGUSON	HENRY S. MORGAN	JUAN T. TRIPPE
W. CAMERON FORBES	SEELEY G. MUDD	JAMES W. WADSWORTH
WALTER S. GIFFORD	HENNING W. PRENTIS, JR.	FREDERIC C. WALCOTT
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Executive Committee

WALTER S. GIFFORD, *Chairman*

ROBERT WOODS BLISS	GORDON S. RENTSCHLER	FREDERIC C. WALCOTT
VANNEVAR BUSH	ELIHU ROOT, JR.	LEWIS H. WEED
	HENRY R. SHEPLEY	

Finance Committee

LINDSAY BRADFORD, *Chairman*

ALFRED L. LOOMIS	HENRY S. MORGAN	ELIHU ROOT, JR.
	HENNING W. PRENTIS, JR.	

Auditing Committee

FREDERIC A. DELANO, *Chairman*

HOMER L. FERGUSON		JAMES W. WADSWORTH

Nominating Committee

FRANK B. JEWETT, *Chairman*

WALTER S. GIFFORD	HENRY S. MORGAN	HENNING W. PRENTIS, JR.

STANDING COMMITTEES

Committee on Astronomy

SEELEY G. MUDD, *Chairman*

ROSWELL MILLER	ELIHU ROOT, JR.	JUAN T. TRIPPE

Committee on Terrestrial Sciences

FRANK B. JEWETT, *Chairman*

HOMER L. FERGUSON	ERNEST O. LAWRENCE	FREDERIC C. WALCOTT

Committee on Biological Sciences

LEWIS H. WEED, *Chairman*

JAMES F. BELL	ALFRED L. LOOMIS	RICHARD P. STRONG
	HENNING W. PRENTIS, JR.	

Committee on Historical Research

HENRY R. SHEPLEY, *Chairman*

ROBERT WOODS BLISS	RICHARD P. STRONG	JAMES W. WADSWORTH
	CHARLES P. TAFT	

FORMER PRESIDENTS AND TRUSTEES

PRESIDENTS

DANIEL COIT GILMAN, 1902—1904

ROBERT SIMPSON WOODWARD, 1904—1920

JOHN CAMPBELL MERRIAM, *President* 1921—1938; *President Emeritus* 1939—1945

TRUSTEES

ALEXANDER AGASSIZ	1904-05	SETH LOW	1902-16
GEORGE J. BALDWIN	1925-27	WAYNE MACVEAGH	1902-07
THOMAS BARBOUR	1934-46	ANDREW J. MELLON	1924-37
JOHN S. BILLINGS	1902—13	DARIUS O. MILLS	1902-09
ROBERT S. BROOKINGS	1910-29	S. WEIR MITCHELL	1902-14
JOHN L. CADWALADER	1903-14	ANDREW J. MONTAGUE	1907-35
WILLIAM W. CAMPBELL	1929-38	WILLIAM W. MORROW	1902-29
JOHN J. CARTY	1916-32	WILLIAM CHURCH OSBORN	1927-34
WHITEFOORD R. COLE	*1925-34	JAMES PARMELEE	1917-31
CLEVELAND H. DODGE	*1923-23	WM. BARCLAY PARSONS	1907-32
WILLIAM E. DODGE	1902—03	STEWART PATON	1916—42
CHARLES P. FENNER	1914-24	GEORGE W. PEPPER	1914-19
SIMON FLEXNER	1910—14	JOHN J. PERSHING	1930-43
WILLIAM N. FREW	1902-15	HENRY S. PRITCHETT	1906-36
LYMAN J. GAGE	1902-12	ELIHU ROOT	1902-37
CASS GILBERT	1924-34	JULIUS ROSENWALD	1929-31
FREDERICK H. GILLETT	1924-35	MARTIN A. RYERSON	1908-28
DANIEL C. GILMAN	1902-08	THEOBALD SMITH	1914-34
JOHN HAY	1902-05	JOHN C. SPOONER	1902—07
MYRON T. HERRICK	1915-29	WILLIAM BENSON STOREY	1924-39
ABRAM S. HEWITT	1902-03	WILLIAM H. TAFT	1906-15
HENRY L. HIGGINSON	1902-19	WILLIAM S. THAYER	1929-32
ETHAN A. HITCHCOCK	1902—09	CHARLES D. WALCOTT	1902-27
HENRY HITCHCOCK	1902-02	HENRY P. WALCOTT	1910-24
WILLIAM WIRT HOWE	1903-09	WILLIAM H. WELCH	1906-34
CHARLES L. HUTCHINSON	1902-04	ANDREW D. WHITE	1902-03
WALTER A. JESSUP	1938-44	EDWARD D. WHITE	1902-03
SAMUEL P. LANGLEY	1904-06	HENRY WHITE	1913-27
CHARLES A. LINDBERGH	1934~39	GEORGE W. WICKERSHAM	1909-36
WILLIAM LINDSAY	1902-09	ROBERT S. WOODWARD	1905-24
HENRY CABOT LODGE	1914-24	CARROLL D. WRIGHT	1902—08

Besides the names enumerated above, the following were ex-officio members of the Board of Trustees under the original charter, from the date of organization until April 28, 1904: the President of the United States, the President of the Senate, the Speaker of the House of Representatives, the Secretary of the Smithsonian Institution, the President of the National Academy of Sciences.

STAFF OF INVESTIGATORS FOR THE YEAR 1947

ASTRONOMY

MOUNT WILSON OBSERVATORY

813 Santa Barbara Street, Pasadena 4, California

Organized in 1904; George E. Hale, Director 1904-1923, Honorary Director 1923-1936; Walter S. Adams, Director 1924-1945.

IRA S. BOWEN, *Director*
WALTER BAADE
HAROLD D. BABCOCK
HORACE W. BABCOCK
fTHEODORE DUNHAM, JR.
JOSEPH O. HICKOX
EDISON HOGE
EDWIN P. HUBBLE
MILTON L. HUMASON
ALFRED H. JOY
ROBERT B. KING
PAUL W. MERRILL
RUDOLPH MINKOWSKI
SETH B. NICHOLSON
EDISON PETTIT
ROBERT S. RICHARDSON
ROSCOE F. SANFORD
OLIN C. WILSON
RALPH E. WILSON

TERRESTRIAL SCIENCES

GEOPHYSICAL LABORATORY

2801 Upton Street, N.W., Washington 8, D. C.

Organized in 1906, opened in 1907; Arthur L. Day, Director 1909—1936

LEASON H. ADAMS, *Director*
NORMAN L. BOWEN
JOHN S. BURLEW
GORDON L. DAVIS
JOSEPH L. ENGLAND
ROY W. GORANSON
JOSEPH W. GREIG
fEARL INGERSON
FRANK C. KRACEK
GEORGE W. MOREY
fCHARLES S. PIGGOT
fEUGENE POSNJAK
*HOWARD S. ROBERTS
JOHN F. SCHAIRER
fGEORGE TUNELL
O. FRANK TUTTLE
WILLIAM D. URRY
EMANUEL G. ZIES

Visiting Investigators

FELIX CHAYES
MACKENZIE LAWRENCE KEITH
TH. G. SAHAMA

DEPARTMENT OF TERRESTRIAL MAGNETISM

5241 Broad Branch Road, N.W., Washington 15, D. C.

Organized in 1904; Louis A. Bauer, Director 1904-1929; John A. Fleming, Acting Director 1929-1934, Director 1935—1946.

MERLE A. TUVE, *Director*
PHILIP H. ABELSON
LLOYD V. BERKNER
DEAN B. COWIE
SCOTT E. FORBUSH
fALBERT A. GIESECKE, JR.
OLIVER H. GISH
NORMAN P. HEYDENBURG
ELLIS A. JOHNSON
fMARK W. JONES
PAUL G. LEDIG
WILFRED C. PARKINSON
RICHARD B. ROBERTS
WILLIAM J. ROONEY
WALTER E. SCOTT
fSTUART L. SEATON
fKENNETH L. SHERMAN
WILLIAM F. STEINER
HOWARD E. TATEL
OSCAR W. TORRESON
ERNEST H. VESTINE
GEORGE R. WAIT
HARRY W. WELLS

Visiting Investigator

HUGH H. DARBY

* Deceased January 30, 1947.
f Resigned in 1947.

BIOLOGICAL SCIENCES

DIVISION OF PLANT BIOLOGY

Central Laboratory, Stanford, California

Desert Laboratory, opened in 1903, became headquarters of Department of Botanical Research in 1905. Name changed to Laboratory for Plant Physiology in 1923; reorganized in 1928 as Division of Plant Biology, including Ecology. Herman A. Spoehr, Chairman 1927-1930 and 1931-1947.

C. STACY FRENCH, *Director*
JENS C. CLAUSEN
WILLIAM M. HIESEY
DAVID D. KECK
HAROLD W. MILNER
JAMES H. C. SMITH
HERMAN A. SPOEHR
HAROLD H. STRAIN

DEPARTMENT OF EMBRYOLOGY

Wolfe and Madison Streets, Baltimore 5, *Maryland*

Organized in 1914; Franklin P. Mall, Director 1914-1917; George L. Streeter, Director 1918-1940

GEORGE W. CORNER, *Director*
ROBERT K. BURNS
LOUIS B. FLEXNER
CHESTER H. HEUSER, *Curator of the Embryological Collection*
SAMUEL R. M. REYNOLDS
DAVID B. TYLER
†WALTER S. WILDE

DEPARTMENT OF GENETICS

Cold Spring Harbor, Long Island, New Yor

Station for Experimental Evolution, opened in 1904, combined with Eugenics Record Office in 1921 to form Department of Genetics. Charles B. Davenport, Director 1904-1934; Albert F. Blakeslee, Director 1935-I94I-

MILISLAV DEMEREC, *Director*
BERWIND P. KAUFMANN
EDWIN C. MACDOWELL
BARBARA MCCLINTOCK
MARGARET R. MCDONALD

Research Associates
ERNEST W. CASPARI
"(-HOWARD B. NEWCOMBE

HISTORICAL RESEARCH

DIVISION OF HISTORICAL RESEARCH

10 Frisbie Place, Cambridge 38, Massachusetts

Department of Historical Research organized in 1903; Andrew C. McLaughlin, Director 1903-1905; J. Franklin Jameson, Director 1905—1928. In 1930 this Department was incorporated as a section of United States history in a new Division of Historical Research,

ALFRED V. KIDDEE, *Chairman*
†ROBERT S» CHAMBERLAIN
MARGARET W. HARRISON, *Editor*
SYLVANUS G. MORLET
EAEL H. MORRIS
ALEXANDER PQGO
HARRY E. D. POLLOCK
TATIANA PlOSKOURIAKOFF
RALPH L. ROYS
KARL RUPPERT
GEORGE SARTON
ANNA O. SHEPARD
EDWIN M. SHOOK
A. LEDYARD SMITH
ROBERT E. SMITH
GUSTAV STEŌMSVIK
J. ERIC S. THOMPSON
+ALFONSO VILLA R.

† Resigned in 1947.

RESEARCH ASSOCIATES

RESEARCH ASSOCIATES ENGAGED IN POST-RETIREMENT STUDIES

WALTER S. ADAMS, Astronomy
HERBERT E. MERWIN, Geophysics
GEORGE L. STREETER, Embryology

RESEARCH ASSOCIATES CONNECTED WITH OTHER INSTITUTIONS

V. BJERKNES (University o£ Oslo), Meteorology
JOSEPH C. BOYCE (New York University), Physics
RALPH W. CHANEY (University of California), Paleobotany
TH. DOBZHANSKY (Columbia University) Genetics
JOSEPH GILLMAN (Johannesburg Medical School), Embryology
FRANK T. GUCKER, JR. (Indiana University), Chemistry
Ross G. HARRISON (Yale University), Biology
ARTHUR T. HERTIG (Boston Lying-in Hospital), Embryology
E. A. LOWE (The Institute for Advanced Study), Paleography
ROBERT REDFIELD (University of Chicago), Anthropology
FRANCE V. SCHOLES (University of New Mexico), History
JOEL STEBBINS (University of Wisconsin), Astronomy
SOL TAX (University of Chicago), Ethnology

OFFICES OF ADMINISTRATION

Office of the President

VANNEVAR BUSH, *President*
PAUL A. SCHERER, *Executive Officer*
SAMUEL CALLAWAY, *President's Secretary*

Office of Publications and Public Relations

FREDERICK G. FASSETT, JR., *Director*
AILENE J. BAUER, *Assistant to the Director*
DOROTHY R. SWIFT, *Editor*

Adviser on International Scientific Relations

JOHN A. FLEMING

Office of the Bursar

EARLE B. BIESECKER, *Bursar*
J. STANLEY LINGEBACH, *Assistant Bursar*
JAMES F. SULLIVAN, *Assistant to the Bursar*

Investment Office (New Yor\ City)

PARKER MONROE, *Investment Officer*
RICHARD F. F. NICHOLS, *Assistant Investment Officer*

ORGANIZATION, PLAN, AND SCOPE

The Carnegie Institution of Washington was founded by Andrew Carnegie, January 28, 1902, when he gave to a board of trustees an endowment of registered bonds of the par value of ten million dollars. To this fund an addition of two million dollars was made by Mr. Carnegie on December 10, 1907, and a further addition of ten million dollars was made by him on January 19, 1911. Furthermore, the income of a reserve fund of about three million dollars, accumulated in accordance with the founder's specifications in 1911, is now available for general use, and in recent years a total of ten million dollars has been paid by the Carnegie Corporation of New York as increase to the Endowment Fund of the Institution. The Institution was originally organized under the laws of the District of Columbia and incorporated as the *Carnegie Institution,* articles of incorporation having been executed on January 4, 1902. The Institution was reincorporated, however, by an act of the Congress of the United States, approved April 28, 1904, under the title of the *Carnegie Institution of Washington.* (See existing Articles of Incorporation on following pages.)

Organization under the new Articles of Incorporation was effected May 18, 1904, and the Institution was placed under the control of a board of twenty-four trustees, all of whom had been members of the original corporation. The trustees meet annually in December to consider the affairs of the Institution in general, the progress of work already undertaken, and the initiation of new projects, and to make the necessary appropriations for the ensuing year. During the intervals between the meetings of the trustees the affairs of the Institution are conducted by an Executive Committee chosen by and from the Board of Trustees and acting through the President of the Institution as chief executive officer.

The Articles of Incorporation of the Institution declare in general "that the objects of the corporation shall be to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind."

The Institution is essentially an operating organization. It attempts to advance fundamental research in fields not normally covered by the activities of other agencies, and to concentrate its attention upon specific problems, with the idea of shifting attack from time to time to meet the more pressing needs of research as they develop with increase of knowledge. Some of these problems require the collaboration of several investigators, special equipment, and continuous effort. Many close relations exist among activities of the Institution, and a type of organization representing investigations in astronomy, in terrestrial sciences, in biological sciences, and in historical research has been effected. Conference groups on various subjects have played a part in bringing new vision and new methods to bear upon many problems. Constant efforts are made to facilitate interpretation and application of results of research activities o£ the Institution, and an Office of Publications and Public Relations provides means for appropriate publication*

ARTICLES OF INCORPORATION

PUBLIC NO. 260. An Act to incorporate the Carnegie Institution of Washington.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the persons following being persons who are now trustees of the Carnegie Institution, namely, Alexander Agassiz, John S. Billings, John L. Cadwalader, Cleveland H. Dodge, William N. Frew, Lyman J. Gage, Daniel C. Gilman, John Hay, Henry L. Higginson, William Wirt Howe, Charles L. Hutchinson, Samuel P. Langley, William Lindsay, Seth Low, Wayne MacVeagh, Darius O. Mills, S. Weir Mitchell, William W. Morrow, Ethan A. Hitchcock, Elihu Root, John C. Spooner, Andrew D. White, Charles D. Walcott, Carroll D. Wright, their associates and successors duly chosen, are hereby incorporated and declared to be a body corporate by the name of the Carnegie Institution of Washington and by that name shall be known and have perpetual succession, with the powers, limitations, and restrictions herein contained.

SEC. 2. That the objects of the corporation shall be to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind; and in particular—

(a) To conduct, endow, and assist investigation in any department of science, literature, or art, and to this end to cooperate with governments, universities, colleges, technical schools, learned societies, and individuals.

(b) To appoint committees of experts to direct special lines of research.

(c) To publish and distribute documents.

(d) To conduct lectures, hold meetings, and acquire and maintain a library.

(e) To purchase such property, real or personal, and construct such building or buildings as may be necessary to carry on the work of the corporation.

(f) In general, to do and perform all things necessary to promote the objects of the institution, with full power, however, to the trustees hereinafter appointed and their successors from time to time to modify the conditions and regulations under which the work shall be carried on, so as to secure the application of the funds in the manner best adapted to the conditions of the time, provided that the objects of the corporation shall at all times be among the foregoing or kindred thereto.

SEC. 3. That the direction and management of the affairs of the corporation and the control and disposal of its property and funds shall be vested in a board of trustees, twenty-two in number, to be composed of the following individuals: Alexander Agassiz, John S. Billings, John L. Cadwalader, Cleveland H. Dodge, William N. Frew, Lyman J. Gage, Daniel C. Gilman, John Hay, Henry L. Higginson, William Wirt Howe, Charles L. Hutchinson, *Samuel* P. *Langley,* William Lindsay, Seth Low, Wayne MacVeagh, Darius O. Mills, S. Weir Mitchell, William W. Morrow, *Ethan A. Hitchcoc*\> Elihu Root, John C. Spooner, Andrew D. White, Charles D. Walcott, Carroll D. Wright, who shall constitute the first board of trustees. The board of trustees shall have power from time to time to increase its membership to not more than twenty-seven members. Vacancies occasioned by death, resignation, or otherwise shall be filled by the remaining trustees in such manner as the by-laws

shall prescribe; and the persons so elected shall thereupon become trustees and also members of the said corporation. The principal place of business of the said corporation shall be the city of Washington, in the District of Columbia.

SEC. 4. That such board of trustees shall be entitled to take, hold, and administer the securities, funds, and property so transferred by said Andrew Carnegie to the trustees of the Carnegie Institution and such other funds or property as may at any time be given, devised, or bequeathed to them, or to such corporation, for the purposes of the trust; and with full power from time to time to adopt a common seal, to appoint such officers, members of the board of trustees or otherwise, and such employees as may be deemed necessary in carrying on the business of the corporation, at such salaries or with such remuneration as they may deem proper; and with full power to adopt by-laws from time to time and such rules or regulations as may be necessary to secure the safe and convenient transaction of the business of the corporation; and with full power and discretion to deal with and expend the income of the corporation in such manner as in their judgment will best promote the objects herein set forth and in general to have and use all powers and authority necessary to promote such objects and carry out the purposes of the donor. The said trustees shall have further power from time to time to hold as investments the securities hereinafter referred to so transferred by Andrew Carnegie, and any property which has been or may be transferred to them or such corporation by Andrew Carnegie or by any other person, persons, or corporation, and to invest any sums or amounts from time to time in such securities and in such form and manner as are permitted to trustees or to charitable or literary corporations for investment, according to the laws of the States of New York, Pennsylvania, or Massachusetts, or in such securities as are authorized for investment by the said deed of trust *so* executed by Andrew Carnegie, or by any deed of gift or last will and testament to be hereafter made or executed.

SEC. 5. That the said corporation may take and hold any additional donations, grants, devises, or bequests which may be made in further support of the purposes of the said corporation, and may include in the expenses thereof the personal expenses which the trustees may incur in attending meetings or otherwise in carrying out the business of the trust, but the services of the trustees as such shall be gratuitous.

SEC. 6. That as soon as may be possible after the passage of this Act a meeting of the trustees hereinbefore named shall be called by Daniel C. Oilman, John S. Billings, Charles D. Walcott, S. Weir Mitchell, John Hay, Elihu Root, and Carroll D. Wright, or any four of them, at the city of Washington, in the District of Columbia, by notice served in person or by mail addressed to each trustee at his* place of residence; and the said trustees, or a majority thereof, being assembled, shall organize and proceed to adopt by-laws, to elect officers and appoint committees, and generally to organize the said corporation; and said trustees herein named, on behalf of the corporation hereby incorporated, shall thereupon receive, take over, and enter into possession, custody, and management of all property, real or personal, of the corporation heretofore known as the Carnegie Institution, incorporated, as hereinbefore set forth under "An Act to establish a Code of Law for the District of Columbia, January fourth, nineteen hundred and two," and to all its rights, contracts, claims, and property of any kind or nature; and the several officers of such corporation, or

any other person having charge of any of the securities, funds, real or personal, books, or property thereof, shall, on demand, deliver the same to the said trustees appointed by this Act or to the persons appointed by them to receive the same; and the trustees of the existing corporation and the trustees herein named shall and may take such other steps as shall be necessary to carry out the purposes of this Act.

SEC. 7. That the rights of the creditors of the said existing corporation known as the Carnegie Institution shall not in any manner be impaired by the passage of this Act, or the transfer of the property hereinbefore mentioned, nor shall any liability or obligation for the payment of any sums due or to become due, or any claim or demand, in any manner or for any cause existing against the said existing corporation, be released or impaired; but such corporation hereby incorporated is declared to succeed to the obligations and liabilities and to be held liable to pay and discharge all of the debts, liabilities, and contracts of the said corporation so existing to the same effect as if such new corporation had itself incurred the obligation or liability to pay such debt or damages, and no such action or proceeding before any court or tribunal shall be deemed to have abated or been discontinued by reason of the passage of this Act.

SEC. 8. That Congress may from time to time alter, repeal, or modify this Act of incorporation, but no contract or individual right made or acquired shall thereby be divested or impaired.

SEC. 9. That this Act shall take effect immediately.

Approved, April 28, 1904

BY-LAWS OF THE INSTITUTION

Adopted December 13, 1904. Amended December 13, 1910, December 13, 1912, December 10, 1937, December 15, 1939, December 13, 1940, December 18, 1942, and December 12, 1947

ARTICLE I

THE TRUSTEES

1. The Board of Trustees shall consist of twenty-four members, with power to increase its membership to not more than twenty-seven members. The Trustees shall hold office continuously and not for a stated term.

2. In case any Trustee shall fail to attend three successive annual meetings of the Board he shall thereupon cease to be a Trustee.

3. No Trustee shall receive any compensation for his services as such.

4. All vacancies in the Board of Trustees shall be filled by the Trustees by ballot at an annual meeting, but no person shall be declared elected unless he receives the votes of two-thirds of the Trustees present.

ARTICLE II

OFFICERS OF THE BOARD

1. The officers of the Board shall be a Chairman of the Board, a Vice-Chairman, and a Secretary, who shall be elected by the Trustees, from the members of the Board, by ballot to serve for a term of three years. All vacancies shall be filled by the Board for the unexpired term; provided, however, that the Executive Committee shall have power to fill a vacancy in the office of Secretary to serve until the next meeting of the Board of Trustees.

2. The Chairman shall preside at all meetings and shall have the usual powers of a presiding officer.

3. The Vice-Chairman, in the absence or disability of the Chairman, shall perform the duties of the Chairman.

4. The Secretary shall issue notices of meetings of the Board, record its transactions, and conduct that part of the correspondence relating to the Board and to his duties.

ARTICLE III

EXECUTIVE ADMINISTRATION

The President

1. There shall be a President who shall be elected by ballot by, and hold office during the pleasure of, the Board, who shall be the chief executive officer of the Institution. The President, subject to the control of the Board and the Executive Committee, shall have general charge of all matters of administration and supervision of all arrangements for research and other work undertaken by the Institution or with its funds. He shall prepare and submit to the Board of Trustees and to the Executive

Committee plans and suggestions for the work of the Institution, shall conduct its general correspondence and the correspondence with applicants for grants and with the special advisers of the Committee, and shall present his recommendations in each case to the Executive Committee for decision. All proposals and requests for grants shall be referred to the President for consideration and report. He shall have power to remove, appoint, and, within the scope of funds made available by the Trustees, provide for compensation of subordinate employees and to fix the compensation of such employees within the limits of a maximum rate of compensation to be established from time to time by the Executive Committee. He shall be *ex officio* a member of the Executive Committee.

2. He shall be the legal custodian of the seal and of all property of the Institution whose custody is not otherwise provided for. He shall sign and execute on behalf of the corporation all contracts and instruments necessary in authorized administrative and research matters and affix the corporate seal thereto when necessary, and may delegate the performance of such acts and other administrative duties in his absence to the Executive Officer. He may execute all other contracts, deeds, and instruments on behalf of the corporation and affix the seal thereto when expressly authorized by the Board of Trustees or Executive Committee. He may, within the limits of his own authorization, delegate to the Executive Officer authority to act as custodian of and affix the corporate seal. He shall be responsible for the expenditure and disbursement of all funds of the Institution in accordance with the directions of the Board and of the Executive Committee, and shall keep accurate accounts of all receipts and disbursements. Following approval by the Executive Committee he shall transmit to the Board of Trustees before its annual meeting in December a written report of the operations and business of the Institution for the preceding fiscal year with his recommendations for work and appropriations for the succeeding calendar year.

3. He shall attend all meetings of the Board of Trustees.

4. There shall be an officer designated Executive Officer who shall be appointed by and hold office at the pleasure of the President, subject to the approval of the Executive Committee. His duties shall be to assist and act for the President as the latter may duly authorize and direct.

5- The President shall retire from office at the end of the calendar year in which he becomes sixty-five years of age.

ARTICLE IV

MEETINGS

1. The annual meeting of the Board of Trustees shall be held in the City of Washington, in the District of Columbia, on the first Friday following the second Thursday of December in each year unless the date and place of meeting are otherwise ordered by the Executive Committee.

2. Special meetings of the Board may be called by the Executive Committee by notice served personally upon, or mailed to the usual address of, each Trustee twenty days prior to the meeting.

3. Special meetings shall, moreover, be called in the same manner by the Chairman upon the written request of seven members of the Board.

ARTICLE V

COMMITTEES

1. There shall be the following standing Committees, *viz,* an Executive Committee, a Finance Committee, an Auditing Committee, and a Nominating Committee.

2. All vacancies occurring in the Executive Committee, the Finance Committee, the Auditing Committee, and the Nominating Committee shall be filled by the Trustees at the next regular meeting. In case of vacancy in the Finance Committee, the Auditing Committee, or the Nominating Committee, upon request of the remaining members of such committee, the Executive Committee may fill such vacancy by appointment until the next meeting of the Board of Trustees.

3. The terms of all officers and of all members of committees, as provided for herein, shall continue until their successors are elected or appointed.

Executive Committee

4. The Executive Committee shall consist of the Chairman and Secretary of the Board of Trustees and the President of the Institution *ex officio* and, in addition, five trustees to be elected by the Board by ballot for a term of three years, who shall be eligible for re-election. Any member elected to fill a vacancy shall serve for the remainder of his predecessor's term.

5. The Executive Committee shall, when the Board is not in session and has not given specific directions, have general control of the administration of the affairs of the corporation and general supervision of all arrangements for administration, research, and other matters undertaken or promoted by the Institution. It shall also submit to the Board of Trustees a printed or typewritten report of each of its meetings, and at the annual meeting shall submit to the Board a report for publication.

6. The Executive Committee shall have power to authorize the purchase, sale, exchange, or transfer of real estate.

Finance Committee

7. The Finance Committee shall consist of five members to be elected by the Board of Trustees by ballot for a term of three years.

8. The Finance Committee shall have custody of the securities of the corporation and general charge of its investments and invested funds, and shall care for and dispose of the same subject to the directions of the Board of Trustees. It shall have power to authorize the purchase, sale, exchange, or transfer of securities and to delegate this power. It shall consider and recommend to the Board from time to time such measures as in its opinion will promote the financial interests of the Institution, and shall make a report at each meeting of the Board.

Auditing Committee

9. The Auditing Committee shall consist of three members to be elected by the Board of Trustees by ballot for a term of three years.

10. Before each annual meeting of the Board of Trustees, the Auditing Committee shall cause the accounts of the Institution for the preceding fiscal year to be audited by public accountants. The accountants shall report to the Committee, and the Committee shall present said report at the ensuing annual meeting of the Board with such recommendations as the Committee may deem appropriate.

Nominating Committee

11. The Nominating Committee shall consist of the Chairman of the Board of Trustees *ex officio* and, in addition, three trustees to be elected by the Board by ballot for a term of three years, who shall not be eligible for re-election until after the lapse of one year. Any member elected to fill a vacancy shall serve for the remainder of his predecessor's term, provided that of the Nominating Committee first elected after adoption of this By-Law one member shall serve for one year, one member shall serve for two years, and one member shall serve for three years, the Committee to determine the respective terms by lot.

12. Sixty days prior to an annual meeting of the Board the Nominating Committee shall notify the Trustees by mail of the vacancies to be filled in membership of the Board. Each Trustee may submit nominations for such vacancies. Nominations so submitted shall be considered by the Nominating Committee, and ten days prior to the annual meeting the Nominating Committee shall submit to members of the Board by mail a list of the persons so nominated, with its recommendations for filling existing vacancies on the Board and its Standing Committees. No other nominations shall be received by the Board at the annual meeting except with the unanimous consent of the Trustees present.

ARTICLE VI

FINANCIAL ADMINISTRATION

1. No expenditure shall be authorized or made except in pursuance of a previous appropriation by the Board of Trustees, or as provided in Article V, paragraph 8, hereof.

2. The fiscal year of the Institution shall commence on the first day of July in each year.

3. The Executive Committee shall submit to the annual meeting of the Board a full statement of the finances and work of the Institution for the preceding fiscal year and a detailed estimate of the expenditures of the succeeding calendar year.

4. The Board of Trustees, at the annual meeting in each year, shall make general appropriations for the ensuing calendar year; but nothing contained herein shall prevent the Board of Trustees from making special appropriations at any meeting.

5. The Executive Committee shall have general charge and control of all appropriations made by the Board. Following the annual meeting each year, the Executive Committee may make allotment of funds for the period from January 1 to termination of the fiscal year on June 30. It may also make allotment of funds for the period from July *1* to December 31 in advance of July 1. The Committee shall, however, have full authority for allotment of available funds to meet necessary

expenditures by other methods, if desirable, and for transfer of balances to meet special needs. It shall make provision for outstanding obligations and for revertment of unexpended balances at termination of the fiscal year.

6. The securities of the Institution and evidences of property, and funds invested and to be invested, shall be deposited in such safe depository or in the custody of such trust company and under such safeguards as the Finance Committee shall designate, subject to directions of the Board of Trustees. Income of the Institution available for expenditure shall be deposited in such banks or depositories as may from time to time be designated by the Executive Committee.

7. Any trust company entrusted with the custody of securities by the Finance Committee may, by resolution of the Board of Trustees, be made Fiscal Agent of the Institution, upon an agreed compensation, for the transaction of the business coming within the authority of the Finance Committee.

ARTICLE VII

AMENDMENT OF BY-LAWS

1. These by-laws may be amended at any annual or special meeting of the Board of Trustees by a two-thirds vote of the members present, provided written notice of the proposed amendment shall have been served personally upon, or mailed to the usual address of, each member of the Board twenty days prior to the meeting.

ABSTRACT OF MINUTES OF THE FORTY-NINTH MEETING OF THE BOARD OF TRUSTEES

The meeting was held in Washington, D. C, in the Board Room of the Administration Building, on Friday, December 12, 1947. It was called to order at 10:30 A.M. by the Chairman, Mr. Gifford.

Upon roll call, the following Trustees responded: James F. Bell, Robert Woods Bliss, Lindsay Bradford, Frederic A. Delano, Homer L. Ferguson, W. Cameron Forbes, Walter S. Gifford, Frank B. Jewett, Ernest O. Lawrence, Alfred L. Loomis, Roswell Miller, Henry S. Morgan, Seeley G. Mudd, Henning W. Prentis, Jr., Gordon S. Rentschler, Elihu Root, Jr., Henry R. Shepley, Juan T. Trippe, James W. Wadsworth, and Lewis H. Weed. The President of the Institution, Vannevar Bush, was also in attendance.

The minutes of the forty-eighth meeting were approved as printed and submitted to the members of the Board.

Reports of the President, the Executive Committee, the Auditor, the Finance Committee, the Auditing Committee, and of the Chairmen of Divisions, Directors of Departments, and Research Associates of the Institution were presented and considered.

The following appropriations for the year 1948 were authorized:

Pension Fund	$95,000
Administration (including expenses of Investment Office and of insurance)	115,800
Expenses of Office of Publications and Public Relations	34?4°o
Departmental Research Operations	1,113,460
	$1,358,660

Lewis H. Weed was elected as Secretary of the Board for the unexpired term ending in 1948. Frederic C. Walcott was re-elected to continue service as a member of the Executive Committee for the ensuing three-year term, Gordon S. Rentschler was elected a member of the Executive Committee for the ensuing three-year term, and Elihu Root, Jr. was elected a member of the Executive Committee for the unexpired term ending in 1948. Lindsay Bradford and Henning W. Prentis, Jr. were re-elected to continue service as members of the Finance Committee for the ensuing three-year term, and Alfred L. Loomis was elected a member of the Finance Committee for the unexpired term ending in 1948.

Amendments to the By-Laws of the Institution recommended by the Executive Committee were adopted. A Nominating Committee provided by the amended By-Laws was organized with Walter S. Gifford as *ex-officio* member and by the election of Frank B. Jewett for the one-year term, Henry S. Morgan for the two-year term, and Henning W. Prentis, Jr. for the three-year term. Frank B. Jewett was chosen as Chairman of the Nominating Committee.

A plan of unified operation of the Mount Wilson and Palomar Observatories was considered and approved in principle.

The meeting adjourned at 12:10 P.M.

REPORT OF THE EXECUTIVE COMMITTEE

FOR THE YEAR ENDING OCTOBER 31, 1947

To the Trustees of the Carnegie Institution of Washington:

GENTLEMEN: Article V, section 3 of the By-Laws provides that the Executive Committee shall submit, at the annual meeting of the Board of Trustees, a report for publication; and Article VI, section 3 provides that the Executive Committee shall also submit, at the same time, a full statement of the finances and work of the Institution and a detailed estimate of the expenditures for the succeeding year. In accordance with these provisions, the Executive Committee herewith respectfully submits its report for the fiscal year ending October 31, 1947.

During this year the Executive Committee held five meetings, printed reports of which have been mailed to each Trustee and constitute a part of this report.

A statement of activities of the Institution is contained in the report of the President, which has been considered and approved by the Executive Committee, and is submitted herewith.

The detailed estimate of expenditures for the succeeding year contained in the report of the President has been considered by the Executive Committee, which has approved the recommendations of the President in respect thereto and has provisionally approved the budget estimates based thereon and submitted herewith.

The Board of Trustees at its meeting of December 13, 1946 appointed Price, Waterhouse and Company to audit the accounts of the Institution for the fiscal year ending October 31, 1947. The report of the Auditor, including a balance sheet showing assets and liabilities of the Institution on October 31, 1947, is submitted as a part of the report of the Executive Committee.

In addition to the report of the Auditor there is also submitted a financial statement for the fiscal year ending October 31, 1947, showing funds available for expenditure and amounts allotted by the Executive Committee, a customary statement of receipts and disbursements since the organization of the Institution on January 28, 1902, and a schedule of real estate and equipment at original cost. These statements together with the tables in the Auditor's report comprise a full statement of the finances of the Institution.

No vacancy exists in the membership of the Board of Trustees.

Frederic A. Delano resigned as Secretary of the Board of Trustees, and the Executive Committee, at its meeting of March 19, 1947, appointed Lewis H. Weed to fill the vacancy in the office of Secretary until the annual meeting. A vacancy, therefore, exists in the membership of the Executive Committee by reason of the resignation of Mr. Delano as Secretary of the Board of Trustees. Tenure of office of Messrs. Forbes and Walcott as members of the Executive Committee and of Messrs. Bradford and Prentis as members of the Finance Committee will expire at the annual meeting.

WALTER S. GIFFORD, *Chairman*

ROBERT WOODS BLISS — HENRY R. SHEPLEY

VANNEVAR BUSH — FREDERIC C. WALCOTT

November 7, 1947 — W. CAMERON FORBES — LEWIS PL WEED

	Balances unallotted Oct. 31, 1946	Trustees' appropriations Dec. 13, 1946	Transfers and other credits	Total available	Executive Committee allotments	Transfers by Executive Committee	Unallotted balances Oct. 31, 1947
Departmental Research Operations:							
Embryology		$90,754	$24,127.69	$114,881.69	$114,881.69		
Genetics		126,760	42,260.84	169,020.84	169,020.84		
Geophysical Laboratory		192,100	32,599.37	224,699.37	224,699.37		
Historical Research		128,153	20,163.91	148,316.91	148,316.91		
Mount Wilson Observatory		234,609	43,842.24	278,451.24	278,451.24		
Plant Biology		72,950	35,525.45	108,475.45	108,475.45		
Terrestrial Magnetism		259,000	149,841.85	408,841.85	408,841.85		
Research Projects of Limited Tenure	$990.55		35,200.00	36,190.55	35,200.00		$990.55
Publication	21,578.49	33,600	30,467.38	85,645.87	72,939.94		12,705.93
Administration		114,900	21,329.56	136,229.56	136,229.56		
Pension Fund		95,000		95,000.00	95,000.00		
General Contingent Fund	61,539.72		154,142.96	215,682.68	71,820.92	$44,952.80	98,908.96
Carnegie Corporation Emergency Fund	215,338.16		3,162.25	218,500.41	101,400.00	1,200.00	115,900.41
	$299,446.92	$1,347,826	$592,663.50	$2,239,936.42	$1,965,277.77	$46,152.80	$228,505.85

AGGREGATF CASH RKCKIPTS AND DISBURSEMENTS FROM ORGANIZATION, JANUARY 28, 1902, TO OCTOBER 31, 1947

RSCSOTS	
Securities Sold or Redeemed	$116,161,248.21
hit›mne from Securities and Bank Balances	56,466.348,12
Sales of Publications	386,231,44
Colburn Estate {Bequest)	52,015.74
Harhny Fund {Gift)	3,050.00
Htirriman Fund (Sale of Land)	4,043.70
Teeple Estate {Bequest)	10,839.76
Van Gelder Fund {Bequest)	1,278.58
Carnegie Corporation of New York {Endowment Increase and for Specific Purposes)	13,705,381.24
From Other Organizations and Individuals for Specific Purposes	487,246.68
Pension Fund {Refunds)	99,197.05
General Reserve Fund	72,323.38
Insurance Fund {Refunds)	13,076.02
National Defense Revolving Fund {Refunds and Advances)	3,094,724.35
Administration Building Addition Account, Rentals and Refunds	18,021.09
Employees' Salary Deductions for the Purchase of V. S. Bonds	91,363.65
Miscellaneous Refunds and Receipts	1,184,406.03
	$191,850,795.04

DISBURSEMENTS	
Securities Purchased	$131,906,931.58
Accrued Interest on Securities Purchased	764,987.18
Pension Fund	1,856,307.10
General Reserve Fund	30,477.43
Insurance Fund	140,532.24
Harriman Fund	298.49
Harriet H. Mayor Relief Fund	250.00
Harkavy Fund	221.20
Special Emergency Reserve Fund	63,819.41
National Defense Revolving Fund	3,062,974.97
General Contingent Fund	342,289.26
Carnegie Corporation of New York Emergency Fund	101,444.77
Administration Building and Addition:	
Construction and Site (Old Building)	309,915.69
Construction (Addition to Administration Bldg.)	416,206.07
Site (Addition to Administration Building)	68,570.96
Miscellaneous Expenditures*	40,825.37
Departmental Research Operations:	
Departments of Research, Buildings and Equipment	3,740,042.88
Departmental Operations	36,222,416.59
Research Projects of Limited Tenure	5,578,395.61
Publication	3,063,801.00
Administration	3,249,282.86
Employees[1] U. S. Bond Purchases	91,255.65
National Research Council	150,000.00
Miscellaneous	9,008.82
	$191,210,255.13
October 31, 1947, Cash in Banks	640,539.91
	$191,850,795.04

•Includes Equipment $7,206.41, Repairs and Alterations to Old Building $18,599.29.

Administration (October 31, 1947)		
1530 P Street, N.W., Washington 5, D. C.		
Building, site, and equipment		$850,933.59
Division of Plant Biology (September 30, IP47)		
Stanford, California		
Buildings and grounds	$74,125.72	
Laboratory	40,714.05	
Library	22,837.13	
Operating equipment	16,049.27	153,726.17
Department of Embryology (September 30, 1947)		
Wolfe and Madison Streets, Baltimore 5, Maryland		
Library	$7,619.92	
Laboratory	28,115.87	
Administration	8,774.90	44,510.69
Department of Genetics (September 30, 1947)		
Cold Spring Harbor, Long Island, New York		
Buildings, grounds, and field	$299,239.47	
Operating equipment	34,397.95	
Laboratory apparatus	50,452.95	
Library	62,541.66	
Archives	45,488.90	492,120.93
Geophysical Laboratory (September 30, 1947)		
2801 Upton Street, N.W., Washington 8, D. C.		
Buildings, library, and operating appliances	$295,654.22	
Laboratory apparatus	182,475.57	
Shop equipment	21,242.25	499,372.04
Division of Historical Research (September 30, 1947)		
10 Frisbie Place, Cambridge 38, Massachusetts		
Operating equipment	$30,978.58	
Library	16,700.24	47,678.82
Mount Wilson Observatory (September 30, 1947)		
813 Santa Barbara Street, Pasadena 4, California		
Buildings and grounds	$222,549.56	
Shop equipment	52,798.69	
Instruments	675,531.90	
Furniture and operating appliances	162,042.62	
Hooker 100-inch reflector	644,803.88	1,757,726.65
Department of Terrestrial Magnetism (September 30, 1947)		
5241 Broad Branch Road, N.W., Washington 15, D. C.		
Buildings, site, and office	$265,794.67	
Survey equipment	21,891.99	
Instruments, laboratory, and shop equipment	457,220.92	744,907.58
		$4,590,976.47

REPORT OF AUDITORS

To the Board of Trustees
Carnegie Institution of Washington
Washington, D. C.

We have made an examination of the attached balance sheet of Carnegie Institution of Washington (and supporting schedule of securities owned) as of October 31, 1947 and the related statement of operating income and expenditures for the fiscal year then ended. In connection therewith, we obtained confirmations from the custodian, Guaranty Trust Company of New York, as to the securities owned by the Institution and held in safekeeping at October 31, 1947 and from the depositaries as to the cash balances in banks at that date. The interest maturing during the fiscal year on bonds owned was accounted for, and the dividends received during the year on stocks owned were compared with published dividend records. With respect to a period of three months selected by us the recorded cash receipts were traced to deposits shown on the bank statements and paid checks and approved vouchers were inspected in support of the head office disbursements. We did not visit the branch offices of the Institution but we reviewed internal audit reports of the Bursar covering examinations of the branch records during the year and it appeared that the internal audits were satisfactorily conducted. We also inspected certified copies of the minutes of meetings of the Board of Trustees and the Executive Committee with respect to the appropriations and allotments for the year.

The securities are stated at cost, amortized cost, or value at date acquired. In accordance with a recommendation made in February 1940 by the Institution's Finance Committee, premiums on bonds purchased subsequent to January 1, 1940 are being amortized on a straight-line basis to the dates on which the bonds are first callable or payable at par. The amortization of such premiums applicable to the year ended October 31, 1947 amounted to $9,034.62. Real estate and equipment are stated at cost, and books on hand for sale are carried at sales prices. In accordance with accepted practice no provision has been made for depreciation of property owned by the Institution.

In our opinion, with the foregoing explanations, the accompanying balance sheet and related statement of operating income and expenditures present fairly the position of Carnegie Institution of Washington at October 31, 1947 and the financial aspects of its operations for the year ended on that date.

PRICE, WATERHOUSE & Co.

Washington, D. C.
December 3, 1947

BALANCE SHEET OCTOBER 31, 1947

ASSETS

Current Funds:			
General:			
Cash in banks and on hand	$403,491.15		
Advances—departmental research operations	31,116.96		
Accounts receivable — U. S. Government	925.51		
Accounts receivable—other	1,703.59		
Inventory—books	152,640.00		
Deferred charges	18,105.78		
Due from Endowment and Other Special Funds (current cash invested in securities)	350,000.00	$957,982.99	
Restricted:			
Cash in banks		71,175.79	$1,029,158.78
Endowment and Other Special Funds:			
Cash in banks		$201,348.17	
Securities, per schedule attached:			
U. S. Government bonds	$15,935,088.46		
Foreign and International Bank bonds	854,368.71		
Public utility bonds	1,757,496.32		
Communication bonds	204,335.50		
Railroad bonds	274,484.45		
Industrial and miscellaneous bonds	2,852,630.45		
Preferred stocks	4,876,395.62		
Common stocks	13,717,495.41	40,472,294.92	
			40,673,643.09
Plant Funds:			
Invested in real estate and equipment:			
Office of Administration		$ 850,933.59	
Departments of research		3,740,042.88	4,590,976.47
			$46,293,778.34

LIABILITIES

Current Funds:			
General:			
Accounts payable		$ 227.25	
Reserved for encumbrances:			
Departmental research operations	$187,506.76		
Research projects of limited tenure	36,659.00		
Publication	81,946.68		
Administration	11,432.25	317,544.69	
Reserved for publications and invoices		154,153.13	
Reserved for General Contingent Fund		135,939.23	
Reserved for Carnegie Corporation Emergency Fund		194,569.26	
Reserved for special reconversion expenses		15,701.40	
Unexpended and unallocated current income, per statement attached		139,848.03	
		$957,982.99	
Restricted:			
Harriman Fund—income account		71,175.79	$1,029,158.78
Endowment and Other Special Funds:			
Due to Current Funds		$350,000.00	
Capital Funds:			
Endowment Fund	$32,000,000.00		
Capital Reserve Fund	5,592,079.67		
Colburn Fund	103,310.80		
Harriman Fund	304,043.70		
Teeple Fund	10,839.76		
Harkavy Fund	2,828.80		
Van Gelder Fund	1,278.58		
Special Funds:			
Pension Fund	189,965.02		
Harriet H. Mayor Relief Fund	9,750.00		
General Reserve Fund	2,109,546.76	40,323,643.09	
			40,673,643.09
Plant Funds:			
Income invested in plant		$4,409,278.42	
Harriman property (gift)		179,628.05	
Harkavy property (gift)		2,070.00	4,590,976.47
			$46,293,778.34

GENERAL FUND

Statement of Operating Income and Expenditures for the Fiscal Year Ended October 31, 1947

Income:			
Interest and dividends on securities			$1,502, 714.14
Less—Amortization of bond premiums			9,034. 62
			$1,493,679.52
Sales of publications			8,811.43
American Cancer Society—grants			14,360.13
Carnegie Corporation of New York—grant			12,000.00
State of Connecticut—contribution for survey			4,000.00
Dormitory and mess			7,842.11
Chiids Frick Corporation—grant			300.00
Life Insurance Medical Research Fund—grant			1,000.00
Research Corporation—grant			5,000.00
United Fruit Company—Bonampak project			10,000.00
U. S. Public Health Service—grant			2,023.00
A. F. Zahm—gift			5,000.00
Other credits			5,428.89
			$1,569,445.08
Expenditures:			
Pension Fund—annuity and insurance		$106,247.18	
Carnegie Corporation Emergency Fund—grants		13,516.13	
Harriman Fund—commissions		49.43	
General Contingent Fund—miscellaneous expenses		17,463.92	
Departmental research operations:			
Salaries	$856,304.11		
Operating expenses	360,428.22		
Dormitory and mess—salaries	3,048.01		
Dormitory and mess—operating expenses	6,707.36	1,226,487.70	
Research projects of limited tenure:			
Salaries	$13,161.52		
Operating expenses	16,954.13	30,115.65	
General publication:			
Salaries	$ 4,767.84		
Operating expenses	35,011.79	39,779.63	
Office of Publications:			
Salaries	$28,513.59		
Operating expenses	5,698.59	34,212.18	
Administration		140,052.27	
		$1,607,924.09	
Less—Salaries and operating expenses charged to previous appropriations		399,516.52	*1*,208,407.57
Excess of income over expenditures			$361,037.51
Less---Credits to General Reserve Fund and other actounte			221,189.48
Unexpended and unallocated current income			$139,848.03

SCHEDULE OF SECURITIES OWNED OCTOBER 31, 1947

Aggregate par or nominal value	Description	Maturity	Cost, amortized cost, or value at date acquired	Market value	Interest income for year
	UNITED STATES GOVERNMENT BONDS				
$304,000	U. S. of America Treasury 2s	1951-49	$304,000.00	$308,085	$6,080.00
312,000	U. S. of America Treasury 2s	1951-49	312,000.00	316,485	6,240.00
200,000	U, S. of America Treasury 2s	1952-50	200,000.00	202,938	4,000.00
4,500,000	U. S. of America Treasury 2s	1954-52	4,500,000.00	4,599,844	90,000.00
800,000	U. S. of America Treasury 2><s	1955-52	800,000.00	824,750	18,000.00
400,000	U. S. of America Treasury 2><s	1959-56	424,813.00*	417,875	9,000.00
1,250,000	U. S. of America Treasury 2Ks	1962-59	1,280,615.71*	1,264,453	5,533.70
2,170,000	U. S. of America Treasury 2Xs	1962-59	2,171,586.74*	2,195,091	48,825.00
1,239,000	U. S. of America Treasury 2^s	1954-52	1,242,073.01*	1,289,334	30,975.00
350,000	U. S. of America Treasury 2Ks	1967-62	350,000.00	362,578	8,750.00
1,200,000	U. S. of America Treasury 2Ks	1969-64	1,200,000.00	1,231,125	30,000.00
400,000	U. S. of America Treasury 2#s	1969-64	400,000.00	410,250	10,000.00
2,100,000	U. S. of America Treasury 2Ks	1972-67	2,100,000.00	2,132,813	52,500.00
50,000	U.S. of America Savings Defense "G" 2#s	1953	50,000.00	47,900	1,250.00
50,000	U.S. of America Savings Defense "G" 2 *l4s*	1954	50,000.00	47,600	1,250.00
50,000	U. S. of America Savings Defense "G" *2l4s*	1954	50,000.00	47,450	1,250.00
100,000	U. S. of America Savings Defense "G" 2^s	1955	100,000.00	94,700	2,500.00
100,000	U. S. of America Savings Defense "G" 2Ks	1956	100,000.00	94,800	2,500.00
100,000	U.S. of America Savings Defense "G" 2#s	1957	100,000.00	95,600	2,500.00
100,000	U.S. of America Savings Defense "G" 2Ks	1958	100,000.00	96,900	2,500.00
100,000	U. S. of America Savings Defense "G" 2^s	1959	100,000.00	98,800	1,250.00
	Income from bonds sold				21,947.41
$15,875,000	Total U. S. Government		$15,935,088.46	$16,179,371	$356,851.11
	FOREIGN AND INTERNATIONAL BANK BONDS				
$100,000	Australia, Commonwealth of, S. F. *Z%%*	1956	$100,000.00	$95,000	$3,250.00
50,000	Australia, Commonwealth of, S. F. 3#s	1957	48,750.00	47,500	—117.35
90,000	Canadian National Ry. Co., 4Ks Guar.	1951	90,146.36*	96,300	4,050.00
100,000	Canadian National Ry. Co., 4^s Guar.	1957	112,000.00	114,000	4,500.00
57,000	Canadian National Ry. Co., 5s Guar.	1969	61,316.64*	62,130	2,850.00
35,000	Canadian National Ry. Co., 5s Guar.	1970	37,531.12*	38,500	1,750.00
100,000	International Bank for Reconstruction and Development, 2Xs	1957	100,000.00	99,000	—81.27
200,000	Shawinigan Water & Power Co., 1st Mtg, & Coll. Tr. S. F. 3s	1971	208,460.00*	208,460	6,000.00
100,000	City of Toronto Cons. Loan Deb. 5s	1949	96,164.59	105,000	5,000.00
	Income from bonds called or sold				16,723.64
$832,000	Total Foreign and International Bank		$854,368.71	$865,890	$43,925.02

*After deduction for amortization of premiums on bonds purchased subsequent to January 1, 1940.

SCHEDULE OF SECURITIES OWNED OCTOBER 31, 1947—*Continued*

Aggregate par or nominal Value	Description	Maturity	Cost, amortized cost, or value at date acquired	Market value	Interest income for year
	PUBLIC UTILITY BONDS				
$243,000	Columbus & Southern Ohio Klectric Co., 1st Mtg. 3#s	1970	$257,782.92*	$260,010	$7,897.50
37,000	Gun'hound Corpmutum, S. F. Deb. 3».	1959	37,363.39*	37,000	1,110.00
2IHI,000	Minnesota P«wer & Light Co., ls;t Mtg. 3 ?i.s	1975	204,593.90*	204,000	6,250.00
KM),000	Ohio Power Co.. 1st **MtK.** *3)is*	1968	101,500.00	106,000	3,250.00
97,(KM)	OkUhnma Natural Gas Co., lbt Mtg. *2 Jis*	1961	98,202.87*	98,940	2,788.75
200,000	Philadelphia Electric Power Co., 1st **MtR.** *2Ha*	1975	204,939.02*	196,000	1,792.75
2(K),000	Public Service Co. of Indiana, Inc., 1st Mtg. *3 Hs.*	1975	204,604.80*	204,000	6,250.00
US ,000	PiiSPt Sound Power & Light Co.. 1st Mtg. 4^3	1972	129,512.42*	132,500	5,,312,.50
216,000	Tennessee Gas & Transmission Co., 1st Mtg. Pipe Line 2#s	1966	218,997.00*	211,680	5,,940..00
300,ouo	United Gaa Corp., 1st Mtg. & Col]. Tr. 2.3/4s	1967	300,000.00	300,000	893..75
	Income from **bonds** called				15,,613,.03
$1,718,000	Total Public Utility		~~$1,757,496.32~~	~~$1,750,130~~	$57,098.28
	COMMUNICATION BONDS				
1150,000	American Telephone & Telegraph Co., Deb. *2 Ms*	1975	$152,587.50*	$145,500	$1,260.42
52,000	New England Telephone & Telegraph Co., 1st Mtg. 5s	1952	51,748.00	54,600	2,600.00
$202,000	Total Communication		$204,335.50	$200,100	$3,860.42
	RAILROAD BONDS				
1100,000	Chesapeake & Ohio Ry. Co., Gen Mtg. 4#s	1992	$99,464.29	$131,000	$4,500.00
75,000	Chicago & W. Indiana R, R. Co., Cons. 4s	1952	70,357.66	77,250	3,000.00
100,000	Pennsylvania R. R. Co., Cons. Mtg. 4#B	1960	104,662.50	111,000	4,500.00
	Income from bonds sold				25,629.75
$275,000	Total Railroad.		$274,484.45	$319,250	$37,629.75

*After deduction for amortization of premiums on bonds purchased subsequent to January 1, 1940.

SCHEDULE OF SECURITIES OWNED OCTOBER 31, 1947—*Continued*

Aggregate par or nominal value	Description	Maturity	Cost, amortized cost, or value at date acquired	Market value	Interest income for year
	INDUSTRIAL AND MISCELLANEOUS BONDS				
150,000	Devoe & Raynolds Co., Inc. S. F, Deb. 2>6s	1965	$51,250.00	$49,500	$3.75
195,000	Eastern Gas & Fuel Associates, 1st Mtg. & Coll. Tr. 3*tfs*	1965	198,819.59*	191,100	6,825.00
100,000	Food Machinery Corp., S. F. Deb. 2*}4s*	1962	100,500.00	99,000	—49.31
300,000	Goodrich (B. F.) Company, 1st Mtg. 2^s	1965	301,342.12*	294,000	8,250.00
148,000	P. Lorillard Co., Deb. 3s	1963	155,327.79*	152,440	880.82
150,000	National Dairy Products Corp., Deb. 2^s	1970	155,812.50	151,500	—114.58
145,000	Phillips Petroleum Co., S. F. Deb. 2H"s	1964	146,188.12*	146,450	3,987.50
23,000	Pittsburgh Consolidation Coal Co., Deb. 3^s	1965	23,170.65*	23,690	264.63
300,000	Seagram (Joseph E.) & Sons, Inc., Deb. 2^s	1966	298,500.00	288,000	7,500.00
400,000	Shell Union Oil Corp., Deb. 2*}4s*	1971	405,629.09*	384,000	10,000.00
250,000	Socony-Vacuum Oil Co., Deb. 2^s	1976	249,185.00	240,000	6,250.00
200,000	Swift & Co., Deb. *2Hs*	1972	203,697.55*	200,000	1,794.76
250,000	Union Oil Company of California, Deb. 2Ks	1970	259,811.88*	247,500	6,875.00
100,000	United States Rubber Co., Deb. 2^s	1976	100,347.85*	94,000	458.87
200,000	Westinghouse Electric Corporation, Deb. 2#s	1971	203,048.31*	198,000	3,959.38
	Income from bonds called				842.73
$2,811,000	Total Industrial and Miscellaneous		$2,852,630.45	$2,759,180	$57,728.55
$21,713,000	BONDS—Funds Invested		$21,878,403.89	$22,073,921	$557,093.13

*After deduction for amortization of premiums on bonds purchased subsequent to January 1, 1940.

SCHEDULE OF SECURITIES OWNED OCTOBER 31, 1947—*Continued*

Number of shored	* Description	Cost, amortized cost, or value at date acquired	Market value	Dividends for year
	PREFERRED STOCKS			
1,000	Anchor Hocking Glass Corp., |4.00 Cum. Pref	$112,750.00	$107,000	$4,000.00
1,500	Appalachian Electric Power Co., *4ji%* Cum. Pref	159,000.00	165,000	6,750.00
2,000	Armstrong Cork Co., $3.75 Cum. Pref	205,500.00	200,000	7,500.00
1,500	Bethlehem Steel Corp., *7%* Cum. Pref	183,637.50	213,000	10,500.00
1,477	Bristol Myers Co.. 3*4% Cum. Pref	156,300.45	152,131	5,538.76
2,000	Buffalo. Niagara Electric Corp., 3.60% Cum. Pref,.	207,990.00	186,000	7,200.00
500	Case <J. I.) Co., 7% Cum. Pref	62,225.00	72,000	3,465.75
600	Cleveland Electric Illuminating Co., $4.50 Cum. Pref	68,112.25	65,400	2,700.00
1,000	Columbus & Southern Ohio Electric Co., \li% Cum. Pref	115,350.00	106,000	4,250.00
2,000	Consolidated Edison Co. of N. Y., $5,00 Cum. Pref	213,490.00	210,000	2,500.00
1,125	Continental Can Co., Inc., $3.75 Cum. Pref	115,312.50	114,750	4,218.76
145	Corn Products Refining Co., 7% Cum. Pref.....	27,183.25	25,955	1,015.00
900	Deere & Company, *7%* Cum, Pref	25,931.25	29,700	1,260.00
1,125	duPont (K. I.) de Nemours & Co.. $4.50 Cum. Pref	116,125.00	138,375	5,062.52
1,500	Electric Power & Light Corp., $7.00 Cum. 1st Pref	253,700.00	241.500	10,500.00
1,000	Kl Pago Natural Gas Co., 4.10% Cum. Pref..	111,442.21	100,000	4,100.00
2,000	General Food:! Corp., $3.50 Cum. Pref	201,000.00	198,000	544.60
1,500	General Motors Corp., S5.00 Cum. Pref	187,937.50	187,500	7,500.00
1,000	General Shoe Corporation, $3.50 Cum. Pref.....	102,250.00	91,000	3,500.00
1,300	Goodrich (B. F.) Co., $5.00 Cum. Pref	129,867.50	131,300	6,500.00
700	Goodyear Tire & Rubber Co., $5.00 Cum. Pref..	73,195.00	74,200	3,500.00
1,000	Grant (W. T.) Co.. 3->4% Cum. Pref	100,447.91	98,000	3,750.00
1,500	McKesson & Robbins, Inc., $4.00 Cum. Pref	144,000.00	144,000	6,000.00
1,000	Northern States Power Co., $3.60 Cum. Pref	103,200.00	91,000	3,600.00
695	Ohio Power Co., *A14%* Cum. Pref	76,552.00	77,145	3,127.52
1,500	Pacific Telephone and Telegraph Co., 6% Cum. Pref	235,220.75	223,500	9,000.00
1,000	Panhandle Eastern Pipe Line Co., 4% Cum. Pref	104,166.68	104,000	4,000.00
1,000	Pillsbury Mills. Inc.. $4.00 Cum. Pref	107,722.00	103,000	4,000.00
1,000	Public Service Co. of Oklahoma, 4% Cum. Pref	105,286.00	97,000	4,000.00
2,000	Reynolds (R. J.) Tobacco Co., 3.60% Cum. Pref	199,683.75	196,000	7,200.00
974	Setvel. Inc., $4.50 Cum. Pref	109,696.75	100,322	4,383.00
1,114	Sherwin-Williams Co.. 4% Cum. Pref	122,781.61	122,540	4,456.00
1,400	Standard Oil Co. of Ohio, 3»f% Cum. Pref. "A"	150,743.69	137,200	5,250.00
250	United States Gypsum Co.. 7% Cum. Pref	45,187.50	45,000	1,750.00
3,100	17. S. Steel Corp., 7% Cum. Pref	443,407.57	440,200	21,700.00
	Income from stock* called or sold.			22,132.95
43,405	Total Preferred Stocks.....	$4,876,395.62	$4,787,718	§206,454.86

SCHEDULE OF SECURITIES OWNED OCTOBER 31, 1947—*Continued*

Number of shares	Description	Cost, amortized cost, or value at date acquired	Market value	Dividends for year
	COMMON STOCKS			
500	Abbott Laboratories	$37,743.78	$36,500	
200	Air Reduction Company	11,989.46	5,800	$200.00
2,200	American Can Company	195,589.64	193,600	6,000.00
4,400	American Cyanamid Co	171,180.54	198,000	6,600.00
2,500	American Gas and Electric Company	107,153.93	92,500	5,225.00
2,700	American Telephone & Telegraph Co	399,025.39	421,200	24,300.00
3,700	Armstrong Cork Company	179,509.03	188,700	7,200.00
3,835	Boston Edison Company	174,036.34	164,905	8,640.00
500	Bristol Myers Co	19,611.25	19,500	
2,800	C. I. T. Financial Corporation	141,857.73	128,800	5,600.00
700	Caterpillar Tractor Co	47,333.73	40,600	2,100.00
2,600	Chase National Bank of N. Y..,	92,769.35	93,600	3,960.00
8,200	Chrysler Corporation	371,763.95	516,600	6,150.00
3,000	Cleveland Electric Illuminating Company	131,512.11	120,000	5,000.00
900	Coca-Cola Company	121,233.75	165,600	3,675.00
1,100	Colgate-Palmolive-Peet Company	43,776.74	49,500	5,775.00
2,000	Commercial National Bank and Trust Co. of N. Y	86,522.22	80,000	4,000.00
6,056	Commonwealth Edison Company	187,717.73	169,568	7,778.40
2,000	Consolidated Edison Company of N. Y.,	67,530.37	48,000	3,200.00
1,000	Consolidated Gas Electric Light and Power Company of Baltimore	90,349.75	71,000	3,600.00
4,300	Continental Can Co..	172,761.85	150,500	4,300.00
1,200	Continental Illinois National Bank & Trust Co. of Chicago	105,810.00	100,800	4,800.00
3,308	Continental Insurance Co	131,593.72	162,092	5,616.00
6,000	Continental Oil Co. of Delaware	162,943.08	294,000	13,500.00
5,100	Delaware Power & Light Company	105,714.47	91,800	5,100.00
2,000	Dow Chemical Co	69,236.04	80,000	500.00
2,500	duPont (E, I.) de Nemours & Co.	399,375.61	462,500	20,625.00
11,500	Eastman Kodak Co	385,460.00	506,000	8,050.00
100	Fireman's Fund Insurance Co	8,700 00	8,900	
17	First National Bank of N. Y	25,982]80	21,930	1,360.00
1,594	Food Machinery Corporation.	90,962.22	127,520	3,187.00
11,200	General Electric Co.	434,582.75	403,200	16,720.00
7,000	General Foods Corporation	293,688.31	266,000	13,650.00
8,000	General Motors Corporation	423,115.49	472,000	22,000.00
500	Goodrich (B. F.) Co	27,775.58	28,500	2,500.00
600	Goodyear Tire & Rubber Co	31,329.19	27,600	3,000.00
10,000	Grant (W. T.) Co	181,260.49	290,000	22,500.00
400	Guaranty Trust Co. of N, Y	98,003.91	104,400	4,680.00
8,500	Gulf Oil Corp..	366,532.37	603,500	21,250.00
1,700	Hartford Fire Insurance Co	148,651.06	175,100	4,250.00
8,000	Humble Oil & Refining Co.	239,092.33	560,000	20,000.00
3,175	Insurance Company of North America	224,972.06	288,925	8,625.00
1,400	International Business Machines Corp.	146,992.04	302,400	8,400.00
1,000	International Nickel Company of Canada, Ltd	30,588.46	28,000	1,360.00
2,700	Johns-Manville Corp.	97,904.61	116,100	3,420.00
1,500	Kennecott Copper Corporation	57,944.06	70,500	4,875.00
3.300	Kresge (S. S.) Company	75,867.59	125,400	9,570.00

(Continued on following page)

SCHEDULE OF SECURITIES OWNED OCTOBER 31, 1947—*Continued*

Number of shares	Description	Cost, amortized cost, or value at date acquired	Market value	Dividends for year
	COMMON STOCKS—*Continued*			
2,100	Liggett & Myers Tobacco Co.	$189,977.30	$186,900	$8,925.00
800	Liquid Carbonic Corporation	21,032.21	16,800	800.00
320	Mellon National Bank and Trust Company	67,193.07	92,800	2,880.00
1,600	Men*k& Co., Inr.	65,303.57	75,200	3,680.00
2,700	Minneapolis-Honeywell Regulator Co.	123,415.63	159,300	6,480.00
6,600	Monsanto Chemical Co.	211,865.19	402,600	13,200.00
6,300	Montgomery Ward & Co.	339,979.26	359,100	18,900.00
5,300	National Cash Register Co.	161,293.63	212,000	10,200.00
1,700	National City Bank of New York	68,487.50	68,000	2,720.00
1,260	National Fire Insurance Co. of Hartford.	72,819.72	56,700	2,520.00
1.800	National Union Fire Insurance Co.	62,056.90	52,200	
10,800	NewlM'rry (J. J.) Co.	143,047.69	313,200	22,680.00
2,300	New Jersey Zinc Co.	147,347.02	138,000	6,900.00
3,600	Owens-Illinois Glass Co.	248,890.37	266,400	10,125.00
2,750	Pacific Gas & Electric Company	121,073.09	101,750	5,125.00
8,400	Penney (J. C.)Co.	267,016.94	369,600	25,200.00
1,000	People.": Gas Light and Coke Company.	106,350.00	90,000	5,375.00
1,700	Pepsi-Cola Company	40,321.03	47,198	1,530.00
700	Pfizer (Chas.) & Co., Inc.	39,886.75	32,900	1,625.00
3,500	Philadelphia Electric Company.	100,048.39	80,500	4,200.00
6,200	Phillips Petroleum Co.	310,446.88	359,600	13,950.00
7,400	Pittsburgh Plate Glass Co.	228,162.48	288,600	9,620.00
2,100	Procter & Gamble Co.	117,585.87	149,100	7,875.00
1.000	Reynolds (R. J.) Tobacco Co, "B".	40,726.30	39,000	
1,500	Scott Paper Co.	61,907.05	69,000	2,850.00
16.400	Sears, Roebuck & Co.	374,427.S7	623,200	28,700.00
1.100	Sharp & Dohme, Inc.	15,513.34	25,300	1,100.00
4,900	Sherwin-WHImnw Co.	280,331.13	338,100	13,800.00
2,400	Southern California Edison Company, Ltd.	92,204.24	72,000	3,000.00
5,600	Squibb (E. R.) & Sons.	140,697.14	168,000	5,600.00
2,800	Standard Brands Incorporated.	106,459.15	75,600	5,880.00
8.300	Standard Oil Co. of Indiana.	274,147.21	340,300	15,600.00
5,800	Standard Oil Co. of New Jersey.	330,717.12	446,600	20,764.00
2,600	Texas Company.	121,589.08	148,200	4,800.00
2,700	Timken Roller Bearing Co.	130,378.34	135,000	6,075.00
3,800	Union Carbide & Carbon Corp.	333,875.55	399,000	14,250.00
9,400	United Fruit Company.	266,728.02	526,400	32,900.00
3,500	United States Gypsum Co.	289,316.34	367,500	12,650.00
9,000	Westinghouse Electric Corp.	234,406.87	261,000	9,000.00
3,600	Woolworth (F.W.)Co.	155,423.59	172,800	8,640.00
	Income from stocks sold or exchanged			26,205.75
322,815	Total Common Stocks	§13,717,495.41	$16,797,088	§739,166.15
366,220	COMMON AND PREFERRED STOCKS—Funds Invested	$18,593,891.03	$21,584,806	$945,621.01
	AGGREGATE INVESTMENTS (BONDS AND STOCKS)	$40,472,294.92	$43,658,727	$1,502,714.14*

•Represents total interest and dividend income before deduction of amortization of bond premiums.

NOTE: Net gain from sales and redemptions of securities for the year ended October 31, 1947 aggregated $98,378.71, and that amount has been credited to the Capital Reserve Fund shown in the attached balance sheet.

REPORT OF THE PRESIDENT

OF THE

CARNEGIE INSTITUTION OF WASHINGTON

FOR THE YEAR ENDING OCTOBER 31, 1947

REPORT OF THE PRESIDENT
OF THE
CARNEGIE INSTITUTION OF WASHINGTON

This report to the Trustees of the Carnegie Institution of Washington, presented in accordance with the By-Laws, is made at a time when the Institution, after the lapse of two years since cessation of hostilities, has generally resumed the fundamental studies to which under its charter it is customarily devoted. The interval of two years has seen the termination of the various war researches to which the skills of the Institution's staff and the facilities of its laboratories were directed while the country was at war. It has seen also a close scrutiny of past programs in the departments of the Institution, a restudy of objectives and of means earlier employed in seeking them, and a consequent reformulation of the basic plans by which the scientific work of the Institution is carried on.

Re-examination of objectives and reassessment of procedures are, or should be, a continuing element in the conduct of any research program; they have been such in the operations of the Institution throughout its history. But only rarely indeed do circumstances so shape themselves that the revaluation becomes itself a primary undertaking extending practically throughout the Institution and done with the perspective gained from several years' preoccupation with activities considerably removed from those ordinarily carried on. The end of the war, however, brought such a situation, and thus an unusual opportunity for rigorous evaluation of the several programs of research by which, taken as a whole, the Institution carries out the mandate of its charter, "to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind."

Fundamental review of the range of departmental activity, comparative estimates of the urgency and the likely productiveness of individual projects, and analysis of the cross-linkages of projects and their impact on one another were thus possible. In this review, some studies carried on for a considerable period were found either to have served their purpose or to have reached a point where they should be carried forward by other agencies. Others were judged to have developed to a point demanding that greater emphasis be placed upon them. There were clearly indicated opportunities for the initiation of new specific undertakings as additional or more powerful approaches to the major objectives of certain departments; the requirements involved were carefully scrutinized, the means available for meeting them were reviewed, and the necessity for additional techniques, instrumentation, and staff was clearly defined.

The programs thus prepared are an able plan of action. The Standing Committees of the Trustees have reviewed certain of them; final study of others is in process or prospect. From the programs as a group we may expect added effectiveness in the application of knowledge to the solution of basic problems. Such programs are not regarded as rigid prescriptions beyond the limits of which no effort is to be

expended, however important the occasion, but rather are seen as efforts to limn the unknowns and to educe ways of ultimately filling in the outlines and rendering the picture sharp.

Two general observations of no small significance emerge from consideration of the process of analysis and formulation which has produced these programs: First, we rightly take from it renewed confidence in the central philosophy of the Institution as an organization engaged in the conduct of fundamental scientific investigation; second, we have in it a further example of the effectiveness of the pattern of administrative organization which has been developed.

From its inception, the Institution's philosophy has stressed a truth often too easily ignored in the marshaling of strength for advancement of knowledge. This truth is that research stands or falls by the men who are called upon to do it. In its earliest days, the Institution followed the consistent policy of seeking the exceptional man, wherever he might be, and making available to him facilities and resources to enable him to pursue problems which he discerned and by methods which he devised. In later years, establishing its own research centers for organized effort in major intellectual fields, the Institution has held to the thesis that such centers, however elaborately and efficiently equipped, are insufficient in themselves and are of ultimate value in the search for knowledge only as they are utilized by groups of investigators including leaders of proved skill and acumen and younger men of brilliant promise. They must be men of ingenuity and initiative; and these qualities must be unified and vitalized for effectiveness by breadth of vision and keenness of perception, in short, by a truly philosophical understanding.

The Institution is fortunate in its scientific staff, and never has this been more clearly demonstrated than in the deliberations leading to the formulation of the programs I have mentioned. Here, in free exchange and uninhibited discussion, the knowledge and aspirations of individual investigators were balanced and combined, the impact of programs one upon another was estimated from the point of view of firsthand comprehension, and a task of analysis and comparison was performed by the joint action of colleagues. Thus the cardinal principle—that in fundamental research the finding of the approach is in essence the function of the scientist himself—has been followed, yet through collaboration and interchange the result has been more than a collection of individual projects. It has been a coherent and consistent general plan.

I have placed great emphasis in the foregoing on the creative work of the Institution's scientific staff in this task of analysis and redirection, because that work is the primary motivating force in the whole affair. I do not at all intend to imply, however, that the resulting general program of the Institution's research was created in isolation from the Institution as an entity. Quite the contrary is true, and it is true because of the effectiveness of the administrative structure of the Institution. I should like to speak next of this, and in some detail.

From one point of view, the Institution as a continuing body is the self-perpetuating Board of Trustees who, responsible for the administering of its funds in the public interest, are the arbiters of its long-range policy. From another point of view, the Institution is the staff of scientific investigators who in the laboratory, the library, and the field are engaged in the actual research whence comes the application of

knowledge to the improvement of mankind, and who are served by the administrative and supporting staffs of the Institution in their various capacities. Actually, the Institution is neither of these singly; rather, it is a dynamic whole incorporating both. Its organization is distinctive, partaking on the one hand of the pattern found in corporate enterprises, and on the other of the intimate relationships existing in university faculties. And not simply on rare occasions, but in the day-to-day functioning of the whole, these aspects of its organization are found to be interpenetrating.

The Trustees, charged with the responsibility of exercising the final, long-range judgment in Institution affairs, do more than this. They are in their capacity as trustees concerned naturally in the first instance with the relationship of the programs of the Departments to the resources of the Institution. Theirs is the important function, moreover, of the final review of programs, the study of over-all planning with the ultimate objectives of the Institution in mind. Here sound sense in weighing possibilities and attainments is imperative for the continued effectiveness of the Institution. The broad outlook of the Trustees and their wide range of interests would by themselves assure the desired keenness of judgment. The Trustees can, however, and do, participate both individually and officially with the staff in the consideration of plans and of particular ways of implementing them, even before the stage of final survey and analysis has been reached. This desirable interchange has been of direct helpfulness and value in the deliberations of the past two years. Individual members of the Board of Trustees possessing special knowledge and experience in various disciplines have contributed therefrom in discussion, with beneficial result in the formulation of programs. The Standing Committees of the Board, acting as such, have similarly shared in the engrossing work of planning. Fortunately enough, there has been a minimum of formality in this joint effort, and the soundness of the programs, as well as the spirit of the Institution, has been enhanced by that fact.

The Directors of Departments and Chairmen of Divisions in the Institution occupy posts demanding a rare combination of abilities. The position of the director is marked even more strongly by that duality which I have noted in the functioning of the Trustees. The director can and should be both an investigator and an administrator. As an investigator he joins with his colleagues on a plane of equality in planning a scientific program in which all participate and in which he has his unique part. As the director he administers the program, resolves differences of view, and maintains contact with the President and Trustees. To meet this dual responsibility, he must be a scientific worker of proved ability, and he must possess the qualities of leadership, inspiration, and firmness that evoke the best efforts of colleagues and keep operations moving in the agreed direction. He must likewise have the ability at understanding and guidance for which younger members of the staff will look to him. Thus as an investigator he shares the duty of all scientific men toward rigor, vision, and collaboration. As an administrator, he faces the same duties and needs the same capabilities as does the head of a department in an academic institution and, to some extent, as does the director of research in an independent laboratory.

It is through his over-all grasp of the programs proposed within his group that interrelationships may most readily be as-

certained, comparative values may be judged, and suitable adjustments may be made to produce an integrated result. As investigator, he sees with a scientist's eye the implications of the problems posed and the procedures planned by his colleagues. As administrator he brings the necessary added strength and resiliency to handle problems of operation as they arise, to focus enthusiasm in such a way as to avert waste effort, to keep a weather eye out for economic hazards. It is a unique combination of skills, and it poses severe demands. The internal relationships through the staffs of the Departments and Divisions of the Institution are cordial and unassuming, and the fact that they are so is evidence indeed that this requirement for a rare combination of insight and initiative is well met. From supporting administrative staffs, Directors and Chairmen receive the best of support, and since the spirit of the Institution is on an excellent plane, the ideal of a community of scholars is approached.

I should say a word about the function of the President of an institution such as this. He is in a post where his responsibility essentially is to work with the staff on the one hand and the Trustees on the other to bring together the aspirations of the staff, as expressed in considered programs of research, with the possibilities and resources of the Institution itself. In doing this, he of course works closely with the Directors and Chairmen and, sometimes through them, sometimes directly, with the members of the scientific staff. Here again, as has already been suggested, formality should be and is at a minimum.

The general plan of organization thus roughly summarized had been proved in effectiveness well before the especial demands of these recent years. In these years, however, and especially as the formulation of programs has gone forward since the end of the war, the structure of the Institution has been stringently tested, and has met the test. The result may be summed up in the thought that immediately before us are sure prospects for coherent, consistent, vigorous work in our special fields of endeavor, with high assurance that the contributions of the Institution to the general welfare will be substantial and that they thus will bring to all the organization, Trustees, administration, and staff, the lasting satisfactions to be had only from work well done.

THE INSTITUTION AND FEDERAL SUPPORT

In common with many other research agencies in the country which because of the nature of their regular undertakings could adapt facilities and allocate staff, the Institution during the war years sought to carry its full share of the burden of research on military matters essential for the maintenance of national security and the defense of the American way of life. Much if not most of the work which the Institution thus did was only remotely, if at all, related to the programs of investigation which it had carried on in peacetime. Virtually all of it was done under the restrictions of secrecy necessary in the military operations of a nation at war. Lastly, the great bulk of the undertaking consisted of applied research. For these reasons, the Institution at the end of the war terminated all research for the government as expeditiously as possible; in view of its original purpose, the Institution needed to return to its own programs of fundamental research and its own policy of free dissemination of results. With the end of hostilities, such action became practicable and proper, for the obligation to share the war burden was past, and the laboratories of

the armed services as well as of industry were available to carry on such secret applied military research as the well-being of the country demanded.

The war experience carried salutary effects for the Institution, altogether apart from its natural pride at having shared in the defense of the nation. The war experience was the principal occasion in the Institution's history when it was engaged in undertakings financed otherwise than through its own income from endowment, and the first occasion in its history when for an extended period and under intensive conditions it operated in close relationship with the government. The comprehension thus gained is of marked value in our consideration of the future.

There is a fundamentally important difference in that future—indeed, in the immediate present—for research in this country. This appears because of the entrance of the government into the financial support of basic research. Federal funds are now going on a broad scale to the support of fundamental investigation in many centers throughout the nation. Much of the flow is from the armed services, notably from the Navy. By no means all of the support is from the military, however. The Atomic Energy Commission, for example, is contributing very substantially through the laboratories which are operated for it under contract by groups of universities. The Public Health Service and the Department of Commerce within their fields are other agencies sharing in the support of research. There is a notable difference not only between this situation and the prewar condition, in which government's role was of slight dimensions, but also between this situation and that which existed during the war. Then, federal money supported great programs, but they were principally programs of applied research for the early attainment of a specific objective, and they were principally secret. Now, federal money is supporting fundamental studies, and the restrictions upon dissemination of results are far less exacting. The policy governing federal grants and contracts for fundamental research under these more liberal conditions has thus far been broad and wise.

Since the end of the war it has been the policy of the Institution not to seek broad support of its research from federal funds. There has appeared no reason why this policy should now be altered. Yet there would be no inconsistency between the policy and occasional participation in federally supported programs, or even the acceptance of direct federal support to a minor degree and in special circumstances for research which is complementary to our regular programs. It is therefore proper to examine again whether the Institution should consider participation in the research efforts being sponsored by the government and supported by public funds, and if so, under what conditions. Should it enter the program, it would be joining many other ranking research organizations, for participation is widely spread through the country. Certain considerations in part deriving from the program itself and in part from the individual characteristics of the Institution must be taken into account in appraising the possibility. Participation could be expected to enlarge operations, but should not be regarded as lessening budgetary problems. The agreements under which governmentally supported programs are conducted are, as they should be, so drawn as to cover all costs, including added overhead, but no more. Were the Institution to undertake a research project supported from federal funds, its regular schedule of operations would not and should not be

affected thereby; its total range of activities, however, would be increased. Such expansion in and of itself has little to recommend it to an institution such as ours, for size is not a true objective for us. In so far as expansion might clearly have an invigorating effect on regular programs by increasing possibilities of cross-fertilization and stimulation, though, it may be considered advantageous.

For many universities, which are carrying on a broad range of research projects supported from federal funds under the present arrangement, there may on the contrary clearly be a special and positive advantage in such expansion. Fundamental research is of course pursued in university laboratories for its own sake, but in addition it is essential in the postgraduate training of scientists and engineers. As the universities, particularly at the graduate level, seek to overcome the deficit of fully trained men resulting from shortsighted handling of special manpower during the war, they hence are confronted by a need for the expansion of research. Participation in the federally supported program has enabled them to expand research opportunities as they otherwise would not have been able to do, inasmuch as university income from endowment has definite limits.

The Institution of course wishes to collaborate in broad programs in which many organizations thus participate. Without seeking government support, it may collaborate in undertakings to which its own regularly programmed investigations are related. -If clear opportunity arises, in which firm values can be discerned from extension of collaborative effort by the Institution through the introduction of particular new projects in addition to regular programs, then the Institution may be well advised to enter forthrightly into the governmentally sponsored endeavor. The policies that should govern acceptance of funds .for the enlarging of research programs are clear, whether the funds in question are made available by the government or by other agencies.

In the first place, a research activity undertaken by the Institution as an addition to its regularly programmed investigations and as a result of the availability of financial support specially provided by government or another supporting agency and specially allocated to the project in question must form a clearly defined addition, as nearly as possible an integral operative and administrative unit by itself. If the support terminates, it is essential that the Institution be in a position to bring the activity to a termination and be free thereafter of any remnants of it. This condition cannot effectively be met unless the project is by nature clearly defined. The funds through which it is supported must be used only for temporary additions to the staff, and the overhead expenses added by the presence of the project must be distinguished from regular overhead so clearly that cessation of payment of overhead charges in connection with the project can almost automatically bring about cessation of the charges themselves.

In the second place, though this criterion hardly need be stated, since it is fundamental in the Institution's philosophy, the activity should be in and of itself worth carrying on. There is no benefit in pursuing a remote research simply because funds for it are available, and there is an obligation on investigating agencies to guard against the disbursement of funds, whether their own or those of others, for the pursuit of secondary objectives, however attractive they may be, as they occasionally are. Beyond this requirement that the project be one of substantial worth

in itself, it should also be a natural addition to the Institution's own regular programs. If this requirement is not met, distraction or diversion of interest or effort which might result from the presence of pronouncedly unrelated projects, however worthy in themselves, could reduce in effectiveness the results sought in the disbursement of our own funds.

In the third place, and closely akin to the second standard, is the requirement that the activity undertaken in addition to regular programs be one to which the Institution can genuinely contribute by reason of the skills and operations of the regular staff and the presence of the regular programs. This is another way of saying that there should be a reason why progress in the new activity promises to be more rapid or more fruitful if the Institution rather than some other agency enters upon it. Throughout the range of scientific investigation, whatever the field, there are potential gains to be had from such intangibles as chance conversations between research workers on related problems, or the spirit of emulation which arises when new projects come into an established program, stimulating it to added effort and in turn being stimulated to match the roundedness and stability which it possesses.

In the fourth place, the conditions under which the Institution accepts added funds, federal or other, to extend its programs should be proper. They should in no way infringe upon the independent status of the Institution in the pursuit of its own regularly programmed research and they should be genuinely adapted to the sound prosecution of fundamental investigation of the highest quality. Acceptance of the funds should impose no obligation upon the Institution other than the obligation to expend them wisely, in accordance with its own practices regarding its own funds, and subject to regular and proper accounting. I have said already that the policy governing grants by the national government for fundamental research has thus far been excellent in its vision and wisdom. It is highly important for the well-being of the country that the federal policy should thus continue, but there can be no warranty that it will. Hence two further requirements should be stated, even although at present there is no need for emphasis upon them. These are that contracts into which the Institution enters should not contain clauses likely to produce later embarrassment, and that they should contain termination clauses which would enable the Institution to withdraw whenever the major criteria here outlined ceased to be met.

The general standards of policy with which we have been dealing apply primarily to undertakings of major size. Certain other types of participation which the Institution might assume in research endeavors outside its own regular programs are very simple and require little analysis. For example, there is no reason why the Institution should not accept gifts or loans of apparatus for use in its own research programs, or in added activities, provided there is no undue risk in the responsibility for return of the equipment in acceptable condition. Similarly, should a federal program involving several organizations parallel one of its own programs, the Institution can become a collaborator with others, using its own funds. Should circumstances warrant, and should the major criteria be met, the Institution might subsequently increase its activities in the field in question, accepting support from outside and undertaking projects in addition to its regularly programmed studies.

In the fields of its special competence, the Institution in the past has had, and now has, much opportunity for collaboration of a different sort. This is in an advisory capacity. If a federal department is carrying on a program in fundamental research closely allied with our own programs, a department of the Institution or the Institution itself may appropriately engage in advisory service if requested. The rendering of advice on undertakings closely cognate with our own has a double benefit; not only may it contribute to the undertaking, but also it may be counted on to aid our own thinking and progress. Such advisory service as this is apart from advisory services to governmental agencies and similar organizations by members of the staff as individuals. There is no doubt that scientists generally have an obligation to respond as individuals to calls from their government particularly for advisory services, and the Institution should assist members of its staff to meet such calls, assuming that they are reasonable in extent and character.

RESEARCH ACTIVITIES

This report year is the first one since 1940 during which all the Departments and Divisions of the Institution have been fully engaged in normal programs of investigation. The evaluation of possible undertakings and the consequent formulation of well rounded programs on which careful effort was expended during the year previous have already more than justified themselves through the coherent and vigorous over-all pattern o£ the Institution's research activities this year. The reports of the Departments and Divisions review these in detail; a few results of particular interest will be summarized here.

Implications of possible significance to several subjects of marked importance attach to the continuing investigation of the general magnetic fields of stars which Dr. Horace Babcock is carrying on at the Mount Wilson Observatory, having made his Initial effort last year. Now, for the purpose of discovering stars possessing strong magnetic fields, he has surveyed likely ones down to the sixth magnitude, finding magnetic fields stronger than 1000 gauss in several, and a polar field of some 5500 gauss in *one.* Since these stars are probably in rapid rotation, the discovery of magnetism in them may contribute to knowledge of the relationship between the magnetic and mechanical properties of large rotating masses, to understanding of rotating stellar systems such as our galaxy, and possibly to theories of the cosmogony of planetary systems.

The newly integrated program of research at the Geophysical Laboratory presented last year specific approaches to the general objectives that had been decided on, and during the present report year active advance on these has been made. The development of a new type of pressure apparatus has facilitated the study of equilibrium relations in hydrous mixtures, the magnesia-silica-water system having been under principal investigation. Here it was found that all the more common natural hydrous silicates of magnesia, as well as two anhydrous silicates, can be prepared with only the solid phases and vapor present. The silicates formed in the experiments performed thus far are common in certain varieties of igneous and metarnoxphic rocks; the conditions of their formation in nature may be more clearly understood as knowledge of their range of stability with respect to pressure and temperature is extended. This fresh start on

the wet silicate problem will contribute to increasing that knowledge. Equilibria up to 900° centigrade at pressures up to 15,000 pounds per square inch, and at 800° centigrade and pressures of 30,000 pounds per square inch, have been determined in the new apparatus.

The cosmic-ray program of the Department of Terrestrial Magnetism over the past twelve years has comprised long-continued observations of the intensity of cosmic radiation at various stations throughout the earth. During these, slight variations occasioned by atmospheric changes and decreases of a few per cent occasioned by the increased magnetic moment of the earth following magnetic storms have regularly been observed. A surprising phenomenon, however, was noted at the time of a marked solar flare and radio blackout on July 25, 1946; the occurrence was accompanied by a large *increase* in the intensity of cosmic radiation at all observing points except at the equator. About a day later, a magnetic storm took place, with its usual effects. Dr. Tuve in reporting this event points out that the known change in the earth's magnetic moment due to ionization by ultraviolet light cannot explain it, and that the flare effects cannot readily be assumed to have altered the sun's magnetic moment enough to pass an increased number of cosmic rays. An accelerating action associated with the flare at or near the sun may possibly have produced the additional rays. Two similar occurrences in 1942 were revealed by search of the records.

Indication that the magnetic field of the earth has not changed in strength, to within the accuracy of the measurement, during the past 30,000 years has been obtained through the use of new procedures developed in the Department's investigations during the past year. The faint residual magnetism in the layers of silt deposited by retreating glaciers at the end of the last ice age had been measured before the war, with the object of tracing deviation of the compass direction from true north. The new techniques, in which the silt from single layers is redeposited out of a water bath in a magnetic field, afford a tentative measure of the intensity of the earth's field in that distant period.

The amazing diversity of the form and structure of plant life is among the most striking developments of the evolutionary process. Yet in one, and a vital, respect plant life today has altered only in minute detail from its earliest progenitors; the fundamental process of photosynthesis by which plants manufacture their food appears to have undergone little change in the long course of evolution during which structure, habit of life, and function itself have been modified. Research in the Division of Plant Biology involving extensive study of a wide variety of plants has given basis for this conclusion. The chloroplast pigments that are essential in the photosynthetic apparatus of all plants are found to have changed but little in the evolution not only of the species in major taxonomic groups, but also of the main groups themselves. Thus it is indicated that the photosynthetically active pigments of present-day green algae, for example, are the same as those possessed by their fossil ancestors of several hundred million years ago. The Division's continuing study of the unicellular alga *Chlorella* has given a result which bears interestingly on this conclusion. The chemical composition of the alga varies with the culture conditions selected for its growth, running to 5 per cent of fat under one set of conditions, and to 85 per cent under another. The chlorophyll content of the cells in the first case is high; in the second case, it is low,

only about one one-thousandth of the content of the cells of low fat production. But in both cases, the nature of the chlorophyll pigments is the same.

The grass-breeding program undertaken by the Division of Plant Biology in cooperation with the Soil Conservation Service of the United States Department of Agriculture for the practical purpose of producing a better range grass to augment food supplies has resulted in nearly three hundred interspecific hybrids, some of which show high promise because of their combination of favorable yield, resistance to disease, and continued activity in dry summer weather. The species used in the crossings produce most of their seed asexually and hence breed true. The program took advantage of this fact to help in the quick establishment of desirable hybrids. Unexpectedly, it was found that two-thirds of the hybrids between asexual parents were themselves sexual. There is possibility that these sexually reproducing hybrids between asexual parents may themselves in later generations produce apomictic, or asexual, forms, which might permit breeders to seal up the variability of plants for an asexual period, then release it for a time, and finally seal it up again. Both theoretical and practical purposes could thus be served. It is unusual in scientific endeavors for a project in essentially applied research for an immediate and utilitarian purpose to eventuate in promising prospects for fundamental investigation, as the range-grass program is doing. Generally, the reverse of this process is true.

The aerosol method developed in the Department of Genetics during the past two years for investigations involving the treatment of *Drosophila* with chemical solutions has been employed to test the power of various cancer-producing agents to bring about mutations in genes. A majority of the carcinogens thus tested have been found to be mutagenic; of substances chemically related to the carcinogens but themselves non-cancer-producing, a majority do not produce mutations. The chemical carcinogens studied behave in the same way as do all known nonchemical cancer-producers, such as X-rays and similar radiations, ultraviolet rays, and heat, for all these are also mutagenic. Dr. Demerec points out that the hypothesis that cancer may originate through a gene mutation occurring in a somatic cell suggests the most probable relation between mutagenicity and carcinogenicity.

The study of the genetic structure of natural populations carried on by Dr. Dobzhansky, Research Associate, as part of the program of the Department of Genetics has shown that the proportion of certain types of *Drosophila* in wild populations changes with the season. Varying the temperature in laboratory experiments produces similar changes in the make-up of populations. The fly thus shows substantially the same kind of differentiation into altitudinal races as was found true for certain plants by Drs. Clausen, Keck, and Hiesey of the Division of Plant Biology in their five-year study of *Achillea*, the results of which are in process of publication. The fly undergoes the process of adaptation regularly and cyclically, twice each year, since it is capable, at least at the lower elevations in the California mountains where the study was conducted, of producing several generations annually.

Among the group of associated studies in which Dr. Louis B. Flexner and his associates are utilizing tracer techniques in the Department of Embryology, one employing radioactive sodium and heavy water has given a definite answer to the important questions of the proportion of water in the body, by weight, in newborn

infants, and the distribution of it as between cells and the blood, other body fluids, and extracellular spaces in the tissues. The newborn infant is found to be 74.6 per cent water, and the extracellular water accounts for 43.5 per cent of its body weight. These figures, obtained from living healthy infants, agree very closely with earlier findings obtained by other means, and reinforce evidence that the ratio of water within the cells to extracellular water increases as growth goes on. This group of studies employs tracer materials prepared in the cyclotron of the Department of Terrestrial Magnetism, and members of the scientific staffs of the two Departments are working closely together in the program. Further studies of the permeability of the placenta are being carried on.

Better understanding of the problems of advanced pregnancy and of parturition is sought through the comprehensive study of the physiology of the pregnant uterus and of the fetus which is being carried on by Dr. S. R. M. Reynolds, of the Department of Embryology, in which the physical forces involved as the uterus accommodates to its growing contents are being investigated. Incident to this work has been the development of an instrument to record the contractions of the late pregnant and parturient human uterus, which employs sensitive strain gages applicable to the abdomen and providing a tape record of the uterine contractions.

Work done during the past year has shown that the discovery at Nebaj in the highlands of Guatemala in 1946 was of even greater archaeological significance than had at first been suspected. The thorough investigation possible during the 1947 field season disclosed a number of burials in the mound opened in 1946, and yielded a plaque regarded as the finest single example of Maya jade carving yet brought to light. Some seven or eight centuries are spanned by the works of art recovered from the burials in this single mound. Another valuable aspect of the work of the Division of Historical Research during the year was in the direction of an expedition to Bonampak in Chiapas, where ruins containing well preserved wall paintings of the highest importance had been discovered by Giles G. Healey, explorer and photographer for the United Fruit Company, in co-operation with which the archaeological study was initiated. The frescoes, dating from the eighth century, are lavish in detail.

STAFF

Administrative responsibilities in the Division of Plant Biology were assumed on July 1 by Dr. C. Stacy French, who succeeds Dr. Herman A. Spoehr as Chairman of the Division. Having served as Chairman for fifteen years, Dr. Spoehr will devote full energies to his researches on the products of photosynthesis.

Dr. French, who came to the Institution from the University of Minnesota, where he was associate professor of plant physiology, has made notable contributions to the study of photosynthesis by his investigations of the Hill reaction—the evolution of oxygen from chloroplasts suspended in solution. The apparent similarity of this reaction to the oxygen evolution step in normal photosynthesis in the living plant makes it of great interest. Dr. French is known also for his investigations of cellular respiration and of the photosynthesis of purple bacteria. He has been a research fellow at the California Institute of Technology and an Austin teaching fellow at Harvard University, where he completed doctoral studies in 1934.

Dr. Spoehr in 1910 joined the staff of the Institution's Desert Laboratory, one of the research units which subsequently were linked in the creation of the Division of Plant Biology. Serving as Chairman of this Division for three years beginning in 1927, Dr. Spoehr then spent a year as director for the natural sciences of the Rockefeller Foundation, returning to the chairmanship of the Division in 1932.

Walter M. Gilbert retired from the post of Executive Officer of the Institution on March 1, 1947, after service of more than forty-two years. Thus a central figure in the operational and administrative conduct of the affairs of the Institution through practically its entire history, he was on his retirement the senior member of the professional staff in length of service. He has been succeeded by Paul A. Scherer, a consulting engineer in heat transfer and refrigeration, whose ability as an administrator was demonstrated during his service as chief of the engineering and transition office of the Office of Scientific Research and Development.

Dr. Margaret Reed Lewis, who retired from the Institution's scientific staff in December 1946 after more than thirty years of research in the Department of Embryology, where she made many valuable contributions in cytology, is continuing at the Wistar Institute her studies of immunity and resistance of cancer cells.

After a year's leave of absence during which he rendered notable service as the first Executive Secretary of the Joint Research and Development Board of the War and Navy Departments, Lloyd V. Berkner returned in the fall to his post as Chief of the Section on Exploratory Geophysics of the Atmosphere of the Department of Terrestrial Magnetism.

The achievement award of the American Association of University Women was presented to Dr. Barbara McClintock, of the Department of Genetics, at the Association's biennial convention in Dallas in April. It is pleasing recognition of the value of her research in the cytogenetics of maize, which is contributing to the advance of knowledge of evolution and heredity.

The Viking Fund Prize and medal in archaeology for 1946 were awarded to Dr. Alfred V. Kidder, Chairman of the Division of Historical Research. Presented annually by the Society for American Archaeology, the award is made to the person considered to have made the outstanding contribution to archaeology in the award year.

FINANCES

Though we are in the midst of a period of generally rising costs, careful study of the programs and commitments of the Institution, in which departmental, divisional, and administrative totals together with various special expenses have been analyzed, has served to keep the Institution operating within its income. The leeway between income and necessary expenditures has of course been seriously lessened **both** by low interest rates and by the widespread increase in the cost of living, which affects institutions as it does individuals. The salary and wage scales of the Institution are steadily being brought nearer a level fully comparable with those of other principal research and educational institutions. Though they are lower than the maximum in the foremost group, they remain well up in that group. In the course of adjustment, we have now reacjied the end of the process of closing down matured or auxiliary efforts, so that the program of the Institution is now reduced

to the central core of its regular departments.

The Institution's reserves continue adequate. During the war years, diversion from regular activities made it possible to augment reserves through revertments of about $1,000,000. Reserves were drawn upon moderately for nonrecurring items in the launching of the new research programs formulated after the end of the war.

Establishment of a new method of budgeting, whereby proposals of expenditures are made on the basis of a total figure determined by the Finance Committee as reasonable for budgeting purposes, is an important change in Institution financial procedures. It is expected to be helpful in stabilizing operations at an effective level within funds available, even although the nature of our portfolio presupposes fluctuations on a long-term basis which will need to be cushioned by the use of reserves.

REPORTS OF DEPARTMENTAL ACTIVITIES AND CO-OPERATIVE STUDIES

ASTRONOMY

Mount Wilson Observatory

TERRESTRIAL SCIENCES

Geophysical Laboratory
Department of Terrestrial ^Magnetism
Special Projects *

BIOLOGICAL SCIENCES

Division of Plant Biology
Department of Embryology
Department of Genetics
Special Projects

HISTORICAL RESEARCH

Division of Historical Research

MOUNT WILSON OBSERVATORY

Pasadena, California

IRA S. BOWEN, *Director*

Last year's report recorded the announcement o£ an agreement between the California Institute of Technology and the Carnegie Institution of Washington for the joint operation of the Palomar Mountain Observatory, with its 200-inch telescope, and the Mount Wilson Observatory. This joint operation of the two observatories will become effective on the completion of the 200-inch telescope, which is expected to occur during the coming year, 1947-1948. In the meantime plans are being actively studied to bring about this unification of the scientific programs of the two observatories in the most effective manner and with a minimum of disturbance to the present personnel of the two institutions.

Pending the initiation of the joint operation and the installation of the permanent administration, a Preliminary Joint Management Committee has been appointed to make the necessary plans. This committee consists of the following members: Max Mason, Chairman of the Observatory Council, Richard C. Tolman, Professor of Physical Chemistry and Mathematical Physics, and E. C. Watson, Chairman of the Division of Physics, Astrophysics, Mathematics, and Electrical Engineering, from the California Institute; Walter S. Adams, Research Associate, Edwin P. Hubble, Astronomer, and L S- Bowen, Director, from the Mount Wilson Observatory.

This committee has made preliminary studies and recommendations in regard to the handling of the budget and other financial problems, the merger or correlation of the various service facilities of the two observatories, and the educational program to be set up at the California Institute. These plans envisage the initiation of graduate instruction in astrophysics in the fall of 1948. Attention has also been given to procedures for the most effective use of the greatly increased facilities which will become available with the completion of the instruments at the Palomar Mountain Observatory. In particular, proposals are under consideration by which observing time that is not required by the staff of the Palomar Mountain and Mount Wilson Observatories may be made available to competent observers from other institutions on the most effective co-operative basis.

Notable among the scientific results of the year's work is the discovery by H. W. Babcock of general magnetic fields in a number of early-type stars. The strengths of the fields at the poles of the stars investigated range up to 5500 gauss. For several decades local magnetic fields of similar strength have been measured in sunspots, and a general magnetic field of 50 gauss or less has been suspected in the sun. The present investigation represents the first observation of magnetic fields in the more distant astronomical objects. The early-type stars investigated by Babcock are thought to have exceptionally high rotational speeds, and the large magnetic fields observed are probably connected in some way with this rotation. The discovery of these very large magnetic fields introduces a new and unexpected factor in the equilibrium of the atmospheres of these stars, and it is hoped that these results may point to a solution

of several outstanding problems in connection with these objects.

Another important project has been the search for the nucleus of our own galaxy. Such nuclei are observed at the centers of other galaxies, but the region in the center of our own galaxy is so obscured by dust clouds that the observation of the nucleus by ordinary means is impossible. Making use of the well known fact that terrestrial haze may be penetrated with infrared light when it is opaque to visual light, Stebbins and Whitford have investigated this central region of the galaxy with infrared light. For this purpose a special infrared photocell was mounted on the 6o-inch telescope, which was held stationary while various regions near the center of the galaxy were allowed to drift past. The measurements of the infrared light incident on the photocell during this process point to the presence of the galactic nucleus at 326.5° galactic latitude.

Because of the great popular interest in astronomy, the Observatory has had, since its founding, a large and increasing number of visitors at its telescopes and other facilities on Mount Wilson. In line with the general policy of the Institution to give wide dissemination to its work, the Observatory has made every effort to allow the public to view its facilities and the results of its investigations in so far as this could be done without serious interference with the scientific operations of the Observatory. A significant advance in the method of handling visitors at the Observatory was made with the opening of the visitors' gallery in the dome of the 100-inch telescope on July 30, 1946. This glassed-in gallery permits large numbers of visitors to obtain a close-up view of the 100-inch telescope and the interior of the dome without interfering with the regular use of the instrument. In addition to the visitors' gallery, a small museum is maintained near by with a representative group of transparencies enlarged from photographs obtained with the 100-inch telescope and other instruments. These facilities, therefore, enable the general visitor to see the Observatory's largest instrument, which, of course, is used almost exclusively as a camera rather than as a visual telescope, and to see a representative group of photographs taken with it. The visitors* gallery and museum are open from 1:30 to 4:30 P.M. Mondays through Fridays, and from 11:00 A.M. to 4:30 P.M. Saturdays and Sundays. It is estimated that more than 100,000 visitors made use of the visitors' gallery during its first year of operation, with 2000 being handled in one day.

The last of the contracts for defense work was completed on September 1, 1946. Since that time, the whole efforts of our shops have been devoted to Observatory work.

STAFF AND ORGANIZATION

RESEARCH DIVISION

Sdar Physics: Harold D. Babcock, Scth B. Nicholson, Joseph O. Hickox, Edison R. Hogc, Edison Pettit, Robert S. Richardson, Mary F. Coffeen, Elizabeth S. Mulders, Myrtle L. Richmond, Phyllis W. Vcit, Irene Whitney.

Stellar Motions and Distances: Ralph E. Wilson, A. Louise Lowen, Myrtle L. Richmond.

Stellar Photometry: Walter Baade.

Stellar Spectroscopy: Paul W. Merrill, Horace W. Babcock, Ira S. Bowen, Theodore Dunham, Jr.,[1] Milton L. Humason, Alfred H. Joy, Rudolph Minkowski, Roscoe

[1] On leave July 1, 1946—March i, 1947.

F. Sanford, Olin C. Wilson, Sylvia Burd, Cora G. Burwell, Dorothy D. Locanthi, A. Louise Lowen, Barbara Olsen.

Nebular Photography, Photometry, and Spectroscopy: Edwin P. Hubble, Walter Baade, Milton L. Humason, Rudolph Minkowski, Alice S. Beach.

Physical Laboratory: Robert B. King.

Editorial Division: Paul W. Merrill, editor; Elizabeth Connor, assistant editor and librarian; Helen Stecki Czaplicki, secretary.

Alfred H. Joy has continued as Secretary of the Observatory throughout the year. In the first serious accident that has occurred in connection with the observing program of the Observatory, Dr. Joy was injured by a fall from the Cassegrain observing platform early in November 1946. His injuries required hospitalization for the following four months. Before the end of the present report year, however, Dr. Joy was able to assume his full load of duties, including his observing schedule.

Dr. Theodore Dunham, Jr., resigned on March 1, 1947, to carry out investigations in the field of biophysics. Dr. Dunham joined the staff in 1929 and has made studies of planetary atmospheres, stellar spectra, and interstellar lines. He has also made very large contributions to the instrumentation program of the Observatory. In particular, he was largely responsible for the design of the present very efficient coudé spectrograph of the 100-inch telescope.

Mrs. Elizabeth S. Mulders resigned, effective March 15, 1947, after eighteen years' service at the Observatory. During this period she was engaged in studies in solar physics and in editorial duties. Her position was taken first by Mrs. Phyllis Veit and later by Miss Irene Whitney.

Dr. Roscoe F. Sanford represented the Mount Wilson Observatory at the celebration of the seventy-fifth anniversary of the founding of the Córdoba Observatory, Córdoba, Argentina. He attended as guest of the Córdoba Observatory.

Dr. Walter S. Adams and Dr. Ira S. Bowen were appointed research associates of the California Institute of Technology. This is in harmony with the plan for the joint management and operation of the two observatories at Mount Wilson and at Palomar Mountain.

RESEARCH ASSOCIATES

Walter S. Adams, Pasadena; Sir James Jeans, Dorking, England; Henry Norris Russell, Princeton University; Frederick H. Seares, Pasadena; Joel Stebbins, University of Wisconsin.

Dr. Adams has continued his search for interstellar lines in high-dispersion spectra of stars of types O and B. In collaboration with Dr. Martin Schwarzschild, he has studied the behavior of a group of iron lines in the spectrum of *r*\ Aquilae throughout the period of its light-variation. During the past year the detailed investigation of the blue and ultraviolet spectrum of u Sagittarii has been completed and prepared for publication by Dr. Adams and Dr. J. L. Greenstein, of the Yerkes Observatory.

Dr. Stebbins and Dr. A. E. Whitford have continued their important photometric studies during the summer of 1946 and the spring of 1947. These investigations include: the establishment of a definitive scale of magnitudes for the extragalactic nebulae; the measurement of the colors of nebulae; the extension of an accurate scale of visual stellar magnitudes down to the seventeenth magnitude; a continuation of the search for the galactic nucleus; and further six-color observations of variable stars.

TEMPORARY ASSOCIATES

Dr. Martin Schwarzschild, of Columbia University, spent several weeks at the

Observatory in the early summer of 1946. In co-operation with Dr. Baade he took an extensive series of plates of Messier 3 to study the type of changes in the periods of the cluster-type variables, and thus to investigate the equilibrium conditions in these objects. In a second investigation the excitation temperature, electron pressure, and density were determined from line intensities in the spectra of *v*\ Aquilae. When correlated with the radial-velocity measurements already made by Dr. Adams, these provide a basis for the theory of the atmospheric pulsations of this Cepheid variable.

During the summer of 1946, Dr. Louis C. Green* of Haverford College, carried out theoretical investigations of the *f*-values or oscillator strengths associated with the transitions from the lowest states of *Ca* n, ^{2}S, ^{2}D, and ^{2}P to the s> p, d, and f continua.

Dr. Lawrence Aller, of the University of Indiana, in co-operation with Dr. Minkowski carried out a photometric investigation of the spectrum of the planetary nebula NGC 7027, covering the range AA3700-9000. With the aid of plates previously taken by Dr. Merrill, a study was also made of the chemical composition of six B stars.

Mr. W. C. Miller, of Pasadena, has continued his search for bright-line objects with the 1o-inch telescope and objective prism. A result of special interest was the discovery of a ninth-magnitude nova in Sagittarius in May 1947. Mr. Miller has also taken many slit spectrograms, chiefly of Be stars, with the 60-inch and 100-inch telescopes.

Dr. A. G. Mowbray, of Pasadena, has taken part in the spectroscopic observing with the 60-inch telescope in addition to obtaining a number of excellent objective-prism photographs with the 10-inch telescope.

INSTRUMENT DESIGN AND CONSTRUCTION

Design: Edgar C. Nichols, chief designer; Harold S. Kinney, draftsman.

Optical Shop: Don O. Hendrix, superintendent; Floyd Day, optician.

Instrument Shop: Albert Mclntire, superintendent; Elmer Prall, instrument maker; Fred Scherff, Oscar Swanson, Albert Labrow, Donald Yeager, machinists; Harry S. Fehr, cabinet maker.

MAINTENANCE AND OPERATION

Office: Anne McConnell, bookkeeper; Dorothea Neuens, stenographer and telephone operator.

Operation: Ashel N. Beebe, superintendent of construction; Kenneth de Huff, engineer; Charles Dustman, janitor and relief engineer; Thomas A. Nelson, Boyd Thompson, Ralph Bennewitz, Stanley Baird, Eugene Hancock, night assistants; Emerson W. Hartong, truck driver and machinist helper; Anthony Wausnock, Margie Wausnock, Pauline Byers, Alexander Kochanski, stewards; Arnold T. Ratzlaff, Homer N. Joy, janitors.

Several of those whose names are listed above have been with the Observatory for only a part of the year. In addition, numerous temporary employees have assisted in construction and repair work.

OBSERVING CONDITIONS

Most o£ the season's precipitation of 42.05 inches fell in November and December* This included a storm on November 11 to 14 that brought 21 inches of snow, disrupted the power line serving the Observatory for over a week, and closed the Mount Wilson road for several days. The total snowfall for the year was 25 inches.

Solar observations were made on 319

days between July i, 1946 and June 30, 1947. The 60-inch telescope was used on 262 nights and the 100-inch telescope 267 nights during this period.

SOLAR RESEARCH

SOLAR PHOTOGRAPHY

Solar photographs were made on 319 days between July 1, 1946 and June 30, 1947, by Hickox, Hoge, Nicholson, and Richardson. The numberr of photographs of various kinds were:

Direct photographs	670
Ha spectroheliograms of spot groups, 60-foot focus	1125
Ha spectroheliograms, 18-foot focus	1,284
K2 spectroheliograms, 7-foot focus	19,520
K2 spectroheliograms, 18-foot focus	1,204
K prominences, 18-foot focus	1107

SUNSPOT ACTIVITY

The magnetic classification and study of sunspots and related phenomena have been continued by Nicholson, Mrs. Mulders, and Mrs. Veit. Co-operative programs have been carried out with the United States Naval Observatory, the Observatory at Kodaikanal, the Department of Terrestrial Magnetism of the Carnegie Institution, and the Central Radio Propagation Laboratory of the National Bureau of Standards.

During the calendar year 1946, observations were made on 334 days. No days were without spots, whereas in 1945 twelve days were without spots. The total number of sunspot groups observed was 416, compared with 220 in 1945. All belonged to the new cycle, no spots belonging to the old cycle having been observed since August 8, 1945. In the new cycle the number of groups in the northern hemisphere increased from 71 in 1945 to 200 in 1946; in the southern hemisphere from 141 to 216.

The monthly means of the number of groups observed daily during the past two and one-half years are given in the accompanying table.

MONTH	DAILY NUMBER		
	1945	1946	1947
January	2.5	4.2	9.9
February	1.1	7.7	10.5
March	1.9	6.7	11.8
April	2.8	7.1	11.5
May	3.6	7.2	16.8
June	3.8	7.3	13.4
July	4.4	8.2	...
August	2.8	8.5	...
September	3.6	8.9	...
October	5.7	9.8	...
November	5.1	9.8	...
December	2.9	8.5	...
Yearly average	**3.4**	**7.8**	...

Last year a huge sunspot group which appeared in February 1946 was reported as the largest ever photographed. Another very large group with about the same maximum area was on the sun from February 5 to May 7, 1947. When it crossed the sun's disk in March, the group contained the largest single spot ever photographed. In April the group as a whole was larger than in March, being then fully as large as the great group of February 1946. Another large group, the third largest on record, was on the sun in July 1946. The number of sunspot groups observed daily in May 1947,16.8, set a new record for Mount Wilson. The relative sunspot numbers compiled at Zurich indicate that sunspots were more numerous in May 1947 than in any other month since 1749 with the exception of May 1778. Whether this great activity in May will

mark the maximum of the present cycle cannot be known for some months. It seems almost certain, however, that the century-long series of alternating high and low cycles has been broken, because this cycle, which should have been a low one in that series, has already exceeded the maximum of the last cycle.

SUNSPOT POLARITIES

Magnetic polarities in each spot group have, so far as possible, been observed at least once. The classification of groups observed between July i, 1946 and June 30, 1947 is indicated in the accompanying table. "Regular" groups in the northern hemisphere are those in which the preceding spot has S (south-seeking) polarity and the following spot N polarity; in the southern hemisphere the polarities are reversed.

HEMISPHERE	REGULAR	IRREGULAR	UNCLASSIFIED
North.	175	7	92
South.	205	6	85
Whole sun.	380	13	177

FLARES

The spectra of bright flares have been studied on plates taken with the 75-foot spectrograph by Nicholson and Richardson. A total of 212 emission lines have been identified; they arise from 17 neutral and singly ionized atoms. The Balmer series can be traced in emission to H21 at A3679. The relative intensities of the flares photographed at Mount Wilson have been compared with those observed by C. W. Allen at Canberra. In most cases, the relative Intensities of the lines correspond as closely as could be expected, but many striking exceptions occur, indicating that flares of about equal brightness do not necessarily have identical spectra.

Photographs have been obtained of H|3 and Hy in the spectra of solar hydrogen "bombs." The bombs appear as bright extensions to the red and violet in the hydrogen lines over active spot groups. If the widening of lines in the Balmer series produced by the bombs is due to Stark effect, the extensions should be greater in Hy than in HP, since Stark effect increases with decreasing wave length. Preliminary results show the widening to be roughly the same in photographs of the two lines taken simultaneously. Up to date, however, no observations have been made under first-class conditions.

PROMINENCES

The photographs of the eruptive prominence of June 4, 1946 have been measured and reduced by Pettit. This prominence was ejected from the earthward face of the sun in latitude $S48^0$ with velocities of 136 and 312 km/sec. When the measures are corrected for the angle of projection they indicate that this prominence reached the unprecedented elevation of 1,703,000 km, or 1.22 solar diameters above the sun. The highest previous record was 1,550,000 km, for the eruptive prominence of March 20, 1938, also observed at Mount Wilson. An interesting feature of the motion of the prominence of June 4, 1946 is that it was accomplished with two velocities in a gravitational field that varied from four-tenths to one-twelfth of that at the solar surface. The prominence was one of the largest ever observed.

Eruptive prominences were photographed also on September 15, 1946 and April 14, 1947, the one on the latter date rising from the vicinity of a great sunspot on the west limb-

An effort is being made to obtain measurable series of photographs of interactive and tornado prominences, in order to study the exchange of gases between two neighboring prominences and to obtain more data on rotary motions.

THE SOLAR SPECTRUM, X6600 TO A13495

Under the foregoing title, Carnegie Institution of Washington Publication 579, by Harold D. Babcock and Charlotte E. Moore, is now in press. The major portion (67 pages) of this volume consists of a table of the wave lengths, intensities, and identifications of about 7350 lines observed in the solar spectrum in the wave-length range mentioned in the title. The 26-page text discusses instruments used, the intensities of disk and sunspot spectra, identifications and excitation potentials, comparisons between solar and stellar spectra, elements present, etc.

GENERAL MAGNETIC FIELD OF THE SUN

Various sources of error in the method adopted for the study of weak solar magnetic fields have been studied in detail by H. D. Babcock with the assistance of Mrs. Coflfeen. Personal errors in micrometer settings on the interference fringes from the Lummer plate, relative errors presented by alternative methods of reducing the observations, properties of some circular analyzers, and other technical details have been included.

Observations made like those of the general field, except that a small single sunspot is held centrally on the window of the Lummer plate, are used for testing the performance of the entire optical train. When the effective magnetic field is weak, as in these tests, the measurability of the spectrum lines is fully comparable to that in observations of the general field. It thus appears that the definitive observations are adequate for detecting a general field whose polar intensity (under usual assumptions) is 13 gauss, or about one-fourth of the maximum value reported by other workers.

Visual observations have been made with a modified method of observing weak magnetic fields, utilizing either a Lummer plate or a Fabry-Perot interferometer. Some merits and some disadvantages are found in comparison with the photographic method long in use here, and further study is required. This visual method rests upon small variations of intensity, rather than of position, among the interference fringes of selected lines in the solar spectrum.

ULTRAVIOLET SOLAR SPECTRUM

Recent reports of the extension of the ultraviolet solar spectrum, through observations with low dispersion from high-altitude rockets, give additional interest to spectrograms made at ground level. Attempts have been made during the current year by H. D. Babcock to improve the data mentioned in earlier reports in the range A2914 to A3060. Because of poor observing conditions in Pasadena, however, only minor additions have been made. All the available data in this wavelength range are being prepared for publication in collaboration with Dr. Charlotte E. Moore, of the National Bureau of Standards.

SOLAR CURVES OF GROWTH

A study of empirical curves of growth for lines of neutral vanadium *(Vi)* in the solar spectrum has been made by R. B. King in collaboration with Dr. K. O. Wright, of the Dominion Astrophysical Observatory, Victoria, British Columbia. Solar equivalent widths, obtained principally from the Utrecht *Atlas,* and *gf~*

values obtained in the laboratory were used to construct the curves. A mean excitation temperature of about 5400°± 200° K was found for *V1*. This may be compared with temperatures of about 4400° and 4900° obtained previously by similar methods for solar 771 and *Fe 1* lines, respectively. A condition commonly ascribed to turbulence in the solar atmosphere (in addition to ordinary thermal agitation of the atoms) was exhibited by the curves of growth for lines arising from the lowest energy levels. The magnitude of this effect corresponds to mean turbulent velocities of about 3 km/sec for lines arising from the ground state; it decreases with increasing excitation potential of the lines. The effect is similar to that found by Wright in curves of growth for lines of *Fei* in F-type stars.

ABUNDANCE OF OXYGEN IN THE SUN

With the aid of a new determination of the wave lengths of the forbidden *0*1 lines at A6300A and A6363A, Bowen has been able to identify these lines as well as the forbidden *0 1* line at A5577A with weak solar absorption lines. Since these lines are all transitions from very low terms in the oxygen atom, their equivalent widths can be used for the determination of the abundance of oxygen in the sun without the use of the very large and uncertain Boltzman-factor correction that has been necessary in previous determinations. Measurements of the equivalent widths of these solar absorption lines gave the amount of oxygen present in the reversing layer as $7X10^{20}$ atoms, or 18 mg, per sq. cm. A comparison of the equivalent widths of these lines with the widths of the high-level permitted lines in the infrared yielded an excitation temperature for oxygen of 5200°.

SOLAR ABSORPTION COEFFICIENTS

Preliminary measurements of the distribution of violet light across the sun's disk have been made by Nicholson in an effort to determine whether short-period fluctuations can be detected in the solar absorption coefficients. Drift-curves have been obtained on about 100 days. Their measurement and reduction are in progress with the assistance of Miss Richmond and Mrs. Veit.

RELATION BETWEEN SOLAR AND TERRESTRIAL PHENOMENA

Nicholson has co-operated with Dr. Oliver Wulf, of the United States Weather Bureau, in the study of solar and terrestrial relations, particularly with regard to ionospheric changes induced by variations in terrestrial magnetism.

PLANETARY INVESTIGATIONS

Positions of Jupiter's satellites JVI, VII, VIII, IX, X, and XI were measured by Nicholson on photographs made with the 60-inch and 100-inch reflectors. The United States Naval Observatory is determining the positions of all the comparison stars used in measuring photographs of Jupiter's satellites since 1938. The re-reduction of the satellite plates and the remeasurement of many of them have been started at Mount Wilson. When completed, this program will give positions of Jupiter and its satellites referred to the same coordinate system. Miss Richmond is assisting in the measurement and reduction of the photographs.

STELLAR INVESTIGATIONS

PHOTOELECTRIC PHOTOMETRY

Stebbins and Whitford made six-color observations of the typical variable stars y] Aquilae and RR Lyrae, similar to the previous measures of § Cephei and Polaris. In both the new series the same phenomenon, a retardation of phase with increasing wave length, was found as in *b* Cephei. In addition, the correlation of the colors with the varying spectral types will throw new light on the processes of these pulsating stars. Incidentally to the program on nebular photometry, the photovisual magnitudes in two Selected Area fields were calibrated photoelectrically down to the seventeenth magnitude.

VISUAL MAGNITUDES OF NOVAE

The measures of the visual light of T Coronae Borealis have been continued by Pettit. T Coronae is the only fast nova for which a pronounced secondary maximum has been observed. The star, which rapidly faded from its initial observed brightness of 3.2 mag. in February 1946 to 9 mag. in March, reached primary minimum 9.9 mag. in May, began to brighten in the last week of May, and reached 7.8 mag. in June and July, after which it declined slowly, and in July 1947 is about magnitude 9.8. The recent light-curve of T Coronae is everywhere nearly the same as that of its outburst in 1866, with a possible general depression of 0.1 or 0.2 mag. Several recrudescences of a few tenths of a magnitude in light were observed, notably in October 1946 and March 1947. The primary minimum, corrected for the M-type companion, was 11.0 mag.

Photographs of the star field have been made with the 60-inch telescope with local color filters for T Coronae which transmit red and blue light for the determination of any shift due to the presence of the companion.

The visual light of Nova Puppis, measured on two nights, declined 0.42 mag. during the year, only about half as much as during the previous year.

VISUAL MAGNITUDES OF DOUBLE STARS AND VARIABLE STARS

Measures of the magnitudes of double stars with faint close companions were continued by Pettit with the wedge photometer attached to the 60-inch telescope. One hundred and twenty measures of double-star systems were made during the year, and measurements on 51 systems have now been completed on three or more nights since this program was started.

Measures of the visual light of HC Herculis, an RV Tauri type star, were made over the period July to November 1946. These measures show that the principal minima occurred on August 9 and October 22, seven days after the dates predicted by Waterfield's formula. The magnitudes at principal maximum and minimum were 6.8 and 8.5, about half a magnitude brighter than the catalogue values.

ANGULAR DIAMETER OF STARS FROM OCCULTATIONS BY THE MOON

During the summer of 1946 Whitford increased the number of occultations observed from the single one previously reported to a total of four. The calculated angular diameters ranged from o".oo8, for the first case of v Virginia, to o'/oooS for the A9 star 44b Ophiuchi. The intensity patterns observed as the edge of the moon's shadow swept across the tele-

scope agreed with those expected from simple knife-edge diffraction theory, and confirmed the view that the method is applicable to the determination of the angular diameter of stars in the range from o".oo2 to o".o2O.

STELLAR SPECTROSCOPY

RADIAL VELOCITIES

Observatory program. For about thirty years the Observatory has carried on observations to determine the radial velocities of stars in several categories, the five principal ones being: (i) the stars of the later spectral classes listed in the Boss *Preliminary General Catalogue;* (2) all stars with proper motions exceeding o'/i per year; (3) stars in Kapteyn's Selected Areas; (4) stars in the four clusters Taurus, Pleiades, Praesepe, and *h* and x Persei; and (5) a selected list of double stars. For those stars visible during the seasons when good observing conditions prevail, the observations are essentially complete. Unpublished radial velocities are available for about 1000 stars, and a sufficient number of plates have been obtained for about 750 others. About 630 plates of 325 stars are needed and must be obtained mainly during the seasons when bad observing conditions prevail. It is hoped that these programs may be completed with the 60-inch telescope during the coming year.

During the past year, in which observing conditions were definitely subnormal, 880 spectrograms were obtained with the 60-inch, 580 on the general radial-velocity programs and 300 in connection with special investigations.

The rapid accumulation of radial velocities since the publication of the Lick catalogue in 1932 makes it desirable from the standpoint of the student of stellar motions that the list be brought up to date. R. E, Wilson, with the assistance of Miss Richmond, has undertaken this compilation and during the year has made a card catalogue of all known radial velocities which contains some 11,750 entries.

Dwarf stars. The radial velocities and spectral types of 180 dwarf stars with proper motions greater than o'.'35 per annum were published by Joy. The list includes no dM-type stars, some of which are of the lowest luminosity thus far observed for radial velocity. Twenty-one subdwarfs, for which the mean radial velocity is 121 km/sec, were recognized. Three or more plates were available for practically all the stars. The probable error of the adopted velocity lay between 1 and 2 km/sec for most of these stars. With the aid of absolute magnitudes determined from trigonometric parallaxes, a table was constructed showing the correlation between absolute magnitude and spectral type from dK4 to dM6. Emission lines of *H* and *Ca* n were observed in 41 stars of types Mi.5 or later, and it was noted that in subdwarfs emission lines are extremely weak or absent.

LONG-PERIOD VARIABLE STARS

Omicron Ceti. Measurements of coudé spectrograms of the long-period variable 0 Ceti, taken by Merrill and Joy from 1934 to 1947, indicate that the mean radial velocities based on the absorption lines vary by a few kilometers per second at different maxima, and also that the curves of velocity variation are subject to considerable changes in shape and range from cycle to cycle.

As a test of the hypothesis that the deformation of the emission lines at certain phases is due to line absorption by overlying atoms of the reversing layer in

the star, 62 lines within a distance of one angstrom from the centers of 28 hydrogen emission lines were measured by Joy on 88 high-dispersion spectrograms and were identified with lines of elements commonly found in absorption in low-temperature stars. The probability of the occurrence of these lines was strengthened by noting the presence in 0 Ceti of other members of the multiplets to which they belong. The iron lines show the same correlation between ionization potential and velocity displacement found for iron lines falling outside the regions of hydrogen emission. By comparing the wave lengths, four lines measured within the JHY emission were attributed to titanium oxide.

Variables of class N. Observations made by Sanford during the past year and those already accumulated now give sufficient coverage of all phases of eight long-period variables of spectral class N to show a definite velocity variation. The velocity in general is highest between minimum and maximum and lowest between maximum and minimum. Present in most of them as a strong emission line at or near maximum light, *Ha* is exceedingly weakened or absent at and near minimum light. Changes in the continuous spectrum between maximum and minimum light are marked in the region AA5800-6700 in some of these variables; in other variables there are changes in the strength of such absorption lines as Di and D2 of *Na* 1.

Variables of class Se. Stars whose spectra are characterized by bands of zirconium oxide have long been recognized as forming one of three parallel branches of giant red stars at the cool end of the stellar temperature sequence. Many years ago the spectra of these stars (class S) were described in Mount Wilson Contributions Nos. 252 and 325. During the past year Merrill has carried out extensive studies of the intricate spectra of two well known variable stars of class Se by means of spectrograms with the relatively high dispersion of 10 A/mm. These studies were comparable with those of Me variables made in the preceding year.

In the spectrum of R Andromedae, measures of more than 1300 dark lines served as a basis for a detailed survey of the multiplets of nearly 30 elements. The displacements of lines of neutral atoms (and probably also of ionized atoms) have a persistent positive correlation with excitation potential. Lines of ionized atoms have positive displacements with respect to lines of neutral atoms. The mean velocity from the dark lines exhibited little variation with phase over a postrnaximum interval of about 100 days.

Atoms of yttrium and zirconium appear to be more abundant in R Andromedae than in Me variables. This tentative conclusion, if confirmed by quantitative photometric analysis, might guide us toward the cosmological interpretation of the trifurcation of the low-temperature end of the stellar sequence.

In the investigation of x Cygni, many new data were recorded concerning the behavior of bright lines during the postmaximum phase of the light-cycle. A two-night exposure with the 100-inch telescope, when the variable, at magnitude 11.4, was 162 days after maximum, brought out nearly 300 bright lines. The total number of bright lines studied was about 400. Most of these are due to hydrogen or to metals (either neutral or singly ionized), but some of them, including a few strong ones, have thus far resisted all attempts at identification. A peculiarity of physical interest is the inordinately high intensity of bright lines from certain atomic levels. These levels appear to be energized by line coincidence—a specialized process far removed from thermal equilibrium. A

new example in the zirconium spectrum was detected by Bowen.

Since the bright-line spectrum undergoes remarkable changes with phase, becoming more interesting as the light of the variable star declines, it is hoped in the future to obtain additional spectrograms still closer to minimum.

ECLIPSING VARIABLE STARS

Spectroscopic observations by Joy during the total eclipses of RW Tauri showed remarkable changes in the intensity of the emission lines emanating from the gaseous ring around the B9 component. On account of its small size, the ring can be observed only at second and third contacts. At 15 eclipses emission of widely varying intensity was observed on one or both limbs, but at 5 eclipses no emission appeared. The ring is evidently quite irregular in structure. The velocities remain constant at about 350 km/sec, but the gases may be distributed in the form of clouds or spiral streamers. S Cancri was observed at minimum for determining the velocity changes of the secondary star.

O. C. Wilson has nearly completed his investigation of the 1939-1940 eclipse of £ Aurigae. The results should be ready for publication in the near future.

VARIABLE STARS OF OTHER TYPES

Joy has continued the observation of certain groups of variable stars for the purpose of supplying spectroscopic material for a study of the physical characteristics and motions of the different classes of variables. Spectrograms o£ stars of the RR Lyrae, RV Tauri, SS Cygni, and R Coronae Borealis classes and of the brightest variables in the globular clusters were obtained at suitable phases. Additional observations of AE Aquarii were made to test the constancy of the period of velocity variation.

In continuation of work begun in preceding years, Sanford, using the 32-inch camera of the coudé spectrograph, has obtained spectrograms of the variable RR Lyrae; a half-dozen Cepheids, including TU Cassiopeiae with the period 2.1 days, one of the shortest known; and T Monocerotis with a period of 27 days. A start was made on observations for the velocity-curve of SV Vulpeculae, a Cepheid with one of the longest periods known, 45 days.

Eta Aquilae. A series of 18 high-dispersion spectrograms of *Y* Aquilae taken throughout the period of light-variation has been measured by Adams in collaboration with Dr. Martin Schwarzschild. Special attention has been given to a list of 42 iron lines selected to provide a considerable range of intensity and excitation potential.

Nova T Coronae Borealis. Spectrograms of Nova T Coronae Borealis with dispersions of 10 A/mm in the blue and 20 A/mm in the red have been obtained by Sanford each month except October, November, and December 1946, when it was too close to the sun. Many changes in emission line structure and in the shell spectrum have been found, and the measurements have been completed. These measures have yet to be sifted and brought into orderly sequence. The lines belonging to the class-M spectrum in this long series of spectrograms show a velocity variation with a period between 200 and 300 days. Definite evaluation of this period should be possible at the end of the 1947 observing season.

SFECTROGRAFHIC STUDIES OF SPECIAL STARS

Wolf-Rayet stars. O. C. Wilson has continued his survey of the spectra of

Wolf-Rayet stars with the following preliminary results:

The star HD 50896 has shown shifts of considerable magnitude in the positions of some of the emission bands. No secondary spectrum is visible, and it is not yet known whether the star is a binary or not. BD+40°422o has an Of-type spectrum and is probably a spectroscopic binary of considerable range with both spectra visible. The star is extremely red for its type. HD 190918 is a Wolf-Rayet star with well marked absorption lines. Observations of the absorption spectrum have shown that the star is a spectroscopic binary. A tentative period of about 82 days has been derived. HD 193793 also is a Wolf-Rayet star with absorption lines, although of poorer quality than those in HD190918. Observations of the absorption spectrum indicate that the star is probably a spectroscopic binary, although no period has been found.

Be stars. Considerable progress has been made during the year by Merrill, Burwell, Miller, and Mowbray in the discovery and observation of bright-line stars. The survey with the 1o-inch telescope is nearly complete for low galactic latitudes; certain areas at higher latitudes are now being photographed. A ninth-magnitude nova was discovered in May 1947. Scores of additional Be stars, detected in the objective-prism survey, are awaiting observation with a slit spectrograph. A number of stars with interesting spectral changes have been found.

Upsilon Sagittarii. Dr. J. L. Greenstein and Adams have prepared for publication the results of a detailed investigation of the spectrum of u Sagittarii in the region AA3564—4861. Approximately 1000 lines have been measured on two spectrograms of high dispersion. In addition to many elements which would be expected, there is considerable evidence for the presence of *Cl* 11 and *Fe* in, and some possibility of Pn and C11; *S*11 is strongly represented, but *C*1 and *He n* appear to be absent. An interesting discovery is the doubling on two of the spectrograms of a considerable number of lines of ionized elements, more especially of *Fe* 11.

GENERAL MAGNETIC FIELD OF EARLY-TYPE STARS

The initial work on general magnetic fields in stars was reported a year ago. Since that time, a survey of likely stars down to the sixth magnitude has been continued by H. W. Babcock with the aim of discovering those that have strong fields. Also, a more detailed study of the Zeeman effect in a few stars, using the highest available dispersion, has been begun. Magnetic fields stronger than 1000 gauss have been observed in y Equulei, 3 Coronae Borealis, BD-18° 3789, and probably two or three others, in addition to 78 Virginis. The polar field of the "europium star," BD—i8°3789, is about 5500 gauss, the strongest yet measured. Several other stars, plates of which have not yet been fully measured, probably have fields of somewhat less than 1000 gauss. A considerable body of evidence now bears out the reality of the effect, and there are no discordant observations. Several stars observed with the analyzer show no discernible Zeeman effect. This group includes *a* Canis Majoris (Ao), a Canis Minoris (F5), £ Pegasi (Ko), and a Tauri (K5). The results so far obtained suggest that strong magnetic fields are a general property of the metallic-line stars of type A, and particularly of the spectrum variables which are a subgroup of this type. The apparent correlation of magnetism with spectrum variability deserves much further study. Consideration of the curve of growth suggests that the Zeeman effect should

increase the equivalent widths of moderate and strong absorption lines; this effect will probably have to be taken into account in studies of the abundances of elements in the early-type stars.

The discovery of magnetism in selected stars (which in all probability are in rapid rotation) has implications that may be of significance as regards the relation between the magnetic and mechanical properties of large rotating masses. In this connection, Babcock has pointed out that the magnetic moments of the earth, the sun, and 78 Virginis (8×10^{25}, 8.4×10^{33}, and 4×10^{36} gauss cm^3, respectively) are at least roughly proportional to their angular momenta, and may be obtained, in each object, by multiplying the angular momentum, in c.g.s. units, by 10^{-15}. This relation may be of fundamental significance, but it should still be regarded with reserve, since the obliquity of the magnetic axes of the earth and of the sun has not yet been explained.

If the proportionality of magnetic moment to angular momentum is a universal law of large rotating masses, it is possible that it is also applicable to a rotating stellar system such as our galaxy or an extragalactic nebula. It then becomes possible to compute the magnetic moment of such a system. For the galaxy and for the Andromeda nebula, one finds a magnetic moment of roughly 10^{59} gauss cm^8, or a corresponding magnetic field of about 10^{-8} gauss in the plane of the system, the lines of force being perpendicular to the plane.

The controlling effect exerted by the magnetic field of a rotating star on ions and electrons in or beyond its atmosphere may well have considerable interest as regards the support of equatorial rings of tenuous material, and possibly even as regards theories of the cosmogony of planetary systems and double stars.

INTERSTELLAR LINES

In a search for faint components of the interstellar H and K lines, measurements have been completed by Adams for about 300 stars of types O and B. About 40 per cent of the stars observed show one or more components to the principal line. With few exceptions, the stars showing the most complex lines are found in the lowest galactic latitudes. The analysis of the material is in progress. -

Interstellar lines are probably formed in relatively thin curtains stretched at irregular intervals between the stars. Lines whose intensities increase (statistically) with distance should be distinguished from lines which show no dependence on distance. Comparison by Merrill and O. C. Wilson of the components of the *Ca* 11 and *Na* 1 lines in a number of stars suggests a dependence of ionization on the thickness of the clouds, the thin curtains being the more highly ionized. Consideration should be given to those conditions (of liquefaction or of chemical combination) under which interstellar atoms may be removed from the state in which they can give rise to atomic lines.

GALACTIC NEBULAE AND STAR CLOUDS

PLANETARY NEBULAE

Minkowski has identified 35 new planetarics during the past year* bringing to 111 the total number found in the survey prior to July 1, 1947. The survey is virtually complete between galactic longitudes 0° and 205°, but a number of objects in the direction of the galactic center still remain to be investigated.

A large number of spectrograms on

infrared- and red-sensitive plates have been obtained by Minkowski for the spectrbphotometric study of NGC 7027 undertaken with L. Aller. The observational program has been completed and the reduction of the material is under way.

The survey by O. C. Wilson of the brighter planetary nebulae with a dispersion of 10.4 A/mm has continued during the year and is near completion. The results in general confirm those reported earlier.

TRANSPARENCY OF THE ORION NEBULA IN THE INFRARED

Since earlier plates suggested that the Orion nebula might be quite transparent for still longer wave lengths, Baade has made a check in the near infrared. The selected region (AA7100-7500) contains only a few weak emission lines, and the light of the nebula is largely suppressed on the photographs. The results are very striking. The area normally filled with the luminous nebulosity is replaced by a corresponding area of high stellar density, far above that of the surrounding region. Obviously the transparency of the Orion nebula for long waves is not restricted to the neighborhood of the exciting stars where it was first noticed (Trapezium cluster), but is characteristic of the whole of the excited nebulosity. The transparency decreases with increasing distance from the exciting stars.

VARIABLES IN THE NUCLEAR REGION OF THE GALACTIC SYSTEM

Baade has continued the search for variables in the field around the globular cluster NGC 6522 ($A = 328^0$, $3 = -4^0$). Although only occasional plates have been blinked during the year, the number of recognized variables in the field has increased to 200, corresponding to 540 per square degree. The observations will be continued until the type of variability has been ascertained for most of the variables.

SEARCH FOR THE NUCLEUS OF THE GALAXY

Dr. Stebbins and Dr. Whitford continued the search for the nucleus of our galaxy, using a band of infrared radiation at effective wave length 10300A. With a photocell and suitable filter on the 60-inch reflector, the sky was allowed to drift with the diurnal motion across the field of a focal diaphragm 8'6 in diameter. As the intensity along each sweep was recorded, the star clouds and individual stars interfered somewhat but did not wholly prevent penetration to the background. The area of the search extended about 2^0 on each side of the galactic equator from longitude 321° to 331°, with intensive coverage within i° of the equator, and with supplementary sweeps of greater extent at selected points. The sweeps at successive longitudes usually gave maxima near the galactic circle, outlining a bulge extending about 8° in longitude and 4^0 or 5^0 in latitude, with center near 326?5-

Concurrent sweeps in the red at wave length 7190A gave a color excess on the red-infrared scale of +1.5 mag., equal to that of the most strongly reddened B stars in the sky. It is shown that the radiation cannot come from a mixture of star clouds and absorbing material like that within one or two kiloparsecs of the sun, but must come from a more luminous object behind absorbing material. The light of the bulge, with maximum apparent photographic surface brightness of 25.4 mag./sq. sec, adds up, when corrected for absorption, to a total quite comparable with the light of an equal section of the Andromeda nebula. That the observed bulge is probably near the galactic center is shown by its position, form, color, and total light.

EXTRAGALACTIC NEBULAE

PHOTOELECTRIC MAGNITUDES AND COLORS

Dr. Stebbins and Dr. Whitford each spent two months at Mount Wilson, measuring photoelectric magnitudes and colors of nebulae and faint stars. The results form the most significant contribution to the photometry of nebulae that has been made up to the present time. The results may be summarized as follows:

1. Photoelectric magnitudes of more than 150 nebulae were measured, ranging from about m = 9 to 18, and distributed over the entire sequence of classification. Apertures used were large enough to include the entire nebula as recorded on photographs. Because the technique is inherently accurate and free from systematic effects, the data establish a definitive scale of nebular magnitudes down to limits of size and brightness well within the range suitable for measurement by photographic methods (jiggle camera, extrafocal images, etc.). In particular, the data serve to calibrate the Shapley-Ames estimated magnitudes of all nebulae brighter than the thirteenth magnitude and the fainter magnitudes used in the formulation of the law of red-shifts.

2. Colors, red and blue, were measured for about 75 of the nebulae, also distributed over the sequence of classification. The systematic decrease in color indices along the sequence, suggested by previous investigations, was confirmed and placed on a quantitative basis. The data thus establish a correlation between integrated color and type of stellar population. The phenomenon was further investigated by measures of the distribution of color over the Images of several very large, intermediate-type spirals. These spirals are transition cases between systems of pure type II (elliptical nebulae) and systems of pure type I (late spirals); and the segregation of types indicated by the color distribution is an important datum in discussions of stellar evolution.

An extensive investigation of colors of elliptical nebulae emphasized the remarkable homogeneity of the group, and established, quantitatively, the relation between color and absolute magnitude (color indices increase with luminosities). Measures of the several brightest elliptical nebulae in the clusters, Virgo, Coma, Corona Borealis, and Boötes (one nebula only), for which red-shifts are available indicated a correlation between color and red-shift according to which the color index increased by 0.4 mag., as the red-shifts ranged up to $dX/X = 0.13$.

3. Colors and magnitudes were measured for 21 stars in Selected Area 57, ranging from magnitude 12.6 to 17.1, and for 34 stars in Selected Area 61, ranging from magnitude 10.1 to 16.8. Connections with the polar sequence insure that the colors and the zero point of the new magnitudes lie In the International System. These data furnish a definitive check on the current photographic scale in the two areas down to about the seventeenth magnitude, and thus provide reliable zero points for the faint extension of the scales (from magnitude 16 to 21) previously established by Baade. This extension represents the photometric standards used in the large-scale explorations of the universe.

Furthermore, the color measures provide a new, reliable scale of photovisual magnitudes which can be readily extended to the limit of the 100-inch telescope In one photographic step (I.e., without the necessity of piecing together successive steps—the process which has introduced most of the uncertainties in pre-

vious fundamental photometry). The data also furnish an approximate scale of red magnitudes, subject to uncertainties of the order of 0.1 to 0.2 mag., because of the short color base line used in the actual measures. A red scale is especially urgent for cosmological studies, which involve the effects of red-shifts ranging up to 1000A or more. In order that the shifted radiation under investigation may come from a well known region of the unshifted spectrum, it is desirable that the investigations be made in the red. The procedure is now practical, because of recent improvements of red-sensitive emulsions, but it cannot provide quantitative data until an accurate scale of red magnitudes is available. The new data represent a first step toward the establishment of the required scale.

BRIGHTEST STARS IN EXTRAGALACTIC NEBULAE

Hubble has measured the brightest stars in about 80 spirals and irregular nebulae, on the definitive scale of magnitudes established by Baade in Selected Areas 57 and 68. The program includes nebulae in clusters, groups, and the general field, and the magnitudes extend down to about 20 and 21 with the 60-inch and 100-inch telescopes, respectively.

The data furnish a revised luminosity function of brightest stars based primarily upon a complete survey of the central region of the Virgo cluster down to nebular magnitudes about 15.5, and reinforced by data from nearer groups reduced to the same distance by means of red-shifts. Provisional results suggest that the mean value of brightest stars in the Virgo cluster is about $m_{pg} = 20.2$, with a range of the order of 1.5 mag. in either direction. The fainter limit is beyond the reach of the 100-inch, but the estimate is partially controlled by the fact that the number of faint, unresolved, late-type spirals is comparable with the number of those to be expected among the superposed nebulae in the general field. The corresponding value of the mean absolute magnitude, about —6.5, will not be much improved until Cepheids have been observed in a more representative collection of spirals than that available at present.

The data clearly indicate that the luminosity of the brightest stars in a nebula increases with the luminosity of the nebula, i.e., with the size of the sample. Since the ranges in the two quantities, M_s and M_n, are widely different (3 mag. and 6 mag., respectively), it is possible to express the data as a correlation between Ms and the difference, $(Ms — M_n)$, or its equivalent, the directly observable quantity $(m_s — mn)$. This procedure reduces the dispersion in estimates of distances of isolated field nebulae and of groups in which only a few of the brighter members can be resolved.

MOTION OF THE GALACTIC SYSTEM WITH RESPECT TO THE NEARER EXTRA-GALACTIC NEBULAE

The improved distances have been used in an investigation of the motion of the galactic system with respect to. the resolved nebulae outside the local group. When the known effects of the galactic rotation and red-shift are removed from radial velocities, the data suggest a motion of the general order of 200 km/sec, in the general direction of $X = 170$, $3 = +25$. Because of the particular location of the galactic system, only small fractions of its motion are reflected in the observed radial velocities of the other members of the local group, and they do not seriously alter the pattern of internal motions within the group as suggested by the uncorrected data.

SURVEY OF THE ANDROMEDA NEBULA

Baade's survey of the south-preceding outer region of the Andromeda nebula out to 2?5 from the nucleus, in the ultraviolet, blue, red, and near infrared, has been practically completed. Of particular interest is an emission nebulosity found on the major axis, about 114' from the nucleus. It is the outermost emission object thus far identified. Humason has obtained an excellent spectrum of this nebulosity, using a dispersion of 230 A/mm at Hy; the radial velocity, —497 ± 10 km/sec (from 10 lines), indicates that, at this distance from the nucleus, differential rotation (Kepler motion) prevails. The new velocity, since it is the first to be recorded in the Keplerian branch of the rotation-curve, furnishes a much improved estimate of the mass of the spiral, namely 1.0 X ro^{11} suns. This value represents the material less than 114' from the nucleus, but the material at still greater distance presumably would represent an almost negligible fraction of the total.

IMPROVED VELOCITIES OF MEMBERS OF THE LOCAL GROUP

Humason has also obtained spectra of emission patches in three other members of the local group, with the same dispersion (230 A/mm at Hy), on each of which it was possible to determine radial velocities from 7 or 8 lines with probable errors of 5 to 3 km/sec. These improved velocities (—343 and —235 for IC 10 and IC 1613, respectively, and —30 and —34 for two patches in NGC 6822) confirm the assignment of IC 10 to the local group and re-emphasize the absence of red-shifts within the group.

SPECTRA OF EXTRAGALACTIC NEBULAE

Humason has continued the work of preparing for publication the data derived from spectra of more than 500 nebulae observed at Mount Wilson. Spectral types have been re-estimated on a uniform system, relative weights assigned, probable errors investigated, and some 20 nebulae reobserved in order to remove gross uncertainties and improve assigned weights.

The spectral types (representing the nuclear regions) vary systematically through the sequence of classification from mean values of G2.9 for 164 elliptical nebulae to F5.6 for 52 late-type spirals. The elliptical nebulae fall almost entirely within the narrow range Go to G5, but the scatter increases conspicuously with progression along the sequence of classification.

A special investigation of the frequency of emission in extragalactic nebulae (in general, nuclear regions only) was based on 233 selected spectra in which A3727 would probably be detected if present. As Mayall found from fewer data, the frequency increases systematically through the sequence of classification, ranging from 20 per cent of the elliptical nebulae to 88 per cent of the late-type spirals. In elliptical nebulae, with stellar populations of type II, emission is restricted to the low excitation line, A3727. It is the only direct evidence available of the existence of interstellar material in these nebulae. The additional lines of higher excitation, which appear in spirals, are presumably excited by the blue supergiants found in stellar populations of type I.

SUPERNOVA IN NGC 3177

A supernova found by Hubble in NGC 3177 (Sb) on March 15, 1947, at m_{Pg} = 16.8, was followed for three months until it reached m_{p}^ = 18.9. The light-curve by Baade and a spectrum by Humason identified the star as a supernova of type II, discovered about a month after maxi-

mum. The radial velocity of the nebula, measured by Humason, confirmed the assignment to the well known group centered around NGC 3190, whose distance modulus is m — M = 27.0. Thus the supernova at maximum reached about M_{pg} = — II? with an uncertainty of about 0.5 mag.

LABORATORY INVESTIGATIONS

RELATIVE TRANSITION PROBABILITIES

The measurement of the relative *gf*-values (transition probabilities) of 471 lines in 100 multiplets of the spectrum of neutral vanadium *(V1)* has been completed by R. B. King. The list includes the great majority of *V* 1 lines of astrophysical importance in the region AX3042—6812, and is complete enough to permit a comparison of the laboratory and theoretical intensities of lines in multiplets and of multiplets in supermultiplets. About 55 per cent of the multiplets appear to exhibit normal line intensities, but the agreement between observation and theory for multiplets in supermultiplets is relatively poor.

The measurement of ^/-values for lines of neutral nickel (A/7 1) in electric-furnace absorption spectra is virtually completed, but is limited to lines of excitation potential less than 0.5 volt. It will include most of the lines of astrophysical interest in the wave-length region AA3010-4400.

Investigation of the intensities of bands in the Swan system of the carbon molecule *C2* is being continued. This has been undertaken primarily to obtain data to aid in interpretation of the well known behavior of these bands in the spectra of R- and N-type stars, where, in many cases, the bandheads belonging to molecules containing the carbon isotope C^{18} appear to be abnormally strong as compared with those due to molecules containing only the principal isotope C^{12}. Preliminary, semiquantitative comparisons by Sanford and King between laboratory and stellar band intensities in the Swan system indicate that additional work to improve both sets of data is justified.

A photoelectric photometer is being developed in the laboratory by Mr. William W. Carter, of the California Institute of Technology, for the direct measurement of line intensities in electric-furnace emission spectra. If successful, the apparatus will be used first to extend the measurements of gf-values in the spectrum of *Fei* to higher-level lines than were obtained by absorption-spectra measurements.

THE SPECTRUM OF DYSPROSIUM

The spectrum of the rare earth dysprosium, with its modifications depending on the laboratory light-source in which it is produced, is being studied by A. S. King. The examination includes wave-length measures of a large proportion of the lines, supplementing the lists at present available, also a classification of lines according to their intensities at different temperatures of the electric furnace, and the selection, by means of the spark spectrum, of lines arising from the singly ionized atom (Z>y 11). The work thus far has covered the region AX4700-9300, in which range about 2500 lines have been listed.

A notable feature of the dysprosium spectrum in this region is the large number of lines which are strong in the furnace at low temperature, many of these having only moderate intensity in the arc spectrum. The low-level lines of the *Dy* 1 spectrum are thus selected; and also those evidently from successively higher energy levels appear at higher furnace tempera-

tures and in the arc. In the latter sources, the more sensitive lines of *Dyn* appear* These lines are found in the spectra of several stellar types.

FLUORESCENCE EXCITATION

A resurvey has been made by Bowen. of coincidences between ultraviolet lines that might lead to the excitation of emission lines with abnormal intensities by a fluorescence mechanism. Three new coincidences that may be of astronomical significance were brought to light by this survey. One coincidence between Lyrnan 3 and an ultraviolet line of 0 i appears to explain the abnormal intensity of the A8446 line of O 1 in the emission spectra of several stars. Another coincidence between A2795 of *Mg n* and a *Zn* line seems to provide an explanation for the abnormal intensity of a small group of *Zn* lines in the spectrum of x Cygni, observed by Merrill.

INSTRUMENTATION

The design of the direct-intensity microphotometer has been completed by HL W. Babcock and Nichols. The calibration spcctrograph for use with this microphotometer is finished, and the construction of the microphotometer is proceeding rapidly.

Babcock has constructed a photoelectric integrating exposure meter which is designed to aid la obtaining the correct exposure for spectroscopic photographs. In this instrument about 5 per cent of the light passing through the slit is directed into an electron multiplier phototube; the resulting photoelectric current is integrated, and the sum is continuously indicated by a counting device. With an ordinary photomultiplier (931-A) and a rather crude circuit, the meter gave useful results on exposures with the coudé spectrograph of A-type stars down to the fifth magnitude. If the best available tube (1P21) and a more refined circuit were employed, the instrument would probably be useful down to about the seventh magnitude.

An automatic guider for the 100-inch telescope has also been developed by Babcock. This guider introduces a new and simple type of optical scanning, whereby a rotating knife-edge modulates the starlight passing to a single photomultiplier and permits a phase-discriminating circuit to control the slow motions of the telescope in right ascension and declination in such a way as to keep the star on the optic axis of the guider and hence on the slit of the spectrograph. When properly adjusted, the guider keeps the star on the slit indefinitely with a precision fully equal to, if not better than, that of an observer doing manual guiding. The original guider, without any refinements, worked on stars to the sixth magnitude or fainter. The temporary addition of a preamplifier adds several magnitudes to its range. Theoretically, the limit of usefulness of a guider using an unrefrigerated 1P21 tube with the 100-inch telescope should be in the neighborhood of the thirteenth magnitude.

MAINTENANCE, OPERATION, AND NEW CONSTRUCTION

Early in 1946 the Observatory embarked on an extensive two-year program of repair and modernization of its physical plant. During the current year this program has progressed rapidly., and it should be nearly completed by the end of the two-year period, except for a few items involving major shop construction. Because of the present labor shortage it has not been feasible to expand the personnel

of the shops to the point where they could handle the increased load of this reconstruction program in the scheduled period.

The following major items of this program have been completed during the current year:

1. Visitors' gallery for the 100-inch telescope.

2. Modernization of cottages and Monastery on Mount Wilson. This included the addition of a room and a deep-freeze unit at the Monastery. The efficiency and economy of operation of the Monastery has been greatly increased by these new facilities.

3. Photographic facilities on Mount Wilson. All darkrooms have been provided with refrigeration units, and a central cold-storage room has been installed for the storage of all unexposed plates on the mountain.

4. Rater for 100-inch telescope clock. This mechanical rater permits the rate of the clock to be changed by remote control from all observing positions without stopping the clock.

5. Stand-by power plant. This is a small gasoline electric plant which automatically starts and takes over the load in case of failure of the power line from Pasadena. The great usefulness of this plant was emphasized after the breakdown of the power line during the storm of November 11-14, 1946.

6. Plate storage vault in Pasadena. In the 43 years of its operation, the Observatory has accumulated a collection of over 50,000 solar photographs, and over 50,000 spectrograms of 11,000 stars, as well as a large number of direct photographs of nebulae and other objects. In order to reduce as far as possible all hazards to this invaluable collection of plates, additional fire walls and an automatic fire-alarm system have been installed in the plate vaults. All equipment (such as comparators and measuring engines) that formerly involved the use of the vault for other purposes than plate storage has been removed in an effort to reduce still further the fire hazard.

All contracts in connection with national defense projects were completed by September 1, 1946, less than 4 per cent of the machine shop time for the year having been spent on these contracts.

THE LIBRARY

During the year 1946-1947, the library has accessioned 216 volumes, 87 from binding, 61 purchased, and 68 gifts, making a total of 15,998 volumes. O£ the gifts, part have come from Dr. Hale's scientific library, a bequest described In previous annual reports, and a few from Dr. van Maanen's library. The yearly number of volumes bound Is still small because of continued binding difficulties.

By the bequest of Dr. Adriaan van Maanen, who died in January 1946, his scientific library was left to the Mount Wilson Observatory. This valuable collection o£ about 500 volumes of bound periodicals and publications of observatories, and separate volumes, has now become the property of the Observatory; the work of marking them with a special bookplate and cataloguing them has begun.

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GEOPHYSICAL LABORATORY

Washington, District of Columbia

L. H. ADAMS, *Director*

It was reported a year ago that, after a review of past work and a redefining of aims, a newly integrated program for research at the Geophysical Laboratory had been outlined, and that the program placed primary emphasis on the study of the melting and solubility relations of silicates in the presence of water and other volatile components under pressure for the purpose of obtaining a more complete understanding of the genesis of rocks, other geologic phenomena, and the constitution of the earth as a whole. In the presentation of objectives and general methods of attack, it was recognized that necessary elements of the program would include the measurement of thermal quantities, further investigations on selected anhydrous silicate systems, and certain field studies, and that active consideration should be given at the earliest practicable date to other means for accomplishing the main objectives of the program.

During the past year a fresh start has been made on the "wet silicate" problem, the "dry silicate" work has continued productively, preparation has been made for experimental work on thermal quantities, some investigations interrupted by the war have been rounded out, and the results of other previous researches have been put in form for publication.

EQUILIBRIUM RELATIONS IN HYDROUS MIXTURES

MAGNESIA—SILICA—WATER

A series of studies (Bowen, Tuttle) on the system MgO—SiO2—H2O was carried out principally with the aid of the type of pressure vessel or bomb already in use at the Laboratory, an autoclave in which the magnesium silicate is heated together with a certain quantity of water. After being sealed, the vessel is heated to the desired temperature, and, depending upon the quantity of water added, a pressure of water vapor is developed which is known only approximately (because of our imperfect knowledge of the properties of water at high temperatures), but with sufficient accuracy to permit useful conclusions to be drawn. With this apparatus it is possible to determine the phases formed at the calculated pressure and at the measured temperature prevailing in the pressure vessel.

The method gives only preliminary orienting values, but in the system MgO—SiO2—H2O it was ascertained quite definitely that no liquid phase is formed at temperatures and pressures attainable with this type of apparatus. Even with only solid phases and vapor present, it was found possible to prepare all the more common natural hydrous silicates of magnesium and also the anhydrous silicates forsterite and enstatite. Moreover, these phases appeared in a systematic manner suggesting that equilibrium was attained or closely approached; but in order to have full assurance of the attainment of equilibrium it may be necessary to add another oxide which will induce formation of liquid at the temperatures and pressures of the experiments. To this end it is proposed to add K2O, but before proceeding farther it seemed desirable to investigate

the "dry" system K_2O—MgO—SiO_2) as reported in a later section.

The magnesium silicates formed in the experiments now completed are common in certain varieties of igneous and metamorphic rocks, and a knowledge of their ranges of stability with respect to pressure and temperature would throw light on the conditions of their formation in Nature. A few experiments on the same materials have been made with another type of apparatus, described below, which was designed to render possible the direct measurement of the pressure in the system and to facilitate all manipulations. With this apparatus it was possible also to go to a much higher temperature than with the conventional pressure vessel. Some of the results obtained in this manner are significant in connection with the supposed magmatic origin of certain serpentine masses. Thus, synthetic serpentine when heated to 900^0 C at 15,000 lb/in^2 water pressure gave forsterite and enstatite. At 8oo° C and 23,000 lb/in^2 pressure it gave the same products, and at 700° C and 30,000 lb/in^2 it gave forsterite and talc, in all cases without formation of liquid. The last-mentioned pressure corresponds to an overburden of some four to five miles of impervious rock of density 2.7. No serpentine magma and no formation of serpentine in any manner can be regarded as possible under temperature-pressure conditions corresponding to those mentioned immediately above.

NEW TYPE OF PRESSURE APPARATUS

The apparatus with which these and other results to be described were obtained (Tuttle) consists of a small cylindrical pressure vessel made of stainless steel with an external diameter of 9/16 inch, an internal diameter of 3/32 inch, and a length of 7/3 inch. The internal chamber is only 3/8 inch deep, so that one end is permanently closed. The other end is finished with a cone of much smaller maximum diameter than the cylinder, and when in use the pressure vessel stands with its closed end upward and its conical end resting in a conical depression in a stainless steel rod, which forms a cone-in-cone joint similar to that commonly used in pressure lines. In the stainless steel rod a minute axial bore is made which enters the bottom (apex) of the lower cone and permits access of water vapor to the charge in the small pressure vessel. A high-pressure pump supplies water at a pressure measured with a gauge. The pressure vessel is held in position and the cone joint is kept closed by means of another stainless steel rod, which rests on the upper, closed end of the pressure vessel and to which a downward pressure can be applied as a dead weight by means of a lever arm, in a manner similar *to* that used in a testing machine. In practice, a charge of 8 to 10 mg of the material to be investigated is placed in a minute platinum crucible, which is set on a silver pedestal that rests on the lower cone surface; the pressure vessel is placed in position over the charge; a weight is hung on the lever arm sufficient to balance the relatively small pressure developed over the very small area of the cone joint; a split furnace, like that commonly used in organic combustions but mounted in a vertical instead of the usual horizontal position, is swung into place around the pressure chamber and its accessory rods; and the chamber is heated to the desired temperature, which is measured by means of a thermocouple inserted in the wall of the pressure vessel. At the same time the water supply is pumped up to the desired pressure, and the water, which is necessarily converted to vapor at the temperature of the chamber, is admitted by opening a valve which re-

mains open throughout the run. When the run is completed the furnace is swung aside and a jet of air is directed against the pressure chamber. By this means the equilibrium is quenched, and after release of the pressure the charge can be removed for examination under the microscope and for determination of water content.

This apparatus has served to determine equilibrium up to 900° C at pressures up to 15,000 lb/in^2 and at 800° C up to 30,000 lb/in^2 in a variety of silicate mixtures in which equilibrium can be obtained in one hour. At lower temperatures and pressures it is possible to determine equilibrium in materials that require much longer runs. By substituting for the stainless steel a material having greater "hot strength" it will be possible to extend the range of experimentation.

STUDIES IN THE SYSTEM POTASH—ALUMINA—SILICA—WATER

The above-described apparatus has been used principally for determination of equilibrium of potassium aluminum silicates with water (Bowen, Tuttle). Glasses which had already been prepared by Schairer and Bowen for their investigation of the dry system K2O—AI2O3—SiC>2 were used in the investigation. The liquidus temperatures for compositions lying on portions of two joins in this system have been determined for two isobars, 15,000 lb/in^2 and 30,000 lb/in^2. The two joins are the K2O*4SiO2—leucite join and the K2O*6SiO2—orthoclase join. The liquidus temperatures as determined for dry melts on the former join are lowered, in the orthoclase field, by a nearly uniform amount of about ioo° C due to water vapor at a pressure of 15,000 lb/in^2. The amount of water dissolved in the liquids at the liquidus temperatures increased from about 5 per cent in the high alumina compositions to about 20 per cent in the K2O'4SiO$_2$ composition itself. At 30,000 lb/in^2 pressure of water vapor there is further lowering of the orthoclase liquidus curve amounting to about 40° C, and the content of water in the silicate liquids at liquidus temperatures is nearly doubled for the more aluminous mixtures, but is increased only about 25 per cent as the K$_2$O$^{\#}$4SiO$_2$ composition is approached.

The other join (K2O'6SiO$_2$—orthoclase) gives comparable results at 15,000 lb/in^2, but at 30,000 lb/in^2 there is scarcely any additional lowering even though the amount of water dissolved in the liquids is significantly greater at the higher pressure. Evidently, the tendency of increased pressure *per se* to raise the melting temperatures acts counter to the effect of pressure in inducing a greater solubility of water and consequent lowering of melting temperatures. It is possible, therefore, that these mixtures may exhibit a minimum melting temperature on their p-t curves, a question that will be investigated further. Such a minimum melting temperature is of particular interest in connection with magma formation, and in the earth might give rise to an asthenosphere (a zone of easy melting) with rigid zones both above it and below it, a situation that would account for some seemingly contradictory geophysical phenomena, such as isostatic adjustment, general earth rigidity, and deep-focus earthquakes.

GRANITE—WATER

The new apparatus affords a simpler means of studying the equilibrium of granite with water, and some experiments are being made in continuation of Goranson's previous studies of these compositions (Bowen, Tuttle).

STEAM-QUENCHING FURNACE

The improvement of this apparatus preparatory to the carrying out of a number of studies that have been planned has proved a somewhat troublesome matter, but work has been progressing satisfactorily (Morey, Ingerson). A new pressure vessel has been designed with a view to eliminating some of the previous difficulties. Another type of apparatus consists of a pump, similar to that used by Bowen and Tuttle, connected to one of the conventional pressure vessels by a screw closure and suspended in an electric furnace, the pressure being led into the apparatus through a capillary hole in the plunger. This hole is threaded inside the vessel and a capillary carries the water down to the bottom. This was found to be necessary to prevent chilling of the copper washer at the seal, with resulting leakage. A collar is threaded on the upper part of this capillary, from which four quenching charges can be suspended. Many runs have been made with this apparatus, and it has worked well.

By proper control of the cooling rate it is possible to cool the charges without their "puffing up," an annoying and mysterious behavior of specimens in the quenching furnace. Several water determinations have been made on homogeneous melts so obtained. It is difficult to summarize the results in tabular or graphic form, but it has been established that the compositions at and near the eutectic between sodium disilicatc and quartz show a continuous solubility past the critical temperature of water; that is, the solubility curve in this region does not intersect the critical region. This leads to great complication in the phase equilibrium diagram of this system. The solubility curves of both sodium metasilicate and sodium disilicate are retrograde below the critical temperature of water, and each curve shows a lower critical end point at a temperature which is practically that for pure water. Previous work has shown that with sodium disilicate this end point lies not much above 380° C and is at a pressure of the order of 750 atmospheres. Moreover, the intersection of the critical curve and solubility curve takes place while the pressure along the three-phase curve is still increasing with decreasing temperature. Since there is no intersection along the boundary curve, it will show a maximum along its p-t curve. Hence, some region of higher Na_2O content will show the transition between these two types. The work on this system should be completed next year.

FILTER AUTOCLAVE

Work is being resumed with the apparatus developed before the war for the purpose of filtering high-temperature solutions *in situ* (Burlew). The apparatus was successfully used for measurements on alkali—carbonate—water solutions. A paper embodying the results of that investigation (Burlew, Morey) will be completed at an early date. Further work with the autoclave will be for the immediate purpose of determining more thoroughly its general utility for equilibrium, studies in mixtures of silicates with water under pressure.

EQUILIBRIUM RELATIONS IN ANHYDROUS MIXTURES

NEPHEUNE—"POTASH NEPHEUNE"—SILICA

Substantial progress was made on the determination of the three-phase boundaries necessary to define the composition of the nepheiine solid solution in equilibrium with liquids, leucżte, and alkali-feldspars in "petrogeny's residua system" (Schairer). Suitable compositions in the very viscous

region near the feldspar-silica boundary curve were prepared and put in furnaces to crystallize for several months or even years, in order to ascertain whether crystallization is possible, or whether because of failure of the melts to crystallize it is impracticable experimentally to determine the phase relations in this particular region.

ALBITE—ANORTHITE—SILICA

Upon examination of the data previously obtained it was found that all results were not consistent, and that for the precise location of some of the three-phase boundaries (those at the lower temperatures) longer runs than had been given were required. These longer runs were made during the year, and the data are now essentially complete (Schairer).

POTASH—MAGNESIA—SILICA

In order to approach the problem of the stability and crystallization relations of biotite in igneous rocks, a knowledge of the dry quaternary system K2O—MgO—AI2O3—SiO2 is necessary before H2O can be included as an additional component (Schairer).

The ternary system K2O—MgO—SiO2 is one of the limiting systems of this quaternary system. Since no information on the phase relations in the ternary system was available, plans were made to begin an investigation of it. Mr. Edwin W. Roedder, of Columbia University, who has been granted a one-year fellowship by the Carnegie Institution, will work with Schairer on this ternary system, beginning in September.

In order that the work might be started promptly, nine compositions were prepared to explore the general relations, and quenching runs were completed on these nine compositions. This preliminary reconnaissance showed that the fields of forsterite and periclase occupy a large portion of the liquidus surface in this system. The only compositions that do not lie in either the field of forsterite or that of periclase are in that portion of the system with less than about 15 per cent MgO or with about 70 per cent or more SiO_2. Two ternary compounds, one isometric and the other hexagonal, but as yet unidentified as to composition, were encountered in the preliminary reconnaissance.

POTASH—MAGNESIA—ALUMINA—SILICA

Work on this quaternary system (Schairer) has been outlined, and K_2O—SiO_2 glasses have been prepared for use as a source of K2O in making the quaternary compositions. Two planes which might be ternary systems within the quaternary system were selected for study. These are forsterite—leucite—silica and potassium disilicate—forsterite—leucite. Reconnaissance compositions have been selected, and six melts in the join forsterite—leucite—silica are now in preparation.

PREPARATION OF MANUSCRIPTS FOR PUBLICATION

A summary paper giving the final diagrams for Na2O—AI2O3—SiO_2 and K2O—$A1_2O_S$—SiO2 and the principal results (but not the detailed data) was prepared and published (Schairer, Bowen) under the title "Melting relations in the systems Na2O—AI2O3—SiO_2 and K2O—AI2O3--SiQ_2."

Another paper already prepared embodied the experimental results for the system anorthite—leucite—silica and some of the applications to petrology (Schairer, Bowen). A broad discussion of the origin of leucite-bearing and other alkaline rocks was not included in this paper and is reserved for a future paper to be written

when the system $KAlSiO_4$—NaAlSiO*—SiO_2 is completed.

Numerous diagrams have been prepared for the systems Na_2O—AUOa—SiC^ and K_2O—AI2O3—SiO_2 (Schairer), and the tables of experimental data are now complete. The manuscripts of the detailed papers will be completed at an early date. Diagrams were made just before the war for a paper entitled "The quaternary system CaO—FeO—MgO—SiO_2. I. Some relations in the join $CaSiO_3$—akermanite—FeO" (Schairer, Osborn). The data are about to be assembled for publication. Another paper will present the results of studies on the melting relations in the system FeO—AI2O3—SiO_2 (Schairer), the measurements on which were completed in 1940.

Work on the system diopside—anorthite—silica (Greig) was undertaken some years ago with the expectation that, except for the region where two liquids coexist, the system would be a simple ternary one with a eutectic, and that it would, therefore, involve but little work. The liquidus surfaces were readily located, but a slight difficulty was encountered, arising from the circumstance that, although tridymite is the stable form of silica at the eutectic temperature, cristobalite rather than tridymite is always formed. There is reason to believe that the tridymite liquidus surface lies only slightly above the cristobalite liquidus surface, and it is, therefore, to be expected that the stable eutectic will be close to the measured metastable eutectic that has cristobalite as the silica phase. A complication was found in the "binary" system diopside—anorthite. Contrary to expectation, this system proved not to be a simple binary one. The results of the investigation are to be prepared for publication without further experimental work on it, and in particular without an attempt to determine the true eutectic with tridymite.

Some time ago, a number of experiments were made on the melting of natural rocks (Greig, Shepherd, Merwin). This work began in an effort to determine the relative melting temperatures of granite and basalt (diabase). After the determination of the temperatures of complete melting and the temperature range of melting, the measurement of the liquidus temperature was extended to cover a series of rocks ranging in composition from a typical basalt to siliceous obsidian. An effort was made to find a practical method for more detailed phase equilibrium work on basaltic rocks. Unfortunately, the melts reacted with all the containers that were tried, so that their composition did not remain constant. It is now planned to write up for publication the results of this investigation with a minimum of additional experimental work.

A comprehensive revision of the first three-component system worked out at the Geophysical Laboratory, namely, the system CaO—AI2O3—SiO_2, has been undertaken by Wright. The results of this work are important not only in petrology, but also in the cement industry, the research organizations of which have encouraged the bringing up to date and republication of this basic information.

The original work on the iron-copper sulfides contained only abbreviated descriptions of the products. Subsequently, further studies of the textures of the products were made, and a series of natural-color photographs were taken (Merwin, Greig). Plans are being made to assemble these results properly and publish them together with some of the color photographs.

The old work on the system NatO—CaO—*S1O2* has been assembled and studied

(Morey). The material ready for publication includes a large number of mixtures—more than in the original publication—made primarily for the density-index study published with Merwin. A phosphate system which is part of the ternary system Na2O—K2O—P2O5 included within the limits $NaPO_3$—$Na_4P_2O_7$—K4P2O7—KPO3 still requires some additional measurements (Morey).

Other past investigations, the results of which are about ready for publication, include the phase relations in the systems tellurium—silver—gold and potassium disilicate—sodium disilicate, and studies of transitions in compounds of silver with sulfur and other elements (Kracek).

As fast as the various subjects included in the investigations carried out in connection with the war work have been declassified, steps have been taken to assemble the results that are of more than ephemeral value and put the information in form for publication. Some of this work has produced results of direct or indirect applicability to the current program of the Laboratory, as, for example, the work on artificial willemite needles (Ingerson, Tuttle, Geophysical Laboratory publication no. 1090). Among papers scheduled for early publication are those on the double fluorides of zinc (Ingerson, Morey); the systems K_2O—ZnO—SiO_2, ZnO—B_2O_3—S1O2, and Zn2SiC>4—Zn_2GeO4 (Ingerson, Morey, Tuttle); and the decomposition of analcite (Ingerson, Morey).

THERMAL QUANTITIES

As was emphasized in the outline of the Laboratory's program for future research, presented in the annual report last year, effective application of the results of laboratory measurements of silicate equilibria requires reliable data on specific heats, latent heats of fusion, heats of solution, and heats of reaction of rock-forming substances. The existing information on this subject is wholly inadequate, and it is, therefore, very important that active attention be given to thermal measurements. As a first step in setting up a calorimetric program, a careful survey of existing data on rock-forming minerals was carried out (Kracek). The report embodying the results and conclusions points the way toward the most profitable lines of experimentation.

For the immediate future we plan to carry out measurements of the heats of solution, in appropriate solvents, of a number of the more important types of silicate minerals, in both the crystalline and the glassy condition. From the differences in the values for the crystals and corresponding glasses, combined with data on specific heats, the latent heats of melting at the melting point will be deduced. It may be noted in passing that by a well known thermodynamic relation the latent heat of a mineral is related to the slopes of melting curves in equilibrium diagrams of which the minerals are constituents.

Values of specific heats in some cases are already available, partly from the early work of this Laboratory and partly from work performed elsewhere. For a well rounded program of thermal studies, it is important that further studies of specific heats be made in the near future.

Apparatus for measuring heats of solution is under construction. It consists of a 900-cm^3 gold calorimeter solution vessel (in which the mineral can be dissolved in hydrofluoric or other acids, or in alkali solutions) and the associated calorimetric equipment necessary for measuring the heat evolved during the solution process. Apparatus for the measurement of specific

heats at high temperatures will be added during the coming year. Calorimetric studies, for our purposes, may be divided into three categories: *(a)* collection of data for a specific purpose, that is, directed toward a particular petrologic problem; *(h)* application of an indirect, thermodynamic, method for obtaining heats of transformation; and *(c)* research in calorimetry, directed toward improvement of existing methods and development of new methods. In the program as planned, the emphasis initially is placed on the collection of data through the medium of methods already developed. The data thus obtained should be fitted to a thermodynamic framework in a more detailed manner than has been the custom heretofore. The substances awaiting study are so numerous that it seems wise to select for immediate study those that are the more important petrologically. Accordingly, we shall begin with measurements on wollastonite, diopside, and enstatite, to be followed by orthoclase, albite, anorthite, leucite, nepheline, "potash nepheline," and various other silicates and aluminosilicates that form the more abundant constituents of rocks.

The essence of the indirect method for determining the stability relations of minerals is to measure the specific heats of the appropriate compounds over a range of temperatures, including very low temperatures, to determine also a heat of reaction at a convenient temperature, and then to utilize a simple principle of thermodynamics so as to calculate the temperature at which the reversible transformation in question takes place at one atmosphere pressure, or the pressure at which the transformation takes place at a specified temperature. It is expected that this procedure will broaden our knowledge of thermal relations in petrology by allowing us to determine the conditions under which a mineral may be formed from another mineral or combination of minerals even when it is impossible by existing experimental techniques to observe the transformation directly.

A splendid start has been made on the thermal part of our program through the efforts of Dr. Th. G. Sahama, who received an appointment as research associate of the Carnegie Institution and who has been generously accorded the privilege of working initially at the Pacific Experiment Station of the United States Bureau of Mines, at Berkeley, California. Using the hydrofluoric acid solution calorimeter developed by Dr. K. K. Kelley and his associates, Dr. Sahama has been attacking the general problem of the stability of the orthorhombic pyroxenes. As is well known, the magnesium compound $MgSiO_3$ (enstatite) is a stable form, and of widespread natural occurrence. The corresponding iron compound FeSiC>3 (orthoferrosilite) has not been found in Nature and has not been prepared artificially. However, isomorphous mixtures of FeSiOs and MgSiOs up to about 80 to 90 per cent FeSiOs are known. Accordingly, it has been concluded that the pure $FeSiO_3$ is unstable.

By determining the free energy change in the reaction $(Mg,Fe)_2SiO4 + SiO_2 = 2(Mg,Fe)SiOs$ with changing Mg-Fe ratio, it should be possible to find out whether or not pure FeSiOs is thermodynamically stable, and, if it is unstable, where the stability limit in the series MgSiOs—FeSiOs lies. The solution of this problem in this way, if it should prove possible, would illustrate the importance, as well as the possibilities, of the application of thermochemical and thermodynamic methods for investigating the formation of minerals in natural rocks. This investigation may shed light on the observation that ferrous iron-magnesium silicate, if extremely rich in iron, crystallizes in the form of the orthosilicate (fayalitc) together with

quartz, and, if containing less iron, reacts with silica and forms metasilicate (pyroxene).

To solve this particular problem, measurements of heats of formation and specific heats of the several compounds are necessary. Fortunately, specific heats at low temperatures were previously measured at the Pacific Experiment Station. The heats of formation of a number of natural olivines and pyroxenes, as well as of artificially made Mg_2SiO_4, MgSiOs, and Fe2SiO4 prepared at the Station, have now been measured with the solution calorimeter.

This calorimeter, as used for the determination of the heats of solution of minerals in hydrofluoric acid solutions, is constructed in such a way as to allow measurements at temperatures somewhat above room temperature, for instance, at $+75^0$ C. The solution vessel is made of platinum so that hydrofluoric acid can be used as solvent. Accordingly, with this calorimeter all silicate or other minerals which are sufficiently soluble in the hot HF solution can be determined. More specifically, the heats can be measured for those silicate minerals of which about 1 gm of material completely dissolves in about 800 ml of hydrofluoric acid during a time of at most 30 minutes and at a temperature of no more than $+75^0$ C. It would be possible, therefore, to make calorimetric determinations on most substances on which a ferrous iron determination can readily be carried out by ordinary analytical methods. Of course, besides pure hydrofluoric acid, all other acids or acid mixtures not attacking platinum can be used as well.

Although, for the time being, primary emphasis is to be placed upon the measurement of thermal quantities by such techniques as are available for immediate use, attention to the development of new methods will be given as the thermal work progresses, with the expectation that more exact and effective procedures will be found.

VOLCANIC PRODUCTS

A variety of interesting rocks, incrustations, and miscellaneous products are being subjected to systematic chemical and microscopic studies (Zies, Merwin) for the purpose of obtaining a better understanding of various aspects of volcanic activity.

Several weeks were spent in reviewing the samples that were collected at Santiaguito (the new volcanic edifice located on the old volcano of Santa Maria in Guatemala), the samples from San Miguel in El Salvador, and the samples from Batoer on the island of Bali in the Dutch East Indies. It has seemed preferable for the immediate future to confine the work to the study of samples collected on the various expeditions to Santiaguito. This work includes the study of (1) the fresh rocks, (2) the rocks altered by fumarolic activity, and (3) the condensates of the fumarolic emanations. These emanations, issuing at a temperature of 350° C, consist mostly of steam, but preliminary examination begun before the war revealed the presence of an unusually large content of hydrochloric acid, sulfuric acid, and sulfur dioxide. Hydriodic, hydrobromic, hydrofluoric, and boric acids were present in much smaller amounts. In view of the fact that these are commonly referred to as minor constituents, the quantities are surprisingly large. The approximate amounts of the acid constituents in one liter of the aqueous condensate are as follows: HC1 and H2SO4, about 8.0 gm each; SO2, about 0.4 gm; HI, 5 mg; HBr, 20 mg; HF, 65

mg; and B_2O_3? 55 mg. Even a casual glance at this list of constituents will impress one with the desirability of enlarging our empirical background, by obtaining additional evidence from combined field and laboratory studies that will broaden our knowledge of the role of volatile constituents in the formation of rocks.

Some time was spent in trying out various known methods for the positive identification of the hydrobromic acid, and a further effort was made to adapt the chosen method for its estimation in the highly acid condensates. This work is now well enough in hand so that the method can be applied to all samples collected. An attempt will also be made to find the various volatile constituents in the fresh rock. This may not prove feasible with respect to the minor constituents, but it is believed that the effort should be made in order to show whether the rock extruded by Santiaguito is the actual source of the volatile constituents.

In the course of these studies, it has been found that the fresh rock is of more than casual interest. The word "fresh" here must be used advisedly, for it appears that the rocks have undergone significant changes during the slow period of their extrusion. It is not improbable that the relatively low temperatures at which the rocks reached the surface can be correlated with the changes in mineral composition and with the volatile constituents. In this connection, it should be noted that in 1940 the temperature of the extrusion of such rocks was measured and found to be approximately 725° C.

STUDIES ON RADIOACTIVITY

Several researches involving the distribution of radioactivity in materials of the earth's crust were interrupted by the war. Most of these were of sufficient importance to justify rounding out the investigations and putting the results in form for publication. During the past year, the work on the radium content of ultramafic rocks (e.g., peridotites and dunites) has been completed, and one manuscript has been prepared (Davis). This project was undertaken in co-operation with Dr. H. EL Hess, of Princeton University, for the purpose of shedding light on the connection between mountain building and the intrusion of masses of serpentine or peridotite. A second manuscript dealing with the interpretation of the results will be ready soon.

Another project interrupted by the war had to do with the radium content of some varved clays obtained through Dr. E. A* Johnson, of the Department of Terrestrial Magnetism of the Carnegie Institution. These clays exhibited some very interesting radioactive properties. There is a definite rhythm in the radium content, the summer portions of the varves having only about 60 per cent of the radium content of the winter portions (Urry). Moreover, the radium content of the summer portions of the varves increases with time, whereas that of the winter portions decreases. A time scale has been established by Antevs, but it has as yet proved impossible to tie this scale in satisfactorily with the historical time scale.

One of the objects of investigating the varved clays was to explore the possibility that relations between the radioelements were similar to those that had previously been found in ocean sediments. In this case the curves of radium content against time would represent portions of one or another of the curves that were given for the radioelements in nonequilibrium systems. Anal-

ysis of the data obtained for the varved clays indicates that this is possible, and, therefore, it may be feasible to extend Antevs' scale to the present.

Messrs. O. W. Torreson and T. J. Murphy, of the Department of Terrestrial Magnetism, kindly collected for us this spring (1947) for determination of the water content some fresh sealed samples of the same varves from which samples were obtained in 1940 by Messrs. Piggot and Johnson. These determinations, which have been completed, are of interest in other fields as well as our own. The radium content of the water portion of the clays was also measured this year.

Independent analyses of the summer and winter curves of radium content against years (Antevs) yield the same age for the varved clays of Hartford, Connecticut, namely, 18,000 years. Although the attack is to be regarded merely as a preliminary one, the measurements as planned by us have been completed, and the results are being written up.

RADIUM AND URANIUM CONTENT OF SEA WATER

An investigation of radioactivity relations in sea water was commenced just before the war in collaboration with Dr. Elizabeth Rona, now of Trinity College, and with the assistance of the Woods Hole Oceanographic Institution. The measurements of the radium content of sea water and also of a few samples of river water—which proved to be of theoretical interest in connection with the work on sea water—were completed in 1942.

Of particular interest is the ratio of radium to uranium, which we find is much higher in river water and much lower In sea water than the ratio pertaining to radioactive equilibrium. The results, which are now being assembled for publication, may have long-range economic importance because they appear to explain the very different uranium contents of fresh-water and marine black shales.

Some determinations of the radium content of meteorites have been made (Davis, Urry) because of the bearing of such results on the radioactivity of ultramafic rocks, mentioned above. The radium content of the iron meteorites and of the olivine-iron meteorites is not well established by existing results, which show wide discrepancies. It seemed desirable, therefore, to make a few determinations (Davis, Urry) on specimens of iron meteorites and pallasites kindly contributed by the United States National Museum. Results obtained by two different methods show puzzling differences and indicate that further research on the methods of determining radium in the metallic parts of meteorites is needed.

As a result of a conversation between Dr. Victor F. Hess, of Fordham University, and Dr. Merle A. Tuve, Director of the Department of Terrestrial Magnetism, regarding the observations by Hess that the ionization produced by the heat radiation from rocks is not accounted for by the measured uranium, thorium, and potassium content of the rock, Dr. Tuve proposed that a sample of rock with a negligible radioactive content be sought in order to test the idea that extraneous ionization might be produced by a cosmic-ray transition in the mass of rock surrounding the ionization chamber. The Balsam Gap dunite seems to be the most suitable for such an experiment, and we undertook to obtain an adequate sample for use by Dr. Hess.

As a further test of the hypothesis, an experiment is being made (Urry) whereby the ionization produced by granite from Quincy, Massachusetts, is measured, first,

in the natural state, and, second, after the addition of amounts of uranium, thorium, and potassium which are equivalent to the amounts of these contained in the granite.

Because of the interest attaching to the dunite deposits near Balsam Gap, North Carolina, two trips were made to this locality. The first, by Davis and Urry, was for the purpose of obtaining material for mineral separation; and the second, by Davis and Urry with Murphy of the Department of Terrestrial Magnetism, was for the purpose of collecting about one thousand pounds of the dunite to be used in the co-operative research, mentioned above, on some apparent anomalies in the radioactivity of rocks.

OTHER INVESTIGATIONS

In addition to the systematic study of volcanic products mentioned above, Dr. Merwin, as research associate, has been preparing a series of diagrams representing the densities, the refractive indices, and the refractive dispersions of organic liquids that are of interest in connection with the determination of refractive index of mineral grains by the immersion method.

A start has been made on a project for the orderly application of statistical methods to some fundamental problems in geology. There are those who believe that progress in the broad field of rock formation is handicapped by the lack o£ clear correlation of laboratory experimentation with field observations, and that in many instances far-reaching conclusions have been drawn by incomplete or haphazard utilization of existing data. As an example of this, it has been stated that in the Bancroft region of Ontario, Canada, granite has been transformed into syenite and then into foyaite, and it is important for the understanding of the genesis pf such rocks to know whether there is actually such a transition or not. Dr. Felix Chayes has been given an appointment as research associate of the Institution for the purpose of conducting studies on the application of certain statistical methods to petrometry. Beginning in May 1947, he started field work in New England areas and has been collecting a series of specimens for examination. As the report year closes, he is about to come to the Geophysical Laboratory to continue the investigation.

The co-operative work with the Department o£ Terrestrial Magnetism on deep seismic prospecting of the earth's outer layers is progressing satisfactorily. Information concerning the status of the project will be found in the report from that Department.

During the year the following papers were completed and submitted to technical journals for publication.

SUMMARY OF PUBLISHED WORK

(1088) Magmas. Norman L. Bowen. Boll, Gcol. Soc. Amen, vol. 58, pp. 263-280 (1947).

Address of the retiring president of the Geological Society of America given at the annual meeting of the Society at Chicago, December 26, 1946.

The address is concerned with some of the much-discussed problems of pctrogeny, including the nature and origin o£ primary magmas and the manner in which derivative magmas arc formed.

High-temperature studies of silicates in the laboratory tend to support the opinion, based on field evidence, that basaltic magma is a primary magma and that most other magmas are derived from it. There is now a general tendency to adhere to this opinion as regards the magmas that arc associated with surface

volcanism and the formation of hypabyssal masses. The question whether the great deep-seated masses of granite and closely related rocks can be regarded as derived from basaltic magma is much debated. Many investigators find no difficulty in accepting a large-scale differentiation in plutonic masses similar to that shown in some hypabyssal masses. On the other hand, many turn to altogether different processes for the production of most granite. These range from the supposed refusion of the granitic shell of the earth, which leaves the problem of the formation of this shell unsolved, to formation by metasomatic replacement of pre-existing rocks by means of hydrothermal solutions, and even to ion wandering in the crystal lattices. There is little prospect of early agreement on these questions.

A fundamental if not a wholly dominating position for basaltic magma being granted, it is important to know the exact nature of this primary material. Whether primary basalt has a notable water content or is nearly "dry" is a question on which divergent views are held. A decision is not readily reached on account of the possibility of contamination by extraneous water, but a comparison of the mineralogy and grain of deep-seated and surface manifestations seems to support the view that the water content is quite small and that it is only in derivative magmas that water may rise to notable proportions.

Pcridotite is regarded as a primary magma by some investigators, and the existence of such magmas with a water content high enough for direct formation of serpentine has been suggested. The balance of evidence seems to favor the cumulative rather than the orthomagmatic origin of peridotite and the secondary nature of serpentine, but many difficulties remain in connection with serpentine "intrusives."

(1089) Melting relations in the systems Na_2O—AL_2O_3—SiO_2 and K_2O—AI_2O_3—SiQ_2. J. P* Schaircr and N. L. Bowen. Amer. Jour. ScL, vol. 245, pp. 193-204 (1947).

The phase equilibrium relations in the ternary systems Na_2O—$A1_2O_S$—SiO_s and KfiO—AlaOg;—S1O2 are presented in this preliminary paper by means o£ four diagrams. Temperature and composition data are given for eleven ternary invariant points and nine binary invariant points in the system Na_2O—$A1_2O_3$—SiO_2 and for eleven ternary invariant points and ten binary invariant points in the system K_2O—$A1_2O_3$—SiO_2. The outstanding features of the two ternary systems are briefly presented. The very numerous data on which the diagrams are based and a full discussion of the preparation of the compositions studied, quenching data, the results, and some of the applications will appear later.

(1090) Artificial willemite needles. Earl Ingerson and O. F. Tuttle. Amer. Jour. Sci., vol. 245, pp. 313-319 (1947).

Clear fluorescent needles of willemite have been grown in heated bombs from SiO_2 and $Zn(OH)_2$-#$Mn(OH)_2$, with ratios of length to diameter up to 1200:1 and with lengths up to 3 cm. The length and length:width ratio increased as pressure was brought below the critical pressure in an 18-cc bomb; also, as the temperature was raised. Optimum pressure was about 1000 lb/in^2 for an 18-cc bomb and about 4000 lb/in^2 for one with a volume of 280 cc.

Fluorescence increased with increasing $Mn(OH)_2$ up to about $Zn(OH)_2$-o.2$Mn(OH)_2$. With higher concentrations, tephroite (Mn_2Si0_4) crystallized along with the willemite. $Mn(OH)_2$ in excess of 0.006 appeared to modify the habit of the willemite, making the crystals shorter and thicker.

Runs in an unlined steel bomb sometimes produced well formed crystals of fayalite in the crucible containing silica. In one such run the temperature was 439° C; pressure, 240 atmospheres.

The results indicate that if proper cognizance is taken o£ geologic occurrence and other factors, crystal habit might give some indication of relative temperatures and pressures of formation, especially in sublimates and in vesicles in extrusive rocks.

(1091) Liquid inclusions in geologic thermometry. Earl Ingerson. Amer. Mineralogist, vol. 32, pp. 375-388 (1947).

A satisfactory method of determining temperatures of crystallization o£ minerals from

the contained liquid inclusions would aid in the solution of many problems of geologic thermometry. The method has been in use for nearly ninety years, but recently published data on the specific volume of water at high temperatures and pressures allow much more accurate determination of the effect of original pressure than has been possible before. These data are here applied to the liquid inclusion problem for the first time. Data on the critical temperature of aqueous solutions of alkali halides provide the basis for better evaluation of the effect of concentration.

The fundamental assumption is that a liquid inclusion cavity was completely filled with fluid at the temperature and pressure under which it was formed. It must also be established that the inclusions are primary and that no leakage has occurred. Other necessary assumptions are that the change in volume of the mineral itself is insignificant and that changes in volume and concentration brought about by deposition of material from the solution as it cools are such as not to affect the results.

Curves have been prepared showing the relation between degree of filling of inclusions and temperature of disappearance of the vapor phase, both for pure water and for a 10 per cent solution of NaCl and K.C1. Two sets of curves show the relation between temperature of disappearance of the vapor phase, pressure at the time of formation, and temperature of formation.

Observational difficulties are discussed, and one is illustrated by means of photomicrographs. Uncertainties of interpretation are also discussed, including those involved in estimating original pressure.

Measurements on quartz from pegmatites indicate temperatures below 250° C, including pressure corrections of 54° to 73° C for specimens whose depth at time of formation can be estimated. As most other vein minerals and many of those in igneous and metamorphic rocks contain liquid inclusions, it is possible that this method may aid in the revision of considerable parts of the scale of geologic thermometry.

(1092) Testing gun steel and other alloys and metals for resistance to surface cracking. Earl Ingerson. Amer. Inst. Min. and Met. Engrs., Metals TechnoL, vol. 14, Tech. Pub. No. 2223, 13 pp. (1947).

During the war, studies on gun erosion were conducted at the Geophysical Laboratory. The so-called heat checks in guns appear to aid erosion. For this reason it was desirable to develop a method for testing the resistance of metals and alloys to surface cracking under conditions of temperature, pressure, and action of powder gases similar to those obtaining in guns.

The test consisted in placing rod-shaped specimens with flat sides in a modified erosion plug and allowing part of the hot explosion gases to flow past the surfaces during a series of shots. The flat sides facilitated examination and photography. The results of tests on various materials are summarized in tabular form, and remarks are made in the text about most of the materials.

Three kinds of cracks are described: (1) "heat checking," (2) "coarse cracking," and (3) "post-fusion cracks." Their development and relations to grain boundaries are discussed, and illustrated with photomicrographs. Heat checking may be due to rapid heating and cooling of the surface; possibly surface changes produced by the hot gases play a part. The coarse cracking is tentatively ascribed to mechanical shock. Post-fusion cracks are produced where there is actual melting of the surface.

In these tests, the erosion per round increases with increasing number of rounds. Erosion of the rods is caused by continued development of cracks and undercutting, with eventual tearing out of fragments, rather than by melting and "wiping off' of metal from the surface.

(1093) Annual report for 1946-1947.

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———and O. F. TUTTLE. Artificial willemite needles. Amer. Jour. ScL, vol. 245, pp. 313-319 (i947)«

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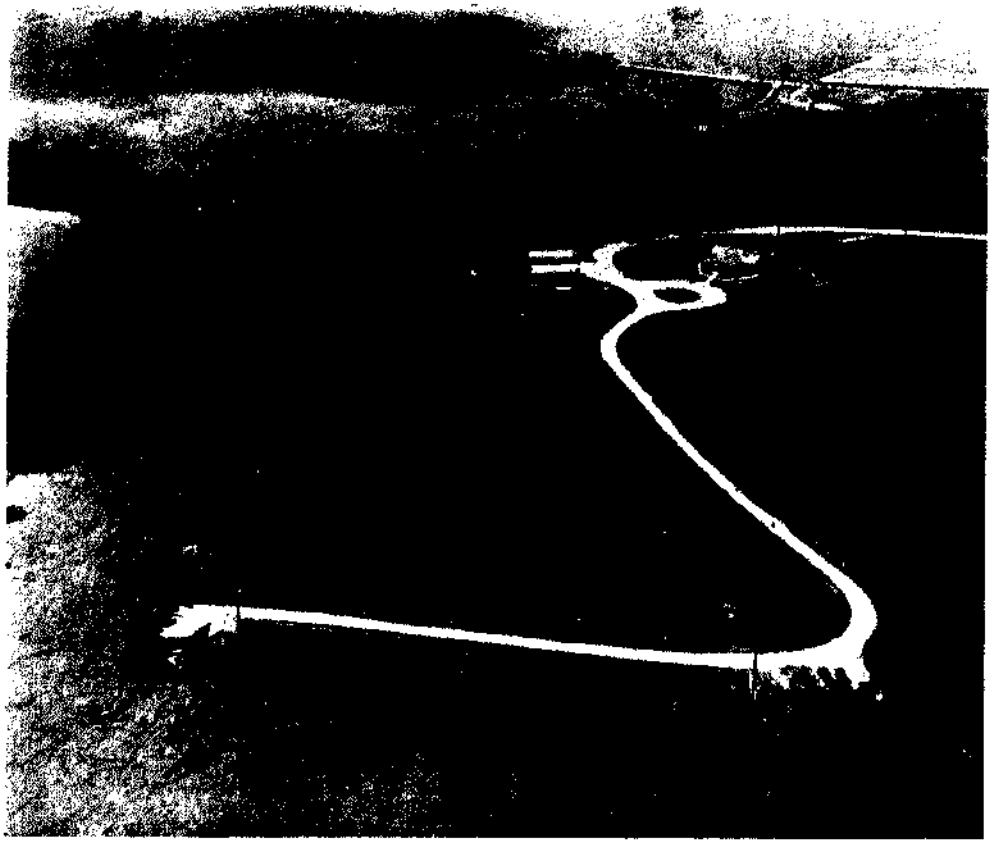
TUTTLE, O. F. See INGERSON, EARL.

PLATE I



DERWOOD EXPERIMENTAL LABORATORY

This Laboratory replaces the Kensington field station and provides the base for experiments in the high atmosphere, ionosphere, and related physical and solar phenomena, including experiments involving radio echo sounding, cosmic rays, solar noise, atmospheric ozone, and many related effects. The building in the upper right at the circle is the main experimental building; across the road to the left are the Qunnsct huts for storage and auxiliary power, and immediately adjacent are the searchlight building and the cosmic-ray building. In the lower right building, rapid-run ionospheric recordings are conducted. At the lower left are the laboratory and associated radar for recording of solar noise, radio field intensity, and the like.

DEPARTMENT OF TERRESTRIAL MAGNETISM

Washington, District of Columbia

MERLE A. TUVE, *Director*

REVIEW OF MAGNETIC SURVEY AND OBSERVATORY PROGRAM OF THE DEPARTMENT OF TERRESTRIAL MAGNETISM, 1904-1946

Introduction, As older programs initiated by this Department approach maturity, it is appropriate to outline their history, the main ideas inspiring their creation, principal results achieved, and tasks left undone, with a forward-looking account of the future potentialities of these programs. Publication of results of the magnetic and electric survey of the earth and of results of observations at observatories is nearing completion, and the time seems now ripe to review these large-scale past operations of the Department, with interest in the high hopes which engendered the programs, and with the perspective afforded by the passing of the years. In much the same way we hope to review in future years the multifrequency ionosphere-recording and nuclear-physics programs of the Department, from which emphasis likewise is being shifted, with effort in fresh directions.

It is to be noted that these programs in which the Department can claim with some truth to have pioneered on a major scale are in no sense terminated. On the contrary, they have expanded, usually far beyond the scope of the most active phase of our participation, in the hands of others. This statement is not true as concerns the magnetic survey of the oceans, which terminated with the sinking of the *Carnegie* in 1929, but the volume of new ocean magnetic measurements by airplane, after suitable instruments are developed, will no doubt in some years much surpass that acquired previously.

Much of the work here described was made possible by the whole-hearted cooperation of many individuals and organizations.

The early program of the Department. The Department's program of magnetic survey and observatory work, now being terminated, was set forth in general terms as two of three problems for attack in the initial proposal of 1903 for the founding of a Department of International Research in Terrestrial Magnetism by the Carnegie Institution of Washington. The third problem suggested was that of magnetic observations in ocean depths and atmospheric regions, and experiments of limited duration along these lines, instead of wide surveys, are included in our present program. However, though the major purpose stated was to investigate such problems of world-wide interest as relate to the magnetic and electric condition of the earth and its atmosphere, there can be little doubt that in the background there was hope of discovering the origin of the earth's magnetic and electric fields.

It is relatively easy to understand why the proposal for a world magnetic and electric survey would appeal to the imagination of the Trustees and President of the Institution in 1904. The earth's fields had been explored in only a few areas. The oceans, covering three-quarters of the area of the globe, as well as the polar regions, were largely open gaps. In vast areas such as the northern Pacific Ocean magnetic observations had never been

made. Here, then, was something to be done toward advancing scientific progress which should be of lasting benefit to mankind.

It seems likely also that Dr. Bauer, the moving spirit in the founding of the Department, hoped much from the more accurate mathematical representation of the geomagnetic field which would be made possible by a survey with wide coverage. Schmidt, in Germany, had earlier noted evidence based on inferior data suggesting a nonpotential part of the earth's field, but even this was incompatible with the observed air-to-earth electric current. These considerations also, strongly supported by men like Schuster abroad, led to expanded scope of the survey program, once under way, including major emphasis on the more difficult phase of ocean magnetic work.

In the enthusiasm of the time the question of a suitable laboratory for the new endeavor was deferred, with funds devoted rather to ocean work, and only modest quarters were occupied during the first few years. A wooden sailing vessel, *Galilee,* was chartered and modified to reduce the amount of magnetic materials near observing platforms, so that magnetic survey measurements could be undertaken. Three successful cruises in the Pacific were made during the years 1905 to 1908, but troubles due to magnetic materials within the ship were not completely eliminated. The effects of these magnetic materials upon measurements of declination, inclination, horizontal intensity, and total intensity of the earth's field'varied with the time of cruise, roughness of passage, and geographical location. In the interest of economy and to improve the quality of the results, plans and specifications for a new nonmagnetic yacht, *Carnegie,* were drawn up in 1908. In December 1908, the Trustees made for this purpose what was up to that time the largest special appropriation of the Institution, and the *Carnegie* was launched June 12, 1909, in the presence of 3500 guests. The total original cost of the ship fully equipped was $115,000. Her early cruises were at once productive. Andrew Carnegie himself was so impressed during this period with the work of the Institution that he made available in 1911 a new and large appropriation. During the period from 1909 until her destruction by fire in 1929, the *Carnegie* made seven cruises covering all oceans, extending to the very boundaries of the north and south polar-ice areas. Together with those of the *Galilee,* these cruises totaled 361,413 nautical miles, and 3836 observations of magnetic declination and 2321 of inclination and horizontal intensity were made. Records were also obtained of atmospheric-electric potential gradient and conductivity. In addition, on the last cruise, extensive data relating to topography of the ocean bottom, oceanography, and the biology of the ocean were obtained and studied. The results have now been published in many volumes.

At the same time, the survey program *on* land was being vigorously pressed, with chief emphasis on South America, Africa, Australia, the islands of the various oceans, and, as opportunity offered, the polar regions. There were in all over a hundred expeditions, which yielded not only measurements at thousands of stations, but also intercomparisons and improvements of magnetic standards in other countries. Simultaneously, a laboratory program was begun which permitted extension to new work beyond that required for design and maintenance of instruments in the mainly observational program. This laboratory phase of attack on the two major background problems, the cause of the magnetic and of the electric field of the earth, became possible when the Department

moved to its present main building, completed in 1914 at a cost of $68,000, on a site of some eight acres in suburban Washington.

Hopes for a vigorous laboratory approach were not realized in these earlier years. At that time the observatory program required the attention of most of the staff, and it was necessary to devote much effort to the design and maintenance of the requisite observing instruments. The organization of the observational material in final form was in itself no small task. By 1920, however, some theoretical investigations of the data accumulated had been carried out, and though the description of the earth's magnetic and electric fields had been much improved, no real clue had emerged leading to their explanation. Bauer showed that all except a small percentage of the earth's field was of internal origin. By this time a laboratory approach by Barnett had shown that a rotating sphere becomes magnetic, but that the amount of magnetization is far too small to account for the earth's main field. Other studies by Swann also failed to solve the problem. The observation of ions in considerable quantity over the oceans, even though sea water is considerably less radioactive than the ground, was one factor leading to the establishment of cosmic rays as of extra-terrestrial origin.

There was uncertainty as to what profitable course might next be followed in relation to the main field problems, which exist in no less degree today. There remained, however, a lingering hope and faith that the surveys would show in some way a profitable approach, perhaps by ascertaining the world-wide pattern of secular change, not then at all available, which could be compared with that of other geophysical phenomena of the earth's crust. The surveys were therefore continued, and on land were facilitated by much greater and increasing participation by other organizations, stimulated by past endeavors of the Department.

The two riddles, the origin of the magnetic and that of the electric field of the earth, remained unsolved, with further progress difficult and uncertain. Because of dissatisfaction with prospects for rapid progress on these problems, attention was directed toward the more accessible magnetic and electric variations. In this way there arose the observatory program of the Department during the period 1916-1920, with particular emphasis on time variations. In an important sense, however, it was a continuation of the survey program, because the estimates of secular change depended for their accuracy on ascertaining and removing effects of magnetic variations recorded at observatories, and because it was possible only at the observatories themselves to obtain accurate estimates of secular changes.

The observatory program, 1920-1930. Following World War I, in which some of the staff were of help in the national crisis, perhaps most tangibly in the development of magnetic navigation for aircraft, and a little ahead of the times in the invention of the magnetic mine, ambitious postwar plans appeared for an observatory program. A good part of the staff formed a skilled and efficient data-gathering organization, and experience had already been obtained in operating magnetic and electric recording stations on a number of eclipse expeditions.

The initial plan for establishing nine magnetic observatories, mainly in the southern hemisphere, seems to have been withdrawn in the face of practical considerations, in favor of establishing one in Australia and one near the magnetic equator in South America, thereby materially improving the world network of observatories. Thus the observatory at

Watheroo, Western Australia, began operation on January i, 1919, and that at Huancayo, Peru, on March 1, 1922. It has turned out that these choices of site were particularly wise and fortunate.

This period was, however, one in which there was at least an undertone of hesitancy in continuing the previous program, then already carried forward for nearly twenty years. In 1922 the main results achieved were reviewed by a distinguished group of scientists, a sort of informal board of inquiry. They expressed general satisfaction with results achieved, and noted that at least the observational aspects of terrestrial magnetism and electricity had been rescued from what had approached a state of chaos. It was decided to curtail survey activities, since other agencies were now active in such work, and to pursue the observatory approach, which promised a better chance of correlations with solar and other phenomena, supported by laboratory and theoretical studies related to these problems.

The observing programs at Watheroo and Huancayo included in the early years continuous recordings of magnetic field components, earth-current potentials, and the vertical potential gradient and conductivity, two of five desirable atmospheric-electric elements. The plans contemplated operation through a sunspot cycle. Valuable recordings o£ variations were obtained at these points, relatively remote from other observatories, which helped considerably, in conjunction with those from other stations, in providing descriptions of these variations on a world-wide scale. The high elevation of the site of the Huancayo station (11,000 feet) seems to have provided no great advantage? The location of the observatory, however, on the geomagnetic equator proved to be opportune, and it was a surprise to find that the daily magnetic variation was more than twice as large as expected. When explained in later years, this feature was to become very useful in attaining rather complete understanding of this variation. Occasion was also taken to obtain recordings at other sites, usually for a period of one year. In co-operation with the United States Coast and Geodetic Survey, earth-current and atmospheric-electric elements were simultaneously recorded for many years at Tucson, Arizona. During this decade the routine accumulation of observatory and survey data (including those for the more extensive program of Cruise VII of the *Carnegie)* all but swamped the facilities of the Department.

There were, however, new influences at work early in the decade, which were destined to affect profoundly the future development of the observatory program in an unexpected manner. The informal recommendation of the conference in 1922 that a mathematical physicist be added to the staff brought Breit to the Department. His first assigned task was that of examining the possible relation of the earth's main fields to the general theory of relativity, then comparatively new. It was quickly found that this line of investigation seemed unpromising, and the search for other problems brought the suggestion of estimating the height of the ionized layers In the atmosphere by means of radio waves. This resulted in the so-called Breit-Tuve experiment, in which a pulse technique was evolved for sending and recording the return of radio waves at vertical incidence. The time taken for the waves to reach the ionospheric layer gave an estimate of its height, since the velocity of the waves

[1] It was the intention to establish the observatory on the magnetic equator somewhere near seat level, tot the magnetic character of all sites examined at or near sea level prohibited this. High altitude was not regarded as being of any special advantage.

was known. Thus was developed a new technique for probing the upper atmosphere, which was much more analytical and unambiguous than the frequency-change interference method simultaneously developed by Appleton in England. This pulse technique also became important much later as a basis for engineering applications such as radar. Although the potentialities of the new technique in the study of geomagnetic variations were not overlooked, the resources of the Department seemed inadequate to explore the new possibilities. After three years this work was set aside, since the National Bureau of Standards was prepared to undertake a large program in the radio field. The Department's program was resumed about five years later.

Following the pulse experiment, research was undertaken with high voltages in an effort to study the forces involved in collisions between electrons and electrons, and between protons and protons. After some years the experiments resulted in the discovery of intense force fields in the neighborhood of the nuclei of atoms, and later in experimental confirmation of the fission of uranium. These laboratory experiments as such had little relation to the objectives of the survey and observatory programs, but they gave expression to the hope that a clue to the source of the earth's main field might be found among unexplored properties of the fundamental particles composing atoms.

In atmospheric electricity the decade 1920-1930 was marked by the discovery, based on studies of ocean electric measurements of the *Carnegie*, that the negative electric charge over the earth's surface as a whole varied periodically by about 30 per cent of its average magnitude each 24 hours, independently of local time. This result stimulated moderately successful efforts to identify thunderstorms as the source of the supply current maintaining the negative charge of the earth, which otherwise would be reduced to a fraction of its observed value in a matter of minutes. This possibility is being checked in our present program, by attempts to measure the assumed current flow from thunderstorms up to the ionosphere, using instruments in airplanes flying above thunderheads.

Continuous measurements of vertical potential gradient and conductivity at the Huancayo, Watheroo, and Tucson observatories were studied. The results found, though interesting, were masked by uncertainties of various kinds due to local conditions, such as smoke from brush fires and smelters, and lack of local information respecting time variations in the amounts of large and small ions. It must now be acknowledged that the value of such records is uncertain in the absence of additional simultaneous measurements of the ionization of the air.

Two members of the Department, Gish and Rooney, introduced and developed early in this decade experimental approaches in the study of natural and induced earth currents. It was soon found that the time variations in earth-current potentials are probably adequately explained as produced by variations in geomagnetic fields of external origin. A practical technique of measuring earth resistivity was developed which is now widely used in geophysical prospecting. Apparatus for making continuous measurements of earth-current potentials were installed at Watheroo in 1923, Huancayo in 1926, and Tucson in 1931, and operated until 1946. The results confirmed the general qualitative agreement expected on the basis of electromagnetic induction, and were of Interest in connection with certain electric-transmission and communication problems of engineering.

By 1932, attempts to discover influences of solar eclipses on geomagnetic fluctuations were abandoned. Some progress was also made in providing more precise information respecting the correlations of geomagnetic, auroral, and earth-current variations with solar phenomena such as sunspots, stimulating efforts of the following decade.

The evolution of the observatory program, 1930-1940. The magnetic survey of the earth was now beginning to provide a descriptive pattern of secular change. This pattern became apparent in the magnetic elements on a world-wide scale for the first time, and was shown on Fisk's preliminary isoporic charts for 1922, published in 1931. Although magnetic surveys on land were continued, mainly for the purpose of improving estimates of secular change, ocean surveys were perforce abandoned because of the loss of the *Carnegie.* Accordingly the observatory program received greatly increased emphasis and expansion after 1930. It was broadened to include measurement of variations of the electron density and heights of ionized layers of the ionosphere, first at Huancayo in 1932 and later in 1933 at Watheroo. Suitable practical and automatic apparatus was developed by Berkner and others to send radio pulses yielding echoes from the ionosphere which were continuously recorded at a wide range of frequencies. This multifrequency equipment was installed at both Huancayo and Watheroo by 1938, and at College, Alaska, in 1941. It was of particular importance in that it provided a record of events throughout the range of about 100 to 300 km and higher within the ionosphere, for study in connection with geomagnetic and other phenomena observed at ground level Possibilities were further broadened by installation of a spcctrohelioscope at each observatory, permitting direct observation of solar phenomena.

In addition, seismographs were installed and operated at Huancayo in 1932. A later feature was the installation of cosmic-ray meters at Cheltenham, Maryland, in 1935; Huancayo, Peru, in 1936; Christchurch, New Zealand, in 1936; Teoloyucan, Mexico, in 1937; Godhavn, Greenland, in 1938; and San Juan, Puerto Rico, in 1947. This was a co-operative observatory venture sponsored by the Cosmic Ray Committee of the Carnegie Institution. The previously inaugurated recordings of the atmospheric-electric elements and earth-current potentials were continued as sustaining programs, though expectations were limited. The expanded observatory program had thus become in effect a broad program in geophysics, although under the directorship of Fleming, who continued the policies of Bauer, the major emphasis was placed upon those theoretical aspects useful in explaining the geomagnetic variations.

On April 8, 1936, a brilliant solar flare, accompanied by a nearly simultaneous change in magnetic intensity, radio fade-out, and earth currents, was observed by Scott, Torreson, and Stanton. This was a direct linkage of a spectacular solar phenomenon with terrestrial effects, though it now appears that the classic observation was in fact a hitherto discredited one of simultaneous magnetic changes during a solar flare made by Carrington in 1859, and that Dellinger had already noted that solar flares were sometimes accompanied by radio fade-outs. Nevertheless, the noting of this effect was dramatic, and McNish quickly found that the solar flare was almost simultaneously followed by an augmentation of the daily magnetic variation on quiet days.

This essentially established the fact that, of several theories proposed to explain the

daily magnetic variation, the only one tenable was the dynamo theory of Stewart-Schuster, later elaborated by Chapman. According to this theory, the daily magnetic variation is caused by electric currents produced in a conducting layer of the atmosphere below the E-region (the region of the ionosphere about ioo km above the earth's surface) by the motion of the layer across lines of force of the earth's main field; the augmentation of the daily variation is of course due to the marked increase in ionization and consequent increased conductivity accompanying the burst of ultraviolet light from the sun during the solar flare. The radio fade-out is due to absorption of the radio pulses near or within the same conducting layer. The changes noted in earth currents are caused by the changing geomagnetic field. The dynamo theory also satisfactorily explains the particularly large amplitudes of the solar and lunar daily magnetic variations discovered at Huancayo, a consequence of the noncoincidence of the geomagnetic and geographic equators.

Chapman, a research associate of the Institution in England, and his students developed, but did not complete, a theory ascribing magnetic storms to effects of electrically neutral streams of corpuscles of solar origin. They also estimated possible electric-current patterns within the atmosphere which could produce the large changes in the geomagnetic field during storms, and roughly estimated the height of electric currents near the auroral zone to be about ioo km. Inconclusive study was also made of the possibility that a part of the storm field was due to an electric ring current encircling the earth at a distance of a few earth radii. It was not shown how the electric current patterns in the atmosphere could arise from neutral streams of corpuscles emitted by the sun. These findings were further clarified in detail by various supporting researches carried out within the Department by McNish and Vestine. On the observational side, Berkner and Wells noted increases to iooo km in the height of the F-region (the highest layer) of the ionosphere during magnetic storms, and Forbush discovered that a decrease in cosmic rays usually appeared during the main phase of magnetic storms. Neither of the latter phenomena is as yet adequately understood. Consequently, it would seem that much remains to be done before all the effects connected with magnetic storms are satisfactorily explained.

Bartels, in Germany, also a research associate of the Institution, carried out extensive statistical studies, and made basic improvements in statistical techniques of universal interest, in correlating solar and geomagnetic disturbance. He showed how geomagnetic variations could be used to indicate variations in solar ultraviolet light and corpuscular emissions, and devised new measures of geomagnetic activity, the so-called K-indices, now widely used in the practical applications of radio communications. He also showed that the large lunar daily magnetic variation at Huancayo could be explained in accordance with Chapman's dynamo theory for this variation.

The data from seismographs installed in 1932 at Huancayo were not studied In the Department, but in the hands of Gutenberg and Richter of the Scismological Laboratory, Pasadena, were particularly valuable in defining the earthquake zones along the Andes and world epicenters, ant! in the discovery of a silent zone for shock waves propagated through the earth, indicating a zone of discontinuity or velocity change at a depth of several hundred kilometers.

There seems to have been no immediate necessity which dictated the inauguration

of the Institution's program of recordings of cosmic-ray intensity at several observatories. This was begun simply to obtain a continuous and world-wide picture of the variations of cosmic-ray intensity. The results found would be completely unexpected even today, on any reasonable basis within our experience. This program is hence a fine example of the truth of the proposition that in geophysical research long-continued recordings of a new geophysical phenomenon will in the end turn up something of value, and is in a measure a justification for the blind faith in this mode of attack in geophysics. By contrast, there was every reason why the Department should have begun its cosmic-ray program before 1920, when members of the staff had been for some years bewildered by the presence of ions in quantity over the oceans; this might have led them to pioneer the development of the field of cosmic rays.

The first important effect noted in the program of cosmic-ray recordings which began in 1936 was the decrease by as much as 10 per cent in cosmic-ray intensity during the main phase of magnetic storms. Examples were also found of intense magnetic storms accompanied by little or no decrease in cosmic-ray intensity. Attempts were made by Forbush, following Chapman, to explain this effect as due to decrease in the effective magnetic moment of the earth through the additive field of an equatorial ring current producing the main phase of storms, but this point is not yet established. A more spectacular finding by Forbush during the current year was that in about ten years of records there were three increases, one as great as 20 per cents in cosmic-ray intensity during large solar flares. This suggests the sun and other light-emitting stars as the origin of cosmic rays.

The early recording programs in earth currents and atmospheric electricity were continued after 1930. In regard to earth currents, adequate data were obtained in polar regions at College, Alaska, and Chesterfield, Canada, which permitted construction of a tentative map of general global circulation of surface earth currents. The existence of the detailed relation was confirmed strikingly by the parallelism between earth currents and geomagnetic variations during the large unexplained increase in activity just after the winter solstice near Tucson. These programs were terminated at the end of 1946, though a few supplementary measurements of missing particulars respecting ions were undertaken early in 1947 at Huancayo. The latter measurements may make it possible to interpret some aspects of the earlier continuous recordings.

Electrical measurements in the stratosphere on the balloon *Explorer II* showed need for some modification of commonly accepted propositions in physics respecting the dependence on pressure of the mobility of negative ions, and the recombination coefficient for small ions at lower pressures. A maximum in electric conductivity of the atmosphere was found at the height of 18 km.

The war program and the shift to governments, 1940-1947. World War II brought many highly technical developments into application, with a resultant demand for highly specialized geophysical information on an unprecedented and world-wide scale. It was hence natural that the accumulated data and experience of the Department should be brought into play in the application of geomagnetic and ionospheric knowledge to warfare. The main demand was for descriptive material and engineering developments.

The effective use of magnetic mines by Germany early in the war stimulated an active development program for various

kinds o£ magnetic mines and countermeasures among the allied nations. The sensitivities and types of mines chosen for development, and for use in various parts of the world, were of course to some extent limited by the natural geomagnetic fluctuations. K-indices for magnetic activity were also required in forecasting radio communication conditions. New and more accurate isomagnetic charts were required in navigation and in the degaussing of ships.

The Department undertook the compilation of existing data on all classes of geomagnetic fluctuations, and especially their frequencies and average magnitudes in all latitudes and longitudes, in a form suited for engineering applications. Of particular value in this undertaking were the microfilmed copies of magnetograms of the International Polar Year, 1932—1933, and the scattered published results available in our rather complete library. This work considerably extended previous work in description of the geomagnetic variations. Also undertaken was the task of preparing new isomagnetic and isoporic charts. In this way the results of voluminous surveys on land and sea, made over many years by the Department and other agencies, were used in improving the description of the earth's main field and its secular change. In the process, the descriptive results of magnetic observations made at over a hundred observatories were derived and collated, for the various geomagnetic variations, in summarized form. This work was required for improving the isoporic charts, which in turn made possible more effective use of existing data in the preparation of main field charts. New survey data were obtained through the loan of magnetometers to other agencies, and magnetographs were built and installed at various locations to meet the requirements of the armed services. The significant feature of this work was that its general objectives were defined by the government, which likewise provided under nonprofit contracts most of the funds for completion of the projects.

A similar condition arose in the radio field. In the case of the ionosphere, an urgent demand arose for information pertaining to radio communication in operational areas. This could be provided only by installation of additional ionosphere stations with multifrequency recording equipment. The Department activities, supervised by Wells, included installation and operation of such equipment at Clyde, Baffin Island; Reykjavik, Iceland; Maui, Hawaii; Christmas Island; and Trinidad. Service personnel were trained to operate equipment at many other stations, including Guam, Okinawa, and Leyte. The Department's ionospheric station and magnetic observatory at College, Alaska, was likewise operated under government contract. The analysis of almost all ionospheric records obtained, including those for Huancayo and, Watheroo, was undertaken by the Central Radio Propagation Laboratory, as was also the continuation of certain researches involving improvement of techniques of forecasting radio communication conditions initiated in the Department.

The temporary expansion of the Department by several fold in personnel and budget during World War II effectively emphasized the truth that modern survey and observatory activities are better undertaken by governments, rather than in part by a relatively small organization such as the Department of Terrestrial Magnetism. Accordingly, following the plans made nearly thirty years ago, in 1946 the Department's observatories at Watheroo and Huancayo were offered with complete complement of equipment, after some changes in program, to the respective gov-

ernments in Australia and Peru. Other survey and observatory activities financed by the United States government had been terminated at the close of the year 1946.

It should, however, be noted that both the survey and the observatory program were in fact continued considerably longer than was originally proposed. Our surveys over the oceans had stopped in 1929, and those over land in 1936. The original intent was to undertake observatory work in regions neglected by others for a period of one sunspot cycle, but, as previously mentioned, the appearance of new possibilities during the period 1920-1930 made it desirable to extend this effort over another similar period.

Summary of main ideas and results. Explanations of the earth's magnetic and electric fields were sought. In order that the picture of these phenomena might be brought into sharper focus, thereby better describing what it was sought to explain, a magnetic and electric survey of the earth was carried out. The world patterns of secular change were obtained for the first time throughout the period 1905-1945, and it was found that the electric field of the earth as a whole varies periodically every 24 hours by about 30 per cent. The search for the cause of these phenomena, however, was unsuccessful. By careful experiments Barnett showed that magnetization by rotation could not explain the earth's magnetic field, and a similar search by Swann, from a theoretical approach, proved likewise unsuccessful. The results of magnetic surveys, however, have beea of great benefit in various practical applications of geomagnetism, and this work is now being extensively carried on by others. A high light o£ the ionospheric work was the development of the pulse experiment, which was elaborated later into the multifrcquency technique for exploring the upper atmosphere. In the atomic-physics program, verification and first measurements were made of the tremendous forces between protons and neutrons at very short distances, which are the forces that bind these particles to form atomic nuclei. Resonance energy levels for nuclear disintegration were also found and measured.

Among the more important of the terrestrial-solar phenomena, now better understood as a result of the Department's observatory program, were the following: determination that the daily and lunar geomagnetic variations are caused by the ultraviolet radiations from the sun and the motions of the upper atmosphere in the presence of the earth's magnetic field; closer linkage of specific (solar flare) and average solar conditions with variations in geomagnetism, the ionosphere, aurora, and cosmic rays; the rather complete description on a nearly world-wide scale of geomagnetic variations of various periods at different times of the sunspot cycle and their possible electric current systems in the atmosphere. The world-wide pattern of surface earth currents was estimated, and technique used in electrical geophysical prospecting was developed. The results of the observatory program were also useful in practical applications such as the improvement of radio communications on a world-wide scale.

Future importance of magnetic surveys and geophysical observatories. Surveys of the changing magnetic and electric fields of the earth, an important part of the human environment, should no doubt be continued, even after their causes have been satisfactorily ascertained. So far as we now know, magnetic secular change gives our only indication of rapidly changing processes deep within the earth's interior. There are also indications of slow trends in vertical conductivity of the atmosphere over decades of time. Hence

the continuity should not be lost between present-day and future descriptive knowledge afforded by such surveys.

It seems well to emphasize, however, that these surveys have greater potential interest if supported in other ways. There is little value merely in the making of measurements to preserve continuity of human record. The present-day effort should therefore be directed more searchingly toward explanations of the phenomena. Something will be learned from more ambitious world surveys of the gravitational field, and from seismic data, which like the geomagnetic field yield indications respecting the earth's interior. Finally, active laboratory and theoretical approaches should be sought in order that there may be desirable rapid evolution in the character of such surveys and in the understanding of their results. There is little point in too great detail, and in too frequent surveys. Although contributions along laboratory and theoretical lines can be expected from private institutions of research, the major survey activities can be effectively undertaken only by or with the continuous financial support of governments, upon which the responsibility ultimately must rest.

Local detailed magnetic surveys by airplane over areas of geophysical interest, such as volcanoes, or from ships towing survey instruments at considerable depth within the oceans, may be expected to yield results of future geophysical significance. It seems likely also that electric surveys by airplane will contribute to the solution of some of the problems of atmospheric electricity.

It is our view that the future activities of geophysical observatories will be highly productive and significant. Magnetic storms and disturbances, not yet well understood, have recently been found associated in time with marked changes in the ionosphere and in cosmic-ray intensity, and these effects, also associated with auroral phenomena, are completely unexplained. There will no doubt be added recordings from time to time of new aspects of geophysical phenomena, using new techniques. Thus, installation of high-speed ionospheric and magnetic recorders, of enhanced sensitivity, is assured, as well as of more sensitive cosmic-ray meters, solar radio-noise recorders, and other instruments. Geophysical observations throughout the atmosphere using rockets are already being undertaken. There will be need to undertake these at many points over the surface of the earth. Unfortunately, a counterpart of this direct approach does not exist for probing the earth's interior.

In the promising future before those engaged in survey and especially in observatory work, the Department hopes as heretofore to make some contribution from time to time in the development of new techniques, in stimulating endeavor, and in the interpretation of measured results.

SUMMARY FOR THE REPORT YEAR 1946-1947

This first year of postwar operations marks a major change in the activities of the Department, with the completion of the observatory and field-party work of the world magnetic survey.

A survey of the situation at the end of World War II disclosed two things. First, our two observatories had achieved worldwide recognition as stations of paramount importance in the uneven world distribution of observing stations, and were recognized as such by the governments and scientific agencies in their areas. Second, our own estimate of the status of the prob-

lems for which they were established indicated that the most striking puzzles connected with the earth's magnetic and electric properties might be approached more fruitfully by attempting geophysical experiments of relatively limited duration than by expending most of the efforts of a small group such as ours on a program of continued observations. Fortunately the governments of all nations are now much more alive to the importance of scientific activities, and the collection of geophysical data over long periods is widely accepted as an appropriate activity for a governmental scientific bureau. Accordingly, a decision was made to transfer by gift the entire establishment of the two observatories to the governments of Peru and Australia, respectively. This proposal was gratefully accepted as of July i, 1947, and arrangements were made for the transfers.

In rounding out our activities toward the completion of this matured program, the publication of seventeen large volumes of data and interpretation was undertaken. Much of the work of computation and study had been done previously, and as the report year closes only minor editorial and assembly work remains to be completed on the last five volumes.

The Department now turns to a new emphasis on laboratory and experimental work. Much of this will involve field trips, of course, as the earth is too large and varied to be studied in one spot. Two outstanding problems remain unsolved by our past program, namely, the origin or cause of the main part (95 per cent) of the earth's very large magnetic moment, and the maintenance of the earth's electric charge In spite of the constant current of many thousands of amperes from the air to the surface of the earth. There are other striking problems relating to the physics of the earth, and there is ample precedent for our confidence that they are not disconnected, and that initiative in attempting new experiments and making fresh approaches will yield results of unexpectedly wide significance.

Most of our studies in the past have been concerned with descriptions of phenomena related to these puzzles, such as the small daily, annual, secular, and storm variations of the large and unexplained magnetic field, the contributions of the ionosphere and earth currents to these magnetic variations, and the behavior of ions and attachment particles in the air which participate *in* the air-earth current. Because these problems of magnetism and electricity embrace the entire solid earth and the atmosphere, and relate directly to some of the great fundamental questions concerning the structure of matter, there also have been vigorous thrusts in several other fields of physics, including studies in high voltages and nuclear physics. The Department is thus in reality a group of investigators trained in physical science concerned with certain specific aspects of geophysics and laboratory physics.

Bearing in mind the special character of the opportunity presented by the Carnegie Institution of Washington, with its unusually large freedom of objectives, and viewing the corresponding obligations which go along with this freedom, it is agreed that we must make every possible effort to emphasize creative work, ideas with new potentialities, and work which lies on the front lines of knowledge. The Institution has no external allegiance or obligations, no students, stockholders, voters, or other special groups to serve. This gives us an obligation to accept greater risks than others, and we should accordingly concentrate our efforts primarily on thrusting forward the very front lines of advancing knowledge. Every program should be scrutinized at regular intervals and pruned or reoriented to meet

this criterion; any new problems or interests or new men or activities should also be required to meet it. It is probable that the front lines of inquiry in many fields need to be more clearly mapped, in order that our efforts may be guided toward problems of importance in our time, in reasonable balance with opportunity, and with some hope of definite progress toward solution or toward new formulation —even failure has value.

There are serious restrictions as to possible size of staff and annual expenditures, and accordingly our program must be chosen with regard to its effectiveness as a stimulus or catalyst to the work of all other groups concerned with a given field. These considerations lead naturally to a major emphasis on co-operative endeavors, in which the Institution and the Department can be of great influence and value if we are capable of vigorous leadership in fresh and significant directions.

Plans for co-operative activities, in which other agencies play a larger part than the Department, in magnetic work, in exploratory geophysics, in laboratory physics, and in biophysics will characterize the entire program of the Department for the next few years as the staff now views it. For any one subject or project only a small group will be concerned here in the Department (often not more than two or thfee), and members of other organizations will participate as importantly in our projects as ourselves. True research, however—creative research—is always done in very small groups, rarely exceeding five or seven individuals. Hence this separation of the Department's staff, as in the past, into small discrete groups, with reasonable fluidity for shifts between groups, is regarded as both realistic and healthy. It is expected that particular attention will be paid to means for assuring the effective impact of young men on our staff leaders and program. Our co-operation with universities and the resumption and expansion of the prewar program of Carnegie Institution fellows are of special importance in this connection.

The activities of the Department and the interests of the research staff divide naturally among three broad areas: *(a)* statistical and analytical geophysics, including observatory results, *(b)* exploratory geophysics, and *(c)* laboratory physics and biophysics. In the past the main emphasis of the Department has been in the first area, but it has been agreed, with the Department's observatory program already carried through two complete sunspot cycles, that there will now be a more general shift of emphasis away from this first area and toward the other two.

Our activities thus move toward those of a physics department with special emphasis on experiments in geophysics and biophysics, making intensive use of the techniques and ideas of modern physics. The biophysical program, which has evolved as a modest new outgrowth of our work in nuclear physics and our studies of the properties of the primary particles of matter, is directed toward studies of the fundamental physical properties of living matter, and is carried on as a joint activity with the many biological groups in the Washington area.

A surprising discovery was made during the year in the cosmic-ray program. Long-continued observations of cosmic-ray intensity have been made at various stations scattered over the earth during the past twelve years as a part of the Department's program. Variations of about i per cent due to atmospheric changes and decreases of a few per cent caused by the increased magnetic moment of the earth following magnetic storms have been regularly noted, but a pronounced solar flare and radio

blackout on July 25,1946 was accompanied by a large *increase* in cosmic-ray intensity at all stations except at the equator, simultaneous with the flare and radio disturbance and lasting for several hours. A magnetic storm and its effects occurred as usual about a day later. The observations cannot be explained by the known change in the earth's magnetic moment due to ionization by ultraviolet light. It is difficult to see how the magnetic moment of the sun, usually assumed as the explanation of the cut-off of low-energy cosmic rays, can have been sufficiently altered by the flare effects to permit a "beam" of cosmic rays to pass by, although we are involved in calculations which it is hoped may settle this point. The only evident alternative is that the additional cosmic rays were produced by an accelerating action associated with the flare at or near the sun, possibly due to a local rate of change of magnetic field, as in a betatron accelerator. The origin of cosmic rays is so mysterious that a hint of this kind, associated with our nearest star and hence observable in some detail, with patience, is of the greatest interest. Search of the records showed two similar occurrences in 1942, or a total of three in ten years.

The measurements by Dr. H. W. Babcock, of the Mount Wilson Observatory, on the magnetic fields of the sun and of 78 Vlrginis have stimulated the British physicist Blackett to speculate again on the possibility that the earth's magnetic field represents a fundamental phenomenon in which the magnetic field is dependent on the mass and angular momentum of the body. There are other explanations of the earth's field which depend on complex internal phenomena in the core of the earth. Theoretical studies are accordingly being made in an attempt to link the rotation of astronomical bodies with convective motions producing internal electromotive forces and electrical current systems, such as those proposed by Dr. Walter M. Elsasser, of the RCA Laboratories at Princeton. To distinguish between these theories is of fundamental importance to geophysics and to physics as well.

The most fundamental lack is that of quantitative data on the behavior of the earth's field with time. Measurements of the faint residual magnetization of the annual layers of silt deposited by retreating glaciers at the end of the last ice age, about 25,000 years ago, were resumed during the year with results of striking interest. Just prior to the war these experiments had indicated that the deviation of the compass direction from true north had varied in a fashion similar to the changes observed during the past 350 years. Numerous tests this year have given strong evidence for the stability of this residual magnetization and hence for the reliability of these measurements as an indication of the compass direction in earlier epochs. In addition, new procedures have been developed, involving the redeposit out of a water bath in a magnetic field of the silt from single layers, which give a tentative measure of the *intensity* of the earth's magnetic field during that distant epoch. A preliminary determination of that intensity at the time of the last glaciation has now been made from clays collected at Bradford, Vermont. This measurement indicates that the earth's field has been unchanged in intensity for the past 30,000 years to within the accuracy of the measurement. The material used was shown to be able to carry the imprint of a field fifty times less or greater than the present value. The direction as well has remained substantially constant. The clays were collected in New England and were dated by the fine work of Dr. Ernst Aritevs, former research associate of the Carnegie Institution. The interpretation of the polarization of the

clays was obtained only after long and tedious work in the laboratory, using the methods of modern physics. It is expected that the measurement of other clays will make it possible to extend this time scale to millions of years and thus to provide the quantitative data necessary to distinguish between conflicting theories. The experiments and observations are being continued, and some tests are under way with sedimentary rocks. There is a touch of romance in measuring a thing as subtle as the earth's magnetic field as it existed 25,000 years ago. If these studies can be successfully extended to rocks and hence to a vastly greater period of time, important limits will be set on theories of the earth's main field, a stupendous magnetic phenomenon which remains both a riddle and a challenge.

An interesting series of experiments using artificially radioactive tracer substances was carried out during the year by the cyclotron staff of the Department and their many colleagues in biology and medicine in the Washington area. Radioactive samples were also supplied to a large number of investigators in many parts of the world. The work here has been concerned primarily with studies of differential permeability and exchange through various membranes and cell walls in animals and in man. Although many of the observations, especially those related to the heavy metal compounds which were the war assignment of our cyclotron, are of immediate interest to medical men, our experiments and plans are directed toward the fundamental physical properties of living systems.

The structure of the atomic nucleus offers another major problem. There is ample evidence that the nuclear constituents (protons, neutrons, and possibly alpha particles) are organized in some systematic way. This is shown in the distribution of the stable elements, the atomic masses, and many other properties such as spin (angular momentum) and magnetic moment. The system, however, is not known. The quantum theory used with such success in explaining the outer structure of the atom meets with great difficulty in the nucleus, first, because the forces are not known, and second, because the approximations used in the electronic structure are not possible in the nucleus, where many particles are interacting. In view of these difficulties a model of the nucleus based on similarity to a liquid drop has been found useful in some cases. This, however, gives only a rough approximation and fails to predict the periodicities of nuclear structure. Measurement of the angular distribution of the particles emitted in nuclear reactions gives a critical test of the theory of nuclear structure. During the past year the electrostatic generators have been used to study the light elements, and the cyclotron the heavy ones. The results obtained show that even the light elements (lithium and oxygen) are not simple in structure. Nor is the behavior of heavier elements (aluminum, copper, and gold) predictable from the liquid-drop model.

THE OBSERVATORY PROGRAM

Preliminary negotiations looking to the shift of the observatories at Watheroo and Huancayo to the governments of the countries in which they are located were initiated before the end of the previous report year. As the decision to move forward rapidly with this transfer crystallized early in the report year, conferences were held regarding the appropriate balance and emphasis of activities at the two observatories,

to insure that a modernized program, well focused on areas of future importance, would be under way before the observatories were transferred. It was clear from the start that the magnetic observations were important and were well carried out, although it was found desirable to institute one or two changes in instrumentation. The radio observations on the ionosphere and radio field-intensity recordings were also considered basic. The present equipment for ionosphere studies has been in operation for many years, and initiative was taken looking toward the availability of new equipment for each station within the next several years, under the new sponsors. The present shortage of equipment, and the high costs of manufacture, prevented its prompt acquirement. The seismic, meteorological, and cosmic-ray programs at Huancayo were of clear importance, and are in a healthy state, and the spectrohelioscope observations at Watheroo fill a gap in that world program. The spectrohelioscope at Huancayo was recalled for overhauling.

Careful consideration was given to the expected future value of the atmospheric-electric program. Observations of potential gradient and conductivity had been made at each observatory over a period of more than twenty years. Study of these data confirmed our earlier convictions that atmospheric-electric measurements near the ground are largely a reflection of local circumstances, being affected by dust, smoke, and weather, and that any reasonable understanding of the detailed processes involved would require separate added registration of large ions, small ions, rate of ionization, and other variables. Expansion of the atmospheric-electric program to include these items, though interesting, would at most result in a better understanding of detailed local processes near the ground. Accordingly it was decided to stop all registrations of atmospheric-electric components near the surface of the ground and turn to specific experiments, probably higher in the atmosphere, for further understanding of atmospheric-electric problems. In order to permit better interpretation of the existing records, however, the decision was made to record the additional elements above indicated for a period of a few months at Huancayo, and these observations were started in the late spring of 1947.

Similar critical examination was given to the earth-current program. During many years of observation at our two observatories and elsewhere, ample evidence accumulated to show that the residual earth currents which can be separated from local phenomena connected with the ground electrodes could be accounted for almost entirely as induced currents in the earth brought about by the changing magnetic field, which field in turn arises from variable currents of rather large magnitude in the ionized upper atmosphere. No evidence was found, nor could it be expected from the physical dimensions of our installations at the observatories, for electrical currents within or below the earth's crust arising from internal causes, as these are at best indistinguishable from electrolytic activity at the grounding electrodes. Magnetic observations at the earth's surface are a more convenient and more analytical measure of the variable currents in the upper atmosphere. Accordingly, the decision was made to stop the earth-current registrations at both observatories. In their place, an effort to devise new experiments, better suited to exploration of electrical conductivity and currents, especially in the deeper layers of the crust, would be made by the laboratory group.

The war activities of the Department relating to world-wide studies of the ionosphere, which involved the installation and

operation of ionospheric observatories at a number of places beyond the continental limits of the United States, have now been transferred to the newly organized Central Radio Propagation Laboratory of the National Bureau of Standards. Since world-wide interest in automatic multifrequency recording has led to the development of organizations such as this and other national laboratories to deal with these problems, it has also been decided to encourage these organizations in the analysis of ionospheric data so that the Department may concentrate its efforts on pioneering research with a view to developing otherwise untouched aspects of the field. With the transfer of responsibility, the decision has been made to redirect the Department's activities in upper-atmospheric research toward experiments designed to answer specific questions regarding the ionized layers. As a consequence, in the future the ionospheric data from Watheroo and Huancayo will go directly to the Central Radio Propagation Laboratory, which is in effect a world center for such studies.

Despite its small size, the Department of Terrestrial Magnetism, in part by reason of its connection with the *Journal of Terrestrial Magnetism and Atmospheric Electricity,* has served as an informal world center for studies of the earth's magnetism. The standard of observatory measurements maintained at Watheroo and Huancayo and the Department's instrument program during the first two decades resulted in world-wide intercomparisons against our instruments, making them informal world standards. With the loss of the *Carnegie* most of our important activities in world-wide survey work were brought to an end, although land parties continued for a few more years. When our two observatories were transferred to government operation* it seemed test to transfer at the same time to the United States Coast and Geodetic Survey any functions needed for a center of information and activities connected with terrestrial magnetism. Appropriate discussions were held, and the Director of the Coast and Geodetic Survey willingly accepted the responsibility for enlarging its co-operative activities connected with arctic and antarctic expeditions, aerial surveys, magnetic standards, and correlation of world-wide results in appropriate simple tables. The Department will continue to foster the exchange of information, working closely with the Coast and Geodetic Survey, and loans of our equipment for expeditions and observatories, together with arrangements for use of our absolute magnetic standards, will be made through 'that agency.

HUANCAYO OBSERVATORY

The geomagnetic, ionospheric, seismic, and meteorological programs were maintained at the Huancayo Observatory during the report year. Fast-run magnetic recording with the la Cour magnetograph, and spectrohelioscope observations of the sun's activity with the Hale instrument, were discontinued on July 31, 1946, and the atmospheric-electric and earth-current recorders were discontinued at the end of 1946. The weekly radio-telegraphic reports of K-indices were terminated at the same time. A complete reduction and tabulation of the final hourly values for all three magnetic elements beginning with September 1946 was undertaken at the Observatory instead of at the Washington office. Attention was given to the appointment and training of new Peruvian personnel and to problems connected with the expected transfer of the Observatory to the Peruvian government. Plans and estimates for new buildings on the Observatory property were prepared- The Institution provided

funds for a guest house for future visiting investigators from all nations.

In March 1947 W. D. Parkinson arrived at the Observatory from Washington to undertake special observations in atmospheric electricity, particularly in connection with the study of ion content and distribution in the air and its correlation with atmospheric conductivity.

WATHEROO OBSERVATORY

The geophysical program of observation and recording of geomagnetic and ionospheric data was continued throughout the year. Recordings of the atmospheric-electric elements were discontinued at the end of 1946 after a continuous series over 24 years had been obtained. The earth-current recorder remained in operation but the values were not tabulated. The reduction of the magnetic scalings to absolute values was undertaken at the Observatory throughout the report year. Current ionospheric data were supplied, as in previous years, to the Radio Research Board, Sydney, and the Central Radio Propagation Laboratory in Washington.

The Institution provided funds for a building for housing guest investigators. Additional staff quarters also were planned and partly constructed, as part of the program under the Australian government.

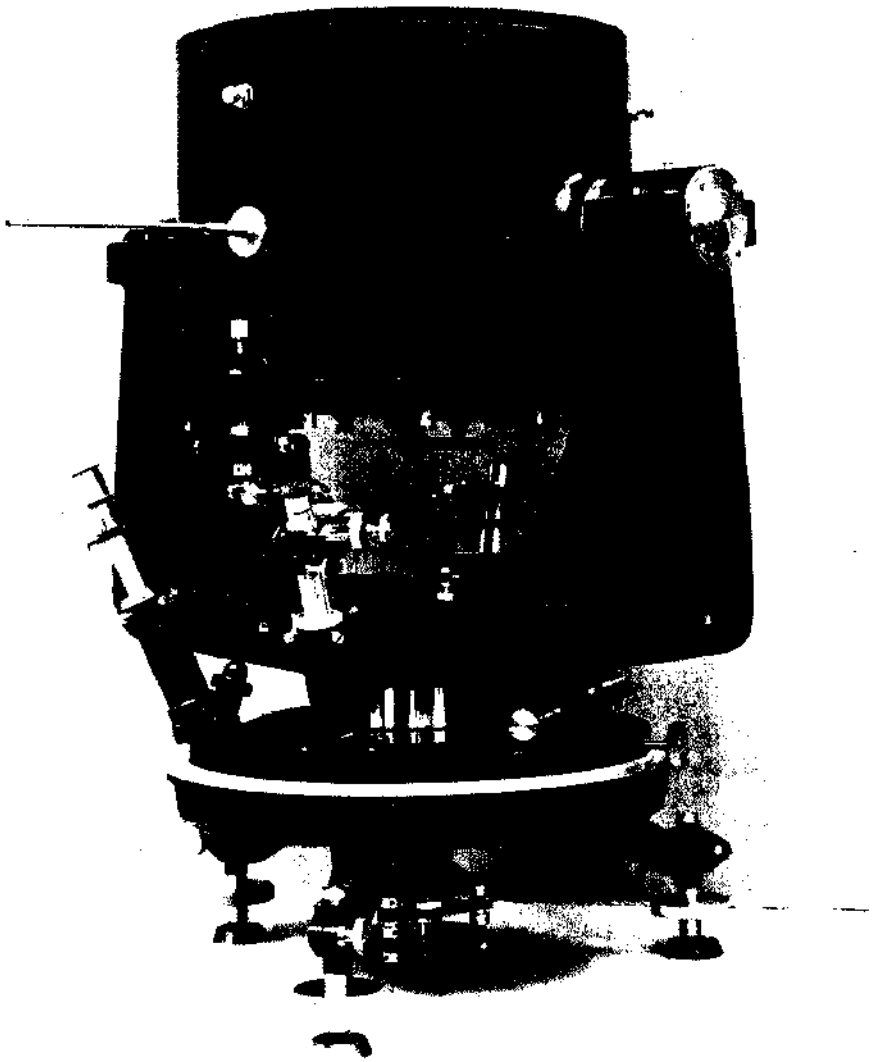
The Observatory was transferred to the Australian government as of July 1, 1947, and will continue to operate under the auspices of the Bureau of Mineral Resources, of the Department of Supply and Shipping.

PRIMARY STANDARD

For many years the Carnegie Institution of Washington has played a leading international role in developing and maintaining the magnetic standards of the world, both by the construction of many of the magnetometers used in field measurements and by comparisons of observatory standards. The last primary standards built are now nearly thirty years old. In anticipation of the grave need of maintaining the international standards and of obtaining international agreement on the value of the gamma, the previous Director, John A. Fleming, initiated in 1934 the design of a new primary standard of great accuracy. This standard has now been completed. It permits, for the first time, the measurement of any component of the earth's magnetic vector, although it is principally designed for the measurement of *H, Z, D,* and /. Its constant is determined by the mutual inductance between a primary coil and a rotating secondary coil. The absolute value of this coil constant is known to three parts in a million. It is expected that this coil will be used by the United States Coast and Geodetic Survey and that when its operation is satisfactory, it will provide a firm basis for the adoption of a standard value for the gamma.

PUBLICATION OF OBSERVATORY AND FIELD OBSERVATIONS THROUGH 1946

A necessary and interesting duty connected with the termination of the Institution's observatory and field-survey programs was the preparation during the year of a great volume of observations for publication—preparation much delayed by World War II. Previous volumes have covered the results obtained on the ocean surveys by the *Galilee* and the *Carnegie,* and numerous scientific papers have been written on the basis of the observatory records. Nevertheless, further study and discussion of this tremendous amount of material was appropriate, and its publication in a form to permit analysis by other groups was an obvious duty.



New absolute standard for magnetic fields built by the Department of Terrestrial Magnetism. Construction was begun in 1938 and was completed in 1947 after interruption by the war. Current coils mounted in grooves on pyrex glass cylinder are accurate to 0.00001 inch. This instrument will be used by the United States Coast and Geodetic Survey for international calibrations. It is accurate to about three parts in a million.

Early in the report year it was decided that the results of researches in terrestrial magnetism, ionospherics, cosmic rays, atmospheric electricity, and earth currents would be presented in tabular form in seventeen volumes totaling approximately 10,000 pages. Several thousand pages of tabulated data were already in hand at the beginning of the report year, and in the ensuing eight months some 7000 additional pages of data and text were prepared by a team of typists and tabulators. Miss Waiburn, of the Office of Publications of the Institution, has assembled the tabulated data into suitable groups for publication in separate volumes, staff members have provided manuscripts, and suitable drawings and photographs have been prepared. During the year six volumes of results have been completed: two containing the magnetic results from Watheroo for the years 1919 through 1944, a volume descriptive of the earth's main magnetic field and its secular change for the period 1905 to 1945, a volume presenting the Tucson Observatory earth-current results for the period 1932 to 1942, the land and ocean magnetic results for the period 1927 to 1944, and ionospheric results from College, Alaska, for the period 1941 to 1946, a total of 3163 pages. Manuscripts for eight additional volumes have been prepared, covering work on geomagnetism, the ionosphere, earth currents, and atmospheric electricity at various observatories, including Watheroo and Huancayo. These require final editing, with the associated tabular data, and final layout for publication. Most of the work has also been completed for the remaining three volumes of the complete series; these will present observatory results on cosmic rays, earth currents, and atmospheric electricity.

In connection with this massive publication program it was acutely realized that the manpower requirements and costs of complete publication have become so prohibitive for continued observatory work in geophysics that a new approach is necessary to insure that data of this kind become accessible for study without waiting for final publication. Accordingly, recommendations were made at our two observatories for relatively prompt publication of the vital summaries of their observations using microfilm techniques, and a suggested small list for world distribution was prepared. The Institution may use this procedure in presenting some of the volumes in the above-mentioned list, particularly those of a specialized character which will be studied and used by relatively few groups throughout the world. It is believed that microfilm is destined to become an increasingly important vehicle for communication in specialized fields, although it cannot entirely replace the delayed complete publication of tabulated original data.

EXPERIMENTAL AND ANALYTICAL GEOPHYSICS

The Department's research in experimental and analytical geophysics is directed toward four principal aspects of the whole field, namely, (1) studies of the earth's crust, (2) studies of the upper atmosphere, (3) cosmic-ray research, and (4) analysis.

STUDIES OF THE EARTH'S CRUST

The earth is such a large and massive body that none of its physical characteristics *is* changed appreciably within the lifetime of a single individual. Its surface cools and heats so slowly and imperceptibly that it is difficult to tell whether we are entering or leaving an ice age. Its magnetic field has such slow and imponderable changes that it is only with difficulty that we are able to ascertain whether or not the main dipole field of the earth is indeed changing. The earth has such great non-

uniformities in the small part that is available on the surface, and it is so difficult to reach very deep into its interior, that the problem of determining its physical structure and its physical history is almost unsolvable.

In the new exploratory approach of the Department to the geophysics of the solid earth there are two main parts. The first is to determine its physical history by reading the record of this history from the evidence of the crust itself; the second, to penetrate as deeply as possible beneath the surface in order to determine its internal constitution. Such an exploratory program requires both an expensive field examination of the earth by extensions of the already developed techniques of geophysical prospecting and the development of new ones, and laboratory verification of the theories required to explain the field data.

Three main problems are now in view. The first concerns the magnetic history of the earth; the second, the strength and structure of the earth's crust to great depths; and the third, the conductivity and the temperature of the crust to great depths.

The magnetic field of the earth as It now exists can be described with some accuracy. The origin and nature of most of its short-time fluctuations are well understood, and many of these can be predicted reasonably well. These fluctuations, however, are merely small perturbations of the main dipole field of the earth, and the cause of the main field Is as much a mystery now as it was a century ago. There appear to be two possibilities. The first Is that the cause Is complex, the field being due to some fortuitous combination of circumstances which can produce circulating internal electric currents. For exampler viscous flow of the interior matter of the earth might bring about temperature gradients, and these by reason of differences in thermal electric power might cause circulating electrical currents deep in the core of the earth, and might have, in spite of the statistical nature, a remaining effect large enough to cause the earth's observed field. The other possibility is that the existence of a magnetic field is a fundamental property associated with large rotating masses. If this were so, then all the planets, and all stars, including the sun, should also be large magnets, with a magnitude depending upon their mass and angular momentum.

The evidence for either set of theories is at present scanty and full of contradictions. Accurate knowledge of the history of the geomagnetic field might go far toward distinguishing between the two sets. The historical data available, which go back about 350 years, are not adequate for this, because the rnassiveness and conductivity of the earth prevent any appreciable change from occurring in much less than 10,000 years.

If the first theory is correct, then it would not be unexpected if the dipole field were to change drastically with time or even to reverse. Historical evidence indicates that the field Is decreasing at the rate of 4 per cent per century. If this were really so, In 1500 years the earth would have no field left, and on the other hand the field 30,000 years ago would have been 12 gauss. It Is, however, uncertain whether or not the historical measurements are of sufficient accuracy to detect such a small change.

Before the war the Department made a small beginning in the measurement of the glacial clays of New England to determine whether or not the earth's field had Indeed changed. An attempt was made to deduce, from the polarization of the clays, the direction of the field at the time when they were laid down. This was made possible by the development of

an extremely sensitive apparatus which extended the previous sensitivity measurement by a factor of 100,000. The results showed that in direction at least, the field was substantially similar to that of today, the variations in direction amounting to ± 30°, a variation similar to that observed historically. These measurements have

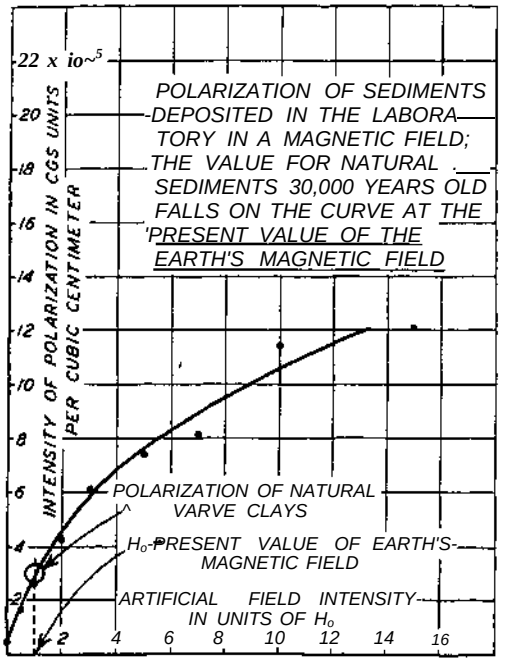


FIG. I. Studies of ancient clay deposits have shown that the compass varied around a northerly direction, and the strength of the earth's magnetic field during the last glacial period was the same as it is now.

now been extended to cover an additional 2000 years of the 6000-year chronology established by Antevs, beginning about 2000 years after the period measured before the war. The results are similar to the prewar measurements: there is an indication of a 300-year period in the variation of the compass.

The most important and significant results, however, have been obtained in the determination of the intensity of the field. The clays are best suited for this purpose, since their magnetization is very simple and can be reproduced in the laboratory. The intensity of the field at the time the clays were laid down was deduced by measuring the polarization of the same clays redeposited in the laboratory with various field strengths. Thus was obtained a curve relating the intensity of the field in which the clays were deposited and the polarization of the freshly deposited clay. For measurements of the clay *in situ* the average intensity about 30,000 years ago was determined to have been about the same as that of the present geomagnetic field within 10 per cent. The historically measured change in the earth's dipole moment can therefore be considered to be due either to inaccuracies of measurement or to a small and insignificant perturbation of the main dipole moment. The evidence thus does not eliminate the possibility that magnetization of the earth is not due to an inherent property of all rotating matter. The results are as yet preliminary, the question of geologic stability has not been satisfactorily answered, and the time scale is too short to draw final conclusions.

Unconsolidated clays are available which cover a time scale of millions of years, and are capable of yielding information on the intensity of the geomagnetic field over this same period. The sedimentary rocks probably contain reliable information on the direction of the earth's field, although at present it does not appear that intensity can be deduced from their polarizations. Only a few of these have been measured, and they indicate that the field has remained substantially constant in direction for many millions of years. There is every expectation that the completion of this research will yield a reliable history of the earth's field and thus provide the basic numerical data against which the two sets of theories may be tested.

Problems relating to the strength and structure of the earth's crust to great depths have occupied geologists and physicists for two hundred years, yet many simple questions remain unanswered, because so few observational and experimental techniques are available for obtaining information concerning the regions even ten or fifty miles below us. Monumental labors in geodesy have limited the acceptable hypotheses, and seismology has greatly increased our knowledge, especially of the deeper regions and the central heavy core, during the past three or four decades. Nevertheless we have but scanty knowledge of the structure of the granitic and basaltic layers which comprise in general the upper 50 km of the crust. Evidence from gravity measurements shows that great blocks of the crust are essentially supported by "floating" at about the 100-km level, but above this level our knowledge of their rigidity and strength, and even their density distribution, is largely hypothetical. Some mountains appear to have "roots," and others not, and we are still uncertain regarding the processes giving rise to mountain ranges, which have arisen many times in geologic history and are still evolving.

Records of near-by earthquakes have been the chief source of data concerning the granitic and basaltic layers which underlie the thin sedimentary rocks. In recent years a few observations have been made on the earth waves produced by explosions, and the large surplus of TNT remaining in the hands of the government after the recent war may provide an opportunity to explore these layers by controlled experiments. A request was made to the United States Navy by the Institution for help in a scries of measurements of this kind to be sponsored by the Geophysical Laboratory and this Department with a group of university investigators, starting with Columbia University and the New Mexico School of Mines. Preliminary observations have been made on a series of small shots, chiefly for purposes of instrument development, and as the report year closes portable instruments for eight to ten observing stations are being completed. It is hoped that arrangements can ultimately be made to carry out observations of this kind in a number of regions of particular geologic interest, including the Appalachian range, the Canadian shield, the Caribbean, the Mississippi Valley, and selected parts of the Rocky Mountains.

One purpose of taking initiative in this direction, perhaps of greater importance than the expected observations themselves, is to interest a wider group of young students in scientific geophysics, and to bring fresh curiosity and imagination to the problems of everyday geophysics. Terrestrial magnetism is only one of these puzzles. New ideas and facts about the earth are of great human significance, and touch on man's philosophical relations in much the same way as astronomy.

A third problem which has been given only preliminary consideration involves the determination of the conductivity of the earth in a single bold, large-scale measurement of the deep conductivity. This has been considered in co-operation with Professor Slichter, of the University of Wisconsin, and the Office of Naval Research. Its aim is to estimate the conductivity and thereby the temperature of the deeper rocks o£ the crust, since the conductivity is highly dependent upon the temperature. The method involves the use o£ a number of mine-sweep generators which can be borrowed from the Navy, together with a great amount of heavy copper cable, forming a loop through which heavy pulses of current can be passed. The magnetic field produced by

this loop will depend upon the conductivity and the susceptibility of the underlying rocks. It is hoped that significant results can be obtained down to a depth of 15 to 20 km, but the experiment will be both costly and difficult in so far as the experimental techniques are concerned. The necessary generators and cables have already been set aside by the Navy.

STUDIES OF THE UPPER ATMOSPHERE

Research in geophysics of the upper atmosphere is of continuing interest to the Department. Following the suggestion of early investigators that the transient changes of geomagnetism were the result of the flow of electrical currents in the atmosphere, it was natural that the Department should turn to direct experiment to examine and expand these hypotheses.

The evolution of the Department's program of upper-atmospheric research as our knowledge of the atmosphere has expanded is worthy of emphasis. Commencing with the original pulse-echo experiments in 1925, which demonstrated the existence of ionized regions of the atmosphere and measured their heights, the Department's research turned to the development of this technique and application of it in automatic recording systems and methods. These methods produced curves from which the distribution of ionization could be directly deduced, and provided continuous information on ion distribution through the atmosphere.

These methods have now been generally adopted by observatories everywhere over the earth. As the mass of data has accumulated, the general structure and many of the principal phenomena of the outer atmosphere have become evident. With the wide use of these techniques especially under the impetus of World War II, the earlier objectives of the Department are now in view. It has seemed profitable, therefore, to reorient the upper-atmosphere program toward examination of special geophysical problems, with expectation that such research would form a stimulus to further evolution of the world-wide program.

The basic geophysical questions concerning the outer atmosphere are: (1) What are the elementary particles of which the outer atmosphere is composed, and how do these vary with time? This question relates not only to its chemistry and the proportions of chemical elements at the several heights, but also to products of photochemical reactions of dissociation from molecular to atomic states, and the ionization products of ultraviolet light and energetic corpuscles. (2) What is the density, pressure, and temperature of the atmospheric envelope and of its constituents at the several heights to its outer limits? (3) What are the regular and irregular movements and flows of the atmospheric gas? (4) What external agencies, either hard or soft electromagnetic or corpuscular radiations, influence the structure and constitution of the atmosphere? (5) What can be inferred of the nature of these external agents from a knowledge of atmospheric fluctuations, especially where evidence of these agents cannot otherwise be observed from the earth's surface?

The present world-wide program of automatic recording and observation insures significant progress toward solution of some o£ these general problems in the foreseeable future. Nevertheless, the techniques at hand do not provide enough information to answer adequately the questions proposed above. The Department is therefore undertaking the development of promising new methods for attacking these problems, with the expectation of substantially advancing the state of our

knowledge. Four general modes of attack seem feasible and profitable for an organization of our size: (i) the adaptation of radio methods to entirely new kinds of measurement; (2) spot measurement using rocket techniques in co-operation with other agencies; (3) aircraft measurements of atmospheric electricity at the limits of aircraft altitudes; (4) analytical deductions based on the expanded experimental evidence. These approaches are complementary: the rocket measurements make possible checks and absolute values not easily obtained by the radio methods, whereas radio methods permit measurement of time changes not possible with rockets. By use of these approaches, together with the more general mass of data becoming available, it seems reasonable to expect that a further real advance can be made.

The work of the Department in this field during the past year has been primarily concerned with the reorientation of its program toward ^uch special experiments. A substantial change in its physical plant has been involved, with transfer of its field facilities at Washington from the Kensington Experimental Station to the new Derwood Experimental Laboratory and with the physical development of that laboratory. The end of the year has seen the Derwood Experimental Laboratory completed to the point where effective experimental work can be commenced; in fact, much has been done in a preliminary way as the several parts of the laboratory were made available.

Staff discussions were fruitful in outlining a general field of interest and in formulating certain specific experimental projects. The following projects have been initiated during the report period.

Radiojrequency noise from the sun. Confirmation of the arrival of radio noise signals from the son on a frequency of 200 Mc/sec was obtained May 28, 1947, using some modified components from war surplus radar sets. Signals dropped to a low level when the directional antenna was pointed away from the sun. On a radio receiver the solar "noise" sounds very much like the internal set noise heard when the receiver is operating at high sensitivity. This is known to fluctuate with varying solar activity and to depend to some extent on the recording frequency. The objective of the research program is to obtain precise measurements of solar noise intensities and other characteristics at frequencies of 200 Mc/sec and lower. Results of the program are expected to contribute to basic knowledge of solar activity, the gaseous solar envelope, and the fundamental problem of existence of a solar magnetic field—a matter which is open to speculation. Progress is being made in design and assembly of instruments for an attack on this problem.

Measurement of solar noise may also be expected to aid in understanding of the mechanism responsible for some sudden and striking increases in cosmic-ray intensity. These appear to be due to acceleration of charged particles by some process on the sun during violent solar flares. The intense cosmic-ray increase of July 25, 1946 coincided with a great increase in solar noise. In addition to providing further evidence on the correlation between the two phenomena, the polarization of the noise measurements may be useful for determining the rate of change of magnetic flux near the sunspot. This would indicate whether the consequent electromotive force could supply the energy for the cosmic-ray increases.

Thunderstorm project. This program is directed toward an answer to the fundamental questions, Why does the earth have a negative charge, and how is it maintained? Measurements of atmospheric

conductivity and potential gradient made during airplane flights above representative thunderclouds may prove or disprove the theory that electrical current flow upward to the ionosphere from the many thunderstorms scattered over the earth's surface is sufficient to maintain the earth's negative charge.

Co-operation of the United States Army Air Weather Service is assured, and close liaison is maintained with the Thunderstorm Advisory Committee. Arrangements are made for installing the instruments in airplanes capable of flying over thunderclouds and for conducting experimental flights during the late summer of 1947, using headquarters of the Thunderstorm Advisory Committee, Wilmington, Ohio, as an operating base.

The instruments have been completed and preparations are made for construction of additional units as required.

Fine structure of ionosphere. The panoramic recorder which was used to make the first motion pictures of ionospheric changes was loaned to the Central Radio Propagation Laboratory, National Bureau of Standards, in January 1947. A fire at the Sterling Field Station had damaged the Laboratory's ionospheric recording apparatus and left it temporarily without adequate means of maintaining the continuity of ionospheric data for the Washington area. The DTM apparatus was returned in June 1947 to our Derwood Experimental Laboratory, where it is now being installed.

Preparations are made for completing the developmental work on this apparatus and for obtaining a representative series of high-speed motion picture recordings of ionospheric disturbances such as the radio fade-out, sporadic E, magnetic storm effects, and similar phenomena. The detailed information on rapid changes and fluctuations of the ionosphere which is obtained with this unique experimental tool should make new data available as a basis for the interpretation and understanding of many fundamental physical processes in the earth's outer atmosphere. One of the main questions of current interest is whether part of the ionization which causes a radio fade-out within a few minutes after the observation of a solar flare is due to particles from the sun traveling at roughly the speed of light. This is of special interest in connection with the cosmic-ray increases described elsewhere in this report.

Upper-air roc\et experiments. New opportunities for direct measurements in the region 100 km or more above the earth have been opened by the experimental firing of the V-2 and other rockets by the armed services of the United States. Members of the Department's staff had close wartime connections with this work, and have participated in the evolution of these experiments and the associated scientific programs. One experiment which is closely related to our interests concerns the direct observation of the large electrical currents which circulate in the upper atmosphere and cause magnetic variations at the surface of the earth. Attention has been given to preliminary designs for apparatus to record the magnetic changes expected when a rocket passes through and above a current sheet in the ionized regions. This would be of great interest in locating the level of the currents causing diurnal variation, which latter changes greatly with location, and would be of very special interest if a rocket could be fired during a magnetic storm. Further development of this project, in co-operation with the Navy and the Applied Physics Laboratory of Johns Hopkins University, is anticipated during the coming year. Other closely related projects may be undertaken later in 1947 with the availability of additional

personnel and greatly improved laboratory facilities. These include (1) measurement of the earth's magnetic field in the ionosphere by radio methods, and (2) experimental measurements of the lower ionosphere. These experiments may be expected to help fill in existing gaps in the composite picture of our knowledge of the upper atmosphere.

In general the over-all research plan is to undertake specific experimental investigations on lines which are not being followed by other agencies or which will supplement and extend work under way in other organizations. Planning is left sufficiently flexible to permit the active prosecution of fruitful developments such as may occur during the execution of a research program and often lead to results exceeding in importance the original objectives.

A large percentage of the activities of the Upper Atmospheric Section during the report year has been devoted to reconversion—terminating the wartime (and prewar) activities and starting on a new program. War contracts with their final reports were concluded late in 1946. The publication program of the Department has involved preparation of texts for several volumes of data, as detailed in another section of this report.

Close liaison and active participation have been maintained with organizations having common interests, such as the Joint Research and Development Board, Central Radio Propagation Laboratory, Institute of Radio Engineers, Applied Physics Laboratory, National Geographic Society, and other private or governmental organizations. Formal and informal conferences with domestic and foreign investigators have been stimulating and beneficial. The Department has been represented at meetings of the principal technical societies, and papers have been presented whenever appropriate. Publications are listed in the bibliography.

COSMIC-RAY RESEARCH

Probably the most valuable observations resulting from some ten years of continuous registration of cosmic-ray intensity at four or five stations, heretofore sponsored by the Institution's Committee on Coordination of Cosmic-Ray Investigations, are of three sudden increases in cosmic-ray intensity. Increases similar to those for Cheltenham, Maryland, were observed at Godhavn, Greenland, and at Christchurch, New Zealand. All three increases began almost simultaneously with unusually long and intense radio fade-outs and solar flares or chromospheric eruptions. The cosmic-ray increases were similar and simultaneous on the day and night side of the earth. Magnetograms from several magnetic observatories indicate that the increase in cosmic-ray intensity cannot be ascribed to changes in the earth's magnetic field due to magnetic storms. Though the increases in cosmic-ray intensity might be ascribed to changes in the sun's general magnetic field, which might permit more cosmic rays from outer space to reach the earth, such a mechanism should be equally effective whether the solar flare occurred on the front or back side of the sun, yet only these three have been observed, all associated with flares toward the earth. Cosmic rays are regularly observed to decrease during magnetic storms.

The implications of this discovery of abnormal increases in world-wide cosmic-ray intensities during a few great isolated solar eruptions are, of course, outstanding in importance. The observation suggests that a changing magnetic field associated with a sunspot or flare may act as a magnetic accelerator giving cosmic-ray energies to charged particles. Similar processes on

or near many stars might then account for all cosmic rays. The question naturally arises: Are there cosmic-ray increases during lesser solar flares, perhaps too slight to be observed because of limitations of existing recording instruments? As a step toward obtaining an answer to this question, a detailed study has been made to determine requirements for coincidence counters and large ionization chambers with sufficient sensitivity and low statistical fluctuation to show the fine structure of cosmic-ray activity without ambiguities arising from the production of "bursts" due to nuclear processes produced by cosmic rays when they strike our atmosphere or materials near the recording instruments. Assembly of a very large cosmic-ray ionization chamber for this purpose is progressing.

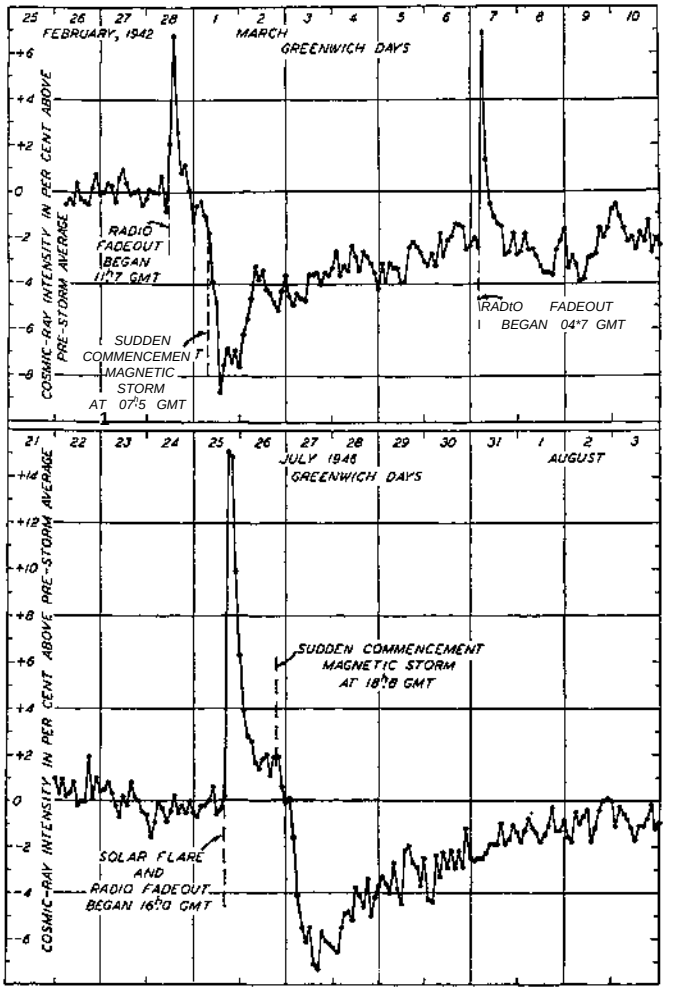


FIG. 2. Three striking increases in cosmic-ray intensity observed shortly after commencement of violent solar flares and radio fade-outs. The origin of cosmic rays is a great puzzle, but this discovery indicates that some particles may be accelerated to cosmic-ray energies by great disturbances at or near the surface of the sun. If this is true, the same thing may occur on myriads of other stars.

In order to provide material for statistical investigations of cosmic-ray variations through one sunspot cycle, much of the effort during the report year has been devoted to the reduction of data from continuous records. Since the work was interrupted by war research, some five or six years of records have accumulated from four stations. The reduction of all the original records is now complete at least through 1945, including tabulated bihourly means of cosmic-ray intensity corrected for barometric pressure for Huancayo from June 1936 through December 1945. Except for completion of the typing, the Huancayo data are ready for publication together with summaries of the data from Cheltenham, Maryland, Christchurch, New Zealand, and Godhavn, Greenland.

ANALYSIS

Extensive new descriptions of the earth's main field and its secular change, 1905-1945, mainly in more accurate mapped form, were unsuccessfully compared with those of other geophysical phenomena manifested in the crust. There were, however, aspects of these comparisons that seem worthy of further examination. For example, there seems to be some correlation of secular change with general features of the stress distributions within the earth's crust, deduced by Vening-Meinesz in his attempt to explain faulting and topography of the earth's surface, again in turn related to other crustal phenomena. Examination of this possibility is being continued.

A spherical harmonic analysis of the earth's main field for 1945.0 was begun and completed during the present report year, analogous to that carried out previously for secular change. This analysis of carefully prepared magnetic charts indicated that the fraction of the dipole component of the main field of external origin was less than 1 per cent of the observed surface field, and thus considerably less than indicated by previous analyses. Examination, of the analyses of secular change at four epochs a decade apart indicated a rather steady decrease of about 20 gammas per annum in the dipole component, though the most recent decrease, that for epoch 1942.5, is considerably less, and may indicate that the dipole component of the main field is now diminishing at a rate less rapid than during the previous century.

An external and nonpotential part of the main field, and variation of the vertical component of curl of field, postulated by the Schrödinger unitary field theory could not be detected from analysis and comparisoas with the new and more accurate descriptions of the geomagnetic field. This result is contrary to Schrödinger's findings based on Schmidt's analysis for 1885.

The new analysis gave the co-ordinates for 1945.0 of the north geomagnetic pole as 78?6 N and 289?9 E, and for the south geomagnetic pole as 78?6 S and 109?9 E; these results differ from those of Bauer for 1922 by only o?i in latitude and I?I in longitude.

Calculations of the main field and its secular change were completed for various levels within and beyond the earth's atmosphere, providing useful data for studies of electrical phenomena of the upper atmosphere. Vertical gradients of the main field and its secular change were calculated for the earth's surface, but attempts to correlate these with other geophysical phenomena were unsuccessful.

Current functions which could produce the main field and secular change calculated for flow of currents on a thin spherical shell at depth 3000 km were found to be highly complex. This renders it unlikely that a major part of the main field or secular change could originate below the surface of the earth's central core, though it might be admissible to postulate flow of current very near the surface of this core, as suggested recently by Elsasser.

H. W. Babcock, of Mount Wilson Observatory, has recently made the epoch-making discovery that various rapidly rotating distant stars have intense magnetic fields. This result is of the highest interest in relation to the origin of the earth's main field, and immediately focuses attention on electric-current hypotheses such as that of Elsasser. A theoretical investigation is accordingly being directed toward discovering the effect of rotation of a body upon internal fluid motions which could generate the geomagnetic field, as well as those of astronomical bodies. Not unrelated to this

problem is our current analytical attempt to check by actual calculation the possibility that the increase in cosmic rays during solar flares may be ascribed to changes in the solar magnetic field.

The unexplained average augmentation in earth currents during January, as compared with December and February, found by Rooney for Tucson has likewise been found in 12-year means for the solar daily magnetic variation at stations throughout the western hemisphere, but not in the eastern hemisphere.

One of the volumes based on the observatory and survey program, entitled *Description of the earth's main magnetic field and its secular change, 1905-1945,* prepared by Vestine and coworkers, was published. This volume summarizes in more accurate mapped form the principal descriptive results and statistics of the extensive magnetic surveys carried out on land and sea by the Department and its collaborators. A forthcoming volume, *The geomagnetic field, its description and analysis,* summarizes new and extensive results of magnetic observatories throughout the world, and includes results of detailed analysis of the main field and its secular change and studies of geomagnetic fluctuations.

LABORATORY PHYSICS AND BIOPHYSICS

FERROMAGNETIC STRUCTURE

One of the remaining puzzles in the behavior of ferromagnetic materials is the exact size of the smallest volume of ferromagnetic material which has an intrinsic saturation. It has been understood for a long time that such small saturated volumes or "domains" were necessary to explain magnetization curves. It was the partial understanding of the effect of such microscopic volumes on microscopic behavior that led to the development of such widely differing magnetic materials as Permalloy and Alnico 5. Yet much of our knowledge concerning the character of domains has remained of empirical and engineering nature.

In December 194^ Dr. Charles Kittel, of the Research Laboratory of Electronics at the Massachusetts Institute of Technology, proposed a theory for the structure of ferromagnetic domains which was susceptible of experimental verification for very thin films. This theory was important because it gave quantitative reasons for expecting that the size and geometry of domains are not invariant, as had usually been supposed, but depend in a very specific way on the dimensions, crystal structure, and other anisotropic energies of the material. This made reasonable the wide range of apparent domain sizes observed by various methods, which gave domain sizes with linear dimensions ranging from 5×10^{-5} cm, indicated by the scattering of polarized neutrons in iron, to about 10^{-3} cm, from measurements of Barkhausen effect and powder patterns. Kittel's theory predicted that a very thin film $\sim 10^{-5}$ cm thick or less would be a single domain infinite in extent in the other two directions.

In co-operation with the Naval Ordnance Laboratory, preliminary measurements were made on very thin films of iron, the Naval Ordnance Laboratory making the thin films and the Department making the necessary magnetic measurements, which were possible with the extremely sensitive apparatus used to measure the magnetization of clays. It was found that such very thin films were in fact single domains saturated at about 16,000 gauss, and that this value of satura-

tion was independent of film thickness. Although no exact magnetization curve has yet been obtained because of the difficulties encountered in dealing with such minute amounts of material, the evidence indicates that such films have a rectangular magnetization curve in which the film actually always remains saturated, but in which the direction of magnetization can be rotated fairly easily through 360^0. In other words, the film can be magnetized *in* any direction in its plane, but it cannot be demagnetized in the way that is possible for a normal magnetic material. The results of this investigation are still preliminary, but there appears to be little doubt of the behavior described above. Thus, Kittel's calculations, together with this experimental verification, provide a considerable quantitative advance in the understanding of the behavior of ferromagnetism.

NUCLEAR PHYSICS

The two electrostatic generators of the Department have been used during the past year primarily for measurements on the angular distribution of protons and alpha particles emitted in the disintegration of several of the lighter elements. One may hope to learn something of the nature of the nuclear-energy levels involved in a disintegration from a study of the angular distribution of the emitted particles, if a situation cao, be found where the energy levels are not too high above the ground level of the nucleus. This is because the energy-level density increases with increasing excitation energy, hence the effect of neighboring levels becomes important.

The first postwar effort was put into getting the one-million-volt generator back into operation. A voltage-stabilizing system was Installed to Improve the performance of the machine. Angular distribution measurements were undertaken on the two proton groups occurring in the disintegration of oxygen by deuterons. This is an interesting reaction for study, since O^{16} (oxygen of mass 17) is supposed to have a closed-shell arrangement of neutrons and protons; an addition of a neutron to form O^{17} would then start a new shell. Also, both an excited energy level, 850 kilovolts above the ground level, and the ground energy level of O^{17} are involved. With the emission of the shorter-range protons O^{17} is left in the excited energy level, and with the emission of the long-range group it is left in its normal ground level. The results with deuterons of bombarding energies up to 1.15 million volts indicated that the long-range proton group had a greater yield in the forward direction with respect to the incident beam, whereas the short-range group had a greater yield in the backward direction. In the spring of 1947 the large pressure electrostatic generator was again put into operation. With this, protons and deuterons up to 3.2 million volts were made available, and the above series of measurements were extended to 3.2 million volts. It was found that the angular distributions varied considerably with energy above 1.5 million volts. A marked change occurred in the energy region around 1.8 million volts, where a competing reaction sets in, in which neutrons are emitted. Dr. David Inglis, of Johns Hopkins University, who has assisted with these experiments, has been working on the theoretical analysis of the oxygen data. How far present nuclear theory can go in explaining the rather complex changes which occur in this reaction is still uncertain.

The angular distribution of the alpha particles emitted in the reaction of protons bombarding lithium of mass 7 has been studied. This reaction had been investigated with proton energies up to 14 mil-

lion volts by several other research groups, who found the angular distribution to obey a rather simple law with the yield of alpha particles equal to $i + A(E)\cos^2 Q$, where 0 is the angle the alpha particle makes with the incident beam of protons (in the center of mass co-ordinate system) and the coefficient $A(E)$ is a function of energy of the bombarding protons. $A(E)$ was found to reach a maximum at about i million volts. We have extended these measurements to 3 million volts and have found that above 1 million volts an additional term $B(E)\cos^4 Q$ is needed to fit the data. Also the value of $A(E)$ continues to decrease with increasing E.

Preliminary observations with deuterons bombarding lithium of mass 6 disintegrating to two alpha particles give a distribution above 0.75 million volts also of the form $i+A(E)\cos^2 Q$. Whether $A(E)$ again has a maximum value has not yet been determined.

A series of interesting observations was made during the year on the splitting of the deuteron when it encounters a target. A beam of 15 MEV deuterons from the cyclotron gives rise to a marked emission of high-speed neutrons in the forward direction when it strikes a target of copper, and this effect is enhanced with a target of aluminum. With carbon, on the other hand, the neutrons are still emitted in the direction of their original velocity as deuterons, but energy loss is evident.

BIOPHYSICS

With the production of isotopes, both stable and radioactive, biology and general physiology have a new approach to many of their unsolved problems. The technique and the philosophy implied by these new physical tools necessitate a knowledge of and respect for two sets of training—that of the physicist and that of the biologist—before a good biophysical approach can be made. The accuracy of measurement and the micro-quantities capable of use both lead to new forms of instrumentation and permit a deeper probing of the life processes than was possible heretofore. The selection of the problems and of the particular animals or plants to be used has to be based on a wide knowledge of general biology. Living processes up to now have not attracted the attention of men trained in the physical sciences to any large degree.

Provision was made for an approach to such studies just before the war by the construction of the cyclotron at the Department of Terrestrial Magnetism. With this tool it is possible to produce the radioactive materials necessary for such investigations. During the war the cyclotron was intensively used for a series of medical experiments and tests with heavy metal tracers carried out in collaboration with the Navy. The knowledge and experience gained in nuclear physics work at the Department can be well utilized in the field of biophysics. The fundamental part played in the life process by light, both in plant and in animal, is another phase of biophysics which has reached the stage of experimentation that calls for techniques of a physical nature. With these facts in mind, a modest biophysical program has been started with the co-operation of biologists in other institutions. The radioactive tracer technique has been the basis of the first series of experiments directed toward problems of general interest in physiology. The cyclotron has also been extensively used for the production of radioactive isotope samples, contributed to many biological and medical groups in the United States and in half a dozen foreign countries.

Passage of minerals from mother to embryo. In co-operation with the Department of Embryology of the Carnegie Insti-

tution and with the Johns Hopkins Hospital, radioactive sodium (Na^{24}) was followed across the placental membrane to the embryo from the ioth week of pregnancy to term. The rate of placental transfer at various times in normal pregnancies has been followed by this technique, and it has been shown that the permeability of these tissues increases about 70 times during the period of gestation. Several modifications due to disease were also followed. The fetus at the 12th week receives 160 times as much sodium as the growing tissues require, and by the 40th week it is receiving 1100 times as much as is required.

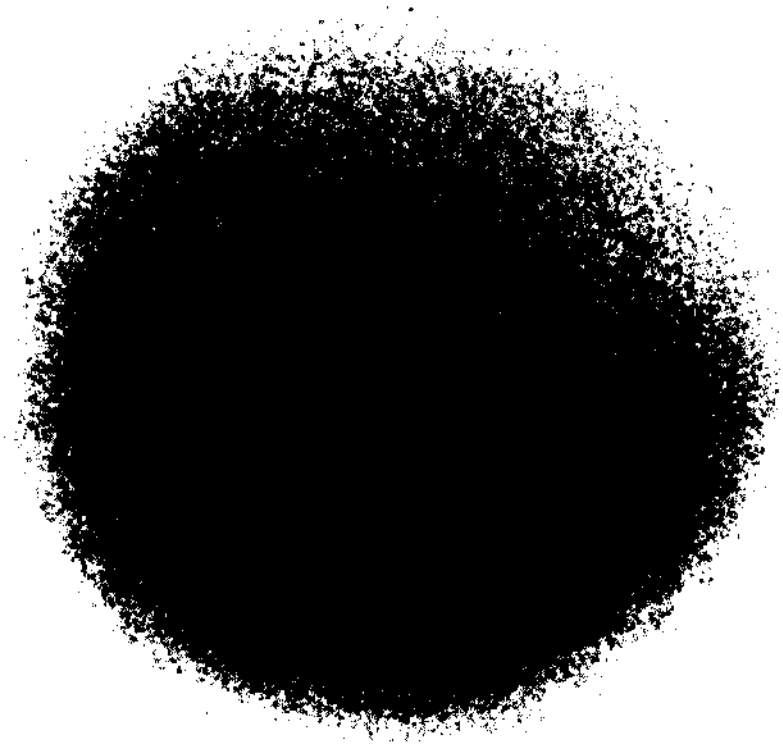
The origin of iron in the fetus. Previously two views have been developed of the origin of fetal iron: (1) that it comes from the hemoglobin of the maternal red cells which are destroyed by the placenta; (2) that it is derived from the iron in the plasma which is put there from the iron stores of the liver of the mother. By tagging red cells with radioactive iron in an animal and then transfusing these red cells into the pregnant animal, the radioactive iron can be followed into the fetus. In a similar manner the plasma iron can be tagged in an animal and this material transfused into a pregnant animal. These studies are now under way and new methods of iron determination have been developed. In a similar manner the permeability of the placental membranes to chlorides is under study.

The rale of exchange of minerals in the aqueous humor and lens of the eye. In co-operation with the Department of Embryology of the Institution at Baltimore, the rate of exchange of radioactive sodium (Na^{24}) between the plasma and aqueous humor of the eye and that between the aqueous humor and the crystalline lens were studied* The radioactive sodium, was injected intravenously, and after a definite period of time the aqueous humor and the crystalline lens were removed. These studies have established that the steady-state ratio of plasma sodium to aqueous-humor sodium is 0.920 in the guinea pig. Because of the difficulties of studying the metabolism of the eye and its various parts, there has been, up to the present, very little research in the physiology of this organ. The tracer technique permits a new approach to this topic.

Permeability and rate of exchange of sodium in the ovarian eggs of the frog. The single-cell nature of the egg and its huge potentialities of development into a complete animal have caused it to be the center of much investigation. Little is known of its complex relations with its external environment, and still less as to its internal specialization. In this study we have examined closely the permeability and the rates of diffusion in a specific cell, the ovarian *egg* in both the living and the dead condition. Quantitative differences in the diffusion of sodium into live and dead *eggs* have been studied. When dead eggs are used, all the sodium is exchanged; that is, the percentage of tracer sodium in the eggs after standing in Ringer solution containing these atoms is the same as the sodium content of the solution. Half of this exchange occurs in about 5 minutes. Calculations for diffusion into a sphere the size of the egg show that the time of half exchange should be about 5 minutes. The dead egg acts like a sphere of Ringer solution, and the egg membrane forms practically no barrier.

This behavior must be contrasted with the conditions found in the living egg. At the end of 4 hours only 10 per cent of the sodium in the *egg* has exchanged, and nearly all this exchange occurs in the first half-hour. Evidence from radio-autographs shows that the Na^{24} is distributed throughout the whole egg as early as 30 minutes

PLATE 3



Photographic imprint made by radioactive sodium diffusing into nucleus of frog's *egg*. Sodium is shown to be admitted or excluded by change in calcium concentration surrounding egg. This print is made from thin frozen *egg* after exposure of 6 minutes to solution containing radioactive sodium.

after the start of the exposure. Thus only 10 per cent of the sodium in a live *egg* is freely exchangeable, and half of this is exchanged in about 15 minutes. This means that the outer membranes do not greatly slow down diffusion of sodium into the egg. It was demonstrated that the diffusion of Na^{24} into the eggs is essentially a reversible process for short-time exposures, but exposures up to 19 hours gave evidence of more exchange after some hours. This may not be reversible.

Calcium excess or deficiency in the ambient Ringer solution does not affect the initial rate or amount of exchange of Na^{24}. After several hours a difference becomes apparent: a deficiency of calcium renders more of the sodium in the *egg* exchangeable, a fact which may possibly indicate that some membranes belonging to an inner structure of the cell have become more permeable.

Radio-autographs of single egg cells. Radio-autographs of egg cells showed definite rates of diffusion and localization of Na^{24}. The striking feature was that Na^{24} was concentrated in the nucleus. An estimate of the density of blackening of the film shows that the nucleus contained about twice as much Na^{24} per unit volume as the cytoplasm. Hence the nuclear membrane is readily permeable to sodium, and the amount of sodium available for exchange is relatively greater in the nucleus than in cytoplasm. Distribution of sodium throughout the remainder of the egg appeared to be relatively uniform, though our technique was not sufficiently refined to detect local variations. The diffusion rate of the mobile sodium in the egg is close to that in water. The diffusion of sodium into the nucleus is influenced by excess or deficiency of calcium, in the surrounding Ringer solution.

The physiology of the blood-forming tissues. The aim of this project is to determine in which cells antibodies are formed. When a foreign protein is introduced parenterally into an animal, gamma globulins are produced after a variable period of time which react specifically with the antigenic protein. Reactions then result in precipitation, agglutination, detoxification, etc., of the antigenic protein.

The early work in this field seemed to indicate that the cells which produced the antibodies were the cells of the reticuloendothelial system. More recently, antibodies have been shown to be present in high concentration in lymphocytes. At the National Institute of Health, Habel and Endicott have studied the problem with rabies virus in mice and have shown that mice given 400 r whole-body X-radiation lose their ability to become immune to rabies for a period of time which corresponds to the time required for the lymphoid tissue to regenerate. During this time there is no demonstrable damage to the reticuloendothelial cells.

In co-operation with Dr. Endicott and his group we have established the techniques necessary for antigen-antibody studies using tagged antigens produced *in vivo* with the choice of proper animals and controls as well as the development of chemical and biological procedures. Two experiments have been carried out with rather striking results.

Studies in Guatemala. The objects of this study in collaboration with the Pan American Sanitary Bureau and the United States Public Health Service were as follows: *(a)* to determine to what extent antimony administered as tartar emetic localizes in the nodules and adult filarids of onchocercosis, using tartar emetic containing radioactive antimony; *(b)* to determine the effect of BAL on the excretion of a single dose of antimony in this form; *(c)* to accumulate further data on the distribution in the human body and excretion of

antimony administered in this form, with especial reference to the blood and urine.

As a result of these studies it was found that BAL did not affect the elimination of the antimony compounds when used under our special dosing schedule. The adult filarids in this study showed very high specific uptake of the antimony, and the nodule containing the filarids also showed some concentration of the antimony over the surrounding subcutaneous tissues used as a control medium.

Pharmacology of heavy metals with specific application to tropical diseases. Thus far we have shown that regardless of the location of the adult filarid (thoracic cavity, heart, or subcutaneous tissues), there has been a specific uptake of antimony and arsenic by the adult parasite. These results have been found in man, dog, hamster, and cotton rat. Concentration of these elements has also been found in the thyroid, parathyroid, and liver. After single or multiple administration of these elements the concentration in the blood has always been low. In fact, 24 hours after dosage the blood level is usually the lowest concentration found in the entire body. The white rat, however, has reacted anomalously to trivalent compounds of antimony and arsenic, the blood level 24 hours after dosage being 100 times greater than that found in any other animal Studies are under way now to determine the nature of this difference.

An improved method of tracer micrography. Conventional methods of radioautograph technique are limited by lack of resolution associated with film grain size. In collaboration with L. Jvfarton, of the National Bureau of Standards, a start has been made toward removing this limitation. The method employed uses an electron optical lens system to obtain a magnified image of the radioactive source.

Cyclotron operation. During the report period the cyclotron was in very active use for both the laboratory physics and the biophysics program. Work on a number of projects was facilitated when an outside beam was obtained. The sale of radioactive isotopes by the Atomic Energy Commission has had a double effect on requests for cyclotron-produced materials. Some of the demand for the isotopes which can be produced by the "pile" has been relieved, but additional interest has been stimulated in tracer studies. It appears that the nuclear reactor cannot produce in high specific concentrations such isotopes as Be^{7}, C^{11}, F^{18}, Na^{22}, Mn^{53}, Co^{57}, Cu^{64}, Zn^{65}, As^{73}. Hence the cyclotron is assured of continued usefulness in preparing tracer substances.

Shipments of radioactive material produced by our cyclotron were made to numerous research groups in the United States and to New Zealand, Sweden, Denmark, France, Australia, South Africa, Great Britain, and Canada.

Long-range biophysics program. To date biophysics has little recognized standing as a separate scientific discipline. Nevertheless, there is a widespread conviction that the processes in living matter involve important physical phenomena. How can physics best make its contributions to answering crucial questions concerning living matter? To date this question has not been answered. The efforts of our group of several physicists interested in biological problems will be directed during the next several years toward the formulation of questions in this field which can be regarded as fundamental to living systems and yet can be made accessible to attack and observation in terms of physical processes. Most of the present specific problems lie squarely across the three fields of physics, chemistry, and biology. Close collaboration with certain workers in each field is necessary and planned.

OPERATIONS AND STAFF

CO-OPERATIVE WORK OF THE DEPARTMENT

In accordance with its general practice of advancing projects through collaboration with other individuals and organizations, the Department has contributed to many co-operative investigations.

In the field of geophysics the Department collaborated with the Air Weather Service in a project designed to ascertain whether thunderstorms supply negative electricity to the earth at a rate which would account for the electric field observed in all typical fair-weather areas. Volcanological investigations were carried out at Umnak Bay in co-operation with the United States Geological Survey.

In order to assist in supplying necessary magnetic data at sea, of which the world's hydrographic offices stand in need, the Department prepared and forwarded detailed plans of the *Carnegie* to the USSR for use in planning a proposed nonmagnetic vessel.

Three sets of cosmic-ray plates were sent to Peru in February 1947 for exposure at different altitudes to test the variation of frequency of cosmic-ray bursts with altitude. This experiment was undertaken in co-operation with the University of Virginia.

Co-operative plans were made for work with Professor Amaldi, of the University of Rome, who visited the Department for a period of two and a half weeks for concentrated technical discussion.

In the field of biophysics, we have cooperated in a wide variety of ways. A month was spent by one of our investigators in Guatemala in connection with filariasis studies in co-operation with the Pan American Sanitary Bureau and the United States Public Health Service. Radioactive materials have been supplied to many institutions throughout the world for use in researches pertaining to biology and medicine.

Much use has been made of data obtained at our observatories in Huancayo and Watheroo, in connection with geophysical and ionospheric studies. Dr. D. F. Martyn, of Commonwealth Observatory, Mount Stromlo, Canberra, Australia, has used Huancayo data exclusively in the preparation of an article on "Lunar tidal variations in the F-region near the magnetic equator," and Dr. O. Burkard, Institut für Meteorologie und Geophysik, University of Graz, requested ionospheric data from Huancayo for use in his investigations of the question regarding the nature of measured radiation.

A research and development task-order contract was negotiated with the Office of Naval Research on January 1, 1947? for cooperative work with the Navy on the deeper layers of the earth's crust by observations on seismic waves produced by artificial explosions.

THEORETICAL PHYSICS CONFERENCE

The Ninth Washington Conference on Theoretical Physics was held in Washington, D. C, October 31 to November 2, 1946, under the joint auspices of the George Washington University and the Carnegie Institution of Washington. The subject of discussion was "The Physics of Living Matter," and a group of investigators in biology and in theoretical physics joined in a series of informal meetings for discussion of the border line between biology and physics. This conference is a continuation of annual meetings which were interrupted by the war. It was attended by representatives of twenty-four universities, research organizations, and government bureaus. The principal purpose of

the conference was to interest and instruct the theoretical physicists with regard to a group of special problems on the frontier of biology.

ADMINISTRATION AND OPERATION

The main laboratory of the Department was repainted during the year, and new ceilings were installed in about half the rooms. Furthermore, as a symbol of the shift of emphasis toward new problems and activities, and to insure orderly handling of the older records and research material, each member of the staff was shifted to a new room or laboratory early in the year to start on his new projects, and all valuable materials connected with past activities were transferred to a special archives space in the attic.

The Standardizing Magnetic Observatory was reroofed, and the interior was changed to make it more suitable for laboratory investigations.

The remaining work on all war contracts still in effect on July i, 1946, consisting largely of final reports and preparation of accounts, was terminated early in the report year except for one contract with the Bureau of Ordnance, Navy Department, which is delayed only for a final bill for publication of a completed volume of maps and data. Final payments have been received except for two war contracts.

The construction of the main building of the Dcrwood Experimental Laboratory was resumed in April and was practically complete at the end of the report year.

The Department continued its support of the *Journal of Terrestrial Magnetism and Atmospheric Electricity* under the editorship of Dr. John A. Fleming, retired Director of the Department.

The Department was fortunate in having a number of outstanding guest investigators attached to the staff for varying periods. These are named in the appended list, which shows also the regular members of the staff, most of whom were employed for the entire report year.

The American Geophysical Union, which occupied office space in our main laboratory for a number of years, moved during the winter to more desirable quarters at the Administration Building of the Carnegie Institution, 1530 P Street, Northwest.

LECTURES GIVEN BY NONMEMBERS OF DEPARTMENT

November 1946, two lectures were given by E. Amaldi, and one by Marcel Schein on cosmic rays.

April 2, 1947, "Terrestrial magnetism and the earth's core," by Walter M. Elsasser.

April 7, 1947, "Wartime development of physics in Holland," by H. B. G. Casimir.

April 9, 1947, "Physical basis of the domain theory of ferromagnetism (with application to the magnetic properties of thin films and small particles)," by Charles Kittel.

May 9,1947, "Investigation of cosmic rays by means of rockets," by Marcel Schein.

May 19, 1947, "The origin of the universe," by E. Teller.

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Fart-Time and Temporary 'Employees: There were 42 part-time and temporary employees engaged during the year, usually for short periods, whose work was concerned largely with the completion of war-contract and publication work. Miss M. Walburn, production assistant, was assigned by the Office of Publications to publication work at the Department for the entire report year.

* Resigned.

** Resigned.

SPECIAL PROJECTS: TERRESTRIAL SCIENCES

FRANK T. GUCKER, JR., Northwestern University, Evanston, Illinois. *Studies on specific heats of aqueous solutions.*

A strong electrolyte dissolved in water causes a contraction in volume, which indicates a compression of the water molecules around the ions. Simultaneously, the heat capacity of the solution is reduced below that of water. In fact, the apparent molal heat capacity of the salt is often negative, showing that the heat capacity of the solution is less than that of the water it contains. The apparent molal heat capacity in dilute solutions is known to increase linearly with the square root of the molality, as predicted by the Debye-Hiickel theory, and this relation often holds within o.oi per cent in the specific heats, up to concentrations of i or 2 *m.* The Debye-Hiickel theory does not predict the value of the apparent molal heat capacity at infinite dilution, but Zwicky has attempted to do so on the basis of the electrostriction of the water, the heat capacity of which is known to be decreased by pressure, at room temperature. However, on the basis of Bridgman's P-V-T data for water, Zwicky calculated that pressure should in-, crease the heat capacity of water at temperatures above about 65° C, and predicted a similar increase for the specific heats of aqueous solutions of strong electrolytes. The present research was carried out to test this theory and obtain some precise specific heat measurements in a range where none existed.

Dr. Frank W. Lamb used the differential calorimeter with variable heaters developed in this laboratory, and modified it to obtain precise results up to 85° C. He determined the specific heats of solutions of potassium chloride, sodium chloride, and sodium bromide from about 0.1 *m* to near saturation, at 20° intervals from 5 to 85° C. The results were similar for all these salts. The apparent molal heat capacities plotted against the square root of the molality increase most rapidly at low temperatures, where the curves are definitely of sigmoid shape, with a maximum slope near the middle. At higher temperatures they all are flatter. The apparent molal heat capacities at infinite dilution increase rapidly from 5 to 25° C, but pass through a maximum at about 60° and actually decrease to 85°. For concentrated solutions, the curves are flatter and the maximum occurs at a lower temperature. These results indicate a discrepancy either in the P-V-T data for water or else in Zwicky's theory correlating electrostriction and specific heat. Further experimental and theoretical work is desirable along these lines, as well as an extension of the experimental study of specific heat of aqueous solutions to temperatures as near the critical as possible, which will be undertaken under this project.

Our present results allow a calculation of the standard entropies of these salts in aqueous solution, over the range of temperature we covered, from the values given by Latimer, Pitzer, and Smith at 25° C. There is a surprisingly large decrease in standard entropy between 5 and 85^0 C, nearly the same for all three salts, and averaging 17 per cent.

DIVISION OF PLANT BIOLOGY

Central Laboratory located at Stanford, California

H. A. SPOEHR, *Chairman*

The interruptions in the regular research programs of the Division, occasioned by the war, have not been without some benefits. Opportunity was provided to gain a little more perspective on the objectives of the major research programs, to examine basic aims afresh, and to give careful consideration to the administrative as well as to the scientific problems involved in an organized research program. Much of the thought on these matters has inevitably been affected by altered social and even political influences which have made themselves felt throughout the world. New scientific instruments, new modes of attack, and recently formulated concepts, many of which are the direct and indirect product of war activity, are relatively easy to apply and install for the solution of particular problems. But important as are these features of a research program, in many ways they are matters of subordinate significance. They give the impression of growth and progress. In them is also inherent the danger that means may be substituted for ends.

In consonance with the changes demanded by present conditions, it seemed an opportune time for change also in personnel. New research plans and undertakings, for which the Carnegie Institution of Washington offers such unique opportunity, should fittingly be entrusted to the men who are to carry them to completion. Of necessity these should be younger men. So also, to achieve effective development, responsibility is a salutary attendant on opportunity. With these thoughts in mind, the Chairman resigned his administrative duties at the end of June 1947. It is impossible for him to express adequately his appreciation of the very cordial relations he has enjoyed for many years with the President and administrative officers of the Institution and of the fine spirit of co-operation among the staff members of the Division. He is particularly grateful for the opportunity which has been granted him to continue his researches through the support of the Institution and to be relieved of administrative responsibility. The Institution has been fortunate in obtaining the services of Dr. Charles Stacy French, who assumes the position of Director on July 1, 1947.

Recurrent in all dispassionate discussions of research programs, and of scientific endeavor in general, is the more fundamental question of the function of science in our present-day society. Though this question has always in a measure engaged the thought of scientists, the outgrowths of the war have forced it upon us as never before in the history of thought. Along with much of the rest of the world, the scientist is caught in a dilemma, one horn of which carries the free exercise of thought with but uncertain support, and the other horn bears the spirit of despotism with the promise of ample support. In brief, we are endeavoring to decide whether the highest function of science is to understand and explain the phenomena of nature, to attain the truth, in the faith that the truth will make us free; or whether we must regard this as an outmoded concept of the function of science, and consider that it cannot justify itself by simply understanding and explain-

ing these phenomena, but rather must become the *primum mobile* to fashion man's evolution.

In the contemplation of this vexed problem, which is so fraught with tremendous consequences, the occupation with various aspects of the evolution of living beings exerts an influence for both humility and skepticism. The concept of a homocentric world, dominated by the will of man, or, perhaps more properly, by the will of a few men, becomes a crumbling doctrine. That something of the nature of evolution has occurred, the great mass of scientific evidence gives ground for belief. But for the vastly more significant question as to how these changes occur, what causes bring them about and what mechanism is involved—for the solution of these problems we are only at the threshold of knowledge.

The race of man is as the race of leaves:
Of leaves, one generation by the wind
Is scatter'd on the earth; another soon
In spring's luxuriant verdure bursts to light.
So with our race; these flourish, those decay.

# # #

The first development of chlorophyll in the illuminated leaf is one of the most remarkable phenomena in the plant world. This greening process makes the plant a self-sufficient organism, capable of manufacturing food by photosynthesis. The detailed chemical steps involved in the process of chlorophyll formation are not yet fully understood, but some of them have now been more clearly elucidated. It has been possible to differentiate several steps In the intricate chemical reactions which lead to the formation of the complex chlorophyll molecule. Some of these steps are accomplished by means of light, others are purely thermal processes, probably effected by special enzymes. It has been possible to follow separately the course of these two types of action by determiiiing certain components of the leaf when this is maintained at different temperatures. This is made possible by the fact that purely photochemical reactions are influenced but slightly by changes in temperature, whereas ordinary chemical reactions obey rather definite laws in regard to the influence of temperature on their rates. From these studies is evolving a concept of a series of integrated photochemical and thermochemical reactions through which simple inorganic and organic substances are elaborated into the highly complex molecule of chlorophyll.

In the course of their evolutionary development plants have taken on an enormous diversity in form and structure. It has been one object of systematics and taxonomy to discover order amid this diversity. By comparative study of the structures of plants it has been possible to trace the development of groups of organisms and to learn something of their present status in relation to their early progenitors. While through their evolution plants have taken on this marked diversity in structure, in habit of life, and, to a considerable extent, also in function, in respect to their means of food manufacture they appear to have undergone little change. This conclusion, the result of an extensive study covering a wide variety of plants, is based upon the observation that chloroplast pigments, which are an essential part of the photosynthetic apparatus o£ all plants, have varied little with the evolution of the species of each major taxonomic group. Even in the evolution of the main taxonomic groups of plants, the variation of these pigments has not been great. Only minor variations of the chlorophyll and carotene pigments have been observed, accompanied by somewhat greater variations of the xanthophyll pigments. It would appear, therefore, that whereas in many respects the plant has adapted itself to

changed conditions and has modified its form and habit of life, the fundamental process of photosynthesis seems always to have required the same extraordinary delicate apparatus.

Another aspect of this apparent rigidity of the synthesizing apparatus of the plant may be illustrated by the results obtained from culture of a unicellular alga, *Chlorella,* under a wide range of environmental conditions. According to the culture conditions selected, the chemical composition of the plant varies enormously; under one set of conditions it will produce, for example, 5 per cent of fat, and under another set of conditions 85 per cent. In the first case the cells maintain a high content of chlorophyll and appear dark green. In the second case, with high fat production, the cells carry on their synthesizing work with about one-thousandth the quantity of chlorophyll found in the former and are a yellow-green. The nature of the chlorophyll pigments in the two cases is the same; qualitatively the synthesizing apparatus appears to be a rigid one. The amounts of the pigments, however, vary tremendously in the two cases, so that quantitatively the system appears to be very flexible, and this flexibility apparently is also reflected in the chemical nature of the products which accumulate.

Nearly 300 interspecific hybrids, representing 35 combinations, have now been produced in the grass-breeding program which this Division has undertaken in co-operation with the Soil Conservation Service of the United States Department of Agriculture. Many of these hybrids and their offspring are now under test in the field stations of the Institution and in the nurseries of the Soil Conservation Service. The test plantings at Pullman, Washington, and other field stations give promise that some of the new grasses will prove valuable, because they combine a very favorable form and yield with disease resistance and extension of activity into the dry summer. As was expected, some of the hybrids are more successful in one location than in another. Grasses of the proper heredity must be selected for each major climatic region, and there is now the possibility of a wide selection from the combinations which have already been made.

These hybrids, of the genus *Poa* or bluegrasses, have been obtained by crossing distantly related species originating from very unlike environments. These species and many of their hybrids produce the bulk of their seed by asexual means, and, accordingly, breed true. The purpose of this program was to explore the crossability and the inheritance of species that produce most of their seed in this manner. One of the most promising grasses combines the heredities of a giant bunch grass from eastern Washington and a subarctic race of the sod-forming Kentucky bluegrass from Swedish Lapland north of the Arctic Circle. Another high-quality grass that promises to provide much-needed summer grazing in the latitude of Pullman, Washington, is a hybrid between the same giant bunch grass and a race of Canada bluegrass from the Mediterranean slopes of Asia Minor. For California Coast Range conditions hybrids are now under test that combine the California bluegrass, which is a tufted type, and various races of Kentucky bluegrass. These hybrids are superior to the native Poas in this region, because they have a considerably more extended period of summer activity.

The grass-breeding program has demonstrated that hybrids can be produced between such distantly related and unlike parents having the asexual reproductive mechanism. It has also shown that only about one-third of the hybrids reproduce ascxually like their parents, and that the

remainder are sexual. The latter, however, segregate some very promising offspring, part of which, in turn, may reproduce asexually. This question is being explored further, and it offers possibilities of selecting out many new grasses unlike anything produced hitherto.

The scientific contribution of this program is now outweighing the practical aspects, which have pointed the way to what can be done in improving plants of agronomic importance that follow this specialized method of seed formation.

BIOCHEMICAL INVESTIGATIONS

H. A. SPOEHR, J. H. C. SMITH, H. H. STRAIN, AND H. W. MILNER

CHLOROPHYLL FORMATION IN ETIOLATED LEAVES

The investigations on the chemistry of chlorophyll formation (Year Book No. 45, p. 104) have been extended by Dr. Smith to include analysis of the process at different temperatures. By following the development of greening in etiolated leaves under these conditions, some differentiation can be made between the reactions which are dependent on light and those which are not. The results show that chlorophyll formation is a combination of pure photochemical reactions and thermochemical reactions, which are integrated in a complicated manner.

ProtochlorophylL Seedlings germinated and grown in the dark possess a small quantity of yellow-green pigment known as protochlorophyll. For many years it has been known that when such seedlings are illuminated, this pigment disappears and chlorophyll is formed conconritantly. Because of the concurrence of the disappearance of one pigment and the formation of the other, it has been assumed that protochlorophyll is the direct precursor of chlorophyll, the change being the result of a photochemical action. Similarities in the chemical structure of the two pigments have strengthened this assumption* though no adequate proof of this relationship has been produced.

Exptriments performed during the past year have yielded some information concerning the role of protochlorophyll in chlorophyll formation. Only a limited amount of chlorophyll is produced by illumination of etiolated barley seedlings at low temperatures, o° C. This fact argues for the existence of a limited quantity of preformed precursor in the seedlings at the time when illumination is begun. During the period of illumination that is required for maximum chlorophyll formation at o° C, protochlorophyll disappears, and the quantity of chlorophyll is directly proportional to the amount of protochlorophyll that was present initially in the leaves. This is perhaps the most direct evidence available at present to support the theory of a physiological relationship between these two pigments.

If protochlorophyll is transformed into chlorophyll by photochemical action, no change in ether-soluble magnesium, extractable from the leaves, should result, because, on a molecular basis, protochlorophyll contains the same quantity of magnesium as does chlorophyll. It was discovered, however, that on illumination, the total ether-soluble magnesium increased to a greater extent than was required by the chlorophyll formed, in spite of the disappearance of the protochlorophyll. The determination of the constitution of this new ether-soluble magnesium compound remains a problem for future investigation.

Because protochlorophyll is destroyed by illumination, it must be regenerated in

order to account for the full production of chlorophyll, if protochlorophyll is to be regarded as the precursor of chlorophyll. Experiments have demonstrated that barley seedlings regenerate protochlorophyll when placed in the dark. Whether the rate of regeneration is sufficient to account for the rate of chlorophyll formation remains to be determined.

Chlorophyll 2, the first chlorophyll formed. Analysis of the chlorophyll produced by illuminating barley seedlings at o° C, after they had been grown in the dark, showed the presence of only chlorophyll *a.* The absorption spectrum of the original ether extracts as well as chromatographic adsorption analysis demonstrated that if chlorophyll *b* was formed at all, it was present only in an exceedingly small amount. These results corroborate the conclusions from other workers' experiments performed under different conditions, and strengthen the general conclusion that in the early stages of greening chlorophyll *a* is formed exclusively.

Greening at different temperatures. In etiolated barley seedlings the initial stage of chlorophyll formation is a photochemical reaction, whereas the later stages are a combination of thermochernical and photochemical reactions. This is evidenced by the fact that during the first two-hour period of illumination changes of temperature affect the quantity of chlorophyll formed, and its rate of formation, very much less than during later periods.

In a leaf which has been grown in the dark and is then illuminated, chlorophyll is rapidly formed and then undergoes photochemical destruction on continued illumination at o° C. At room temperature, however, there is a continuous rapid rise in chlorophyll content up to the maximum attainable quantity. These facts indicate that synthesis and decomposition may take place concurrently. The course of chlorophyll formation at 7^0 C. is also in accord with this supposition. Three stages are clearly discernible: first, a rapid rise in chlorophyll content during the first two hours (photochemical reaction); second, a period of several hours in which the pigment increases slowly (largely thermochemical reaction); and third, a period of very rapid pigment increase (integrated photochemical and thermochemical reactions). The results of these experiments indicate that when constancy of chlorophyll content is attained it represents a condition of balance between destruction and synthesis of the pigment.

The effect of illumination at different temperatures on the total ether-soluble magnesium is not yet entirely clear. At o° C, the effect of light on both the formation and the destruction of ether-soluble magnesium compounds is greater than on chlorophyll itself. At 7^0 C, the ether-soluble magnesium compounds follow much the same course as chlorophyll, but the changes are more pronounced. At 19^0 C, the total ether-soluble magnesium increases more rapidly at first than the magnesium in chlorophyll; but in the later stages of greening at this temperature, the increases of these two nearly coincide. These facts give evidence for direct photochemical activity of the ether-soluble magnesium compounds, but are not sufficient to determine the relation between the thermochemical and the photochemical reactions.

When etiolated barley seedlings are illuminated under conditions such that different portions of the leaves are at two different temperatures, 4^0 and n ° C, the portions at the lower temperature remain yellow, whereas the portions at the higher temperature become green. Obviously, the effect of temperature on chlorophyll formation is local.

Organic compounds of phosphorus. The

formation of ether-soluble phosphorus compounds accompanies the formation of chlorophyll. At room temperature these compounds increase very rapidly at first, but reach a nearly constant quantity in the last stages of greening. At *y*° C. they behave differently from what they do at room temperature; they decrease for the first few hours of illumination, then increase rapidly, the rise corresponding to the rise in chlorophyll At o° C, the ether-soluble phosphorus behaves erratically, but on the whole increases. The connection between chlorophyll formation and the production of organic phosphorus compounds is obscure, but in the light of present-day concepts regarding photosynthesis and phosphorylation, it may be significant.

CHLOROPLAST PIGMENTS

It is a self-evident fact, yet one which has been insufficiently realized, that the life and survival of plants throughout their evolutionary development has depended upon the utilization of radiant energy by the chloroplast pigments. Although a great deal is known about the changes of form and habit which plants have undergone in adapting themselves to various environmental conditions on land and in the sea, little is known of the concomitant changes that may have occurred in that function which is basic to all plants, namely the process of photosynthesis. A clue to such possible changes may be obtained from a comparison of the chloroplast pigments of plants which have followed different paths of evolutionary development, in short, in representatives of widely different taxonomic groups.

Our present knowledge of chloroplast pigments is based upon investigations of relatively few plants. Moreover, these investigations have usually been restricted to plants representing only a few taxonomic groups. In order to gain a more comprehensive understanding of the nature of the chloroplast pigments throughout the plant kingdom, several dozen additional plants, representing a wide variety of taxonomic groups, have recently been investigated by Dr. Strain. In conjunction with earlier results (Year Book No. 42, p. 79) this increased information has provided new clues to the composition, function, and evolution of the photosynthetic apparatus. Indications have been found of new relationships between particular pigments and products elaborated by photosynthesis. Suggestions have been obtained of new factors that may have determined the development of particular pigments in plants subjected to different environmental conditions. Along with fresh concepts regarding the evolution of the photosynthetic apparatus, unsuspected relationships have been revealed among plants of several taxonomic groups.

Number of pigments. About 50 chloroplast pigments have now been isolated from plants of various kinds, and there are indications that many more have yet to be described. All these pigments fall into three principal groups: *(a)* the green, fat-soluble chlorophylls, of which about 10 are known; *(b)* the yellow, fat-soluble carotenoids, usually subdivided into carotenes (hydrocarbons, with about 6 representatives) and xanthophylls (oxygen derivatives of carotenes, with some 20 or more representatives); and *(c)* the water-soluble phycobilins, usually subdivided into red phycoerythrins and blue phycocyanins, with a total of 4 or more representatives.

Distribution of the pigments in relation to taxonomy and evolution. All plants capable of photosynthesis contain one or two chlorophylls, one or more carotenes, and two or more xanthophylls. In some autotrophic plants, phycobilins accompany

the chlorophylls and carotenoids, but phycobilins have never been found in the absence of chlorophylls and carotenoids.

Distribution of the individual chloroplast pigments in the plant kingdom follows a definite pattern. This distribution pattern is more dependent upon the evolutionary (phylogenetic) development of the plants than upon the environment.

All the autotrophic plants, ranging from the blue-green algae to the seed plants, contain the same principal green pigment, chlorophyll *a.* Except for a small group of green algae (certain Siphonales), which contain large proportions of a-carotene, all autotrophic plants contain 3-carotene as the principal carotenoid hydrocarbon. These facts may be taken to indicate that the chloroplast pigments originated from a photosynthetic apparatus common to the progenitors of the present-day plants.

From the investigations made thus far it would appear that with the evolution of some of the principal plant groups there have occurred only minor variations of the chlorophylls, but great variations of the xanthophylls and phycobilins. It is significant that certain chlorophylls (e.g., chlorophylls *c* and *d)* are restricted to a few groups of lower plants. This is also true of all the phycobilins and to a lesser degree of some of the xanthophylls, some of the latter pigments occurring in several groups. The uniformity of individual pigments within plants of each group shows that pigment composition has not varied with the evolution of the species. Variation of the pigments among plants of different groups must have occurred very early in their evolutionary development.

Most green algae, mosses, ferns, and higher plants contain the same chlorophylls (chlorophylls *a* and *b)*$_9$ the same xanthophylls (lutein, neoxanthin, violaxanthin, zeaxanthin^ and cryptoxanthin), and the same carotenes (3-carotene ± a-carotene). These facts support the view, long held by phylogeneticists, that all these organisms arose from a common ancestry. It is probable, therefore, that the chlorophycean ancestors of present-day green algae and of higher plants contained the same pigments now found in their descendants.

Fossil green algae similar to those living today have been found in geological formations believed to be several hundred million years old. It is probable that the photosynthetically active pigments of these plants have varied little, if any, in the course of these millions of years. In view of the great chemical lability of the chlorophylls and carotenoids, this constancy of the pigments in the course of countless generations that have led to the evolution of multitudes of forms is truly remarkable.

Pigments of the Siphonales. In the past year, a minor variation of the xanthophylls has been observed in the green algae of the order Siphonales. All species of this group examined thus far contain a unique xanthophyll and its ester in addition to the chlorophylls, xanthophylls, and carotenes characteristic of other green algae. Some of these species were obtained from the temperate waters near Monterey, California (through co-operation of Dr. Gilbert M. Smith and Dr. L. R. Blinks), others were collected in subtropical waters near Miami, Florida (by Dr. F. G. Walton Smith), and some were collected in the tropical waters of the Caribbean at Puerto Rico (by Dr. J. van Overbeek and Dr. H. F. Warmke). Formation of the unusual xanthophyll in the Siphonales must have occurred before evolution of the several species, which are among the oldest and most specialized of the green algae. A related group of green algae, the Siphonocladiales, obtained also in Atlantic and Pacific waters, was found not to con-

tain this uncommon xanthophyll, which, therefore, may serve as an important taxonomic character.

Chromatic adaptation and bathymetric distribution of algae. Owing to the selective absorption of red light by water, plants growing more than a few meters below the surface receive a preponderance of blue-green light. As chlorophyll has less absorption capacity for blue-green light than for red light, it is usually assumed that the presence of complementary pigments which absorb blue-green light is essential to the growth of algae in deep water. Calculations based upon the spectral absorption curves of the extracted pigments show, however, that the high concentration of chlorophyll in the chloroplasts would enable the plant to absorb a large fraction of the incident blue-green light even if complementary pigments were not present. It has, moreover, been found that green algae of the order Siphonocladiales often grow near the greatest depths inhabited by plants, about ioo meters. Yet these organisms contain the same pigments found in shallow-water green algae and in higher plants. It would appear, therefore, from this and other evidence recently collected, that our ideas of chromatic adaptation are in need of reexamination on the basis of more thorough investigation of pigment content by modern methods.

Pigments and the products of photosynthesis. Comparison of the individual chloroplast pigments with the principal structural materials and storage products synthesized by autotrophic plants has revealed that no single pigment is associated with the formation of any one principal organic substance. The great variety of organic storage products in different species of plants suggests a complex and varied reaction mechanism for the production of organic matter. The universal association of chlorophyll *a* with oxygen production in photosynthetically active plants points to a similar reaction mechanism for oxygen liberation in all plants.

It has frequently been pointed out that *Vaucheria,* an alga of the order Siphonales, differs from other green algae in containing no chlorophyll *b* and in not forming starch. These conclusions are presumably based upon observations made on the freshwater species. It is not without interest that a brackish-water species of *Vaucheria* has been found to contain much chlorophyll *b* (about 40 per cent of the total chlorophyll), and that, after exposure to sunlight, it also contained a large amount of starch. Obviously, with respect to chlorophyll composition and to its capacity for starch formation, this species of *Vaucheria* resembles other typical green algae.

Pigments and chromatographic adsorption analysis. Experience gained through continued use of chromatographic adsorption methods for the preparation and identification of chloroplast pigments has revealed new relations between adsorbability and the molecular structure of complex carotenoid molecules. With some adsorbents such as powdered sugar, the adsorbability of carotenoid pigments is determined largely by the hydroxyl groups and not by the unsaturated, hydrocarbon portion of the molecules. With other adsorbents such as magnesia, adsorbability of the carotenoid pigments is determined by the unsaturated, hydrocarbon portion of the molecules as well as by the hydroxyl groups. Apparently different adsorbents attract different parts or regions of the complex molecules. Maximum separation of mixtures of similar pigments has been attained when the adsorbent attracts preferentially those structural regions that differ most. This relation between adsorbability and molecular structure may become a valuable

guide in the selection of adsorbents for use in adsorption columns.

THE SYNTHESIS OF ORGANIC MATTER BY CHLORELLA CELLS

In previous reports on this subject (Year Book No. 42, p. 83; No. 45, p. 109) mention has been made of a means of determining the degree of reduction of the total organic constituents of the cells of a *Chlorella* culture and of its designation by the term R-value. The concept of the R-value may be simplified somewhat by the realization that it is proportional to the heat of combustion.

In a mineral nutrient medium limited in available fixed nitrogen, *Chlorella* cultures reached higher yields and the cells were of higher R-value when they were supplied with 5 per cent carbon dioxide in nitrogen than when 5 per cent carbon dioxide in air was supplied. Also, it was noted that the yield and R-value of cultures grown in 5 per cent carbon dioxide in nitrogen continued to increase over long periods of time. A comparative study of cultures grown in these two gas mixtures demonstrated that with carbon dioxide in air the maximum yield and R-value were reached after 49 days of continuous illumination. For such cultures the yield of cells was 1.20 g. dry weight per liter and the R-value 58.72. A corresponding culture grown in 5 per cent carbon dioxide in nitrogen gave a yield of 1.63 g. dry weight per liter and an R-value of 61.87. ^n ^t cultures grown in the air mixture, after reaching a maximum, both the yield and the R-value decreased progressively with increased age. This is contrary to the experience with cultures supplied with carbon dioxide in nitrogen, in which the yield and R-value increased continuously with age up to 75 days. It is not known, however, how much longer such increase could be maintained. Considering the different effects of age upon cultures in the two gas mixtures, as well as the fact that the maximum yield and R-value with air are less than with nitrogen for a culture of equal age, it is apparent that the very high yields and R-values attained in nitrogen cannot be reached in air. The extreme conditions are, of course, provided by cultures grown in a mixture of carbon dioxide and pure oxygen. Under these conditions very small yields of cells and low R-values are obtained. Whether these differences in the nature of the products formed by the *Chlorella* cells under aerobic and anaerobic conditions reflect differences in the course of the photosynthetic reactions, or whether the variation in the nature of the products results from subsequent metabolic reactions, is a subject for further investigation.

Another difference between cultures grown in mixtures of carbon dioxide and nitrogen and those grown in carbon dioxide and air appears in the effect of continuous and intermittent illumination. In cultures with nitrogen mixtures, essentially the same yields and R-values were obtained under equal time of illumination, whether this was continuous or intermittent. By contrast, in mixtures with air, intermittent illumination produced higher yields and higher R-values as compared with cultures receiving continuous illumination on a basis of equal hours of illumination. Thus, the maximum yield and R-value were reached after 49 days of continuous illumination and after 98 days of intermittent illumination of 12 hours in the light and 12 hours in the dark. The yield for the continuously illuminated cultures was iao g. dry weight per liter of the culture with an R-value of 58.72, and for the intermittently illuminated cultures the yield was correspondingly 143 g. and the R-value 60.86. For other periods of time, extending to 154 days o£ intermittent il-

lumination, the continuously illuminated cultures, on a basis of equal time of illumination, were lower in both yield and R-value than the intermittently illuminated cultures. It is not without interest that the intermittently illuminated cultures in a mixture of carbon dioxide and air are still not equal to those grown in carbon dioxide and nitrogen in regard to yield and R-value.

Chlorophyll content of *Chlorella* decreases sharply as high R-values are attained. For example, the chlorophyll content of cells with an R-value of 50 may be but 10 per cent that of cells with an R-value of 40. At the highest R-values attained, the chlorophyll content may fall to less than 0.1 per cent of that of the dark-green cells of low R-value.

THE LIPOIDS OF CHLORELLA

In an earlier report (Year Book No. 45, p. in) was given the probable composition of *Chlorella* cells of different R-value, based upon calculations and certain assumptions. Mr. Milner has now carried out chemical analyses of the lipoid fraction of this plant material. For this purpose larger quantities of cells of high R-value had to be cultured. The quantitative extraction of the lipins from this material is associated with some difficulties and entailed the development of special methods. In each case, the quantity of lipoid obtained by solvent extraction agreed well with the value calculated from the R-value by the method just referred to. This confirms the conclusion that it is lipoid accumulation which is mainly responsible for the increase in R-value of developing *Chlorella* cells.

As the R-value of the cells increased from 42 to 60, there was an increase in the fatty acid content of the lipoid fraction from 28 to 87 per cent; this was accompanied by a decrease in the unsaponifiable fraction from 12 to 3.3 per cent. It is apparent from these figures that the increase in R-value of the cells is caused principally by the increase in the fatty acid content. The progressive decrease in unsaponifiable fraction as the R-value increases shows that no material accumulation of hydrocarbon has taken place.

The iodine number and neutralization equivalent of the total fatty acids show that, as the R-value of the cells increases, there is a small increase in the average molecular weight of the acids, and that this is accompanied by a definite increase in the degree of saturation. Both these trends tend to increase the R-value of the acids themselves. But the large increase in the R-value of the cells is principally due to the increased quantity of the fatty acids rather than to changes in the composition of these acids.

The fatty acids from each sample were fractionated by the lead salt separation and ester distillation methods. The fatty acids from *Chlorella* cells appear to be almost entirely Cie and Cis members of the series. With the quantities available it was not possible to estimate with any accuracy the minor amount of lower and higher fatty acids which may have been present. The principal saturated acid is palmitic, which varies between 8 and 17 per cent of the total. The quantity of stearic acid is small, 0.4 to 4 per cent. Unsaturated fatty acids comprise about 85 per cent of the total, there being 29 per cent of the C@ and 54 per cent of the Cis from low R-value cells, to 18 per cent of the Cie and 67 per cent of the Cis from cells of an R-value of 60.

The noteworthy feature of the fatty acids from *Chlorella* cells is the great unsaturation of the liquid acids, particularly of the Ci© fraction. These acids had 2x15 and 2.18 double bonds per carboxyl group from cells of an R-value of 42.5 and 54.9 respec-

tively. The Cis liquid acids from the same two samples had 2.23 and 1.17 double bonds per carboxyl. Apparently the increase in saturation of the total fatty acids with increase in R-value occurs in the Cis rather than in the C16 liquid acids. It is probable that there is little oleic acid in the cells of low R-value.

EXPERIMENTAL TAXONOMY

JENS CLAUSEN, DAVID D. KECK, AND WILLIAM M. HIESEY

A major research project extending over a period of five years has been brought to conclusion during the year with the submission for publication of a manuscript on "Environmental responses of climatic races of *Achillea*." This will appear as the third number in the series "Experimental Studies on the Nature of Species" (Carnegie Inst. Wash. Pub. 581). In it are detailed the results obtained from transplant experiments conducted in the climatic series of field stations across central California and from physiological experiments under controlled conditions, together with their implications (Year Book No. 45, pp. 112-117).

A complementary paper prepared by the late Professor W. E. Lawrence, of Oregon State College, shortly before his death in February 1947 further rounds out the story. This paper, "Chromosome numbers in *Achillea* in relation to geographic distribution," was prepared while Lawrence was a guest investigator at this laboratory. He had spent the year 1943—1944 and the summers of 1945 an<^ X946 here, working, in addition, on the climatic races of the tufted hair grass, *Deschampsia caespitosa*. He brought to our group his thorough knowledge of the classic approach to ecology. By combining with that the experimental approaches leading to the concept of climatic and other ecological races, his papers have contributed to modern ecology.

The bluegrass program, employing species of the genus *Poa*, has advanced materially during the year. This program, which is carried out in co-operation with the Soil Conservation Service of the United States Department of Agriculture, explores the evolutionary avenues in a group of asexually propagating plants of value on western range lands. In it, basic scientific research and its practical application are combined.

Sixteen new Poas, all developed through hybridization between species belonging to different taxonomic sections and coming from very different climates, were sent for testing to the regional nursery of the Soil Conservation Service at Pullman, Washington, in the spring of 1946. These were studied in detail and compared with their parental species in June 1947 by Dr. Clausen in company with Dr. A. L. Hafenrichter and other members of the staff of the Soil Conservation Service. Several of these hybrids show promise, both on account of their favorable combination of characters and on account of their apparent ability to extend the length of the grazing season into the dry summer.

The response of the bluegrasses in the garden at Pullman differs from that of divisions of the same individuals growing in any of the three environments at the California transplant stations. Forms that grow poorly at Stanford may be vigorous at Pullman, and vice versa. From these preliminary tests we can begin to assign the new hybrids, with some confidence, to those kinds of climates to which they may be best fitted. Their fitness is largely predetermined by the characteristics of the parental species, which, in turn, are in harmony with their native climates. The

apparent success of hybrids between such remotely related species opens new possibilities to plant breeders for tapping unutilized sources of variation in wild grasses. Some of the superior wild strains used in these crossings had been saved from probable extinction by their introduction into the nurseries of the Soil Conservation Service.

Early in 1947 fifty-one additional hybrid strains from other *Poa* crossings were given to the Soil Conservation Service for testing. On the basis of this year's experience, some of these will be grown in the nursery at San Fernando, southern California, and others at Pullman. Their Fi parents are under test at the three altitudinal transplant stations of the Institution. The San Fernando nursery is 25 miles from the coast at 34° 15' north latitude; the Institution stations lie in a transect across central California near 38° north from near the coast to the crest of the Sierra Nevada; and Pullman is at 46° 40' north in a continental climate well east of the Cascades. These plants are therefore subjected to tests in both a latitudinal and an altitudinal range of environments that should yield conclusions of both scientific and practical importance.

Seed of six of the more promising *Poa* hybrids were sent to the Scottish Association for Research In Plant Breeding at Edinburgh at the request of Dr. J. W. Grcgor for winter-active grasses suitable for the mild coastal climate of western Great Britain. The trial plantings made there will further extend the range of climates under which the new Poas arc tested.

THE PHYSIOLOGIC AND GENETIC BASES OF CLIMATIC RACES

A primary step in the evolutionary process is the organism's development of fitness to a new environment. No plant can survive that is not timed in its development with the seasonal and diurnal rhythms of its climate. The evolution of such fitness is independent of, and precedes, the evolution of interspecific barriers. A species that occupies a series of climatically contrasting environments may therefore consist of many races. The analysis of the physiologic experiments on *Achillea* conducted by Dr. Hiesey in the controlled greenhouses at the California Institute of Technology has brought this clearly into focus. In the two species of *Achillea* that populate a transect across central California, a dozen or so climatic races can be distinguished, as described in the last report. Their periods of activity and dormancy are closely synchronized with the seasonal conditions in their native environments and are as different as are the climates of this varied topography. But among the most interesting racial differences are the requirements for different day and night temperatures, as brought out in the controlled greenhouse experiments.

These experiments show that members of one species from adjacent geographic areas but in different climatic zones may require very different temperatures and light conditions for their best development. *Achillea lanulosa* from a mid-altitude on the west side of the Sierra Nevada developed best under warm days and cold nights, conditions characteristic of the spring and early summer seasons in its native environment, when most of its growth is made. Forms from a similar altitude but on the Great Basin side of the Sierra Nevada develop most rapidly under warm days and warm nights. Alpines of the same species from the Sierran crest were not activated by cither of these two sets of experimental conditions, but responded when additional light was sup-

plied. This is consistent with the higher light intensity found at high altitudes. On the other hand, the races of *Achillea millefolium* from northern latitudes in Denmark and Lapland are physiologically similar to the Great Basin race of *lanulosa* from so much farther south, for they also develop rapidly when both days and nights are warm. They and the Great Basin plants are so constituted that they can take full advantage of the brief, warm summers of their native environments.

In marked contrast with these, the *Achillea borealis* forms from the mild but uniformly cool California coast grow best under cool days and cold nights, but they grow slowly, coming from an environment with a long growing season. On the other hand, a giant race of this species from moist habitats in the hot San Joaquin Valley utilizes primarily the long summer for its growth, and, even under controlled conditions, develops most rapidly under warm days and nights.

Such differences in physiological behavior between plants that are morphologically so similar that taxonomists distinguish them only with difficulty reveal remarkably close correlations between their activity patterns and their native environments. The existence of such correlations suggests the manner in which natural selection must operate.

It is evident from these and other experiments that the balance between the plant and its environment is intricate, and that it may be attained in different ways. Such differences are controlled by heredity, as is shown by the genetic experiments on climatic races of *Potentilla glandulosa*. Furthermore, a suitable balance with any given environment may be obtained through very different heredities, and plants that have evolved different genetic mechanisms for controlling their physiology may not be able to exchange their genes freely without disturbing the intricate developmental processes in their offspring. The organization of groups of plants into climatic races and into species, therefore, appears to depend upon genetically determined physiologic differences.

NEW HYBRID POAS FOR DIFFERENT ENVIRONMENTS

The working principles of this program and the previous progress have been discussed in Year Books Nos. 43, 44, and 45. Briefly, the basic idea has been to utilize the gene supply from a much wider source than that of the individual species in order to produce outstanding hybrids of agronomic importance. The inheritances of species fitting very different climates were combined to produce for intermediate climates hybrids having wider climatic tolerance than either parent. The probabilities of success in such an endeavor are enhanced by crossing forms that do not occur together in the wild; in those that occur together, hybridization and natural selection have presumably already sorted out the best combinations. Advantage was also to be taken of apomixis as an aid in quickly establishing desirable new nonsegregating hybrids.

The finding that two-thirds of the hybrids between apomictic parents were sexual, and only one-third apomictic, was unexpected. Some of the apomictic hybrids were rather highly sterile, also, and some were weak, but still others had qualities of promise. Compensation for the unexpected segregations was found in the great variety of recombinations obtained, many of which were very vigorous, affording much more opportunity for selection than in strictly apomictic forms.

Eleven species of *Poa* have been utilized in the crossings. These are *Poa ampla* Merr., *nevadensis Vzsey*$_9$ *scabrella* (Thurb.)

Benth., *Canbyi* Piper, and *gracillima* Vasey, all west American bunch grasses; P. *pratensis* L., *compressa* L.? *arida* Vasey, and *nervosa* Vasey, of the rhizomatous group; and the two more distantly related species P. *longifolia* Trin., a bunch grass, and P. *arachnifera* Torr., a dioecious rhizome grass. Forty different strains of these species, from very different climates, were used in the crossings* Of the 53 hybrid combinations attempted, 35 succeeded5 resulting In 281 Fi hybrids and 10 triple hybrids, obtained from among more than **52,000** seedlings. Fourteen different interspecific combinations were **made,** which arc listed in table 1. Many of these were made several times, using different races.

The first seven combinations listed in the table have been the most successful. Five species—*ampla, scahrella, pratensis, compressa,* and *arida*—enter into these. Of the II species tried in these experiments, then, these appear to have the gene sets (genomes) from which new forms can most successfully be synthesized. It is noteworthy that it has been impossible to use Kentucky bluegrass, *P. pratensis,* as the female parent in any of the hybrids, although it was frequently used successfully as the male parent.

TABLE 1

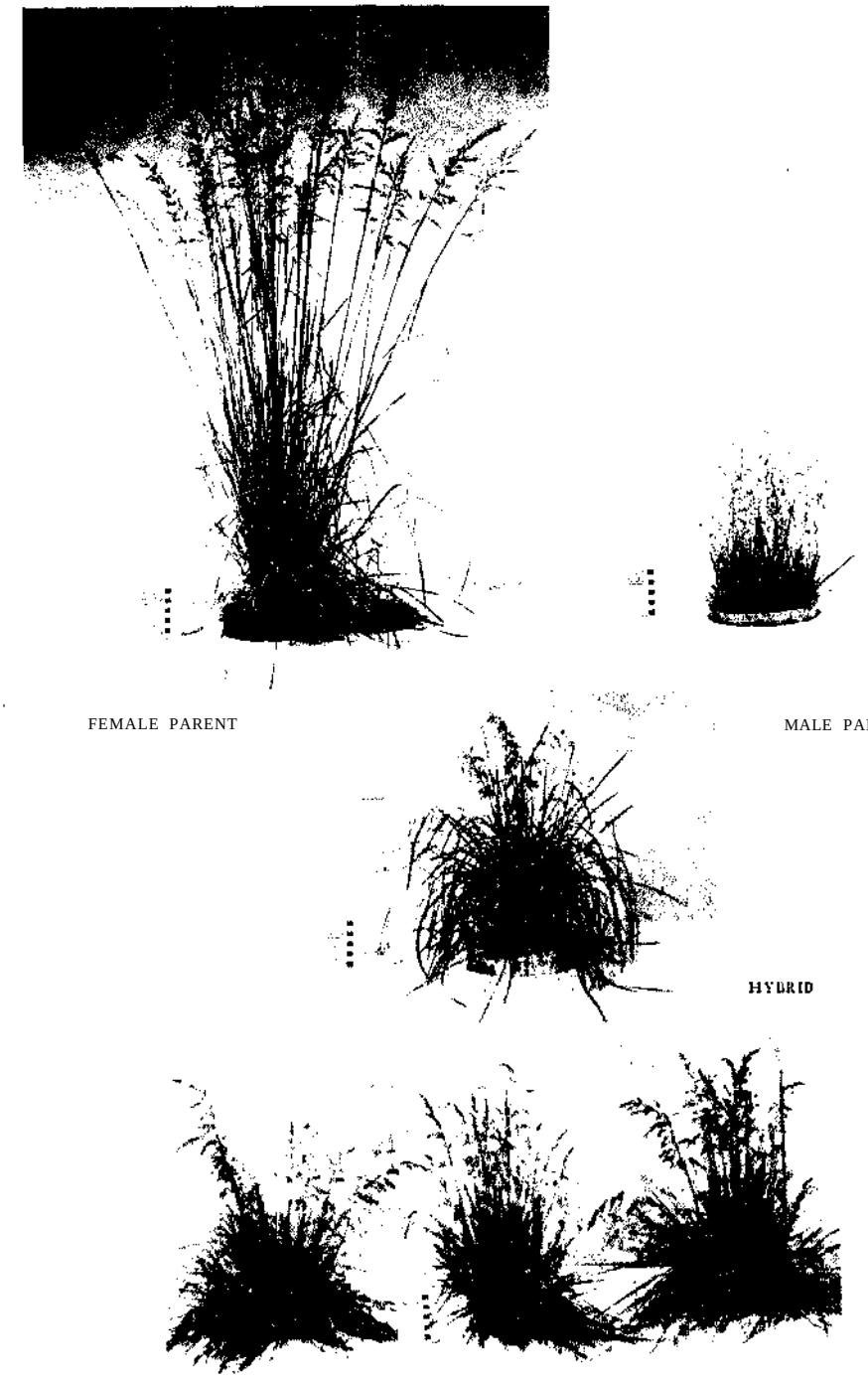
INTERSPECIFIC CROSSINGS IN POA

SPECIES COMBINATIONS	RACIAL COMBINATIONS		No. OF Fi PLANTS
	No. tried	No. succeeding	
1. Poa ampla X pratensis	10	10	162
2. P. ampla X compressa (and reciprocal)	3	2	9
3. P. ampla X arida (and reciprocal)	1	1	2
4. P. scabrella X ampla	2	1	3
5. P. scabrella X arida (and reciprocal)	1	1	5
6. P. scabrella X pratensis	14	8	56
7. P. scabrella X pratensis X ampla	2	2	10
8. P. scabrella X compressa	2	2	5
9. P. scabrella X arachnifera	4	1	1*
10. P. Canbyi X pratensis	2	2	3
11. P. gracillima X pratensis	1	1	12
12. P. gracillima X scabrella (and reciprocal)	2	2	18
13. P. nevadensis X compressa	4	1	**4f**
14. P. nevadensis X longifolia	1	1	It
15. P. nevadensis X pratensis	1	0	0
16. P. eervosa X scabrella	1	0	0
17. P. nervosa X Canbyi	2	0	0
Totals	***53***	35	291

*Sterile.
ISubtethaL

RESPONSES OF THE POA HYBRIDS TO DIFFERENT CLIMATES

The new hybrids resemble wild species in that they fit certain.environments better



AsF.XT:\L PROGENY OF HYBRID

Big bliicgrass frntn Palouse Prairie, Washington, the subarctic form of Kentucky bluegrass from Swedish Lapland, and one of their nonsegregating hybrid lines. All these are shown as they grow at Stanford.

than others. Their practical utilization depends upon discovering to which climatic conditions they are best adapted. A few examples will serve to illustrate the kind of differences in climatic response that have been uncovered.

Poa ampla X *pratensis alpigena.* One of the most promising new Poas in the Pullman nursery is an apomictic 63-chromosome hybrid between a giant form of the big bluegrass, *P. ampla,* from near Pullman, and a subarctic form of Kentucky bluegrass, *P. pratensis alpigena,* from Swedish Lapland (plate 1). It is moderately vigorous even as far south as Stanford, but becomes much more productive farther north at Pullman. It is unlike any known species of *Poa.* At Pullman it is a freely tillering, very leafy form that has inherited from *ampla* glaucous herbage, large inflorescences, and winter-active habit, even when subjected to heavy frosts, and from *pratensis alpigena* rust resistance, increased tillering, rigid culms that do not lodge, and extended summer activity. This hybrid does not benefit by being moved from Stanford to the higher altitudes of the Sierran transplant stations, but from its performance at Pullman seems to be especially suited to more northern latitudes.

A 70-chromosome sister hybrid of the same parentage is morphologically very different. It is weak at Stanford, but at the mountain stations is stronger, and there it flowers freely- Unlike its apomictic sister hybrid, it is sexual and segregates freely in the second generation. At Stanford only 19 out of 300 second-generation seedlings survived, but at Pullman 80 per cent survived, and there, among others, very rhizomatous, summer-active, and late-flowering forms are segregated. Some of these derivatives combine the best characters from both parental species and are very vigorous. Two additional hybrids of the same parentage also proved to be stronger at the mountain stations than at Stanford, but were not tested at Pullman. These results indicate that the hybrids between *Poa ampla* from eastern Washington and P. *pratensis* from Lapland require winters that are colder than those in the California lowlands.

Poa ampla X *pratensis.* A 96-chromosome spontaneous hybrid of this combination, originating in the Pullman nursery and discovered among seedlings grown at Stanford, was described in Year Book No. 44, pp. 76-77. It makes excellent growth at Stanford, much exceeding in vigor either parental species. It reproduces sexually, as is shown by the segregation among the second-generation offspring, which also grow vigorously at Stanford. At Pullman, however, this hybrid is less vigorous than at Stanford and less vigorous than its *ampla* parent.

An explanation of these different reactions in the two environments may be inferred from the characteristics of the parental forms, neither of which is native in the Stanford region. The *ampla* parent is unsuited to the conditions of the California coastal valleys, because during the warm, early summer it is heavily attacked by rust and can seldom mature seed. Forms of *pratensis,* likewise, are not ideally fitted to this environment, because the winter dormancy of this species places it at a disadvantage as compared with the winter-active native plants in this mild climate. When, however, the *ampla* and *pratensis* inheritances are combined in the hybrid, a winter-active grass is produced that is fairly resistant to rust and that remains active well into the summer, far outperforming either parental species at Stanford. At Pullman the more severe winters force the hybrid into dormancy, but the *ampla* parent remains active. The hybrid is thereby at a disadvantage and produces less total growth during the

season than its *ampla* parent. Here, then, are two species which, for different reasons, are unable to populate the Coast Ranges o£ central California, but whose hybrid is successful in this environment rather than at its place of origin in eastern Washington, where both species grow spontaneously.

Not all the *ampla-pratensis* combinations are winter-active at Stanford like the one described above. For example, a cross between the giant form of *ampla* from the Palouse Prairie near Pullman and a montane strain of *pratensis* from a meadow at Mather, at 4600 feet in the Sierra Nevada, yielded offspring that are for the most part winter-dormant. Moreover, all the 57 first-generation hybrids of this combination grew very vigorously in the very different climates of the Stanford, Mather, and Timberline transplant stations. At Stanford they undergo a short winter dormancy, but remain active during the dry summer when the native Coast Range races of *Poa* are forced into dormancy. Their very rhizomatous character and rust resistance are notable at this station. At Mather this population is even more uniformly vigorous and much more floriferous than at Stanford, a fact which indicates that it is generally better fitted to these montane conditions. At Timberline it survives with surprising success, breaking its winter dormancy more rapidly than do any of the other hybrids tried at that station and developing faster than those that are winter-active at Stanford. The vigorous, rapid development of this hybrid at the mountain stations and the relatively poor flowering of many individuals at Stanford suggest that it is better fitted for environments with colder winters. The individual variation within this population is such, however, as to make possible the selection of outstanding performers at any one of the three stations, for some individuals are winter-active and most vigorous at Stanford and others most vigorous at Mather. A study of the second-generation progenies now under way will provide more information regarding opportunities for selection in this combination.

These examples of differences in environmental responses provided by three hybrid combinations between different races of *Poa ampla* and P. *pratensis* illustrate the evolutionary possibilities *in* combining climatically different races of the same two species to produce forms suited to very different climatic niches.

Poa ampla X *compressa.* Only a few high-quality grasses are available to provide grazing in the West during the summer months. Late flowering is associated with prolonged vegetative activity and is one of the best means of keeping a grass green during the summer. *Poa compressa,* the Canada bluegrass, is one of the latest-flowering species, and a hybrid between a form of it from the Mediterranean slopes of Asia Minor and a late-flowering Palouse Prairie form of *Poa ampla* is the latest of all the *Poa* hybrids. It remains green throughout the summer and is resistant to rust. Unfortunately,* however, all except one of these hybrids are highly sterile. This fertile individual proved to be sexual and produced highly variable offspring, but the second hybrid generation was so weak at Stanford that only 80 out of 240 seedlings survived, and of these only 22 flowered. It was found that a sample of this second generation grown at Pullman was much more vigorous.. than that at Stanford, so that the apparent hybrid incompatibility in this case is influenced by the environment. Although some inferior forms appeared at Pullman also, approximately 30 per cent of the offspring were very vigorous grasses that had inherited the rhizomes, late flowering, and rust resistance of their *compressa* parent, and some of the size

and leafiness o£ their *ampla* parent. A highly desirable grass can probably be developed from this combination, but it would doubtless require a climate with a cold winter and a warm summer, such as is found in our Great Basin areas.

Poa scahrella X *pratensis.* This hybrid between the California bluegrass and the Kentucky bluegrass combines a winter-active, summer-dormant bunch grass with a winter-dormant, summer-active rhizome grass. Some 33 second-generation progenies of this combination have been studied, all from hybrids between a coastal southern California form of *scabrella* and races of *pratensis* from Lapland, Canada, the Sierra Nevada, and the Great Basin. Some of these progenies are apomictic, others are sexual and segregating.

In the garden at Stanford this hybrid is as winter-active as *scabrella,* developing culms in midwinter and flowering from late February through March. It and the apomictic, nonsegregating F2 progenies are also moderately summer-active, thus lengthening the growing season over that of the *scabrella* parent by a month or two in the early summer and again in the fall; they are briefly dormant in midsummer. The *pratensis* influence has also increased the number of tillers considerably, although this hybrid cannot be classified as rhizomatous. The result is a freely tillering bunch grass that in the California Coast Range environment is more productive and stays green longer than the native *scabrella.*

Its sexual F2 progenies are also winter-active, but they segregate summer-dormant and summer-active forms and also the entire gamut from strict bunch grasses to fully rhizomatous types. Some of the most promising of these scgregants are summer-active and rhizomatous, having the advantages of an almost continuous growing season and a sod-forming habit.

Although these forms grow vigorously through the winter near the coast, where only light frosts occur, at Mather and Timber line the much lower temperatures force them into winter dormancy. As a consequence they are considerably weaker at these stations than at Stanford, although they are stronger than their *scabrella* parent. At Pullman, also, most of the *scabrella-pratensis* hybrids are forced into winter dormancy and are less vigorous than at Stanford, although still much stronger than their *scabrella* parent, which barely survives. The most successful hybrid of this combination at Pullman received its *pratensis* chromosomes from a Great Basin race coming from a climate not unlike that of Pullman. This hybrid was the only one of this combination that remained green through the winter at Pullman, and, accordingly, it had some advantage over the others.

These tests indicate that the present *scabrella-pratensis* combinations are best fitted for climates with mild winters, like those where *scabrella* is native. Here, from the agronomic viewpoint, it is superior to the *scabrella* forms, because of its extended season of growth. By using *pratensis* races from climates with severe winters, it may be possible to produce hybrids that can tolerate colder winters. Through selection in the progenies of sexual hybrids, it should be possible to develop winter- and summer-active rhizomatous grasses for the coastal slopes on the west sides of the continents, where the winters are relatively mild.

PARTIAL APOMIXIS: AN EVOLUTIONARY LABYRINTH

Most of the wild perennial Poas are partially apomictic, that is, they reproduce principally by seed formed without fertilization, but 5 to 10 per cent of their off-

spring differ in appearance from the uniform apomictic sister plants and presumably arise through the sexual process. Such aberrant individuals are regularly weaker than the normal apomictic offspring and accordingly are seldom seen in the wild. Aborted seed is also common in wild forms. Since the apomictic Poas are chromosomally very irregular, it is probable that not only the weak aberrant seedlings, but also the aborted seed represent sexual offspring that are genetically so unbalanced that they are unable to develop.

Some apomictic species, such as *ampla* and *scabrella*, are only about 30 to 40 per cent fertile, whereas in others, such as *pratensis*, the seed fertility approaches 100 per cent. But even in *pratensis*, highly apomictic individuals may produce a small fraction of weak, sexual aberrants, and other individuals may be highly sexual. Thus it is evident that apomictic and sexual processes exist concurrently in this genus, and that apomictic and sexual fertility may vary independently.

Although the sexual process is still active in the apomictic Poas, the apomictic type is maintained through selection, because the apomictic fertility is greater than the sexual, and the apomictic offspring are the more vigorous. In the wild only those apomicts survive which possess this kind of balance between the asexual and sexual processes. In the experiment field, however, we find that many new situations arise when one apomictic species is crossed with another. This can happen because under cultivation natural selection does not operate so rigorously on the new genetic combinations as it would in the wild.

In the garden, for example, some hybrid strains are predominantly apomictic yet so sterile that they could not maintain themselves under competition, although the offspring they do have are sufficiently vigorous. One such apomictic strain, derived from some 15,000 seeds of a 59-chromosome *compressa* X *ampla* hybrid, consisted of 53 vigorous plants of the apomictic maternal type and 13 weak, sexual aberrants. This is a fertility of only 0.44 per cent. A very different situation was found in one of the fertile hybrids of *scabrella* X *pratensis* which was predominantly sexual. It produced 55 apomictic and 185 sexual offspring among a total of 240, and in this case the two kinds of offspring were about equally vigorous.

A weak apomict throwing some vigorous sexual aberrants was found in a 73-chromosome sister plant of the *ampla* X *pratensis alpigena* hybrids already mentioned. This plant was predominantly apomictic, for 217 of 240 second-generation progeny were of the maternal type but so weak that only 70 survived the winter at Stanford and only a few were able to flower. In addition there were 23 variable offspring that had arisen by the sexual process. Most of these far outperformed the apomictic offspring, and one was outstanding—the best of all the hybrids of this combination—a tall, vigorous, many-culmed, very leafy and strongly rhizomatous individual. In this case there is a complete reversal of the situation characteristic of wild apomicts, for the apomictic offspring are weak and the sexual much stronger. This is an indication that even the weak apomicts may in time yield superior offspring.

It was mentioned that two-thirds of the hybrids between apomictic *Poa* species reproduce exclusively by the sexual process. Some of these are weak and rather sterile, others are weak but fertile, still others are strong but fairly sterile, and, finally, a few are fertile and have a high percentage of vigorous offspring.

In the sexual hybrid progenies of *Poa* not all the parental characters segregate completely. For example, all the second-

generation progenies of *scabrella* X *pratensis* were winter-active despite the fact that the *pratensis* parent was winter-dormant. The explanation of this unexpected observation probably lies in the fact that all the *Poa* species used in these crossings have high chromosome numbers, and there is independent evidence that their chromosomes are already much duplicated. In hybrids between such species, the chromosomes of each parent should be able to pair between themselves, preventing segregation of the characters determined by such duplicated chromosomes. This theory is supported by the observation that chromosome pairing is as extensive in the *Poa* hybrids as in the parental species. Both parents and hybrids have some unpaired chromosomes. Considerable segregation is possible on account of random distribution of these to the gametes.

The possibility exists in *Poa* that when hybrids between apomictic species are formed which reproduce sexually, these may in later generations produce apomictic forms again. From an evolutionary point of view and for practical breeding purposes such a situation would be of utmost importance, for a period of sexuality after crossing would be of benefit as a means of more thoroughly exchanging the parental characteristics.

Apomixis is a remarkable means of storing potentially great variation for possible later use in the evolutionary process. It would indeed be of considerable practical and theoretical importance were we able to break the apomictic bond periodically, releasing the variability and then sealing it up again after a period o£ recombination. The first of these steps has already been taken.

USE OF THE STATION FACILITIES

The natural opportunities for biological studies in the environs of the Sierran transplant stations are increasingly being realized, and many biologists have visited the stations for various purposes. Dr. Th. Dobzhansky, research associate of the Carnegie Institution from Columbia University, has spent his third consecutive summer at the Mather station investigating native populations of the fruit fly *Drosophila* along the Sierran transect. This year he has studied the occurrence of these races in relation to season and altitude.

Dr. G. L. Stebbins, Jr., of the University of California, visited the transect from Mather to Timberline several times, studying the genetic races of blue wild rye *(Elymus glaucus)* and California brome *(Bromus carinatus)*. He has also established small, uncultivated test plots in sun and shade at Mather for studying the establishment from seed of races and hybrids of *Bromus.*

Dr. Mogens Westergaard, of the University of Copenhagen, Denmark, visited Timberline station in order to study and preserve for cytological examination alpine plants that also occur, or have close relatives that occur, in Greenland. He was accompanied by Dr. F. W. Went, of the California Institute of Technology, who made a study of the dwarf alpine annuals there and collected seed for growing under controlled conditions.

A round-table discussion was held at the Mather station on the role of genetics, physiology, and environment in the evolution of natural local populations, climatic races, and species. Almost all the participants spent two days at Timberline station either preceding or following the session at Mather. Those attending included: Drs. Th. Dobzhansky, Columbia University; F. W. Went, California Institute of Technology; Mogens Westergaard, University of Copenhagen, Denmark; D. G. Catcheside, Cambridge University, England; M. J. Heuts, University of

Leuven, Belgium; G. L. Stebbins, Jr., University of California; Carl Epling, University of California at Los Angeles; Reed C. Rollins, Stanford University; Carl Sharsmith, National Park Service, Yosemite; and Clausen, Keck, and Hiesey of the Institution staff.

Informal progress reports on current research programs of the participants brought out the diversity of patterns of fitness to environment of plants and animals, as well as the similarities in the ultimate objectives of the group. Emphasis was placed on the physiological development of the organism as synchronized with the periodicities of the environment, and on the genetic control of the physiological responses. Examples were taken from recent investigations on natural races of *Achilka, Potentilla,* desert annual plants, tomatoes, *Drosophila,* the stickleback fish *{Gasterosteus),* guayule *(Parthenium),* evening primroses *(Oenothera),* interspecific hybrids of *Poa,* and natural hybrids between wheat grass *(Agropyron)* and wild rye *(Elymus)*; and from germination experiments at Mather on climatic races and hybrids of brome grasses.

A decision was reached to search for a group of plants having as nearly as possible ideal characteristics for co-operative investigations on genetics, cytology, physiology, ecology, and evolution. A feature of this conference was that cytogeneticists, physiologists, and taxonomists began to see clearly how the investigations in their respective fields contribute mutually to a comprehensible picture of how the evolutionary processes operate.

Other scientists who attended the Mather conference on evolution used the opportunity to advance their own botanical interests at the Sierran stations. Particular mention should be made of the representative collection of mosses and liverworts assembled in the Harvey Monroe Hall Natural Area around Timberline station by Dr. D. G. Catcheside, of Cambridge University, England, the first such from this area. All these investigations will contribute to the knowledge of the flora and the ecology of the Hall Area, a preserve established for scientific purposes some years ago by the Forest Service in which is found a characteristic sample of the high-altitude flora of the central Sierra Nevada.

PALEOBOTANY

RALPH W. CHANEY

Our studies during the past year have continued to place emphasis on the record of Tertiary forests in the John Day Basin of eastern Oregon. The Mascall and other Miocene floras of western North America are largely composed of genera which came in from the north. Cretaceous and Eocene ancestors of many deciduous hardwoods, such as *Acer, Alnus, Betula, Carpinus, Cercidiphyllum, Fagtis, Quercus,* and *Ultnus,* lived largely at high northern latitudes; their migration southward in post-Eocene time is indicated by many fossil records both in North America and in Asia.

It is therefore of particular significance to consider the time and place of appearance of the black oaks (subgenus *Erythrobalanus*) with deeply lobed leaves. They arc first recorded in rocks of Lower Miocene age in the Gorge of the Columbia River east of the Cascades, and before the end of the epoch were among the most numerous trees. They have not been recorded much farther northward either in fossil or in living floras, and are wholly

unknown in Eurasia. Had they been members of the Arcto-Tertiary Flora, their remains might be expected to occur with those of oaks of other types in the Eocene of Alaska, and in the Miocene of China, where a flora including many holarctic plants has been found in Shantung; they should also be found in the modern forests of Asia, where other oaks are common. The only known ancestor of the deeply lobed black oaks has been recorded by MacGinitie in an Eocene flora from the foothills of the Sierra Nevada. This flora from Chalk Bluffs contains numerous genera which are believed to have migrated northward from low latitudes, and it is wholly possible that *Quercus jalapensis* came with them. Students of modern oaks have suggested a center of origin for the black oaks on the plateau of Mexico, where there are many living species; in any event, they could scarcely have come to Oregon from the north.

From Miocene time down to the present, black oaks have made up an important part of the forests in North America. More than most Tertiary fossils, they and other oaks provide an illustration of gradual speciation during geologic time, with suggestions both of divergence and of convergence into a meshlike pattern of development. Recent discussion with Professor E. B. Babcock and Professor G. Ledyard Stebbins, Jr. has indicated that the high variability of leaf form in *Quercus* is consistent with the genetic make-up of modern members of the genus. Like most widespread living plants, the oaks are heterogenic, including large numbers of biotypes which may be grouped into more or less distinct ecotypes. Ready interpollination by wind has tended to accentuate their heterozygosity, and great genetic variability is the result. Ultimately we may anticipate the extinction of many living species, and the more restricted distribution of their survivors.

The beginnings of such local extinction and restriction may be noted during the later Tertiary history of the western United States. Whereas the Miocene record includes a wide range in leaf form among the black oaks, the floras of the Pliocene show reduction in numbers, in size, and in variability. Prevalence of semiarid climate over much of the western interior since the Pliocene, and of dry summers adjacent to the Pacific coast, seems directly related to the smaller size and reduced number of species of surviving black oaks as compared with their occurrence in the eastern United States under a continuing summer-wet climate. During the same time, oaks with small, thick leaves and an evergreen habit (subgenus *Protobalanus)* have greatly increased in numbers and range in California and Mexico. With the oaks as with other Tertiary trees, climate appears to have exerted a controlling influence over distribution, leaf characters, and survival. Climatic changes of the future may be expected to modify further the forests as we know them today.

A remarkable case of the survival of a forest with little modification from Middle Miocene time down to the present has been discovered during comparisons of the Mascall flora with existing vegetation. On the flood plain of the Wabash River in southern Indiana, most of the common trees such as swamp cypress *(Taxodium distichum),* red oak *(Quercus borealis),* shagbark hickory *(Carya opatd),* slippery elm *(Ultnus fulva),* and swamp cottonwood *(Populus heterophylla)* have Miocene equivalents in the Mascall flora which lived thirty million years or more ago. Several genera recorded as fossils no longer live in Indiana, but the resemblance between these two units of vegetation is so

close as to permit more than usually accurate reconstruction of the Miocene climate and topography of Oregon.

As was suggested above, the vegetation of the Eocene at middle latitudes appears to have had its origin largely at the south. Preliminary studies of the Clarno flora from the John Day Basin are showing the presence of cycads and ferns, as well as broad-leafed evergreens, whose living equivalents are confined to low latitudes. The northward movement of these and other members of the early Tertiary forest, to which the group designation Neotropical-Tertiary Flora has been assigned, and their southward shift later in the Tertiary period, constitutes another well documented record of plant migration under compulsion of climatic change. Lingering behind, certain of the hardier members of the Neotropical-Tertiary Flora, such as *hind era*, *Cedrela*, and *Oreopanax*, were absorbed by the Miocene floras from the north. Together with the black oaks above mentioned, these southern genera illustrate the manner in which plants from more than one center of origin may become mingled in a fossil flora, and suggest an explanation for the survival of certain aberrant trees in the forests of today.

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DEPARTMENT OF EMBRYOLOGY

Baltimore, Maryland

GEORGE W. CORNER, *Director*

The Department of Embryology is happily able to report a year of undistracted work, during which all the members of the Department have been present and with a number of competent younger associates and guests have been engaged upon their respective parts of our program of investigation. The details of their work will be reported below.

In December 1946, Dr. Margaret Reed Lewis retired from the Carnegie Institution. Dr. Lewis was appointed "collaborator" on January 1, 1915, and thereafter until the current year was continuously engaged in research in the Department of Embryology. Her numerous valuable contributions have dealt with problems of blood cells and connective-tissue cells in tissue culture, with various aspects of experimental cytology of the living cell, with vital staining, problems of growth and immunity in malignant tumors, and other related topics in the field of normal and abnormal cytology. In 1940, when Dr. Warren H. Lewis retired from this department and joined the staff of the Wistar Institute for Anatomy and Biology in Philadelphia, Dr. Margaret Lewis transferred her work to the Wistar Institute, remaining however a member of the Carnegie Institution. It is a pleasure to add that arrangements have now been made for Dr. Lewis to carry on at the Wistar Institute her investigations in immunity and resistance of cancer cells, which have attracted international attention.

The staff now consists of five senior investigators, including the Director. Associated with these is a varying number (usually four or five each year) of fellows, guest investigators, and other persons giving their full time to research in the laboratory, and several medical students and other guest investigators giving part time to research.

Dr. Walter S. Wilde, who joined the staff in 1944 as assistant and collaborator of Dr. L. B. Flexner, resigned in March 1947 to accept a very favorable appointment in the National Institute of Health. During his relatively short connection with the Department of Embryology, Dr. Wilde proved himself a fertile and stimulating investigator.

Washington Buño, M.D., professor of histology and embryology in the University of Montevideo, spent the year from May 1946 to May 1947 in the Department on a Guggenheim fellowship. His work on early abnormal embryos will be reported below.

L. J. Wells, Ph.D., associate professor of anatomy in the University of Minnesota, came as Guggenheim Fellow from January to May 1947,

Dr. S. Culver Williams, assistant professor in charge of dental anatomy in the University of Pennsylvania, devoted two months in the summer of 1946 to the study of early development of the teeth. Dr. E. Carl Sensenig, at the time connected with the Department of Anatomy in Tulane University, New Orleans, returned in the summer of 1946 as in the previous years, to work on the embryology of the spinal column.

Mrs. Poldi Grabherr, staff photographer of the Chilean National Department of Health Laboratory, Santiago, spent a fortnight in the laboratory observing technical methods in scientific photography,

PROGRAM OF INVESTIGATIONS

Morphological studies. Dr. C. H. Heuser, curator of the Embryological Collection, has continued during the year his investigations on early stages of primate embryos. In particular, he has prepared a model and made intensive studies of a human embryo lent to the Department by Professor Bradley M. Patten, of the University of Michigan. This is of special value in connection with the problem of the origin of the yolk sac in man, a question that has been much debated in recent years, and to which it is hoped the embryos of the second week being accumulated in this laboratory will ultimately give a clear answer. Dr. Heuser has also given considerable time to the study of the early baboon embryos obtained at Johannesburg by Dr. Joseph Gillman (see below, "Cooperative activities").

Dr. George L. Streeter has completed another two stages of his extensive work on horizons of development (see recent previous Year Books), and has devoted much time, during the year just past, to a study of the development of bone in human embryos, with special reference to the time sequence of the stages of development and their relation to the growth and differentiation of other organs.

Dr. Elizabeth M. Ramsey, of Washington, has been spending two days each week in the laboratory for several years except when interrupted by her wartime service at the National Research Council, making an intensive study of the development of the blood vessels of the placenta of the rhesus monkey. For this work a number of monkeys were especially bred by Dr. C. G. Hartman and later by Dr. Corner, and the placentas at selected stages of pregnancy were prepared for study by injection of the **blood** vessels with India ink. Dr. Ramsey has completed her arduous work on this subject, which will appear in volume 33 of Contributions to Embryology with drawings by Mr. Didusch based on intricate plastic-sheet models by Dr. Ramsey.

Dr. Washington Burio devoted about half his time to studying a collection of abnormal early embryos of the rhesus monkey that were set aside by Dr. Heuser when he and Dr. Streeter were making their comprehensive study of the normal embryology of rhesus (Contributions to Embryology, no. 181, 1941). The material thus placed at Dr. Buiio's disposal is unique, because the embryos were bred in the laboratory by Dr. Hartman and are accompanied by breeding data, by the endometria, and in many cases by the ovaries, so that the condition of the uterus and corpora lutea may be studied.

Dr. Sensenig continued his investigation of the embryology of the human vertebral column, which he proposes to carry on to deal also with the anomalies of development, many of which, e.g. spina bifida, are of importance in surgery.

Dr. Wells undertook a study of one of the most complicated topics in human embryology, the development of the diaphragm and the pleural cavities. Dr. F. P. Mall, founder of this Department, was deeply interested in the same subject and wrote what was the standard contribution in his day. Dr. Wells has been able to reinvestigate the same embryos that were used and illustrated by Mall, comparing them with many newer specimens. In work of this type the command of modeling techniques possessed by the staff of the Department is of especial value. Dr. Wells' models were demonstrated at the April meeting of the American Association of Anatomists. An article based upon them will be published later.

Mr. Lawrence R. Wharton, Jr., of Johns Hopkins Medical School, working under the guidance of Dr. Streeter and Dr. Burns, completed an account of a case of duplication of the ureter in an embryo of the collection, comparing it with a second, less advanced anomaly of the same sort generously placed at his disposal for study by Dr. S. I. Kornhauser, professor of anatomy at the University of Louisville.

Collection of very early human embryos. Dr. Arthur T. Hertig, of Boston, research associate of the Carnegie Institution of Washington, and his colleague Dr. John Rock have submitted a report on their work done under a special grant from the departmental budget, from which the following is excerpted:

During the past year twelve uteri obtained at operation, and thought likely to contain early embryos, have been studied. Most of the effort was concentrated on seeking preimplantation phases of the human embryo. Two such specimens were found free in the uterine cavity. The younger specimen (no. 8450) consisted of eight blastomeres arranged in a discoid instead of a spheroid form as normally expected, and is considered to be abnormal. The associated endometrium and corpus luteum indicated that the ovum was about 3¾ days old. Coital data were not inconsistent with this estimate, but not precise enough to be of much use.

The older specimen (no. 8452) was composed of twelve blastomeres of various sizes, shapes, and staining densities arranged in the customary spheroidal fashion. The specimen, which is estimated to be 4 days of age, was found on the 18th day of the menstrual cycle. As in the previous specimen, coital data are consistent but not critically useful.

It will be recalled that in 1943 a free nine-cell morula (no. 8190) was discovered in the uterine cavity on the late 17th or early 18th day of the menstrual cycle. Although this specimen is probably abnormal, these three specimens, constituting as they do the only preimplantation stages of the human ovum thus far observed, tend to prove that the segmenting ovum reaches the uterine cavity early on the 4th day after ovulation (and fertilization). At this stage it has approximately six to eight blastomeres and as yet shows little if any segmentation cavity. It still has a vitelline membrane.

That two and indeed possibly all three of these very early human embryos are probably abnormal is not surprising. Dr. Corner has shown that in pigs about 30 per cent of all embryos are abnormal, and that one-third of these are already defective in the phase of segmentation. Thus, ability of an ovum to implant, even though it is or subsequently becomes defective, probably requires more robustness of the embryo than does mere segmentation. Hence the "very bad eggs" are weeded out in this phase of development and will therefore be proportionately more numerous among these very early embryos than among those which have the ability to implant on the endometrium. It will be recalled that of the 23 implanted human ova found by Hertig and Rock in the past nine years, almost 40 per cent show some abnormality, often of such a serious nature that it is incompatible with normal continuation of the pregnancy.

Experimental embryology. Dr. R. K. Burns has continued the study of opossum embryos (pouch young) subjected to experimental treatment with sex hormones. He was able to resume on a small scale the program of new experiments, which had become impossible during the latter part of the war period because of the unavailability of experienced trappers.

Miss Faith Wilson, fellow in zoology at Johns Hopkins University, has been as-

signed to this Department to do her thesis work under the direction of Dr. Burns and has made our laboratory her headquarters during the past two years. Miss Wilson is studying certain phases of embryological development of reproduction in the Syrian hamster, *Cricetus aureus.* This little animal, similar to the rat in its anatomical structure, has the shortest gestation period known among mammals (except the marsupials). Its young, born only 16 days after ovulation, are in some respects quite immature at birth. This is particularly true of the reproductive system, which is the object of Miss Wilson's research. The testis and ovary do not exhibit the kind of internal structure which indicates endocrine function until about 25 days after birth. The chief aim of the investigation is to study the degree to which the sex pattern of the accessory sex organs may be altered, during their relatively indifferent early stages, by administration of sex-gland hormones and by early castration. An effort is also being made to find out whether the adrenal cortex influences the differentiation of the accessory sex organs. For this study the hamster has another advantageous peculiarity: in the newborn female certain rudimentary male structures are more than ordinarily well developed. The female hamster develops good-sized corpora cavernosa, a relatively large glans clitoridis, an os priapis, and even a rudimentary prostate glaad. If the adrenal cortical hormone is androgenicj the female hamster offers a test object in which such an androgenic property should show its effects with especial readiness. Miss Wilson's studies are progressing well and will, no doubt, reach publication In her doctoral dissertation.

Dr. L. J, Wells, who before coming to visit the laboratory developed an ingenious method of removing the hypophysis of the fetal rat by operation in utero, attempted a similar operation in two monkeys with the assistance of Dr. Corner and Mr. Rever, who have had much experience in abdominal surgery in the monkey. Success in hypophysectomizing the fetal monkey would contribute much to our knowledge of the effect of the pituitary gland in fetal growth. The relatively long term of gestation, and the thorough knowledge of the proportions and weights of fetal and neofetal monkeys with which experimental material could be compared, made the enterprise tempting; but formidable technical difficulties were encountered and it does not seem profitable to continue along this line at present.

Biophysics; growth; enzymes. The program of investigation of the physiology of the placenta as an organ of transfer, led by Dr. Louis B. Flexner, was explained at some length in Year Books Nos. 41 (1941-1942) and 43 (1943-1944). As was mentioned in last year's report, these researches and associated studies on the still broader questions of the permeability of blood capillaries elsewhere in the body, and the distribution of water in the tissues, have been resumed after a lapse caused by the war. The Department of Embryology has been fortunate in having the active cooperation of the Department of Terrestrial Magnetism.

Dr. Gilbert J- Vosburgh, of the Department of Obstetrics of the Johns Hopkins University and Hospital, has actively participated in the studies on general and placental permeability. Dr. Louis Hellman, a senior member of the same department, has collaborated in consultation and by the provision of clinical material. Dr. Roy O. Scholz, of the Wilmer Ophthalmological Clinic at Johns Hopkins, has taken part in studies on general permeability and especially on the transfer of fluids in the chambers of the eye.

Dr. Flexner is also conducting research under a grant from the Committee on

Growth, National Research Council, acting for the American Cancer Society. The general aim of this program is to investigate the morphological and biochemical changes which occur in cells during embryonic growth, to correlate these changes, and to relate them to -the onset of characteristic functions in an organ. The liver and cerebral cortex of the embryonic guinea pig are now being investigated from this viewpoint. With Virginia Peters, on leave from the National Cancer Institute, quantitative cytologic analyses of liver and cerebral cortex are being made for the purpose of determining what proportion of the growth of these organs is due to the increment in volume of their several constituent morphological parts: hepatic cell cytoplasm, hepatic cell nucleus, extravascular blood-forming cells, and extracellular space in the case of the liver; nucleus and cytoplasm of nerve cells and extracellular space in the case of the cortex. Biochemical investigations with J. B. Flexner have as their major aim an evaluation of the energy-rich phosphate compounds (creatine phosphate, adenosine di- and triphosphates) as they may be related to rate of growth and to degree o£ morphological and functional differentiation. The first step is to investigate the activity of phosphatases which are concerned, according to current concept, in liberating energy from these compounds. The critical time in the development of adenosine triphosphatase activity in cerebral cortex and liver is at about the 42d day of gestation (term 66 days). Prior to this time the activity of the enzyme is at a constant and low level. At the 42d day the activity begins to rise sharply to reach the adult level at birth. Acid phosphatase in the cerebral cortex is at a constant level of activity during the whole of that period of gestation which has been studied, and is about twice as active per unit dry weight of tissues as in the adult. The activity of acid phosphatase in the liver at all stages of gestation is greater than in the cerebral cortex, and unlike that in the cortex is relatively low up to a gestation age of about 42 days, when it begins to increase to the adult level, reached at birth.

Physiology of gestation. Dr. S. R. M. Reynolds has continued his comprehensive study of the physiology of the pregnant uterus and of the fetus. The results of this study are now appearing in various scientific journals. A summary of those articles which were published during the year will be found below, in the section on "Published research." Dr. Reynolds has found that calculable hydrostatic forces in the uterine tissues play a large part in the reduction of local blood flow. These forces depend upon the characteristics of growth of the uterus, the shape of the products of conception, and the prevailing hormonal relations of the ovary and placenta. Detailed studies of the rearrangements of the blood vessels of the uterus during pregnancy have shown how these interrelations operate. Investigations of this sort point the way toward better understanding of the problems of advanced pregnancy and of the mechanisms concerned in the onset of parturition- Dr. Reynolds has also studied the anatomy of the blood vessels of the ovary, utilizing the beautiful technique of injection with a colored plastic substance (vinylite) followed by removal of the tissues by digestion with acid pepsin, leaving the blood vessels, or rather a cast of them in durable plastic. The results of this study of the ovarian vessels are summarized below under "Published research."

Dr. Reynolds has devised and constructed, with the aid of Mr. Heard, of this Department, and of engineering firms (in particular the Statham Laboratories, Inc., Los Angeles, California), an instrument for recording the contractions of the

late pregnant and parturient human uterus. By the use of ingenious devices employing "strain gauges" which are highly sensitive to local pressure, and which can be applied to the patient's abdomen, the contractions of the underlying uterus may be detected at several places at once and may be recorded on a paper tape. The apparatus is expected to be useful in studies of normal and abnormal parturition, and will be put into use at once in the Woman's Clinic of Johns Hopkins Hospital in collaboration with members of the Department of Obstetrics, Johns Hopkins University.

Mrs. Lyla T. Bradin, a graduate student of zoology at Johns Hopkins University, has been working under the direction of Dr. Reynolds, with financial support from the Ciba Corporation, of Summit, New Jersey. Her investigations deal with the susceptibility of newborn animals to oxygen deprivation. It is obvious that the sudden substitution, at birth, of air breathing for intrauterine respiration of oxygen borne by the mother's blood is a change to which critical adjustments must be made. The young of various species differ widely as to the degree of maturity at birth, and the response to oxygen deprivation appears to be an index of maturity. Utilizing this index, correlation is being sought between it and conditions existing in the uterus before birth, chiefly as these are affected by the shape of the conceptus. Promising results are being obtained, which will be published at a later time.

Dr. Irwin S. Kaiser devoted part of his time during the year to a study, under the general direction of Dr. Reynolds, of the effects of certain hormones and drugs, i.e. the estrogens, acetylcholinc, atropine, and the antihistarninic substance pyribenzaminc, upon the blood flow through the uterus. The observations, which were made chiefly upon grafts of uterine tissue growing in the anterior chamber of the eye of the rabbit, have yielded information bearing upon the theory of the menstrual cycle, part of which is detailed below under "Published research."

Histology and physiology of the reproductive cycle; experimental teratology. Dr. George W. Corner, director, has continued his studies on the histology of the ovary. Ovaries from women of known reproductive history, collected by Dr. E. J. Farris, of the Wistar Institute, have been subjected to study and are yielding information as to the structure of the early human corpus luteum at successive stages of development. Dr. Corner has also been collaborator with Dr. Buño and Dr. Kaiser in the studies next to be reported.

Dr. Buño and Dr. Corner began during the year an experimental attack on the problem of prenatal mortality in mammals. Using rabbits, which are especially suitable for such experiments, the attempt was made to produce an unfavorable environment for the early embryos by introducing toxic substances into the mother's blood stream. In a relatively large number of experiments, a few anomalies of development were produced, presumably as a result of the experimental procedure. Since Dr. Buño's departure in May, Dr. Corner has continued the work.

At Dr. Corner's suggestion Dr. Kaiser took up and expanded some unpublished experiments of Dr. Corner on the action of the drug prostigmine upon menstruation in the rhesus monkey. In recent years a number of physicians have reported that this drug will bring on menstruation in women when the flow is delayed. Dr. Corner conceived the idea of trying prostigmine on rhesus monkeys during the summer, when menstruation is generally in abeyance. The negative results of his tests were confirmed by Dr. Kaiser, who also tried the effect of prostigmine upon spayed monkeys treated with estrogen,

with and without progesterone in various combinations. The menstruation-inducing action of prostigmine reported in women has therefore not been confirmed for monkeys in the special circumstances under which these experiments were done. Subsequent tests by Dr. Corner, in part on the same individual monkeys, show that they are capable of menstruation-like bleeding in the summer, if given a brief course of treatment with progesterone. Sudden termination of such treatment is usually followed by menstruation-like bleeding.

Dr. Kaiser also undertook a study of the arteries of the uterine lining (endometrium) in various species of primates, using material from the Department's collection and also a number of specimens provided by courtesy of the Department of Anatomy, Harvard Medical School. He found that certain New World monkeys which are stated to undergo periodic breakdown of the endometrium resembling menstruation do not have intricately coiled endometrial arteries like those observed in Old World primates (human, chimpanzee, rhesus monkey, etc.). It is thus probable that the coiling is not *per se* necessary for cyclic hemorrhage.

A paper by Dr. Kaiser on this subject, offered in competition, won the Foundation Prize of the American Association of Obstetricians, Gynecologists and Abdominal Surgeons, awarded in September 1947.

Cerebral blood vessels. Mrs. Dorcas H. Padget, whose monograph on the development of the cerebral arteries of man will appear in volume 32 of Contributions to Embryology, is now working on a similar study of the later development of the cerebral veins, under a grant made to Dr. Corner for the purpose by the Life Insurance Medical Research Fund.

CO-OPERATIVE ACTIVITIES

The co-operative association with Dr. Joseph Gillman, of the University of the Witwatersrand, Johannesburg, South Africa, mentioned in Year Book No. 44 has continued. During the past year Dr. Gillman sent two more baboon uteri. That these both proved not to contain embryos was disappointing, but not altogether a surprise, for all investigators who have attempted the breeding of very early mammalian embryos have obtained a certain proportion of infertile matings. Although the fund provided for this work by the Carnegie Corporation of New York has been expended, the facilities set up in Johannesburg will continue, it is confidently expected, to furnish material for embryological studies. Dr. Gillman visited the laboratory again in July 1947, at which time plans were laid for continuation of the effort to obtain implantation stages of the baboon. Meanwhile the embryos previously sent by Dr. Gillman have all been serially sectioned and are under study by Dr. Heuser, as mentioned above.

Co-operative enterprises carried on with Dr. A. T. Hertig and Dr. John Rock, of Boston, with the Johns Hopkins obstetrical and ophthalmological clinics, and with the Department of Terrestrial Magnetism of the Carnegie Institution have been mentioned in the section on "Program of investigations."

The facilities of the monkey colony have been made available for experiments by Dr. Roger B. Scott, of the Department of Gynecology, Johns Hopkins Hospital, on the experimental production of endometriosis, a subject close to the interests of this department. As in former years, we have housed several monkeys which are subjects of a long-continued and thus far

negative experiment on the production of tumors in monkeys by estrogenic hormones, begun by Dr. C. F. Geschickter in consultation with Dr. Carl G. Hartman when the latter was a member of the Department.

THE CONTRIBUTIONS TO EMBRYOLOGY

Since the foundation of the Department of Embryology it has been the custom to publish many of the completed investigations in a series of Contributions to Embryology. The Contributions include suitable articles written by our own immediate staff, by our colleagues in the Department of Anatomy of Johns Hopkins University when relevant to the Carnegie program of research, by visiting investigators, and in rare cases by outside authors, if they have used material from the Department's collections or in some other way have been especially associated with the Department. Experimental work in physiology and biophysics from the Department laboratories not requiring elaborate graphic illustrations is published in the special journals of those branches of science.

Manuscripts for volume 32 were turned over to the Office of Publications in July 1946. Owing to wartime conditions, some of them had been in hand, awaiting clearance of volume 31, for as much as two years. The volume was almost ready for press at the end of June 1947 and will doubtless appear before this annual report is circulated. Inasmuch as the printing of the Contributions to Embryology is expensive and the edition, both of bound volumes and of reprints, is therefore limited, the contents of the long-delayed volume will be summarized here for the benefit of professional readers who may wish to know what is forthcoming.

The articles are as follows:

207. George W. Comer* *At\dine phosp-hatase in the ovarian follicle and in the corpus luteum.* The conclusions were summarized in the annual report for 1944-1945, Year Book No'. 44. Preliminary note in *Science,* vol. 100, pp. 270-271, 1944.

208. Harold Speert, *The normal and experimental development of the mammary gland of the rhesus mon\ey, with some pathological correlations.* This is a comprehensive report with 19 plates dealing with problems not dealt with or only tentatively discussed in Dr. Speert's several papers in various journals 1940-1942 (see *Index Medicus* for references).

209. Emil Witschi, *Migration of the germ cells of human embryos from the yol\ sac to the primitive gonadal folds.*

210. Joseph Gillman, *The development of the gonads in man, with a consideration of the role of fetal endocrines and the histogenesis of ovarian tumors.*

These two articles, written by well known investigators on the basis of studies made during visits to the Carnegie laboratory, provide definitive accounts of the embryology of the gonads and the germ cells in man.

211. George L. Streeter, *Developmental horizons in human embryos. Description of age groups XV, XVI, XVII,* and *XVIII.* Third of the series mentioned in Year Book No. 44, bringing the survey and classification of the human embryos of the Carnegie Collection down to about 36 days ovulation age.

212. Dorcas Hager Padget, *The development of the cranial arteries in the human embryo.* Illustrated by comprehensive graphic reconstructions. Mentioned in Year Book No. 44.

PUBLISHED RESEARCH

PHYSIOLOGY OF THE UTERUS

During the year 1946-1947 the work of Dr. Reynolds on the physical forces involved in accommodation of the uterus to the growing products of conception (embryo, placenta, membranes, and amniotic fluid) yielded valuable results which he has published in the anatomical, physiological, and obstetrical journals (see bibliography below). A summary of these results was presented at the annual meeting of the American Physiological Society. The following résumé is based largely on a general discussion which Dr. Reynolds published in the *American Journal of Obstetrics and Gynecology* for June 1947, and which sets forth in full detail the concepts he has developed.

The work has been done on the rabbit. To make subsequent statements clear, the reader should be reminded that in this species the embryos are spaced along the two tubular horns of the uterus. As they grow, each embryo causes local enlargement of the surrounding uterus, in approximately spherical form, so that each uterine horn bears a series of nodular enlargements. When pregnancy is about two-thirds advanced (about day 22), the conceptuses no longer increase in diameter, but enlarge lengthwise, so that the entire uterine canal is filled out by the now roughly cylindrical conceptuses, and the uterine horn itself is no longer nodular but cylindrical.

From his geometrical analyses and calculations Reynolds points out that the significant feature of this change of shape, as it is related to pressure within the conceptus and to the flow in the uterine walls, is that in the last third of pregnancy the radius of curvature of the transverse section of the uterine horn no longer changes. When the single-chambered uteri of the rhesus monkey and the human species are similarly measured, it appears that a similar change of form of the enlarging uterus takes place at approximately the same proportionate phase of gestation. It is possible and indeed likely that the analysis made by Dr. Reynolds will help to explain the physiological and pathological phenomena of uterine accommodation in women.

Dr. Reynolds has measured the rate of blood flow in the pregnant rabbit's uterus by the ingenious method of injecting a small dose of cyanide into the uterine veins and recording the time required for the poison to reach the carotid sinus and cause a respiratory gasp.

He finds that the local circulation of maternal blood in the uterus about the conceptus decreases gradually as the latter increases in size. Suddenly, as the conceptus reaches maximum spheroid size, a profound decrease in uterine circulation (i.e. ischemia) takes place. As soon as the conceptus changes shape, by elongation, the rapid circulation of maternal blood is restored.

Hydrostatic forces within the uterus are also related to the shape of the conceptus. While the latter is spheroid the radii increase, with growth, in three dimensions, but after it becomes cylindrical only the lengthwise dimension increases. By simple calculation it is shown that the tension of the wall now increases in linear rather than in geometric proportion, thus easing accommodation of the uterus to its contents during the period of greatest absolute growth of the conceptus.

Reynolds has shown previously that the growth of the uterus itself, necessary to enable it to contain the conceptus, occurs chiefly during the period of maximum uterine tension. Consequently, after the change in form, the uterine tissue, already

sufficiently increased in amount, is "paid out" as it is stretched.

It is further shown by use of perfected technical methods (plastic corrosions) that the uterine ischemia, mentioned above, and its ensuing relief follow a pattern which may be explained on the basis of the hydrostatic forces and that the arrangement of the uterine arteries and veins is such as to make them readily adaptable to the abrupt change of form. There is reason to believe that rabbit, monkey, and human have in common the feature that during the phase of principal elongation of the uterus, conditions are such that local tension of the tissues about the region of entry and exit of the uterine blood vessels is held to the lowest possible level compatible with rapid enlargement of the fetus.

The period of transitory ischemia just before the change of form is a time of special danger to fetal nutrition.

Expulsive force of the uterus. At the 1947 meeting of the American Physiological Society, Dr. Reynolds and Dr. Kaiser presented the results of experiments in which the highly sensitive strain-gauge dynamometer was adapted to measure the absolute expulsive force of the uterus (of animals). The report concerned itself with the apparatus and technique.

Physiology of the endometrial blood pessels. At the same meeting Dr. Kaiser discussed the effects of certain drugs and hormones on the blood vessels of the endometrium in intraocular grafts. Both atropin and estrogens were found to halt the rhythmic activity of the vessels. Estrogens also cause dilatation and increase the number of functioning capillaries. Atropine does not prevent or reverse the action of estrogens in this respect* These observations necessitate a revision of the so-called cholincrgic concept of the acute action of estrogens on the endometrial vessels. The increase in acetylcholinc content of the whole rabbit uterus observed following estrogen administration is probably due to changes in the myometrium. A different mechanism must be invoked to account for the phenomena seen in the endometrium.

The possibility that estrogens act on endometrial blood vessels, dilating them, by means of local production of a histamine-like substance can be explored, as Dr. Kaiser also reported to the American Physiological Society, by the use of antihistaminic agents. One of these, pyribenzamine, is found to cause no change in the color of a piece of endometrium growing in the anterior chamber of the eye and under the influence of estrogen from the animal's ovaries. It does, however, produce an increase in the frequency and duration of contraction of the myometrium in the graft. The implication, which requires further study, is that the active circulation in the small endometrial vessels, under the influence of estrogen, is not caused by histamine.

THE OVARIAN ARTERY

Using the vinylacetate corrosion method, Reynolds has demonstrated, in the rabbit, the previously unnoticed fact that the ovarian artery runs through the hilum of the organ in a conspicuously spiral course. From the coils of this spiral artery, secondary branches carry blood to the tissues of the ovary. Two suggestions are offered as to the functional value of this striking arrangement:

(1) The coiling may serve to allow for orderly lengthening of the artery as the ovary is enlarged by successive pregnancies. This hypothesis has been tested experimentally by Dr. Reynolds *(Endocrinology,* June 1947; see bibliography below) by causing the rabbit's ovaries to grow rapidly by injection of gonadotrophic hormoee. The spiral arteries were found to undergo

wider spacing of their coils, with extension of the loops so that two or three days after the stimulating injections the coiling had been altered to mere sinuosity.

(2) The coiling may serve to bring about orderly and rapid reduction of the blood pressure in the artery. It follows from this that irregularities in the pattern of the ovarian artery may contribute to the development of pathological states of the ovary. This possibility receives a certain degree of confirmation from the observations of Reynolds on rabbits' ovaries in which hemorrhagic cysts of some of the corpora lutea occurred as a result of stimulation with gonadotrophic hormone. In these ovaries the injection-corrosion preparations of the blood vessels showed distortions of the coiled arteries in the vicinity of the cysts. It is suggested that distortion of the spiral artery may contribute to development of the cysts by permitting the transmission of excessive blood pressure during the growth of the ovary under the influence of gonadotrophic hormone.

PERMEABILITY OF THE PLACENTA

During the current year another contribution on placental permeability has been published by Drs. Walter Wilde, Dean B. Cowie, and Louis B. Flexner. Previous studies of the group led by Dr. Flexner have been devoted to comparing the permeability of placentas of the four principal types found in mammals. For this purpose radioactive sodium was used as the test substance. A striking systematic difference in permeability, related to the known differences in structure, has been demonstrated.

The next step is to study the permeability of the placenta to various substances which normally occur in the maternal blood. For this purpose the guinea pig has been chosen, because its placenta belongs to the same type as the human (hemochorial) and because its period of gestation is long enough to permit separation of different stages of development.

The present research deals with the permeability of the guinea pig's placenta to inorganic phosphorus. Radioactive sodium hydrogen phosphate was used as the tracer substance; it was prepared in the cyclotron of the Department of Terrestrial Magnetism. As usual in such experiments, measured amounts of the tracer substance, of known radioactivity, were injected into the veins of pregnant animals. After appropriate intervals of time the fetuses were delivered by abdominal hysterotomy ("Caesarean section") under anesthesia, and the amount of radioactive substance in them was determined by an electroscopic instrument (pressure ionization chamber connected to a string electrometer). The necessary technical precautions and mathematical calculations are explained in this and previous articles by Dr. Flexner and his colleagues.

The chief conclusions from the experiments are: (1) The rate of transfer of inorganic phosphorus per unit weight of placenta increases about 10 times from the 31st day of pregnancy until term. (2) The placenta is about 10 times as permeable to water as to sodium, and about twice as permeable to inorganic phosphate as to sodium. (3) Unlike sodium and water, which in previous investigations have been found to be supplied to the fetus in amounts much larger than the quantities incorporated in the growing tissues, inorganic phosphate reaches the fetus from the maternal plasma in an amount approximately equal to the total phosphorus retained in growth. The quantity of phosphorus thus retained by the fetuses is large as compared with the amount of inorganic phosphorus in the maternal blood plasma.

A ioo-gm. fetus, for instance, retains in each hour 1.5 to 2 mg. of phosphorus, a quantity about equal to all the inorganic phosphorus in its mother's plasma. The implication is that maternal phosphorus stores are essential in the maintenance of growth of the fetus and that these stores may be the organic molecules containing phosphorus, from which the phosphorus is liberated by enzyme activity as needed.

DISTRIBUTION OF WATER IN THE INFANT

Tracer techniques afford the possibility of estimating the proportion of the total water in the body that is extracellular, i.e. in the blood, other body fluids, and extracellular spaces in the tissues, rather than within the cells. The volume of extracellular fluid in adult man has been measured repeatedly by use of sodium tagged with its radioactive isotope. The first such estimate for the newborn human infant has now been reported by Flexner, Wilde, Proctor, Vosburgh, Cowie, and Hellman. The results obtained give essential information for the current studies on the permeability of the human placenta, as well as a sharp, consistent answer to the significant questions: What proportion of the body, by weight, in the newborn is water? and how much of this water is extracellular?

Sodium chloride, tagged by radioactive sodium having an intensity of radiation safely below that known to produce biological effects, was dissolved in water containing deuterium oxide (heavy water). The solution was injected into a vein of the infant. Two and one half to three hours later a sample of blood was drawn from a vein. It is known that such an interval is long enough to permit thorough distribution of the heavy water, that is* to get it into equilibrium between the blood and the water outside the blood vessels. It is also known to be long enough to permit practically complete equilibration of sodium between blood and extravascular water. The deuterium oxide goes everywhere in the body along with the ordinary water; the tagged sodium goes everywhere that ordinary sodium goes, that is to say, into all the extracellular fluid, but not into the cells, which it does not normally enter. As a consequence of this difference, the sodium distributes itself between the blood, on one hand, and the fluid that lies between and about the cells and in the body spaces, on the other hand. The water distributes itself between the blood, on one hand, and all the rest of the body, including the cells, on the other hand. Having thus a larger space to fill, more of it (proportionately) than of the sodium leaves the blood. Thus the blood sample after 3 hours has lost more of the heavy water than of the tagged sodium. The difference tells us what proportion of the water has gone into the cells; and the degree to which the heavy water in the blood becomes diluted with ordinary water, exchanging with it from the tissues, tells how much of the body is water. The calculations are explained by Dr. Flexner and his colleagues in their paper.

The result is that the newborn infant is found to be 74.6 per cent water. This figure, obtained as described from living healthy infants, is almost exactly the same as that found by previous investigators (lob and Swanson) who desiccated a stillborn infant. Flexner and his colleagues found that the extracellular water in the newborn infant is 43.5 per cent of the body weight. This too agrees well with an estimate (43 per cent) made by Harrison, Darrow, and Yannet by calculation from the chloride content of the stillborn infant. The new observations greatly strengthen available evidence that the process of growth is accompanied by an increase in

the ratio of the intracellular to the extracellular water.

THE ANATOMY OF HARELIP

Dr. Ferdinand C. Lee, of the Johns Hopkins Hospital Surgical Clinic, became interested in the orbicularis oris muscle, which serves as a sphincter of the mouth, because of his experience in several operations for double harelip. Finding that it is important to know how much of the orbicularis oris is present in such cases, he undertook a detailed study of a specimen in the Carnegie Collection (no. 5605), a 5-months-old Negro infant whose body was presented by Dr. Harold Cummins, of Tulane University, because of multiple congenital abnormalities. The deformities of the hand and foot have been described previously by Dr. Streeter. Dr. Lee's description will be of interest in detail to plastic surgeons. In brief, the orbicularis oris muscle in this child with double harelip was found to be well developed at the corners of the mouth but to become thin and fragmentary as the ala of the nose is approached.

ACTION OF DYESTUFFS ON TUMORS

The observations of Dr. Margaret R. Lewis, of the Department's staff, and her coworkers at the Wistar Institute on the effect of the dyestuff Nile blue on sarcomas have been followed by tests of a large series of related dyes. Two dyes of the oxazine series (Nile blue and cresyl violet), twelve xanthine dyes, including acridine red and rhodamine B, and five acridine dyes were found to stain transplanted sarcomas selectively and to retard their growth when administered to the host mice in their diet. All these dyes also stained spontaneous mammary gland adenocarcinomata when fed to tumor-bearing mice.

Studies are under way on the possibility of modifying these dyes so as to make them more effective in their action on tumors and less toxic for animals.

MICROTOMY

One of the chief problems in the precise sectioning of delicate structures such as human embryos is distortion of the section caused by compression by the knife. Most microtomes abruptly shear the section from the block of paraf&n or celloidin (or paraffin-celloidin) in which the specimen is embedded, by pushing the knife edge directly through the matrix. Thus the tissues are compressed in the direction of the cut. Although the error thus introduced may be minimized by proper embedding and by skillful arrangement of the conventional microtome, residual distortion remains a problem even with expert technique. Mr. O. O. Heard, senior modeler of the Department of Embryology, has given a good deal of thought to this problem and has attempted a solution by making the knife slice, rather than push, through the block. To this end he modified an ordinary sliding microtome by fitting it with a circular knife that is made to undergo rotary motion as it passes through the block, thus slicing through the tissues like the familiar rotary meat cutter seen in butcher shops. The knife, however, does not rotate continuously, but stops for manual removal of the section and then reverses its rotary movement as it is returned to the starting point of the microtome track to begin the next cut. The cutting is done with a wet knife, as is usual in this laboratory in sectioning human embryos embedded in paraffin-celloidin.

Mr. Heard had to design and construct not only the knife and the knife-carrier assembly, but also a special machine for sharpening the circular edge, under microscopic observation, to a high precision both

of radius and of cutting edge. The apparatus is fully described in his paper.

The instrument as constructed causes about 40 per cent less compression of the section in the direction of advance of the knife, all other conditions being equal, i.e. embedding media, knife angles, and working temperature. The use of a microtome so unorthodox introduces new problems in handling the sections, which to some extent counterbalance the reduction of distortion. Whether or not the circular knife ultimately wins general adoption, it is certain that the thoughtful work of Mr. Heard has greatly enriched the knowledge possessed by our staff of the physical and mechanical problems involved in the cutting of thin serial sections.

DIFFUSION AND POPULARIZATION OF RESULTS

Several members of the staff (Burns, Flexner, Corner) each lectured once or twice by invitation to the first-year medical students of Johns Hopkins University, Dr. Burns was asked to discuss his work before the seminar of the Department of Biology of Princeton University. Dr. Reynolds spoke by invitation to the Spring Seminar of the Ciba Corporation, Summit, New Jersey, discussing responses of the uterus to drugs. He also took part in a panel discussion on menstrual disorders, held by the Section on Obstetrics and Gynecology of the American Medical Association at its annual meeting in June 1947. In April Dr. Reynolds addressed a large meeting of the (Negro) Women's Cooperative League, in connection with National Negro Health Week, speaking on problems of the menopause.

Dr. Flexner gave the Director valuable assistance in arranging a symposium of the National Academy of Sciences on radioactive tracers, and took part himself. Dr. Corner served during the year on the committee that organized a series of scientific broadcasts in the intermission of the Sunday afternoon concerts of the New York Philharmonic Orchestra. On April 13 he gave the concluding talk of the series, "Light on the blood capillaries."

Arrangements have been made by which the motion picture films on cell growth, segmentation of the egg, and tumor cells made by Dr. Warren H. Lewis prior to his retirement in 1940 are to be made available for distribution by the American Cancer Society. The Department of Embryology will retain title to the negatives, leaving them in the care of Dr. Lewis, who will supervise the editing of the films and the preparation of duplicate negatives from which prints will be made for distribution. A set of prints of all the films thus far edited from negatives made in this laboratory has been deposited with us.

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DEPARTMENT OF GENETICS

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In many ways the year 1946-1947 was very different from any we have experienced in recent times. In comparison with the early postwar period, a definite improvement was evident in respect to the accessibility of scientific instruments, laboratory equipment, and chemicals. Some improvement was noticeable also in the obtainability of materials needed for the upkeep of our plant, but many essential items were still hard to procure. During this year our Department received two grants: one from the United States Public Health Service, for Kaufmann's research dealing with the nature of the changes induced in the living cell by irradiation; and the other from the American Cancer Society, for studies of the mutagenic capacities of carcinogens.

An expansion in research activities in general, brought about by the influx of new funds, has accentuated the shortage of scientific personnel. We have felt this shortage particularly as it relates to specialized workers eligible for fellowship appointments. Fortunately, we have not yet experienced any difficulty in filling research assistantships.

The research activities of the Department are making satisfactory progress toward the goals set by our program. In McClintock's work on maize, a number of mutable loci have appeared during the past few years in the cultures grown to determine the factors involved in a particular but unrelated type of mutation process. Preliminary investigations of some of these mutable loci indicated that a common underlying phenomenon was probably associated with the expression of instability in all the cases examined. Two separable factors are known to be associated with the expression of instability. The first factor is concerned with the particular state of the unstable locus in cells of a developing tissue. The state of a locus is reflected by the time of occurrence of phenotypically visible mutations and by the frequency and distribution of these mutations. During development, the state of a locus may change abruptly. The second factor is concerned with a change at the unstable locus that gives rise to a phenotypically recognizable altered expression of the locus. Both the changes in state and the change that alters the action of a locus appear to be associated with events that occur during a mitotic cycle. During the past year Dr. McClintock's attention has been concentrated on one of these mutable loci because its actions and its location in the chromosomal complement are particularly favorable for an analysis of the factors associated with mutability. Instability of this locus occurs only when an independently inherited dominant factor is likewise present in the nucleus. When this dominant factor is removed from the chromosome complement by appropriate crosses, the mutability of the unstable locus is completely suppressed. When the dominant activator is reintroduced into the nucleus by appropriate crosses, instability of the locus reappears. Mutations at the particular locus may be followed in all tissues throughout the life cycle of the plant. In the sporophytk tissues mutations occur only late in development. In the endosperm, on the contrary, mutations may occur at all stages In de-

velopment. Changes in state of the unstable locus, however, may occur at any time during the development of either the endosperm or the sporophytic tissues. Although changes in state of a locus and the subsequent changes in frequency and distribution of visible mutations are interrelated, the alteration that is associated with a change in state and the alteration that results in a phenotypically visible mutation are distinct and separable. Because the action of the unstable locus chosen for intensive study lends itself to cytological as well as genetic analyses, efforts are being concentrated on the visible chromosomal alterations that accompany mutations at the unstable locus.

McClintock interrupted her studies of the mutable loci in maize during the fall and early winter of 1946 in order to continue, at the California Institute of Technology, the investigations of the chromosomes of *Neurospora* begun several years earlier. There were two primary objectives for this interim study: (1) to improve the techniques so that chromosome conditions in the important stages might be more readily revealed, and (2) to obtain a set of photographic illustrations of the behavior of the chromosomes during ascosporogenesis. These primary objectives were accomplished. In addition, a more detailed and complete knowledge of chromosome organization and behavior was obtained.

In an extension of the series of studies utilizing near infrared radiation, Kaufmann has found that this agent, which previously had been shown to increase the frequency of X-ray-induced chromosomal rearrangements in *Drosophila melanogaster,* decs not modify the frequency of X-ray-induced recessive lethal mutations in this species. Since about 35 per cent of these lethals were found to be associated with chromosomal rearrangements, it seems clear that lethals. of this type are not caused by a position effect and do not depend on the production of the rearrangement for their origin and expression. From a consideration of the extensive data that he has now collected, Kaufmann has concluded that near infrared radiation acts as a "sensitizing" agent in increasing the frequency of X-ray-induced chromosomal rearrangements by facilitating recombination, probably at the expense of restitution, among the group of potential breaks induced by the ionizing radiation. The precise definition of the time of action of near infrared radiation emphasizes the potentialities of this agent as a tool in experiments designed to modify the recombination aspect of the process of induced structural change.

Working in Kaufmann's laboratory during the summer of 1947, Marcia Kelman Iddles has extended the series of observations on the extent of nonhomologous association among the discs of the salivary-gland chromosomes of *D. melanogaster.* About 350 cases of this type of association have now been observed in a study that is furnishing information concerning the distribution of heteroehromatic and duplicated euchromatic regions along the various chromosomes of this species-

McDonald has continued her efforts to perfect methods for the preparation of purified crystalline enzymes. She was successful in devising a method for the preparation of ribonuclease—an enzyme capable of depolymerizing ribonucleic acid but not desoxyribonucleic acid—free from all measurable traces of proteolytic activity. By using this enzyme in cytochemical studies, Kaufmann has been able to show that the chromosomes, as well as the nucleolus and cytoplasm, contain measurable quantities of ribonucleic acid. Kaufmann and McDonald, with the assistance of Miss Helen Gay, whose services have been provided by a grant from the United States Public

Health Service, have also succeeded in developing a test for the *in situ* localization of tryptophane-containing proteins.

MacDowell has confirmed earlier indications of a mother's-age factor in mice that strongly modifies the incidence of spontaneous leukemia in hybrids from non-leukemic mothers. Young mothers give many leukemics, old mothers few. For a new experiment to test the possible transmission of this inhibiting factor through mother's milk, the four classes of young from old and young mothers divided between young and old nurses have been born, nursed, and weaned. A filterable, virus-like agent of mild pathogenicity has been separated from the leukemic cells of line-I leukemia, with which it has probably been long associated.

Within the past two years methods have been developed by Demerec and his collaborators for studying the mutagenic properties of chemicals, using *Drosophila* and bacteria. During the summer of 1947 a general survey was made of the genetic effectiveness of carcinogens, which are suspected by geneticists of being mutagenic. Extensive experiments carried on by Demerec with aerosols of a number of carcinogens and chemically related substances have shown that mutations may be induced by some of these in *Drosophila* males, A considerable degree of correlation was observed between mutagenic and carcinogenic capacities, indicating a common causative relation between the two. The most obvious and probable relation between mutagenicity and carcinogenicity is the one suggested by the hypothesis that cancer may originate through a gene mutation occurring in a somatic cell.

Newcombe has made a detailed investigation of the spontaneous mutation rate in bacteria. He found that when resting bacteria are used to begin an experiment the mutation rate is high during the first few divisions, as compared with later divisions.

Beale perfected the method devised two years ago (Year Book No. 44, p. 115,1945) for studying the mutation rate in dividing bacteria. He was able to follow the mutation rate during about twelve bacterial generations. For mutation from B (bacteria sensitive to phage) to B/i (bacteria resistant to phage Ti), the rate is 7 X 10^{-9} per bacterial division.

It was previously known that in the gall midges (Diptera, Cecidomyidae) the nuclei of the germ-line cells (primordial germ cells, oogonia, spermatogonia) contain far more chromosomes than the somatic cells, and it was assumed that the germ-line cells were polyploid (octoploid, decaploid, etc., according to the species). An investigation made by White of a species of cecidomyid which is a pest of box hedges has shown that this assumption is untrue; and it now appears that there are two kinds of chromosomes in cecidomyids—those that are confined to the germ line and those that occur both in the soma and in the germ line. The former are eliminated from the future somatic nuclei at one of the early cleavage divisions. Dr. White has studied the mechanism of this elimination in the species mentioned above. He has also carried out work on the salivary-gland chromosomes of a number of species of gall midges.

Professor Th. Dobzhansky, of Columbia University, research associate of the Carnegie Institution, has studied the dynamics of changes occurring in *Drosophila pseudoobscura* by investigating natural populations of the fly in localities near the gardens of the Division of Plant Biology of the Carnegie Institution at Mather, California, and also by observing the behavior of mixtures of various types under controlled conditions in the laboratory, where flies

are raised in specially constructed "population cages." He has found that the proportion of certain types in wild populations changes with the season. Similar changes are observed under laboratory conditions when the temperature is varied. Since these changes are extremely rapid, the differences in the adaptive values between various types must be very great. Professor Sewall Wright, of the University of Chicago, has computed that, taking the adaptive value of heterozygotes to be i.o, the adaptive value of one homozygote is about 0.7, and that of another homozygote as low as 0.4. The finding of such large differentials among normal constituents of a natural population is most unexpected, since it has customarily been assumed in modern biology that the intensities of natural selection operative in nature are, except for abnormalities and pathological conditions, very low. The material accumulated by Dobzhansky on *Drosophila* is sufficiently extensive to be compared with material obtained by Clausen, Keck, and Hiesey, of the Division of Plant Biology, in their work on the local races of some plant species. It is of interest to note that the fly *Drosophila fscudoohscura* exhibits essentially the same kind of differentiation into altitudinal races that has been observed by them for certain plants.

It is well known that mutations that arise in the laboratory are mostly deleterious, or at best neutral, to the viability of their carriers. This seems to contradict the view, now held by most biologists, that the mutation process supplies the raw materials of evolution. The apparent contradiction is usually resolved by supposing that some mutations, although harmful in a normal environment and in combination with genes normally present in the species, may be useful in other environments and in combination with other genes. Dobzhansky has obtained evidence in support of this view by conducting specially designed experiments with *Drosophila.*

During the year several changes in scientific personnel have occurred. Dr. S. G. Stephens, who had held the position of research associate since June 1, 1945, left the Department in December 1946 to collect cotton in Mexico and Central America for the Empire Cotton Growing Corporation and the United States Department of Agriculture. At present he is continuing research on the cytogenetics of cotton at the Department of Agronomy, Texas Agricultural Experiment Station. Professor Michael J. D. White, of the University of London, stayed with us as a guest investigator from April through August 1947. Dr. Evelyn M. Witkin held a fellowship of the American Cancer Society.

With the return of peacetime activity, the benefits to be derived from our cooperation with the Biological Laboratory of the Long Island Biological Association are increasing. The 1947 summer symposium on "Nucleic Acids and Nucleoproteins" brought to Cold Spring Harbor a distinguished group of scientists interested in the problems being investigated by members of our Department, and provided opportunities for our staff to discuss their work with them. Of the approximately 150 participants, seven had come from Europe for the purpose of attending the meeting. These were Professor and Mrs. Edgar Stedman from Edinburgh, Professor J. N. Davidson from London, Professor J. M. Gulland from Nottingham, Drs. H. Hyden and B. Thorell from Stockholm, and Professor André Boivin from Strasbourg. Three years ago, as part of the summer activities of the Biological Laboratory, a course was organized by Dn M. Delbriicfc on methods used in studies with bacteriophages. This course, which has been offered each year since

then, is designed primarily for research workers who either expect to work with phages or wish to obtain a better understanding of the problems involved in such research. It attracts particularly those scientists who are interested in the borderline fields of biology, physics, and chemistry. This year the course was given by Professor Mark Adams, of New York University. It brought to Cold Spring Harbor, among others, the nuclear physicists Drs. Leo Szilard and Aaron Novick, from the University of Chicago, P. Morrison, from Cornell University, and R. B. Roberts, from the Department of Terrestrial Magnetism of the Carnegie Institution, with whom we were glad to discuss our problems.

THE GENE

M. DEMEREC, E. M. WITKIN, H. B. NEWCOMBE, AND G. H. BEALE

The principal object of our group during the past year has been the study of spontaneous and induced mutability in bacteria *(Escherichia coli)* and in *Drosophila*. Using methods previously worked out, an effort was made to determine the mutagenic properties of various chemicals. In this work we were assisted by Misses M. N. Crippen, Nancy McCormick, and Jessie Flint, Mrs. Jennie Buchanan, and Mr. John Derby, and during the summer months by Mr. W. E. Baty, science teacher at the Huntington High School, Misses Margaret Lieb, Patricia St. Lawrence, Dorothy Wei, and Reba Mirsky, and Mr. Clifford Tengelsen.

MUTAGENIC POTENCY OF CARCINOGENS AND CHEMICALLY RELATED COMPOUNDS

During the past two years M. Demerec has developed an aerosol method for the treatment of *Drosophila* males with solutions of various chemicals. This method was considerably improved during the summer of 1947 by the introduction of various technical refinements. At present, air pressure is generated by an electric air pump, and a constant air flow of approximately 6 liters per minute is passed into a DeVilbiss glass nebulizer, no* 40, containing about 5 ml. of the solution to be used in treatment. The nebulizer generates the aerosol, which is piped through plastic tubing into a half-pint milk bottle, where the large droplets occasionally thrown out by the nebulizer are retained. From this bottle the aerosol is piped into a similar bottle containing fly food and the flies to be treated. Excess aerosol is carried from the bottle containing the flies through another tubing into the air; or, if the chemical being used in treatment is toxic, the excess aerosol is passed through activated charcoal before being discharged into the exhaust. Aerosol generation is started by turning on the pump. Treatments are usually of long duration—up to 200 hours or longer, depending on the toxicity of the chemical used. As a rule, flies are kept in the same bottle throughout treatment, but the bottle is changed if it becomes too moist or sticky. The aerosol is generated periodically, every 30 minutes for 30 seconds. Since this is regulated by an electric time switch, treatment can be carried on without any attention except for occasional examination of the flies to make certain that they are surviving the treatment. By means of this system, flies are kept in an atmosphere containing an aerosol of a chemical solution, and this atmosphere is renewed every 30 minutes. Since a majority of the aerosol droplets have a diameter of 1.5 microns or less, they arc able to penetrate into the tracheae of the heavily

tracheated testes, and thus the chemical used in treatment may reach the sperm present there.

Sperm from treated males was tested for possible genetic changes by the usual methods. For determining the frequency of gene changes, observations were made on X-chromosome lethals. In the early experiments, the *CIB* method was used, but in all the more recent work Muller's double-inversion stock $sc^{8}\ w^{a}\ B$ was utilized. The advantage of using this stock is that cultures containing only a few flies as well as those containing lethals can be tested with ease through another generation. Because of the difficulties involved in such tests when *CIB* is used, cultures having a few flies are disregarded, and since they contain a larger proportion of lethals than other cultures this tends to lower the frequency of lethals shown in the final results.

In the early part of the work, which was begun in June 1945 (Year Book No. 39, pp. 215-216; No. 45, pp. 156-157)? several reducing and oxidizing chemicals, as well as dyes, were tested, but no evidence of mutagenic effect was obtained. At that time the maximum length of exposure was 16 hours, and so it is not certain that a longer period of treatment might not have been effective in some cases. Positive evidence that the aerosol method was effective in inducing mutations was obtained when nitrogen mustard—methyifoV(bctachlorocthyl)arainc—wasused.The work of Auerbach and Robson, of the University of Edinburgh, had shown that mutations may be induced in the sperm of *Drosophila* males by exposure to vapors of cither mustard gas or nitrogen mustard. Therefore it was reasonable to expect that an aqueous aerosol of nitrogen mustard would be effective. Our experiment was made as soon as the chemical became available to D5^ shortly after the end of the war. As already reported (Year Book No. 45, pp. 156-157), it gave positive results.

Since the work began we had been planning to test the mutagenic capacity of carcinogens; but we were hesitant to start work with aerosols of such potentially dangerous chemicals until we were certain that our method was effective. In 1940 we had made an attempt, in cooperation with Dr. A. Hollaender, of the National Institute of Health, to induce mutations in *Drosophila* by raising them for 12 generations on food containing dibenzanthracene, and also by treating the flies so obtained with ultraviolet radiation. Both experiments gave inconclusive results. When proof of the effectiveness of the aerosol method was obtained, experiments with 1,2,5,6-dibenzanthracene were undertaken. As indicated in table 1, these gave positive results (*Nature,* vol. 159, p. 604, 1947).

With the aid of a grant from the American Cancer Society, the research to test the mutagenic potencies of carcinogens was considerably extended, beginning in July 1947. During the summer, tests were carried on with 21 carcinogens and related chemicals. These tests covered: (1) induction of mutations (lethals) in the X chromosome; (2) location of mutations along the chromosome, in order to discover possible specific effects; (3) detection of chromosome rearrangements coincidental with mutations, and cytological analysis of such rearrangements; and (4) detection of translocations involving any two of the four chromosomes, with cytological analysis of such translocations. These experiments are still in progress, so that only a preliminary report will be given here. The tests concerned with induction of mutations have progressed farthest, and some of the data obtained in these experiments are given In table 1. Experiments with 17

chemicals have advanced far enough so that these chemicals may be classified into four groups so far as mutagenic capacity is concerned: (1) positive; (2) probable, where the results so far are positive, but tests have not yet been carried through the third generation; (3) questionable, where results indicate a slight effect, and additional experiments are needed before a conclusion is reached; and (4) negative, where the data now available do not show any effect. See table 2.

Up to now, chromosome aberrations have been detected only in experiments with dibenzanthracene and benzpyrene. Three cases of inversion (one consisting of two inversions in the same chromosome) have been found among 28 chromosomes carrying lethals induced by dibenzanthracene, and one inversion has been observed among 15 lethals from benzpyrene.

In the materials tested, induced mutations have been distributed at random along the X chromosome, indicating that the mutagens responsible for these mutations are not specific, but affect genes at random.

An examination of table 2 shows that three potent polycyclic hydrocarbon carcinogens—namely, dibenzanthracene, methylcholanthrene, and benzpyrene—are also positive mutagens. Of the four chemically related noncarcinogens, pyrene and phenanthrene are not mutagenic, and anthracene and benzanthracene are in the questionable class, that is, they are either nonmutagenlc or slightly mutagenic. For the tested chemicals of this group, therefore, the correlation between mutagenicity and carcinogenicity may be considered very good.

A carcinogenic member of the naphthylamine group (beta) has questionable mutagenic potency, and a noncarcinogenic member (alpha) is nonmutagenic. In this case the mutagenic potency of beta (as

TABLE 1

SUMMARY OF DATA ON X-CHROMOSOME MUTATIONS (LETHALS) OBTAINED FROM MALES TREATED WITH SEVERAL CARCINOGENS

TREATMENT	No. SPERM TESTED	MUTATIONS		DIFFERENCE	D./S.E.
		No.	% db S.E.		
Control:					
none	1342	2			
sesame oil	2540	7			
total	3882	9	0.23 db 0.077		
Positive:					
1,2,5,6-dibenzanthracene	3257	31	0.95 db 0.17	0.72 ± 0.19	3.8
methylcholanthrene	3727	24	0.64 ± 0.13	0.41 db 0.15	2.7
benzpyrene	4299	25	0.58 d= 0.12	0.35 db 0.14	2.5
sodium desoxycholate	2561	26	1.02 db 0.20	0.79 ± 0.21	S.S
^-hydroxyazobenzene	2416	15	0.62 db 0.16	0.39 db 0.18	2.2
Negative:					
alpha-naphthylamine..,	2591	5	0.19 ± 0.086		
^-diethylaminobenzene	1690	2	0.12 db 0.084		
^>-dimethylaminobenzene	3219	8	0.25 db 0.088		
pyrene	1172	3	0.26 d= 0.15		

tested with *Drosophila),* if present at all, is not so high as its carcinogenic potency.

Of the six azo compounds tested, two are mutagenic, two are probable, and two are negative. In this group three noncarcinogens are either mutagens or probable mutagens, whereas only one carcinogen (p-dimethylaminoazobenzene) has not shown mutagenic potency. This is being tested further with a higher concentration. It is evident that among the azo-group compounds used in our tests a larger proportion shows mutag&icity than carcinogenicity.

TABLE 2

LIST OF CARCINOGENS AND RELATED CHEMICALS ARRANGED ACCORDING TO MUTAGENIC CAPACITY, AS DETECTED IN DROSOPHILA

	Carcinogenic
Positive mutagens:	
1,2,5,6-dibenzanthracene	yes
20-methylcholanthrene	yes
3,4-benzpyrene	yes
^-hydroxyazobenzene	yes
sodium desoxycholate	not tested
^-aminoazobenzene	no
Probable mutagens:	
azoxybenzene	no
azobenzene	no
Questionable mutagens:	
anthracene	no
x,2-benzanthracene	no
beta-naphthylamine	yes
Negative:	
alpha-naphthylamine	no
pyrcne	no
phenanthrene	no
p-diethylaminoazobenzene	no
^-diinethylamlnoazobenzene	yes
acetylarninofluorine	yes

The experimental results can be seen in better perspective if the conditions under which the effect was produced arc kept in mind* Presumably the aerosol droplets enter with air through the spiracles of a fly, and are distributed within the body through the tracheae and tracheoles. Since the testes are well supplied with tracheoles, a considerable amount of the aerosol must reach them. In order, however, that an aerosolized chemical may reach the sperm and induce a genetic change there, it must pass through the tracheolar cells, the hemolymph, and the cells constituting the membrane of the testes. Any obstruction or failure at any point along this path would reduce the effectiveness of the chemical or suppress it entirely. Consequently, failure to obtain positive results after treatment with a certain chemical does not necessarily mean that this chemical is not mutagenic; it may mean that it is not able to enter any of the several cells which it has to pass through before reaching the sperm, that it is not able to pass through these cells in sufficient quantity, or that it is not able to penetrate into a sperm once it is reached. It is also to be expected that permeability for different chemicals may vary with the tissues or that it may be different in different species. A similar set of conditions probably has to be met when mammals are treated with carcinogens.

The results of our experiments show that a majority of the carcinogens tested are mutagenic, and also that a majority of the chemically related noncarcinogens are not mutagenic. Nonmutagenic carcinogens and mutagenic noncarcinogens were observed as well. Nevertheless, considering the important role played by biological factors in the expression of both mutagenicity and carcinogenicity, and considering the biological differences between the materials in which these two effects were studied *(Drosophila* and mammals), the observed correlation between the two effects appears to be quite striking. From this correlation it seems unavoidable to infer a common causative relation. This inference is further strengthened by the behavior of all known nonchemical carcinogens, such as X-rays

and related radiations, ultraviolet rays, and heat, all of which are mutagenic. The most obvious and most probable relation between mutagenicity and carcinogenicity is the one suggested by the hypothesis that cancer may originate through a gene mutation occurring in a somatic cell. Such a cell and the cells derived from it by division would have their properties changed so that they would behave as cancerous. This would mean that higher organisms possess a gene—or, more likely, a number of genes—whose mutations can initiate a cancer-type cell. Such mutations, in common with a great majority of mutations in other genes, occur spontaneously with a very low frequency. The human body has a tremendously large number of cells, however, so that it becomes probable that a cancer-type mutation will occur a number of times among the cells of an individual. Not all of these need give rise to cancer, since a large proportion of the cancer-type cells may be prevented by normal cells from dividing, or may be eliminated in some other way. This hypothesis readily explains the observed differences between various cancers, as being due to mutations in different genes. If a gene mutation is responsible for the origin of cancer, then all mutagenic agents would be expected to increase the frequency with which such mutations occur and consequently to behave as carcinogens. In our fight against cancer, therefore, precautions should be taken to avoid exposure to all rnutagens—chemicals as well as radiations. Such precautions, however, even i£ rigorously enforced, would only lower the incidence of cancer; they could not entirely prevent its occurrence. There would still be a chance left for cancer-type mutations to occur among the billions of cells that constitute the human body, and if such a mutated cell should continue to diYide it would give rise to cancerous growth. We know that mutations do occur with great regularity, caused by some force as yet unexplained, and that we have no means of stopping or controlling their occurrence. Consequently, if cancer originates through a genetic change, our chances for finding ways to prevent it are very, very slight. We should be able to reduce its frequency by avoiding contact with carcinogenic and mutagenic agents. In this effort a more extensive knowledge of the mutagenic capacities of various substances should be a valuable asset.

INDUCTION OF MUTATIONS IN BACTERIA BY CHEMICALS

Early in 1947, Dr. Evelyn M. Witkin, fellow of the American Cancer Society, began work on the induction of mutations by chemicals in *Escherichia coli*. Demerec had described experiments (see Year Book No. 44, p. 115) in which mutations in *E. coli* from sensitivity to resistance to bacteriophage Ti were induced by ultraviolet radiation and X-rays. It was reported that some of these mutations express themselves before the bacteria pass through the first division after irradiation (zero-point mutations). In the investigation of the mutagenic activity of chemicals, zero-point mutations to resistance to bacteriophage Ti were used as the genetic index of positive or negative effects.

Strain B/r of E. *coli*, the strain used in the experiments of Demerec, was employed throughout. It was established first of all that bacteria from full-grown cultures of this strain, washed free of nutrient medium and resuspended in distilled water, undergo no changes, over a period o£ 48 hours of incubation at 37° C, in the number of viable cells and in the number of mutants resistant to bacteriophage Ti (B/r/i). Thus, under these conditions there Is no division or death of the bacteria, and no

spontaneous mutations to phage resistance occur. A given chemical was tested for mutagenic activity by the following procedure: The concentration of the chemical required to kill about 99 per cent of the bacteria suspended in it in a standard time period (usually 2 or 3 hours) was determined in preliminary toxicity tests. A full-grown culture of strain B/r was divided into two equal parts, and each portion was centrifuged to eliminate the nutrient medium. The bacterial pellet of one portion was resuspended in distilled water to serve as a control. The other was resuspended in the concentration of the chemical known to kill 99 per cent of the exposed bacteria in the standard time period. The two tubes were incubated at 37^0 C. for this period of time, and were then assayed to determine the number of living bacteria per milliliter and the number of B/r/i mutants in a series of carefully measured samples. It was then possible to compare the number of B/r/i mutants per ro^s living bacteria in the control with the number per io^8 survivors in the treated culture. When the number of B/r/1 mutants per io^8 living bacteria was found to be significantly higher in the treated culture than in the control, experiments were conducted to determine whether selection might be responsible for this result. It was concluded that zero-point mutations were induced by a given chemical if the following conditions were met: (1) the proportion of B/r/i mutants among the survivors of treated cultures was significantly higher than in controls; (2) selection in favor of the mutants could be ruled out as responsible for this increase; and (3) the mutants isolated from the treated cultures proved to be stable, bona fide B/r/i mutants.

Four compounds have been tested for mutagenic activity by the procedure outlined above. These substances, the first of a series to be investigated in an extensive survey, were selected because of their more or less well defined physical or chemical effects upon nucleoproteins or nucleic acids.

Sodium desoxycholate, which is known to dissolve the desoxyribose nucleoprotein complex of bacteria and animal tissues, was found to be effective as a mutagenic agent. In a typical experiment, the proportion of mutants among the survivors of a 3-hour exposure to a 5 per cent solution of desoxycholate was 58 per io^8 bacteria, as compared with 3 per io^8 bacteria in the controls. The sensitivity of B/r/i mutants to the toxic action of the chemical was the same as that of the nonmutants, so that selection could not be responsible for this increase. The mutants obtained after treatment with desoxycholate were stable and typical B/r/i mutants. The possibility that the chemical might interfere with the process of infection by Ti, thus permitting the sensitive survivors of the treatment to divide before lysis and give rise to new mutants spontaneously, was carefully investigated. It was found that desoxycholate-treated bacteria are infected by bacteriophage at least as rapidly as untreated bacteria from the same culture. Thus, interference with the action of the bacteriophage was eliminated as a possible explanation of the heightened proportion of mutants among the survivors.

The number of induced mutations per io^8 survivors was found to be directly proportional to the time of exposure to a 5 per cent solution of sodium desoxycholate. A similar linear relation was reported by Demerec and Latarjet between the number of induced zero-point mutations and the X-ray dose. A comparison o£ the curves obtained for X-rays and sodium desoxycholate reveals that a dose of 100,000 rocntgen units corresponds to an 8-hour exposure to 5 per cent desoxycholate, in

that about no mutations per 10^8 survivors are induced under each of these conditions.

Of the other compounds tested, pyronin Y and acriflavine, both of which are dyes known to combine with nucleic acids, showed positive mutagenic effects. Methyl green, another basic dye, was clearly non-mutagenic within the limits of the experimental technique.

It is hoped that this method can be developed as a rapid screening procedure for detecting mutagenic activity among various chemical groups, and as a tool for investigating certain aspects of chemically induced mutations, such as dosage-effect relations and delayed effects.

POSSIBLE DELAYED EFFECT IN SPONTANEOUS MUTATIONS

Rates of mutation to phage resistance in *Escherichia coli* have in the past been obtained in two ways: (1) by calculating from the proportion of small cultures having no mutants, and (2) by calculating from the average number of mutants per culture. These have yielded figures differing by a factor of from 2 to 5 in the different mutations studied, the latter method giving the higher estimate in all cases (Demerec and Fano, 1945). Such a difference could result from a high mutation rate during the period of rapid growth, or from a delay between the occurrence of the gene change and its phenotypic expression in the descendants of the original genetic mutant.

To discriminate between these two alternative possibilities, Dr. H. B. Newcombe has made a study of mutation rate in relation to the stage in the growth of the bacteria. The method used was essentially that employed earlier for investigating mutation in irradiated material (Demerec, 1946). Bacteria were grown on agar and, after varying periods of incubation, sprayed with the phage Ti. By this process all bacteria susceptible to Ti are eliminated and any clones of resistant bacteria survive to form colonies on further incubation. Thus mutations are detected as units, regardless of the numbers of individuals that have descended from them. To determine the extent of growth, plates incubated at the same time and for the same period were washed with saline and the resulting suspensions assayed.

From these experiments it was found that clones of mutants appeared at a high rate during early growth (12.0 per 10^s bacterial divisions during the first generation on agar) and that the rate declined, after approximately four divisions, to 0.74 per io^8 bacterial divisions. This latter figure is approximately that obtained previously (Demerec and Fano, 1945) from the proportion of cultures having no mutants.

If the high mutation rate obtained from the average number of mutants per culture (2.7 per io^8 bacterial divisions) were due to a high rate during the period of rapid growth, then one would not expect the rate as determined from the appearance of resistant clones on agar to drop to 0.74 per io^8 until after a considerable period of growth. It may therefore be assumed that there is a delay in the phenotypic expression of the genetic change determining phage resistance.

On this basis the rate of genetic change would be greater than the rate of appearance of resistant clones by a factor of 2^n_f where n is the number of generations between mutation and phenotypic change, regardless of whether the character was expressed in all 2* descendants simultaneously or in only one.

To obtain a better estimate of mutation rate from liquid cultures, and to avoid the statistical fluctuations inherent in the method using scries of small cultures started from small inoeula., the increase in

resistant bacteria in cultures from large inocula was studied. In such cultures, grown for a period of approximately six to seven generations, the estimated mutation rate was 4.1 per io^8 bacterial divisions. The fact that this is larger than the figure obtained from cultures started from small inocula has been tentatively ascribed to the carry-over in the inoculum, when it is large, of a certain number of "hidden" mutants which have not yet achieved phenotypic resistance.

Assuming a delay, this is still a minimum estimate of the actual rate of gene change, since it does not take into account the number of "hidden" mutants present at the end of growth. An attempt was therefore made to estimate mutation rate from clones of mutants known to be relatively old, in the belief that a greater proportion of the genetic mutants would have acquired phenotypic resistance. Using the data of Demerec and Fano, and calculating only from the culture in each series having the highest number of resistant bacteria, an estimated rate of 6.3 per io^8 was obtained. Whether or not all the descendants of early mutations in these cultures had become phenotypically resistant is not known, and upon this depends whether the figure 6.3 per io^8 is to be considered an approximation to the rate of gene change or whether it is again an underestimate. If the delay is of the order of that observed in irradiated material, as it may well be, then the true rate of gene change would be many times this figure.

The high mutation rate (12.0 per io^8) observed during the first division on agar is less easy to interpret. The distribution over the plate of mutants that were Hot yet phcnotypically resistant would not be expected to give rise to a rate higher than that observed in liquid cultures, namely, 4.1 per io^8. The difference might be interpreted as due to a genuine increase in the mutation rate during this division, to a failure of the bacteria in the early stages of growth to adsorb phage, or to a physiological state favoring phenotypic expression of genetic resistance. Of these possibilities, an increase in the rate of gene change during the first division presumably would not—in view of the delay postulated—be detected until some time later; and the failure to adsorb phage seems unlikely, since it would have to be a matter of complete failure over a period of two full generations. It is tentatively suggested, therefore, that a greater than normal proportion of "hidden mutants" becomes phenotypically resistant during this division.

MEASUREMENT OF SPONTANEOUS MUTATION RATE

In 1943 Luria and Delbriick made a study of the rate of occurrence in bacteria of mutations from phage sensitivity to phage resistance. These workers adopted the technique of growing cultures of *Esckerichia coli* in liquid broth medium for given periods of time and subsequently plating out known small amounts of the culture onto nutrient agar, together with an excess of phage. After further incubation the number of resistant colonies on each plate was counted, and estimates of the mutation rate were made from *(a)* the percentage of cultures that did not contain any resistant mutants at all, and *(b)* the average number of resistant bacteria per culture. Demerec (1946) modified this method by growing bacteria on nutrient agar instead of in broth, and by applying the phage as a fine aerosol, which was sprayed onto the plates at a time when the bacteria had increased to approximately the desired number. The advantage of this method was that clones of mutants

remained collected together and, after spraying with phage, could be counted as single mutations. The problem then was to determine accurately the number of bacteria on a plate at the time when the phage was applied.

This has now been investigated by Dr. G. H. Beale. Growth of bacteria on nutrient agar was measured by flooding the plates with dilute saline, scraping the bacteria from the agar with a glass spreader, and assaying the supernatant solution thus obtained. It was found that the growth rate on nutrient agar is practically identical with that in broth, and that the initial lag period is also the same. As regards the stage at which growth rate on nutrient agar slows down, it was found that this is determined by two conditions: (1) the absolute number of bacteria on a plate, and (2) the size of individual colonies. Division slows down when the total number of bacteria on a plate exceeds io^{10} or when the number per colony exceeds $5 \times io^5$ (i.e., the number produced from a single bacterium by 19 divisions). It was also found that if bacteria are taken from a fresh, unsaturated culture of titer io^r bacteria per cubic centimeter or less (which may be chilled for 30 minutes), and plated onto nutrient agar that has been preheated to 37^0 C, growth starts immediately without any initial lag phase at all. Thus, by using bacteria from an unsaturated culture, and by determining beforehand the growth rate on nutrient agar by the washing technique, it is possible to estimate the number of bacteria on a plate accurately, simply from a knowledge of the number plated and the time of incubation.

Making use of this knowledge, nutrient-agar cultures were prepared, containing about 10^s actively dividing bacteria. After growth had been checked by chilling, approximately io^{10} phage particles were sprayed onto each plate, and after a further incubation period of 48 hours the numbers of phage-resistant colonies were counted. The mutation rate was calculated simply by dividing the mean number of mutant clones per plate by the total number of bacteria per plate (the number of mutants originally present on each plate before growth being zero, and the total number of bacteria originally present being negligible in comparison with the final number). By this method it was found that the mutation rate, expressed as the number of phage-resistant bacteria per cell division, was $0.7 \times io^{-8}$, and this figure did not vary significantly whether the rate was measured after 12 bacterial generations on a plate or after 18 generations. It was therefore concluded that, provided the bacteria are in an actively dividing condition, the mutation rate is a constant function of the number of cell divisions.

Further work has shown, however, that the mutations measured in these experiments constitute a composite group. It had already been known that there are two kinds of mutants resistant to the phage Ti—namely, B/i and B/1,5—and also that the phage Ti produces a mutant TiA capable of lysing B/i mutants. Cross-resistance tests have now shown that a proportion of the B/i mutants are however resistant to **TiA,** and that a proportion of the B/1,5 mutants are sensitive to TiA. Consequently each of the mutants B/i and **B/1,5** exists in at least two forms. Furthermore, the relative proportions of B/i and B/1,5 mutants have been found to vary (from 1 per cent to 25 per cent B/i) in different experiments, depending on the strains of bacteria and Ti phages used. It is therefore clear that the over-all constancy of mutation rate can only be guaranteed with one particular culture of *iL coli* and one particular culture of the phage Ti.

ORGANIZATION OF THE CHROMOSOME

B. P. KAUFMANN, M. R. MCDONALD, H. GAY, K. WILSON, AND R. WYMAN

During the past year our studies of the structure of the chromosome have proceeded in general along the broad lines indicated in Year Book No. 45. Analysis of the modifying effect of near infrared radiation on X-ray-induced lethal mutations in *Drosophila* has now been completed, and a series of experiments has been undertaken to measure the effect of this agent on the frequency of chromosomal aberrations induced by a nitrogen mustard compound. Progress has been made in developing techniques for the direct observation of the effects of ionizing radiations on living cells; other cytological observations have extended our knowledge of the specific patterns of nonhomologous pairing between the discs of the salivary-gland chromosomes of *D. melanogaster*. The chemical and histochemical studies for localization of chromosomal constituents have advanced despite the necessity of surmounting innumerable technical difficulties, and have enabled us to plot in a rough way the distribution within the cell of different types of proteins and nucleic acids. Close co-operation between biochemist and cytologist has facilitated the progress of the work and enabled us to coordinate the chemical and histochemical approaches to the problems in hand. Our general program has also been furthered by a grant from the United States Public Health Service, which has provided us with an additional scientific investigator during the greater part of the year now ending.

MODIFYING EFFECTS OF NEAR INFRARED RADIATION

We have now completed the study$_3$ outlined in Year Book No. 45, of the effect of supplementary treatment with near infrared radiation on the frequency with which X-ray-induced recessive lethal mutations are produced in *Drosophila melanogaster*. Earlier work, summarized in Year Book No. 44, had shown that when near infrared radiation (wave length about 10,000 A) is used prior to X-rays in the treatment of the spermatozoa, a marked increase occurs in the frequency of detectable chromosomal rearrangements over that in controls receiving only the X-ray dose. On the other hand, pretreatment with near infrared does not increase significantly the frequency of the dominant lethal type of change. The additional data now available indicate that such supplementary treatment has no significant effect in this species on the frequency of production by X-rays of sex-linked recessive lethals.

Utilizing the *CIB* technique, we have examined about 10,000 F_2 cultures (as indicated in table 1) obtained in experiments in which near infrared rays and X-rays were tested independently and in combination with each other. It is evident from these data that near infrared radiation in itself is not effective in inducing the types of change that are represented among the group of recessive lethals. Nor does this type of radiation, when used prior to or subsequent to a 3000-roentgen dose of X-rays, modify to an appreciable extent the frequency of induced lethal mutations, which is about 7 per cent in all these cases.

An additional step in the analysis involved determinations of the frequency of chromosomal rearrangement among the group of recessive lethals. For this purpose, 100 of the 526 lethal mutations detected in our experiments were selected

at random in equal numbers from the combination-treatment series and the controls, and analyzed by the salivary-gland-chromosome method. Among the 50 derived from the combination treatment, 18, or 36 per cent, showed gross rearrangements involving the X chromosome; 11 were found among the 25 lethals examined in the pretreatment series, and 7 among 25 in the posttreatment series. In the control group, 14 out of 50, or 28 per cent, revealed X-chromosome rearrangements. The precise location of the lethal has not been determined with respect to the points of breakage involved in each rearrangement, but in the light of other studies it is assumed that a lethal and a breakage point will coincide in a large proportion of cases.

Rearrangements of the types represented in this analysis had been found in our earlier experiments to increase about 50 per cent when treatment of the spermatozoa with near infrared radiation preceded a 4000-rocntgcn dose of X-rays. Since we have not found a corresponding rise in the frequency of the recessive lethals, it appears that the lethals associated with gross chromosomal alterations do not depend for their expression on the production of rearrangements. This might seem to confirm the inference, derived from a consideration of dose-frequency relations, that radiation-induced recessive lethals and rearrangements result independently from a single type of primary effect. Lea and Catcheside had previously developed a detailed theory of the production of recessive lethals based on this assumption, but Fano has shown in a recent note in *Science* (vol. 106, p. 87, 1947) that their theory meets with serious objections.

Dr. Fano, who is now on the staff of the National Bureau of Standards, was permitted by that agency to spend the summer of 1947 at Cold Spring Harbor, and thus had occasion to apply the methods developed in his recent comment on the Lea-Catcheside theory to a further discussion of the effect of combination treatments with X-rays and near infrared rays. He has estimated the effect of supplementary treatment with near infrared radiation (1) on the frequency of sex-linked recessive lethals, (2) on the fraction of these lethals which is associated with a rearrangement, and (3) on the frequency of dominant lethals. This was done in each case on the assumptions: *(a)* that the lethals associated with a rearrangement are due to a position effect, and *(b)* that recessive lethals and rearrangements result independently from a single type of primary

TABLE 1

LETHAL MUTATION RATE (C1B TESTS) AMONG SPERMATOZOA OF MALES EXPOSED TO X-RAYS OR TO X-RAYS + NEAR INFRARED RAYS

TYPE OF TREATMENT (X-RAYS IN ROENTGENS, NEAR INFRARED IN HOURS)	NUMBER		PER CENT MUTATIONS
	Sperms tested	Lethal mutations	
NIR (48hrs.).--	2316	4	0.17 db 0.08
X-ray (3000 r).	3393	253	7.46 ± 0.45
3000 r + 48 hrs.	1989	145	7.29 ± 0.58
48 hrs. -f 3000 r.	1770	124	7.01 ± 0.61

effect. The symbols developed by Dr. Fano for his note in *Science* have been utilized in the calculations presented below; *A, B, C,* and *D* represent classes of lethals associated respectively with no rearrangement, a minute rearrangement, a viable gross rearrangement *(VGR),* and an inviable (lethal) gross rearrangement *(LGR).*

The frequency of viable gross rearrangements among sperms available for testing will be indicated by $x = VGR/(i - LGR)$. We have previously shown that this frequency is raised from about 30 per cent to about 45 per cent (i.e., by about 50 per cent of its value) when infrared pretreatment is combined with 4000 roentgens of X-rays. It will be assumed tentatively that the same increase of 50 per cent takes place when the X-ray dose is 2000 or 3000 r. It will also be assumed that the mean number of breaks per rearrangement is independent of the X-ray dose (within those limits) and of the near infrared treatment.

The frequency of sex-linked recessive lethals among sperms available for testing—i.e., $A + B + C/(i - LGR)$, in Fano's notation—will be indicated by y. The frequency of those among these lethals which are associated with rearrangements—i.e., $C/(i - LGR)$—is proportional to *x* and will be indicated as $\backslash x$.

(id) In this case the frequency o£ lethals of types *A* and *B*—namely, $y - \backslash x$—should not be affected by infrared treatment, and will be called *K.* Hence, without infrared treatment, $y = y\& = K + {}^{\wedge}x_0$; with infrared, $y = y_i z = K + J^{\wedge}XL$ With 3000 r and no infrared, $\backslash x®/y® = 1/(1 + Kf\backslash x®)$ *-* 1/3; hence $K/\{x_Q \sim 2$ and $yi/y® = (K/\backslash x® + xi/xo)/(K/{}^{\wedge}xo + 1) = 3.5/3 = 7/6$, since $xi/x^* = 1.5$. As stated previously, an increase of this magnitude, expected on the position-effect hypothesis,, was not obtained experimentally.

(ib) In this case, it is $K' = A + B + C + D$ which should not be affected by infrared treatment. We can write $K' = A + B + C/(i - LGR) - C/(i - LGR) + C\,\frac{1 - LGR}{1 - LGR} + {}_{D}\,\frac{i - LGR}{C}\,\frac{C}{i - LGR} = y - kx\,[1 - (i+D/C)\ (i-LGR)]$. Using Fano's notation, $D/C = pq$; also $1/(1 - LGR) = i + LGR/(i - LGR) = i + (LGR/VGR)\ VGR/(i - LGR) = x + px$. Then: $K' = y - \backslash x\,[i - (i + pq)/(i + px)]$, $_{yi} - y_0 = \backslash xi\ [i - (i + pq)/(i + pxi)] - \backslash x_a\,[i - (i + pq)/(i + pxo)]$, yi/yo — $i = ({}^{\wedge}o/yo)$ "! $(x_t/xo)\ [i - (i + pq)/(1 + px_i)] - [1 - (1 + pq)/(1 + pxo)]\}$. This difference is negative, since $p \wedge 1$, $q \wedge 1$, indicating that the prevalent effect of infrared is to turn *A'$* and S's into unobservable D's. Its value is closest to zero in the somewhat unrealistic case $p = q = 1$; in this case, using $fao/yo = 1/3$, $Xi/xo = 1.5$, $xo = 0.2$ (for 3000 r), we find $y\%/yo = 1 - 0.046$. Thus a depression of about 5 per cent or more would be anticipated following pretreatment with near infrared radiation on the assumption that recessive lethals and chromosomal rearrangements result independently from a single type of primary effect, as indicated in table 1. A depression of approximately this order of magnitude has in fact been obtained, although it cannot be claimed to be significant.

(2a) The quantity to be estimated is $\backslash xi/yi = (xi/xo)\ (yo/yi)\ (fao/yo)$. Using the data from *(id),* this amounts to 3/7 = 42.6 per cent at 3000 r.

(ib) Using the data from $(ib)_9$ the same quantity amounts to 0.525 when- $p = q = 1$, otherwise to a still larger fraction. The data obtained experimentally are difficult to appraise with respect to *(id)* and *(2b),* since the numbers are small and the standard errors correspondingly large. Four-

teen rearrangements were detected among the 50 lethals examined in the control series (28 per cent), and 11 among 25 (44 per cent) obtained with pretreatment, which is the type of treatment that effected a 50 per cent rise in chromosomal rearrangements. The increase (from 28 to 44 per cent) can be reconciled with the value expected on the assumptions considered in *(2b),* but no great significance can be attached in view of the smallness of the sample.

(30 and *b)* According to current ideas on dominant lethals (see, for example, Demerec and Fano, *Genetics,* vol. 29, p. 348, 1944), the fraction of the number of *eggs* fertilized by treated sperms which develops into adults is given by the product of three factors: (1) the fraction which is fertilized by sperm having no unjoined broken chromosome ends; (2) the fraction fertilized by sperm transmitting no lethal gross rearrangements; and (3) the fraction that escapes other, accidental causes of death. The second of these fractions can presumably be reduced "by infrared treatment combined with X-rays, and may be written as $F^{(2)} = 1 - LGR = 1/(1 + px)$. The effect of increasing x is smallest, as usual, when $p = 1$. Taking, therefore, $p = 1$, and (for 2000 r) $x_0 = 0.11$, $xi/xo = 1.5$, we find $Fi^m/Fo^{i2)} = (1 + p*o)/(i + pxi) = 0.95$. In our previous study, reported in Year Book No. 44, 51.4 per cent of the eggs hatched after a dose of 2000 r of X-rays, and 46.7 per cent when treatment with near infrared preceded the X-rays. The ratio of these two percentages is 0.91.

These calculations based on a consideration of the effects of X-rays and near infrared rays, together with all the remaining evidence, still indicate that no general theory of lethals and chromosomal rearrangements in *Drosopkila* is warranted on the basis of the information now available.

The data provided by these near infrared studies now permit a more comprehensive view than was previously possible of the action of near infrared radiation.in modifying the frequency of X-ray-induced chromosomal rearrangements. Since near infrared radiation in itself is not effective in inducing either lethal mutations or chromosomal rearrangements, and since, when used in conjunction with X-rays, it does not alter the frequency of dominant or recessive lethals, we are inclined to the view that this agent operates by so modifying the materials of the chromosome that the chances of recombination are increased among the potential breaks induced by the ionizing radiation. The precise definition of the mode of action of near infrared radiation emphasizes the potentialities of this agent as a tool for separating experimentally the breakage and recombination phases of the process of induced structural change.

The studies combining X-rays and near infrared rays have been extended in an effort to obtain a precise quantitative measure of the effect of posttreatment on the production of induced chromosomal rearrangements. It had previously been found that treatment of males with near infrared rays for any considerable period of time after exposure to X-rays accelerated the mitotic processes so that cells that were not mature at the time of X-ray treatment became available for transfer in copulation sooner than if the males had been stored at temperatures within the range from 18° to 28° C. The technical difficulties involved in this type of experimental procedure have been obviated by exposing females, inseminated by males previously treated with X-rays, to the near infrared rays under conditions so unfavorable for oviposition that very few eggs are deposited during the period of treatment. Larvae developing from eggs laid subsequently,

following removal of the females to yeasted food, have been utilized for salivary-gland-chromosome preparations that are now being analyzed to determine the frequency of chromosomal rearrangement.

The effectiveness of near infrared radiation when used in combination with X-rays in increasing the frequency of chromosomal rearrangement raises the question whether such modification might be obtained if near infrared were combined with other agents that induce chromosome breakage. Chief among these are mustard gas and the nitrogen mustards. We have accordingly undertaken a series of experiments to determine whether the process of structural change induced by nitrogen mustard, methyl-Z>zV(betachloroethyl)amine, is modifiable by pretreatment or posttreatment with near infrared. The tests were begun recently, so that no statistically significant data are available at this writing, but the study is being continued with the assistance of Mr. Harvey Rothberg, Jr., of Princeton University, who has joined the group that is carrying this enterprise to completion.

OBSERVATIONS ON INDUCED CHROMOSOME BREAKS IN THE LIVING CELL

We have long considered that many of the problems concerning the time and mode of action of ionizing radiations in the production of chromosomal breaks might be resolved by direct observation of the living cell. The possibilities of such an experimental approach were explored during the winter of 1946-19475 in cooperation with Dr. J. Gordon Carlson, at the Industrial Hygiene Research Laboratory of the National Institute of Health in Bethesda, Maryland. Cultures of 14- to 16-day embryos of various species of grasshoppers were prepared in a manner that permitted direct observation, under oil-immersion objectives, of the giant neuroblast cells that cover the ventral surface of the embryo. We had anticipated that the phase-difference microscope might be of considerable aid in obtaining good resolution of the unstained chromatin threads, but in actual practice this optical system provided little advantage over the ordinary microscope, since the mass of cells underlying the neuroblasts in our preparations caused extensive and confusing diffraction patterns. As Dr. Carlson had demonstrated in his earlier studies, however, the trained cytologist soon learns to identify the various phases of mitosis in these hanging-drop preparations, and we were thus able to follow through mitosis cells which had been irradiated at a carefully identified stage in the cycle. In this way we were able to ascertain, for example, that breaks may be induced in the chromosomes of a cell irradiated at late prophase, and that chromosome fragments can then be observed at the succeeding anaphase. Extensive quantitative data remain to be collected before any appraisal can be made of the relative sensitivities of different stages of mitosis. It will be necessary, moreover, to develop methods more adequate than those now available for maintaining the cultures in a state of active division for several hours following their recovery from the mitotic inhibition that is effected by even a small dose of X-rays. Experiments along these lines are being continued at Cold Spring Harbor.

NONHOMOLOGOUS ASSOCIATION OF BANDS OF SALIVARY-GLAND CHROMOSOMES

The project reported in Year Book No. 43 of mapping the positions of heterochromatic and duplicated euchrornatic regions along the chromosomes of *Drosophila melanogaster* has been furthered by a scries of observations made during the summer

of 1947 by Marcia Kelman Iddles. Up to the present time about 350 cases of pairing between nonhomologous bands in the salivary-gland chromosomes of the Oregon-R stock have been analyzed. In these cases a strand of chromosomal material is stretched between two bands or between one band and a series of others that occupy different loci. Association of this type is more frequent between bands in the same chromosome limb than between bands in different limbs. Sometimes adjacent bands are involved; the two bands may adhere at one end, but separate widely at the other to present a V-shaped or linear pattern, the chromosome appearing broken open at these regions. Pairing of this type has been observed to occur occasionally between the parts of a recognized doublet (for example, between 33A1 and 33A2, or between 70C1 and 70C2); more frequently it occurs in subdivisions, such as 3C, 11A, and 12DE of the X chromosome, which are known from previous studies to include heterochromatic materials. Thus, by accepting nonspecific pairing of the type described as an additional criterion for the localization of heterochromatin, it has been possible to map heterochromatic regions in the autosomes as well as in the X chromosome.

Apart from the association of bands in the presumptive heterochromatic regions, there is a great deal of what appears to be random pairing between a given band and a series of others that occupy various positions in the different chromosomes. Occasionally, corresponding bands in the two closely appressed homologues that constitute the chromosome limb may each be associated with a different band in another chromosome. An appraisal of these diverse observations must await a more complete analysis of the accumulated data. It has been possible, however, to obtain a crude quantitative determination of the amount of nonhomologous association in the different chromosome limbs. As was to be anticipated from previous observations, bands in the left limb of the second chromosome show the highest frequency, whereas those in the right limb of this same chromosome are least often involved. In earlier studies there had also been intimations of a high degree of association between the tips of the various chromosome limbs, but the data now available suggest that this end-to-end pairing is not much more frequent than the association between the tips and various intercalary regions.

CHEMICAL AND HISTOCHEMICAL STUDIES

Another approach to the problem of the organization of the chromosome at the submicroscopic level involves chemical identification of its constituent materials. Our experiments along these lines have combined the use of enzymes with various histochemical tests. Since such methods of analysis require enzymes of known purity and specificity of action, as well as reliable histochemical procedures, we have devoted considerable energy to attaining these conditions. Isolation by chemical techniques of various cellular constituents will enable us to obtain substrate materials for test-tube confirmation of the nature of the action of the enzymes being studied. In the preliminary phases of the development of these methods we have gained some Insight into the organization of the chromosome with respect to the distribution of both proteins and nucleic acids during the various phases of mitosis.

The preparation and assay of crystalline enzymes. Experiments on the preparation and assay of trypsin, chymotrypsin, pepsin, ribonuclease, and desoxyribonucleasc for use in our histochemicai studies of chromosome structure have been continued. The

results obtained emphasize once again the dangers resulting from the assumption that crystallinity is of itself evidence of purity. Conclusions as to enzyme specificity are certainly unwarranted unless the enzyme being investigated conforms to all the known criteria of chemical and biological individuality, as indicated in Year Book No. 45.

1. The specificity of crystalline ribonuclease: A method for the preparation of crystalline ribonuclease, an enzyme capable of dcpolymerizing ribonucleic but not desoxyribonucleic acid, was described by Kunitz in 1940. Since that time various workers have shown that at least some samples of ribonuclease had, in addition to the ability to degrade ribonucleic acid, the property of hydrolyzing proteins. It was not demonstrated whether this was due to an intrinsic property of the ribonuclease molecule or to the presence of contaminants. Numerous workers have used such preparations to demonstrate the presence of ribonucleic acid in cytoplasm, nucleoli, etc* The above findings, however, raised the question whether the loss of properties, considered by the latter group to be due specifically to the depolymerization of ribonucleic acid, may not be attributed either to the loss of protein or to the nonspecific loss of ribonucleic acid due to degradation of the protein to which it was originally bound. It was essential, therefore, to determine the specificity of action of crystalline ribonuclease before using it in our studies of the chemical composition of the chromosomes.

TABLE 2

ASSAY OF VARIOUS SAMPLES OF CRYSTALLINE RIBONUCLEASE

(All values are expressed in activity units per mg. protein nitrogen. The differences between columns 5 and 4 are a measure of the amounts of proteolytic precursors; those between columns 4 and 3, of the amounts of trypsin inhibitor.)

SAMPLE	RIBONUCLEASE UNITS	TRYPSIN UNITS X 10^{-6}, ASSAYED AFTER		
		1 hr. at pH 7.6	1 hr. at pH 1.0	Complete activation
Ribonuclease 1	1,490	14	*38*	*3$*
2	1,430	6	26	26
3	1,390	134	340	13,500
4	1,375	520	1,824	2,640
5	1,368	290	1,190	3,650
6	1,224	154	702	**21,000**
Trypsin	....	170,000	170,000	170,000
Chyinotrypsin	....	45,000	**45,000**	45,000

Samples of crystalline ribonuclease prepared In our laboratory by the method of Kunitz, and samples prepared by Dr. Kunitz In the laboratories of the Rockefeller Institute for Medical Research, were tested for their ability to hydrolyze denatured hemoglobin. Several representative assays are given in table 2. Every specimen checked showed some proteoiytic activity, and many of the samples also manifested additional proteolytic activity after activation, thereby indicating the presence of precursors. Some were also found to inhibit the action of trypsln^ and

to a lesser extent that of chymotrypsin, at pH 7.6 but not at pH 1.0. Experiments have now shown, however, that all these properties were due to impurities present in the preparations and not to ribonuclease itself, since *(a)* the ratio of these activities to ribonuclease activity varied with the different preparations, and *(b)* it was possible by varying the experimental conditions to destroy differentially the various activities.

[1] The samples of ribonuclease tested were also found to clot milk and to hydrolyze a substrate specific for trypsin, *a*-benzoyl-/-arginineamide. We are indebted to Dr. Joseph S. Fruton, of the Yale University School of Medicine, for the latter preparation. The proteolytic activity of the ribonuclease could therefore be due to contamination by both chymotrypsin and trypsin. Other peptidases may also be present, but these have not been tested for experimentally. Assuming that one-half of the proteolytic activity was due to trypsin and one-half to chymotrypsin, the median value found for the proteolytic impurities was 0.07 per cent, the range being from 0.035 t0 2*6 P^er cent- E^ven these small amounts of contaminants, however, may lead to erroneous conclusions when ribonuclease is used as a specific tool; at least one such instance has been described in published material.

The increase in proteolytic activity noted in some samples of ribonuclease after activation was not due primarily to chymotrypsin, since there was little increase in milk-clotting ability. Calculated on the basis of trypsinogen, the precursor(s) constituted from 0 to 12 per cent of the total nitrogen.

2. The preparation of proteolytic-free crystalline ribonuclease: Much effort has been devoted to contriving a method for the preparation of ribonuclease free from proteolytic and potential proteolytic activity; for, although it was relatively simple to destroy all the proteolytic enzymes while simultaneously destroying some of the ribonuclease, it was much more difficult to destroy all the former without losing any appreciable amounts of the latter. The method finally devised consists essentially in boiling solutions of crude (or previously crystallized) ribonuclease in 0.2 saturated ammonium sulfate at pH 3 for 5 minutes and then fractionating such preparations with ammonium sulfate between 0.5 and 0.8 saturation. As can be seen from table 3, which gives the results of a typical preparation, this procedure destroys all proteolytic and potential proteolytic activity but leaves the ribonuclease practically intact. The latter can then be crystallized by a slight modification of Kunitz' procedure. Ten different preparations have now been made by this method. In no case has any measurable amount of proteolytic activity been found; that is, there was less than 0.005 P^er cent °f proteolytic enzyme as measured by the digestion of denatured hemoglobin. These preparations did not degrade, proteolytically or otherwise, egg albumin, protamine, histone, thymus nucleohistone, or desoxyribose nucleic acid. The absence of proteolytic enzymes in these preparations has been confirmed by Dr. Walter C. Schneider at the University of Wisconsin, who found, in contrast with results with some preparations previously tested, that they had essentially no effect on the succinoxidase system.

Localization of cellular materials. Chemical analyses carried out in other laboratories during past years have shown that the chromosomes of higher plants and animals consist at least of desoxyribonucleic acid, histones, and tryptophane-containing proteins. Little is known, however, concerning the quantitative changes in the concentration, location, and organization

of these materials during mitosis. There have been some intimations, derived by using ribonuclease, that the ribose type of nucleic acid might also be present in the chromosomes. Since the possibility existed, however, that the action of the ribonuclease preparations used in these tests was attributable not to their nuclease but to their proteolytic properties, these observations were quite inconclusive. The development of a method for the preparation of proteolytic-free ribonuclease, reported in the preceding section, has now given us a tool that will permit a decisive test for the presence or absence of this component.

TABLE 3

DESTRUCTION OF PROTEOLYTIC CONTAMINANTS

	CRUDE RIBONUCLEASE		
	Before boiling	After boiling	After boiling and ammonium sulfate fractionation
Ribonuclease units per mg. N	646	789	894
Total ribonuclease units	1,000,000	960,000	828,000
Trypsin units X 10^{-6} per mg. N*	916	9	<0.1
Total trypsin units X 10^{-6}*	1,420,000	10,944	<100
Potential trypsin units X 10^{-6} per mg. Nf	7,100	<4	<4
Total potential trypsin units X 10^{-6}	11,000,000	<5,000	<4,000

*Assayed after 1 hr. at pH 1.0.
fAssayed after complete activation.

We have used in this study—both separately and in conjunction with enzymatic degradation of the cellular components—hlstochemical tests capable of revealing the presence and location, or the absence, of the different types of nucleic acids and proteins. Most workers have relied upon the Feulgen reaction for the localization of desoxyribonucleic acid, and we have temporarily adopted this test, recognizing that certain objections may be raised concerning its *in situ* specificity. We hope that our enzymatic studies will eventually settle this controversy, but we still lack, despite our efforts to prepare them, the purified crystalline preparations of desoxyribonuclease necessary for critically evaluating the merits of the arguments pro and con. For coloration of ribonucleic acid, a series of basic dyes such as toluidine blue and safranin has been found satisfactory; the pyronin and methyl green combination developed by Pappenheim and Unna has also proved extremely useful. There is no satisfactory method for selectively coloring the histone type of protein, since, with the exception of tryptophane, all the amino acids and types of linkage that are present in proteins and that form the basis of all the protein color reactions are also present in histoncs. They can be removed from the cell, however, with 0.2 JV hydrochloric acid. For localization of the tryptophanc-containing proteins we have continued to apply modifications of the Bates test reported in Year Book No. 45, Because of the drastic action of concentrated hydrochloric acid on protoplasmic substances, it has been

necessary, in order to lessen the time of the reaction, to make an extensive survey of the effects on the reaction of (1) the concentrations of the different components of the reagent (hydrochloric acid, p-dimethylarninobenzaldehyde, and sodium nitrate), (2) oxidizing agents other than sodium nitrate, (3) the age of the solutions, and (4) the various components that constitute the ordinary cytological fixatives. We have now been able, by using smears and sections fixed in alcohol-acetic acid and subsequently hardened, and by greatly increasing the concentration of sodium nitrate, to reduce the reaction time for the development of the blue color specific for the indole nucleus (tryptophane) from one hour to between 30 and 60 seconds. In root tips of *Alliurn cepa* and of *Lilium tigrinum,* we have found that the blue color is pronounced in the cytoplasm and in the spindle. It is also conspicuous in nucleoli during the prophases and resting stages. The chromonemata in our preparations have shown only a very pale blue color, and we are now attempting to improve the reaction further, so as to determine more precisely the changes that occur in the concentration of the tryptophane-containing proteins during the cycle of mitosis.

A comparison of color reactions before and after treatment with a given enzyme should permit determination of the efficacy of the enzyme in eliminating from the cell the substrate being tested. In actual practice, however, clear-cut results often depend on the degree of control over a series of accessory factors. As an example, the action of the enzyme ribonuclease in removing ribonucleic acid from cells of root tips has been found to be retarded or even inhibited by certain fixatives. In a typical experiment, sections of root tips fixed in five different fixatives—acetic alcohol, and Heiiy\ Navashin's, Bcnda*s, and Bouin's luids—were attached to one slide, and this preparation was immersed in a ribonuclease solution of ca. 400 ribonuclease units per milliliter (2.5 mg. enzyme per ml.) at 60° C. In one-half hour, the pyronin staining component had been completely removed from the acetic-alcohol-fixed root and partially removed from the Navashin- and Helly-fixed roots. The Benda material was untouched by enzymatic action after two hours, and the Bouin-fixed root showed such poor coloration even in the control that no decision could be made about the amount of digestion that had occurred. The type and concentration of buffer in which the enzyme is dissolved greatly modifies the concentration of enzyme required; under certain conditions the buffer itself may effect the removal of cellular materials, or it may interfere with the specificity of the staining reaction. Veronal buffer alone was found to be highly effective in removing the pyronin staining component from control sections. On the other hand, an enzymatic solution containing ca. 700 ribonuclease units per milliliter dissolved in 0.1 *M* phosphate buffer, pH 7.6, gave no reduction in intensity of pyronin staining in 4 hours at 45° C, whereas the same concentration of ribonuclease dissolved in water at the same pH completely removed this component. Even the type of adhesive used in affixing the paraffin ribbons to the glass slide preparatory to digestion and staining was found to alter the reaction. Pitfalls such as these have been recognized by students of histochemistry; they emphasize the necessity for formulating the precise experimental conditions under which a given test is carried out with each type of material.

Having taken these variables into consideration, and recognizing that our experiments are still in their preliminary stages, we have nevertheless been able to demonstrate by histochemical methods that

mitotic chromosomes contain appreciable quantities of ribose as well as desoxyribose nucleic acid. The latter appears to be restricted to the chromosomes, whereas the ribose type is present in the chromosomes, nucleolus, and cytoplasm. Its distribution seems to parallel that of the tryptophane-containing proteins, and it is indeed tempting to suggest that the two may exist in close combination as nucleoprotein. Specific patterns of distribution, however, must await a detailed analysis of the action on cells at various stages in the mitotic cycle of the nucleases and proteases when used independently and in combination with each other. The completion of such a study, in which we are now engaged, should lead us closer to an understanding of the chromosome as a physiological as well as a morphological entity.

CYTOGENETIC STUDIES OF MAIZE AND NEUROSPORA

BARBARA MCCLINTOCK

THE MUTABLE DS LOCUS IN MAIZE

General considerations. In last year's report a summary account was given of several newly arising unstable gene loci. The instability of all but one of these loci was phenotypically expressed by the appearance in an otherwise recessive plant of sharply defined sectors of dominant tissue or of tissue showing an intermediate condition between recessive and dominant. Each of these sectors arose following a mutation in the unstable locus occurring in an individual cell during the development of the tissue. When an unstable locus is present, the tissues of the plant show a pattern of variegation which is related to the time and frequency of mutations occurring in particular cells during the development of the tissue. Observations of the behavior of the unstable loci have suggested that a common underlying phenomenon is associated with the expression of instability in all the cases examined. Several generalizations may be formulated concerning this phenomenon. Two separable factors are known to be associated with the expression of instability. The first factor is concerned with the particular state of the unstable locus in the cells of a developing tissue. The state of a locus is reflected by the time of occurrence of phenotypically visible mutations and by the frequency and distribution of these mutations. The second factor is concerned with the mutation at the unstable locus that gives rise to the phenotypically recognizable altered expression of the locus. During the development of a tissue, the state of a locus may remain unchanged. This results in a tissue showing one particular and readily recognizable type of variegation pattern. Changes in the state of a locus may, however, occur. These changes arise abruptly and appear to be associated with an event that occurs during a mitotic cycle. Following such a change, the variegation pattern is altered in the descendants of this cell. There may be fewer or, conversely, more mutations in the descendent cells than would have occurred had the event that gives rise to a change in state not taken place. The evidence suggests that the change in state may be related to the reproductive cycle of the chromosome, for it has frequently been observed that when a change occurs the state of the mutable locus in each sister chromatid may become altered. The state of the mutable locus may be quite different in the two chromatids, and the state in each chromatid, in turn, different from

that which existed in the immediate mother cell. In brief, it is the state of the locus at a particular stage in development that determines the time and rate of future mutations, and this state may be altered by an event occurring at a mitosis often considerably in advance of the genotypic mutation itself.

During the past year attention has been concentrated on one of the mutable loci, because its action and its location are particularly favorable for an analysis of the factors associated with mutability. Furthermore, the type of action at this locus is unique in its cytogenetic aspects and of considerable general interest in this respect alone. In this one case, mutability is expressed not by a visible phenotypic change in the action of a gene, but rather by dissociation of the bonds that normally would maintain a linear cohesiveness of this locus with an adjacent locus in the chromosome. As an ultimate consequence of the mutation, the chromosome is dissociated into two completely detached segments. Because one of these segments is acentric, it is not capable of directed movement in the spindle figure and subsequently is lost to the nuclei of descendent cells. This mutable locus has been designated *Ds* because the most readily recognizable consequence of its action is this dissociation. By both cytological and genetic methods, the *Ds* locus has been placed in chromosome 9 at approximately the position that demarcates the proximal third of the short arm. The acentric segment that is produced as a consequence of a dissociation mutation is composed, then, of the distal two-thirds of the short arm. This segment contains the loci of most of the known mutants of chromosome 9. Collectively, these mutants affect characters of the pollen, the endosperm of the kernel, the seedling, and the mature plant. Consequently, dissociation mutations at the *Ds* locus may be traced by genetic analyses in all stages of the life cycle when a plant carries dominant alleles and *Ds* in one chromosome 9 and recessive alleles and a normal *ds* locus in the homologous chromosome 9. Whenever a dissociation mutation occurs in a cell during the development of a tissue of such a plant, an acentric segment carrying the dominant factors is produced. This acentric segment is subsequently lost from the nucleus during a mitótic cycle. The result is a nucleus having only the recessive alleles that are present in the homologous segment of the ^--carrying chromosome 9. All the cells arising from this cell will be recessive in genotype and also in phenotype, if the expression of the particular recessive factor is cell-specific and if this phenotypic expression is not subject to changes that may be caused by diffusible gene products from the adjacent dominant cells. The presence of a recessive sector in a mature tissue indicates that a dissociation mutation occurred in the ancestor cell that gave rise to this sector. In plants of the given constitution, therefore, the mature tissues can be expected to show variegation for recessive sectors. From the size, frequency, and distribution of these recessive sectors in any one tissue the state of the locus in this particular tissue or sector of tissue can be recognized.

Control of Ds activity by Ac. Accumulating evidence indicates that the *Ds* locus will undergo dissociation mutations only when a particular dominant factor is present. This factor is designated *Ac* because it activates *Ds*. *Ac* is probably located in the long arm of chromosome 9, but its exact position has not been determined. By the end of this growing season, the analysis of the action of *Ac* on the *Ds* locus should be well advanced. At the present time the evidence suggests the following relations between *Ac* and *Ds*. If *Ac* is not present, the *Ds* locus is com-

pletely normal in behavior and indistinguishable from *ds.* If, by appropriate crosses, however, *Ac* is introduced into the primary endosperm nucleus, the *Ds* locus again becomes mutable and dissociations may begin to occur shortly after the introduction of *Ac. Ac* will not affect a normal *ds* locus, however; in the presence of *Ac, ds* remains stable.

Cytological aspects of the action of the Ds locus. Genetic evidence indicated that the dissociation mutations take place relatively late in the development of the sporophytic tissues. This was confirmed by cytological observations of the sporocytes of *Ds Ac* plants. In the sporogenous cells of the anthers of the majority of plants examined, the dissociation mutations—recognized by the constitution of the chromosome 9 bivalent—most frequently occurred in a late-premeiotic nucleus or sometimes in the meiotic nucleus itself. Genetic and cytological evidence also indicates that dissociation mutations may be delayed throughout the period of meiosis and only begin to take place in the following gametophytic nuclei. In some plants, however, dissociation mutations were observed to have occurred in relatively young premeiotic nuclei. The relation of this variable timing of dissociation mutations to the particular state of the *Ds* locus will be discussed later.

In making preparations of the sporocytes with the usual aceto-carrnine staining techniques, considerable difficulty was encountered in obtaining an adequate number of well spread and sharply stained meiotic prophase figures. Consequently, it was necessary to attempt an improvement in the techniques. Methods that had been developed in the fall of 1946 for the study of meiotic prophase chromosomes of the fungus *Neurospora* were tried, and found to be likewise superior for similar stages in maize. These methods introduce the use of lactic acid, either in the fixing fluid or in the staining solution. Young anthers were fixed for 12 to 24 hours in a fresh mixture of four parts of 95 per cent alcohol to one part of lactic acid. The sporocytes in the meiotic prophase states were forced out of the anther in a drop of aceto-orcein; a cover slip was placed over the drop, and the slide gently heated. An unusually sharp differential stain resulted. The cytoplasm was only slightly stained; the chromosomes, in contrast, were brilliantly stained, and the centromeres were sharply delimited in each chromosome. Considerable stretching of the chromosomes sometimes occurred, however, during the flattening of the sporocytes. When equal parts of lactic acid and acetic acid were used in the fixative in place of lactic acid alone, the chromosomes stained sharply with aceto-orcein but were less subject to stretching during the flattening of the sporocytes. A third method involved the restaining of aceto-carmine preparations with an orcein stain consisting of 1 per cent orcein in a mixture of equal parts of lactic acid, acetic acid, and water. Brilliant contrast in staining resulted. Initial use of this stain on the sporocytes did not give satisfactory results.

Some of the major aspects of chromosome 9 behavior that are associated with the presence of the *Ds* locus were reviewed in Year Book No. 45. It is now suspected that the dissociation mutation process is not a simple breakage of bonds at the *Ds* locus, although this is usually the eventual consequence. In making observations of the chromosomes, it was necessary to be able to identify accurately the Di-carrying chromosome in the sporocytes of a *Ds ds* plant. Crosses were made, therefore, between Di--carrying plants with morphologically normal chromosomes 9 and *ds ds* plants having a chromosome 9 with a small terminal knob at the end of the

short arm and a short duplication of chromatin extending beyond the knob. The heteromorphic end of the short arm of the chromosome 9 bivalent in the meiotic prophases of the resulting plants allowed the *Ds*- and dV-carrying chromosomes to be readily identified. In these plants, a number of sporocytes were observed in which the ZXf-carrying chromosome was deficient for the terminal two-thirds of the short arm as a consequence of a previous dissociation mutation in an ancestor cell. In all cases, without exception, it could be determined that only the Dx-carrying chromosome had been affected by this action. Some sporocytes were observed, however, in which the Dy-carrying chromosome had not simply lost two-thirds of its short arm, but had been subjected instead to some other modification, whose history is not understood at present. Among the aberrant types, those showing the complete loss of the Dj-carrying chromosome in a sector of sporocytes in the anther were the most frequent. In the recognized cases, the losses occurred earlier than the more frequently observed dissociations at the *Ds* locus. In other cases, a small sector of sporocytes was present in which the Dx-carrying chromosome was missing; in these cases, however, a small ring-shaped chromosome was present in the cells of these particular sectors. This ring chromosome probably is composed of a segment of the D^-carrying chromosome 9, although positive identification could not be made. A few other types of aberrant configurations also were observed. In all these relatively rare types of aberrant behavior, only the Z?<r-carrying and never the ^-carrying chromosome was involved. It is obvious that the presence of the *Ds* and *Ac* loci is in some way responsible for these aberrant types of chromosome 9 behavior. It is hoped that a more complete analysis of these relatively rare types of sporocytes will yield some insight into the nature of the action that occurs as a consequence of the combined presence of the *Ds* and *Ac* loci. It will be necessary to observe many thousands of sporocytes before a sufficient number showing aberrant types of chromosome 9 behavior can be found. With the improved techniques recently developed, it is hoped that this may be more readily accomplished. Until this needed information has been obtained, it would be premature to attempt to project a sequence of events that result directly in a dissociation or in one of the rarer types of alterations involving the *Ds*-carrying chromosome 9.

The stability of the state of the Ds locus. As mentioned previously, abrupt changes may occur in the expressed pattern of dissociation mutations in a tissue or sector of tissue. The general pattern, in each case, is the product of the time, the frequency, and the distribution of dissociation mutations that have occurred in individual cells during development. At present it is not known to what extent these changes in the expression of dissociation mutations are controlled by altered conditions at either the *Ds* or the *Ac* locus, or at both, or by other genetic conditions not yet identified. Until further evidence has accumulated, the observed patterns will be considered a reflection of the state of the *Ds* locus even though this restricted definition may later require modification. The patterns of dissociation mutations are visible in tissues of plants that have a ^-carrying chromosome 9 with recessive factors in its short arm and a Dx-carrying chromosome 9 with their dominant alleles. The recessive factors *wd, pyd,* and *yg (wd,* white leaf tissue; *pyd,* pale-yellow leaf tissue; *yg>* yellow-green leaf tissue), located at or close to the end of the short arm, have been used to determine the pattern of dissociation mutations in leaf tissues of seedlings

or mature plants. The series of alleles *c* (colorless aleurone), *C* (colored aleurone), and *I* (inhibitor of *C* color)—located approximately at the position demarking the distal third of the short arm—and the recessive factors *sh* (shrunken endosperm), *bz* (bronze, modifier of *C* color), and *wx* (waxy starch in endosperm and pollen)—located, in the order given, between *C* and *Ds*—have been used to examine dissociation mutations in the endosperm of the kernel. The alleles *Wx* and *wx* have been used to estimate the number of pollen grains in individual anthers of *Wx Ds/wx ds* or *wx Ds/Wx ds* plants that are deficient for the terminal two-thirds of the short arm of chromosome 9 because of previous dissociation mutations in ancestral nuclei.

When silks of plants that were homozygous for *ac* and for *C, sh, bz, wx,* and *ds* received pollen from plants carrying *Ac* and a chromosome 9 with the dominant alleles *I, Sh, Bz, Wx,* and *Ds,* a number of kernels on the resulting Fi ear were variegated because of the presence of sectors of cells with the phenotypic constitution *C sh bz wx** With a few exceptions, each sector composed of multiple-recessive cells arose following a dissociation mutation that had occurred in the ancestor cell of the sector. Subsequent elimination, during a mitosis, of the acentric segment of the chromosome 9 carrying *I Sh Bz Wx* resulted in the absence of these dominant factors from the descendent nuclei. In crosses involving any one male parent carrying a particular *Ds* and a particular *Ac* locus, the majority of variegated kernels fell into one main class with respect to the type of variegation pattern they exhibited. Great differences in pattern types exist. For example, the majority of variegated kernels on the Fi ears may show a speckled appearance because of the presence of a number of small patches of cells that are *C sh bz wx* in constitution. The size of a speckle here depends on the time of occurrence of the dissociation mutation. If it occurs very late, the colored speck may be composed of only one, two, or a few aleurone cells, but if it occurs somewhat earlier, the colored speck is composed of more aleurone cells. Crosses involving a different male parent may give rise to Fi ears in which the majority of variegated kernels show early dissociation mutations. These kernels are characterized by large areas of recessive tissue and, in extreme cases, by only small patches of dominant tissue—residual areas where dissociation mutations have not occurred.

In a number of variegated kernels, there were relatively large, sharply defined sectors in which the pattern of dissociation mutations within the sector contrasted greatly with the pattern exhibited by other parts of the kernel. These sectors indicated that a change of state had occurred in the ancestor cell that gave rise to the sector. Often these changes in state occur at a relatively early period in the development of the endosperm. The most instructive cases were exhibited by those kernels in which a change of state could be traced to the first or second mitotic division in the endosperm. A change in state in the first division may give rise to a kernel one-half of which shows one pattern of dissociation mutations and the other half a contrasting pattern of dissociation mutations. Or a kernel may be divided into three or four sectors, each with its own particular pattern, following changes of state that occurred in the first and second mitotic divisions of the endosperm. Because of the free nuclear division that takes place in the early development of the endosperm, this tissue is not ideal for a study of early cell lineages. Nevertheless, early changes in state can be recognized in many kernels. The prospects of de-

termining the contrasting nature of the altered states of two sister chromatids, following a mitotic cycle that introduces a change in state in both chromatids, are considerably better in this tissue than in the sporophytic tissues.

In the sporophytic tissues, dissociation mutations occur late in the life of any one tissue. This is in contrast with the endosperm tissue, where dissociation mutations may occur at any time during development. Changes in state, however, may occur at any time during the development of the sporophytic tissue. In this respect, the two tissues are comparable. Barring heterofertilization, the *Ds* locus in the first endosperm nucleus and that in the zygote nucleus are carried by sister chromatids. If no change of state had occurred in the division that gave rise to these two chromatids, the conditions that govern the states of both *Ds* loci should be alike. Several lines of evidence have indicated that this is probably true. Kernels showing early dissociation mutations in the endosperm give rise, in general, to plants having relatively early dissociation mutations in the sporophytic tissues. Conversely, kernels with late dissociation mutations in the endosperm tissues give rise to plants showing relatively late dissociation mutations in the sporophytic tissues. Present evidence indicates that the state of a particular *Ds* locus may remain relatively unchanged in most of the cells of a plant. Plants arising from kernels that showed early dissociation mutations gave rise in the next generation to variegated kernels the majority of which showed early dissociation mutations. Conversely, plants arising from kernels that showed late dissociation mutations gave rise in the following generation to variegated kernels the majority of which showed late dissociation mutations. Even though a *Ds* locus may remain in one state throughout a number of consecutive mitoses, changes in state nevertheless are not infrequent. At present, no critical evidence is available concerning possible genetic or environmental factors that may influence the state of a locus or its expression as reflected in dissociation mutations. Although changes in state of a locus and the subsequent changes in the frequency and distribution of dissociation mutations are interrelated, the alteration that is associated with a change in state and the alteration that results in a dissociation mutation are distinct and separable.

CONTINUATION OF STUDIES OF THE CHROMOSOMES OF NEUROSPORA CRASSA

Study of the mutable loci in maize was interrupted during the fall and early winter of 1946 in order to continue the investigations of the chromosomes of *Neurospora crassa* begun several years earlier. The earlier work was preliminary and exploratory, and no time was spent in obtaining the necessary illustrations of chromosome morphology and behavior during ascosporogenesis. In addition, the preliminary study indicated a need for improvements in techniques in order that consistently good preparations could be obtained of the chromosomes and nuclei of the ascus. Efforts were concentrated, therefore, on these two objectives. The investigations were conducted at the California Institute of Technology, with the collaboration of Mr. Jesse R. Singleton. Approximately one hundred photomicrographs were taken, illustrating chromosome and nuclear behavior from the prefusion stages in the crosier to the binucleated stage in the ascos}>ore. New or modified techniques were devised, which greatly improved the quality of the preparations. This applied significantly to the meiotic prophase stages,

where the chromosomes are greatly extended. In the previous investigation, the minute morphology of the extended chromosomes could rarely be observed, but with the present techniques this morphology is sharply defined in many figures. Mr. Singleton has succeeded in mapping the chromomere organization of each of the seven chromosomes. Each chromosome has an individually recognizable chromomere organization, including deep-staining regions which, because of their positions in the chromosomes, probably represent the heterochromatic regions known to be adjacent to the centromeres. It can now be stated with certainty that no heteromorphic pair of chromosomes is present in *Neurospora crassa.* These techniques have also made it possible to observe more critically the mutual relations of the two homologues of a bivalent during the mid-meiotic prophase stages, that is, before diplotene. Many bivalents were observed in which the two homologous chromosomes were lying side by side but not in direct contact at any point along their length. These favorably oriented bivalents showed no relational coiling of the two homologues about each other, and it was obvious that the distance between them was quite constant—amounting to approximately half a micron—so that in their spatial relation they resembled railroad tracks. Technical methods were devised by Mr. Singleton for softening the ascus wall in order to flatten the asci, and also for achieving a sharp differentiation of the spindle figures and the centriole. From preparations kindly donated by Mr. Singleton, photographs were taken to illustrate the peripheral position of the chromosomes in the spindle figures and the rather bizarre organization and behavior of the centriole in the third division in the ascus.

Though the primary objectives of this interim study of the chromosomes of *Neurospora* were fulfilled, a supplementary factor of possibly greater value was the progressive realization of the possibilities for utilizing this material in attacking a number of cytological and cytogenetic problems, both old and new.

MOUSE LEUKEMIA

E. C. MACDOWELL, M. J. TAYLOR, AND L. LEWIS

MATERNAL INFLUENCE UPON SPONTANEOUS LEUKEMIA

In previous Year Books the following steps have been recorded in the study of influence of the mother upon the incidence of spontaneous leukemia: (i) Less leukemia appeared, in reciprocal first-generation hybrids between the leukemic strain C5S and the nonleukemic strain StoLi, when the mother came from the nonleukemic strain. (2) Less leukemia appeared within either form of this cross when the Fi young were nursed by StoLi than when they were nursed by C58 females. (3) Less leukemia appeared in the second backcross to inbred StoLi females when these mothers were old than when they were young.

An experiment to confirm this influence of mother's age was started in 1944 (Year Book No. 43, p. 140). During the present year the last mouse in this experiment died, and a preliminary, report can be given, although final figures await microscopic diagnosis of certain cases. Young and old StoLi females were mated at the same time to the same C58 males; each mother nursed her own young. Among the 75 female hybrids at whose birth the mothers were IO to 18 weeks old, the first death

from leukemia occurred at 309 days; by 800 days, 70 per cent had died with leukemia. Among the 89 female hybrids at whose birth the mothers were 34 to 50 weeks old, the first leukemic death occurred at 570 days; by 800 days, 20 per cent had died with leukemia. Thus, with many fewer variables involved, the original indications of a maternal age factor are fully substantiated. If this factor that increases with age and inhibits the development of leukemia should prove to be transmitted by the milk, it would not only provide an interpretation for most of our observations on maternal influence, but also offer an opportunity to isolate the substance so transmitted.

An experiment to test for an effect of the age of the nurse has been in preparation during the past two years, and in the summer of 1947 the 400 test animals were born (within a period of 24 days) and nursed and weaned. As in the previous experiment, the fathers were all from the leukemic strain and the mothers all from the nonleukemic strain: one group 9 to 15 weeks old at the birth of their young (two-thirds being 11 to 12 weeks old); the other group, 36 to 42 weeks old (one-half being 38 to 39 weeks old). Newborn young from each group, which had received no milk from their own mothers, were nursed by mothers of the other group; as controls, others were nursed by their own mothers or other nurses of the same age group. These mice are housed in a room of their own, with the same number from one class in each box, and with the four classes in rotation along the shelves.

A FILTERABLE AGENT ASSOCIATED WITH LINE I

From the beginning of our studies on resistance to transplanted leukemia induced by normal tissue, it was observed that the mice resisting leukemic cells of line I were regularly sick in about a week after the test dose, and later recovered. Since the controls were dying at this time, this sickness seemed to be merely a phase in the process of resistance. But this condition became more interesting when the same symptoms appeared in the same number of days after an injection of microsomic material prepared by Dr. Claude by differential high-speed centrifugation from line I, and also after injection with heated line-I cells (46^0 C. for 10 minutes), which do not transmit leukemia but do induce active resistance. For years the cause of this sickness has been an outstanding question.

Although many unsuccessful filtration experiments with the early transfers of line I were carried out by Drs. Richter and Zucker at the College of Physicians and Surgeons, the recent development of genetic theory to include self-reproducing, gene-like units free from chromosomes seemed to justify a return to filtration techniques. This was further justified by the apparent activity of certain of Dr. Claude's centrifugates. After 1500 transfers, line I might give different results. The first objective was to obtain the contents of leukemic cells as unchanged as possible, without an intact cell.

The following report covers work undertaken by Miss Taylor. Numerous procedures were eliminated by finding intact cells in the product upon microscopic examination. Dr. Spiegelman, having had a similar objective, proposed his technique of breaking cells by glass beads and carborundum powder in a slowly revolving flask at a low temperature. Dr. McDonald co-operated in working out techniques, shared her cold room (o° C), and provided apparatus. The ground material, after passing through a pyrex fritted glass

filter, grade *fine,* was found by Dr. R. Miller to include the same population of microscopic particles as before filtration, but whole cells were unquestionably eliminated. This filtrate injected into leukemia-susceptible mice (C58) failed to transmit leukemia, but a sickness appeared in a week that could not be distinguished from the condition mentioned above. Second and third treatments of the same mice with similar filtrates called forth no symptoms, but after the third treatment such mice were still susceptible to line-I leukemia, even when given in a highly dilute dose. This result with cell-free filtrates agrees with earlier experiments in which mice were inoculated with line-I cells subjected to 46.5-50° C. for 10 minutes; the sickness was called forth, and after recovery the mice were still susceptible to intact line-I cells. Miss Taylor discovered that curves of daily body weights show a characteristic pattern for this sickness that records the course of the illness far more objectively than estimations of the reduced activity, dampness of hair, and stickiness of eyes that are its indications. For the first week there is no weight deviation from the controls; then appears a precipitous drop of a gram or more a day for about three days, followed by a leveling off and a slow rise that may not restore the original weight for two or more weeks, many days after other signs of sickness have disappeared. Subsequent experiments proved that the preliminary grinding was unnecessary for the transmission of the sickness. The simple passage of even a highly dilute (10^{-f}) suspension of leukemic tissue through a pyrex *fine* filter gave a material that Induced the sickness in the regular time. Within wide limits the concentration of the dose made no difference. Further independence of this agent from leukemic cells was demonstrated by transferring spleen from a filtrate-treated mouse at the height of the sickness to a normal host. The sickness appeared at the end of a week, and the same result followed a second subtransfer.

Drs. E. Racker and Mark Adams, of the Department of Bacteriology, New York University College of Medicine, in summer residence at the Biological Laboratory, became interested in this problem, and they have followed the work in detail and have made valuable suggestions. Both men were inclined to interpret Miss Taylor's results as indicating the presence of a virus, but subsequently in the hands of a virus specialist a bacterial infection was reported that caused intensive efforts for half the year to be turned toward a search for significant bacteria. To this work Dr. Kelner, of the Biological Laboratory, gave considerable time and assistance, and the bacteriological services of the Department contributed sterilized glassware and media. But this endeavor was fruitless. Various bacteria were found both in the transplanted leukemias and in uninoculated mice directly from the breeding colony, but there was little consistency in occurrence and their pathogenicity was in question. Bacteria found in one transfer of a transplanted line would be entirely absent from a later transfer without recognizable change in the characteristics of the line. When it gradually became clear that neither was the colony threatened by an epidemic, nor the transplanted lines by extinction, the road became clear to undertake the critical filtration experiment which, with Dr. Adams' active co-operation, has just been carried out. A broth suspension of spleen from a mouse inoculated with line-I leukemia was passed through a pyrex filter *(fine);* part of this was inoculated into normal C58 mice and part was passed through a Seitz filter and then inoculated. Both filtrates induced the characteristic symptoms and the sudden

weight loss beginning on the eighth day. It seems probable that this filterable agent has been present in line I for a long time and has been responsible for the "sickness" that has held our attention. It has regularly appeared in C58 mice about a week after first inoculation with line I, when death from leukemia was prevented by previously induced resistance or was sufficiently delayed by high dilution of the dose of cells. Although this sickness has been observed many times over the years, very little can be said about its internal effects. The white-blood-cell counts are high, and the smears of blood have been called leukemoid by Dr. R. Miller. Two mice killed at the height of the sickness after inoculation with a filtrate showed mild lymphoid hyperplasia and moderately enlarged spleens.

To summarize, a filterable virus-like agent of mild pathogenicity, carried along with the transplanted leukemia of line I, has been found, which can be passed from mouse to mouse by tissue transplantation without mortality or the appearance of leukemia. This agent has probably existed in line I for more than ten years. A single infection is followed by firm immunity, which has been tested after two months and found still effective. All C58 mice tested have been susceptible. The failure of mice immunized to this agent to resist even highly dilute doses of leukemic cells indicates that the resistance that can be induced to line-I leukemia is a different phenomenon. The action of this virus-like agent upon lymphoid tissues, however, is definitely leukemoid; and questions are raised bearing on its origin, its variations, its modification of the pathology of leukemia, and its possible influence upon resistability and variability of leukemic cells.

GENETIC STRUCTURE OF NATURAL POPULATIONS

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Cyclic seasonal changes in the genetic structure have been discovered in the populations of the fly *Drosophila pseudoobscura* on Mount San Jacinto, in California (see Year Books Nos. 40, 43, 44). The changes involve the relative frequencies of certain gene arrangements in the third chromosome of the fly. The frequency of the so-called Standard gene arrangement decreases during the spring and increases during the summer, whereas the frequencies of the Chiricahua and Arrowhead gene arrangements wax In spring and wane in summer. The changes seem to represent adaptive responses of the species to the seasonal alterations in the environment in which it lives. This finding has presented an opportunity for an observational and experimental approach to the problem of the action of natural selection.

EXPERIMENTS WITH FLIES DERIVED FROM THE PIÑON FLATS POPULATION

A simple apparatus called the population cage has been constructed, which enables one to maintain populations of *Drosophila pseudoobscura* of known genetic composition, and to study the changes that may occur under controlled laboratory conditions (see Year Books Nos. 43, 45). Some changes analogous to those known to take place in nature have, indeed, been observed in the population cages. The early experiments were made with flics descended from wild progenitors collected at the locality called PiñoE Flats, on Mount San **Jacinto,** California. Artificial populations were made consisting of flies with Standard **and** Chiricahua, Standard and Arrowhead, and Arrowhead and Chin*

cahua chromosomes. It was found that at a temperature of i6° C. the relative frequencies of the chromosomal types present in the initial population of a cage remain unchanged generation after generation. In the same way, no changes take place in the population at Piiion Flats during autumn and winter, when low temperatures prevail. But at temperatures close to 25° C, changes do occur in the population cages, as they do in summer in the natural populations. Furthermore, these changes proved to be of a very interesting kind. No chromosomal type entirely supplants its competitor (an exception to this rule, found in a population of flies descended from Mather progenitors, is mentioned below). Instead, the population gradually approaches an equilibrium state, in which the competing chromosomal types are present in definite proportions. In mixtures of Standard (ST) and Chiricahua (CH), and of Standard and Arrowhead (AR), the Standard chromosomes reach at equilibrium a frequency of about 70 per cent. In mixtures of Arrowhead and Chiricahua, the equilibrium value of Arrowhead chromosomes appears to be around 75 per cent.

The failure of the competing chromosomal types to displace one another is best explained on the assumption that individuals homozygous for the respective chromosomes (ST/ST, CH/CH, AR/AR) have lower adaptive values (i.e., survive and reproduce at lower rates) than the chromosome heterozygotes (ST/CH, **ST/AR, AR/CH).** Since the changes observed in the population cages, as well as in nature, are extremely rapid (see Year Books Nos. 44, 45), the differences in the adaptive values must be very large. Professor Sewall Wright, of the University of Chicago, has computed that, taking the adaptive value of ST/CH heterozygotes to be 1.0, that of ST/ST homozygotes is about 0.7, and that of CH/CH homozygotes as low as 0.4. The finding of such large differentials among normal constituents of a natural population has been most unexpected, since it has been customarily assumed in modern biology that the intensities of natural selection operative in nature are, except for abnormalities and pathological conditions, very low. Moreover, these differentials characterize the chromosomal types only at relatively high temperatures, and seem to be diminished or removed altogether at 16° C. The origin and the biological meaning of so extraordinary a situation present a fascinating problem.

The first question that arises is whether the adaptive properties of the ST, CH, and AR chromosomes discovered in the Piiion Flats population are intrinsic attributes of the chromosomes having these gene arrangements. Indeed, these chromosomal types occur not only in the Piiion Flats population, but also in populations of the whole Pacific coast, from British Columbia to Lower California. Would the ST, CH, and AR chromosomes behave similarly, then, regardless of the particular locality from which they were derived? Such a similarity would, in general, be expected if the adaptive properties of a chromosome were caused directly by the arrangement of the genes in it (position effect). Chromosomes with the same gene arrangement may behave differently if their properties are determined by the quality of the genes that they carry. Observations and experiments on the populations of several localities have, therefore, been undertaken.

POPULATIONS LIVING AT DIFFERENT ELEVATIONS IN THE SIERRA NEVADA

Thanks to the courtesy of the Division of Plant Biology of the Carnegie Institution, the writer has been able to make ob-

servations on the population of *Drosophila pseudoobscura* of the Sierra Nevada, using as a base the facilities of the Division at Mather, California. The unfailing hospitality of Drs. J. Clausen, D. D. Keck, and W. M. Hiesey, as well as of Drs. H. A. Spoehr and C. S. French, the former and present Chairmen of the Division, is gratefully acknowledged. Mather is located slightly more than 300 miles northwest of San Jacinto, at an elevation of about 4600 feet, on the western slope of the Sierra Nevada.

During the summers of 1946 and 1947, samples of the populations of *Drosophila pseudoobscura* and of the related species *Drosophila persimilis* were taken at Jacksonville (elevation 850 feet), Lost Claim Campground (about 3000 feet), Mather (4600 feet), Aspen Valley Ranger Station (6200 feet), Porcupine Flat (8000 feet), Tuolumne Meadows (8600 feet), and Timberline Station (9900 feet). These localities form an approximate west-east transect of the Sierra Nevada. The distance between the extreme localities, Jacksonville and Timberline, is about 60 miles.

The data are still incomplete, but the main conclusion that follows from them is no longer in doubt. The populations that live in the different localities sampled differ in relative frequencies of Standard and Arrowhead chromosomes, the differences being correlated with the elevations of the respective localities. The Jacksonville population contains about 45 per cent of ST and 25 per cent of AR chromosomes. At Lost Claim, the average frequency of ST falls to about 40 per cent, and that of AR rises to about 35 per cent. At Mather, ST amounts to, roughly, 30 per cent, and AR to 35-40 per cent. At Aspen Valley, ST dwindles to between 20 and 30 per cent, and AR rises to between 40 and 50 per cent. In the higher localities the species *Drosophila pseudoobscura* becomes much less frequent than *Drosophila persimilis* (the latter being rare at lower elevations), but samples obtained had 15 per cent, or less, of ST chromosomes, and more than 40 per cent of AR chromosomes. In contrast with Mount San Jacinto—where Standard and Chiricahua do, and AR chromosomes do not, show elevational changes—in the Sierra Nevada the frequencies of the CH chromosomes are relatively uniform at different elevations (or, possibly, increase slightly at the higher altitudes).

The details of the seasonal changes in the Sierran populations are not quite clear at present, although there is no doubt that seasonal changes do occur. The data now available suggest that at Aspen Valley, Mather, and Lost Claim seasonal changes are rather pronounced, but that these changes are quite different in kind from those observed on Mount San Jacinto. In the three Sierran localities the relative frequency of the ST chromosomes increases, while the frequency of AR decreases, as the season progresses from spring to autumn. A reversal of the changes evidently takes place during winter. At Piñon Flats and Andreas Canyon, on Mount San Jacinto, no changes have been recorded in autumn and in winter, whereas during the spring and summer ST and CH chromosomes are involved in the cyclic alterations of frequencies. On Mount San Jacinto, as well as along the Sierran transect, the fly populations of the higher localities reach maximum densities during late summer, whereas in the lower localities the populations contract in size during the summer, owing presumably to the excessive heat.

The chromosomal composition of the populations in the lower localities on San Jacinto (Andreas, Fiñon) approaches in late spring and early summer that of the population of the higher locality (Keen Camp), which at this time is expanding

in numbers. This fact has misled some authors into believing that the changes in the chromosomal constitution observed at Andreas and Pifion were due to an influx of flies from the higher localities. It stands to reason, however, that a migration of flies from Keen to Pifion and Andreas could change the composition of the populations of the latter two localities in the direction of the Keen population, but could not produce the reverse change so as to make the changes cyclic. Moreover, the populations of Piiion and Andreas change during the summer in the direction away from the composition of the Keen population, at the time when the population of the latter locality is expanding and reaching maximum density. Finally, the rate of dispersal of the flies is known to be far too low to produce the postulated migrations (see Year Book No. 45).

Comparison of the altkudinal differences in the incidence of the chromosomal types in the localities of the Sierran transect with the seasonal changes in these localities is very instructive. It will be recalled that the frequencies of ST chromosomes decrease, and those of AR increase, as one ascends from the lower to the higher elevations. However, in at least some of the localities, at mid elevations, the frequencies of ST increase and those of AR decrease as the growing season progresses and the weather becomes warmer. In other words, the populations of relatively higher localities come, during the warm season, to resemble in composition the populations of the lower localities. One reason for excluding the migration hypothesis is that the population densities in the lower localities dwindle when the populations of the higher localities begin to resemble the former in composition. The available facts are consistent with the view that, in the Sierran populations, the carriers of ST chromosomes arc better adapted to the environments prevailing at lower elevations and at warmer seasons, whereas the carriers of AR chromosomes prefer cooler localities and seasons. If this is so, natural selection would tend to increase the frequencies of ST chromosomes in the populations of the lower localities and during the summer, and to have the opposite effect in the higher localities and during cold weather.

It is most instructive to compare the results just outlined with those obtained by Drs. Clausen, Keck, and Hiesey, of the Division of Plant Biology, in their very important work on the local races (ecotypes) of some plant species. These investigators found that plant species that occur in diverse environments are often differentiated into genetically distinct populations—races—which are adapted to survive and to reproduce most efficiently in the particular environments of their occurrence. This is very often the case with representatives of the same species growing at different elevations. A transect of the Sierra Nevada, approximately coinciding with the one used by the present writer, has disclosed many excellent examples of altitudinal races of plants. Clausen, Keck, and Hiesey have explained the origin of the adaptive differentiation observed by them by supposing that natural selection leads to differential increases in the frequencies of different genotypes in different environments. The genotypes best fitted to survive in each environment become established, then, as the predominant, or exclusive, components of the populations in that environment. The fly *Drosophila pseudoobscura* exhibits essentially the same kind of differentiation Into altitudinal races that was found by Clausen, Keck, and Hiesey in the plants studied by them. Since the fly* however, is capable—at least at the lower elevations—of producing several generations per year, it under-

goes the process postulated by these investigators regularly and cyclically, twice every year.

BEHAVIOR OF THE MATHER AND KEEN CAMP CHROMOSOMES IN POPULATION CAGES

The observations on the altitudinal and seasonal changes in the frequencies of the chromosomal types in the Sierra Nevada strongly suggest that these chromosomes have different properties from the analogous chromosomes on Mount San Jacinto. Beginning with the winter of 1945-1946, a series of experiments has been conducted with population cages that contained known mixtures of chromosomes derived from the Mather population in the Sierra Nevada, and from the Keen Camp population on Mount San Jacinto. These experiments are now in the main completed, but their results have not yet been subjected to a proper mathematical analysis. The following statement of the results of these experiments is therefore tentative.

A population cage (no. 30) was started in December 1945 with 33 per cent Standard and 67 per cent Chiricahua chromosomes of Mather origin, and was kept at 25° C. By June 1946 it contained about 77 per cent ST and 23 per cent CH. In September 1946 this cage was transferred to a temperature of 15° C. Its population underwent no further change till January 1947. The behavior of the ST and CH chromosomes of Mather origin is, thus, about the same as that of the same chromosomal types from Piñon (see above), except that the equilibrium value for ST seems to be slightly higher for Mather than for Piñon.

Two population cages (nos. 29 and 32) were started in December 1945 with mixtures, respectively, of 70 per cent ST and 30 per cent AR» and 19 per cent ST and 81 per cent AR, chromosomes of Mather origin. The cages were kept at first at 25° C. The frequencies of the ST and AR chromosomes in these two cages converged, reaching an approximate equality by June-July 1946. Cage no. 32 was transferred in September 1946 to a cold room at 15° C. No changes took place in this cage until January 1947. From then until June 1947, this cage was exposed alternately to room temperature and to a cold-room temperature of about 2^0 C. The transfers from one temperature to the other were made at first at approximately weekly, and later at daily, intervals. No significant changes occurred till June 1947, although, taken at face value, the frequency of ST rose slightly (to 56-57 per cent). Since the competition of ST and AR chromosomes from Piñon Flats leads to equilibrium at about 70 per cent ST (see above), it may be taken as established that the Sierran chromosomes and those from Piiion Flats have different properties. The competition of the AR and CH chromosomal types of Sierran origin also leads to a result clearly different from that obtained with the same chromosomal types from San Jacinto; the equilibrium value is about 57 per cent AR and 43 per cent CH for Mather chromosomes, compared with more than 70 per cent AR and less than 30 per cent CH for Piñon chromosomes.

The Keen Camp locality is only about 15 miles distant from Piñon Flats and from Andreas Canyon. Despite such close geographical proximity, the Keen Camp population showed remarkably different behavior from the populations of Piñon and Andreas. In contrast with the regular cyclic changes at these two localities, no cyclic seasonal changes in the frequencies of the chromo'somal types have been observed with certainty at Keen. Instead, the Keen population showed a sustained trend of change from 1939 to 1946 (the period for which observations are available),

which led to a gradual increase in the frequency of Standard, and to a decrease in the frequencies of Arrowhead and Chiricahua chromosomes (see Year Book No. 45). It seemed a most intriguing problem to investigate whether the difference in behavior between the Keen population, on the one hand, and the Pifion and Andreas populations, on the other, was due to differences in their genetic structures or to differences in their environments. Experimental evidence suggests that the former are at least partly responsible. A population cage (no. 26) was started in November 1945 with a mixture of 32 per cent ST and 68 per cent AR chromosomes of Keen Camp origin. The cage was kept at 25° C. By March 1946, an equilibrium was attained at 60 per cent ST and 40 per cent AR, which persisted till June of the same year, when the cage was transferred to a cold room at 15° C. No further changes occurred until January 1947. The equilibrium point for ST-AR chromosomes of Keen Camp origin seems, then, to lie between those for the same chromosomes of Pifion Flats origin and of Mather origin (see above). An experiment with AR and CH chromosomes of Keen Camp origin gave results resembling those obtained with the same chromosomal types from Mather, but differing sharply from the results with flies from the geographically much nearer Piiion Flats locality.

AN EXCEPTIONAL EXPERIMENT WITH MATHER CHROMOSOMES

In all the experiments referred to up to now, whenever the composition of the population in a population cage underwent changes, these changes led to the establishment of an equilibrium at which all the chromosomal types introduced into the population were preserved with definite frequencies. As stated above, this indicates that the adaptive values of individuals heterozygous for chromosomes with different gene arrangements are higher than those of chromosome homozygotes. The populations of the Sierra Nevada include, besides the frequently occurring chromosomal types having Standard, Chiricahua, and Arrowhead *gene* arrangements, some less common chromosomal types, which, because of their relative rarity, could not be used in artificial experiments. Only one of these rare types, called Tree Line (TL), was found in the Mather population in numbers which permitted its inclusion in the experiments (its frequency at Mather ranges from 4 to 10 per cent of the total number of chromosomes).

Population cage no. 31 was started in December 1945 with 45 per cent ST and 55 per cent TL chromosomes of Mather origin. By May 1946, the frequency of TL had fallen to only 18 per cent, and by November of the same year to about 1 per cent. It seems that in this cage the changes were leading to a complete displacement of TL by ST chromosomes. Such an outcome of the competition between the two chromosomal types is possible only if the heterozygotes (TL/ST) are less well adapted, at least under the conditions of the experiment, than the Standard homozygotes (ST/ST).

It may be asked why the Tree Line chromosomes continue to exist at all in the Mather population. If both the heterozygotes, TL/ST, and the homozygotes, TL/TL, are inferior to ST homozygotes, natural selection would be expected to eliminate the TL chromosomes completely. A possible answer to this question is provided by the results obtained in population cage no. 33, which contained Tree Line and Arrowhead chromosomes derived from the Mather population. The outcome of this experiment was quite different from that of no. 31 described above. The

population of no. 33 reached equilibrium at about 75 per cent AR and 25 per cent TL. It must be concluded that the TL/AR heterozygotes are adaptively superior to both TL/TL and AR/AR homozygotes. Now, in the natural populations of Mather and other Sierran localities, the Tree Line, Standard, and Arrowhead chromosomes always occur. TL/ST, as well as TL/AR, heterozygotes are always present in these populations, together with some ST/ST and AR/AR, and a few TL/TL, homozygotes. Although the adaptive value of TL/ST heterozygotes is low as compared with that of ST/ST, that of TL/AR heterozygotes is higher than that of AR/AR, and possibly also than that of ST/ST. Natural selection would tend, then, to retain TL chromosomes in the population, but at a frequency level lower than that of AR and of ST chromosomes. This is precisely what was observed.

ARTIFICIAL POPULATIONS CONTAINING MIXTURES OF CHROMOSOMES OF DIFFERENT GEOGRAPHIC ORIGIN

As the experiments reviewed above had demonstrated that chromosomes with the same gene arrangement derived from geographically different populations may have different properties, the logical next step in the experimental program was to test the behavior of populations composed of chromosome types of different geographic origin. Such populations may easily be created artificially in population cages by crossing flies whose ancestors were collected in different localities. In nature, they are probably rare, since the only way in which they can be formed is through accidental transport (for example, by wind) of individuals from one population to a foreign territory. Nevertheless, the behavior of such artificial populations may be very enlightening in its bearing on several problems relating to natural populations.

The experiments were started in December 1946, and are at present well under way. After some preliminary trials, the following technique was adopted. Flies homozygous for a certain gene arrangement—say, for Standard of Mather origin—are crossed, in regular *Drosophila* culture bottles, to individuals of the opposite sex homozygous for another gene arrangement of different origin—say, for Chiricahua from Piñon Flats. The offspring of this cross are all heterozygous for Mather and for Piñon Flats chromosomes. These offspring are placed in a population cage in numbers sufficient to produce an overpopulation of larvae in the food introduced into the cage. Since the initial population of the cage consists of heterozygotes only, the first generation of eggs and larvae in the cage will necessarily consist of 25 per cent homozygotes of each of the two types (ST/ST from Mather, and CH/CH from Piñon), and 50 per cent heterozygotes (ST/CH) for chromosomes of the two different geographic origins. If at any developmental stage before the emergence of the adults the two types of homozygotes and the heterozygotes are not equally viable, the theoretical proportions, 25:50:25, will not be realized among the adults. Accordingly, the adults of the first generation emerging in the population cages are tested for their chromosomal constitution. Although such tests are very laborious if many flics are involved, this experimental procedure is expedient. Indeed, comparison of the theoretical proportions with the ratios in which the three chromosomal constitutions actually appear among the adults permits a direct estimate of the coefficients of the differential mortality that may have taken place in the population cage. Such estimates arc difficult to obtain by any other procedure.

Five successful experiments of this type, carried out in collaboration with Miss C. Madison, have given quite consistent results, showing that the viability of individuals heterozygous for chromosomes with different gene arrangements of different geographic origin lay between the viabilities of the two corresponding homozygotes. In all these experiments, chromosomes from Mather and from Piñon Flats were involved. In four out of the five experiments, the viability of the homozygotes for chromosomes of Mather origin proved to be higher than that of the homozygotes for Piiion Flats chromosomes.

The differential viabilities observed in the experiments described above may or may not reflect differences in the adaptive values of the individuals of the different chromosomal constitutions. It must be kept in mind that higher survival value of a genotype in, for example, the larval stage may be offset by lower survival or reproductive value of the same genotype in the adult stage. If, however, the observed viability differentials may be taken as indications of the selective values in general, then the outcome of the experiments with population cages containing chromosomes of geographically different origins will be radically different from that of the experiments with mixtures of chromosomes derived from the same population. As shown above* individuals heterozygous for chromosomes with different gene arrangement from the same population are, with the single exception mentioned in the preceding section, adaptively superior to chromosomal homozygotes. Hence, in experiments of this kind, the selective process leads to an equilibrium state in which all competing chromosomal types are preserved. This is what happens in the population cages as well as in natural populations. On the other hand, if the hcterozygotes for chromosomes of different geographic origin are adaptively inferior to at least one of the homozygotes, the selective process will lead to the establishment of one and to elimination of all other competing chromosomal types. Whether or not this will actually be the outcome of the experiments on populations of geographically mixed origin remains to be seen.

ADAPTIVE EVOLUTION IN SOME POPULATIONS OF DROSOPHILA PSEUDOOBSCURA

The evidence reviewed above permits some insight into the nature of the evolutionary processes which lead to the adaptation of populations to their environments. It has been known for some time that natural populations of some species of *Drosophila* vary with respect to the gene arrangement in their chromosomes, most of the variation being due to inversions of chromosome sections. It is now clear that the evolutionary significance of the chromosomal inversions is due to their property of reducing or suppressing crossing-over in some chromosome sections in the inversion heterozygotes. Thus adaptively valuable gene combinations, A'B'C'D' and A"B"C"D", may exist in the same population without a constant loss of adaptive fitness, owing to crossing-over and to the production of adaptively inferior types, A'B"C"D", A'B'C'D", etc. The possibility that some gene arrangements may be valuable because o£ the position effects which they produce is not to be dismissed, but there can be no doubt that the adaptive properties of chromosomes in natural populations are often determined by their gene contents rather than by the gene arrangement.

The adaptive value of a chromosomal type in heterozygotes with other chromosomal types present in the same population may be more important than the adaptive

value of the same type when homozygous. This situation is made possible because, in many natural populations of *Drosophila pseudoobscura*—including the populations that have been employed in our experiments—structural (inversion) heterozygotes are more common than are the homozygotes. The process of natural selection, therefore, encourages the spread of those gene complexes in the chromosomes with one gene arrangement which produce superior heterozygotes with the gene complexes carried by the other chromosomal types present in the same population.

This "coadaptation" of the gene complexes apparently takes place separately and independently in populations which reside 300 miles, or perhaps even as little as 15 miles, from each other. A type (or types) of structural heterozygotes is evolved in each population, which is adapted to the environment prevailing in the particular region where that population lives. The coadaptation of the gene complexes being independent in local populations, the hybrids produced when the populations are intercrossed are adaptively inferior to the members of the parental populations. Thus, intrapopulational heterosis is compatible with a loss of vigor following hybridization of populations. This, evidently, will restrict the effectiveness of migration of flies from one population to another. It may also, under conditions which cannot be discussed in this report, initiate the splitting of an originally single species into two or more derived ones, and the development of reproductive isolating mechanisms between the latter. Further studies in this field may lead to a clarification of the very difficult problem, why some species retain their unity despite a wide geographic distribution and despite the occupation of a variety of environments, while other species split up into swarms of derived species, each restricted to a small area and each ecologically specialized. However that may be, the situation observed in *Drosophila pseudoobscura* is among the best evidence available for the efficiency of natural selection in evolution. The coadaptation of the gene complexes in local populations could not arise in any other way than through natural selection. It is interesting to find that in some populations the process of coadaptation has not been completed, and one of the chromosomal types, such as Tree Line in the Mather population, produces heterozygotes adaptively superior to the homozygotes only with some (Arrowhead) but not with other (Standard) chromosomal types. Possibly this situation indicates that one of the chromosomal types is a relative newcomer to the territory in which it is now found.

It must not be supposed, however, that the evolutionary pattern found in the populations of *Drosophila pseudoobscura* examined will occur in all organisms, or even in all species of *Drosophila*. Perhaps the most remarkable feature of this pattern is precisely that it permits an extreme plasticity and diversification of the evolutionary adaptations. In some of the San Jacinto, and in the Sierran, populations of *Drosophila pseudoobscura* the biological function of the chromosomal polymorphism is at least partly concerned with the adaptation to different seasonal environments. Yet in the Keen Camp population no seasonal changes occur. There is some evidence that the chromosomal polymorphism in *Drosophila persimilis* and in *Drosophila robusta h* not connected with seasonal adaptation. Finally, some populations of *Drosophila pseudoobscura* that occur in Arizona and In New Mexico are homozygous for a single chromosomal type (Arrowhead). This may mean that,

occasionally, a highly adapted homozygous type is selected, which would make the chromosomal polymorphism unnecessary.

NATURAL SELECTION OF BENEFICIAL MUTATIONS IN LABORATORY CULTURES OF DROSOPHILA

It is well known that mutations that arise in laboratory cultures of *Drosophila* are mostly deleterious, or at best neutral, to the viability of their carriers. This fact seems to contradict the view, now held by most biologists, that the mutation process supplies the raw materials of evolution. The apparent contradiction is usually resolved by supposing that some mutations, although harmful in the environment. in which the species normally lives and in combination with other genes normally present in the species, may be useful in other environments and in combination with other genes. Indeed, the "normal" species genotype is a product of a long process of natural selection which has brought about an adjustment of this genotype to the "normal" environment; any mutation that is likely to be observed in our experiments has probably taken place many times in nature, and, consequently, has had the chance of being tested by natural selection and of becoming a part of the "normal" genotype. It follows, then, that "useful" mutations can be found mainly in experiments in which a living species is placed in "abnormal" environments, or in which the initial materials have an "abnormal" genetic constitution. This working hypothesis has been tested by means of experiments conducted, in collaboration with Mr. B. Spassky, from 1942 to 1946.

In these experiments, we used seven strains of *Drosophila pseudoobscnra* which were homozygous for second or for fourth chromosomes known to reduce the viability of their carriers below the normal (wild-type) level. Mutations were looked for which would bring the viability of these strains back to normal. Some of the strains also showed development rates slower than that characteristic of "normal" flies; and mutations that might accelerate the development to the normal level were expected. The technique of detection of the hoped-for mutations (or modifier recombinations) was as follows. The seven initial strains, each in two parallel sublines, were kept in deliberately overcrowded cultures for fifty consecutive generations. The male progenitors of one of the sublines of each strain received, in every generation, 1000 roentgen units of X-rays, the other subline receiving no treatment. The overpopulation resulted in acute competition for food among the larvae and the adults, and in a stringent natural selection for genetic variants that would improve the viability, or accelerate the development rate. At intervals of several generations, the viability and the development rates of all the sublines were tested, with the aid of a genetic method which cannot be described here in detail; suffice it to say that this method consisted in observing the deviations from the ideal Mendelian proportions that arose when the chromosomes of the lines subjected to selection were tested against chromosomes marked by standard mutant genes.

In eleven out of the fourteen homozygous sublines, statistically significant improvements of the viability were observed. In seven sublines, these improvements were quite striking; in some cases, the viability of a line which acted as a semilethal at the beginning of the experiment was brought up to normal or nearly so. The improvements first became noticeable in some of the lines near the beginning, in others toward the middle, and in still others toward the close of the experiments.

Accelerations of the development rate were also observed. No appreciable difference was noted between the X-rayed and the untreated sublines.

In parallel experiments, the seven initial strains were kept for fifty generations in a "balanced" condition. "Balancing" is a genetic technique whereby a chromosome is transmitted from generation to generation through heterozygotes only, the homozygotes not being used as parents. A chromosome kept in a "balanced" condition is sheltered from the effects of natural selection, to the extent that any recessive mutant that arises in it is retained regardless of the viability effects that this mutant may have when homozygous. Two parallel sublines of each strain were kept, one being treated with X-rays and the other untreated, as described above for the homozygous sublines. Recessive lethals or semilethals appeared in three of the untreated and in five of the X-rayed "balanced" sublines. Three untreated and two X-rayed sublines did not change in viability to any appreciable extent, and one untreated subline showed a slight improvement* The contrast between the homozygous and the "balanced" lines was thus very striking; improvements were observed in most of the former, and degeneration in most of the latter.

CHROMOSOME STUDIES ON GALL MIDGES

M. J. D. WHITE

The gall midges (Cecidomyidae) are a group of dipterous flies which are unique in that the number of chromosomes in the germ line (primordial germ cells, spermatogonia, and oögonia) is very much greater than the number present in the somatic nuclei. Previous studies had shown that in *Miasior metraloas* there are 48 chromosomes in the germ line of both sexes, 12 in the somatic cells of females, and 6 in the somatic cells of males. In this species the size differences between the individual chromosomes are sufficiently great so that one can be sure that the male soma is haploid and the female soma diploid. Actually, a number of the somatic tissues are endopolyploid in both *sexes, so* that much higher numbers of chromosomes occur in some of the somatic cells, but male and female embryos begin their development with haploid and diploid somas, respectively, and this condition is retained in some of the adult tissues such as the nervous system.

Originally, the germ line of *Miastor* was interpreted as polyploid (i.e.» octoplold), and this conclusion seemed to be strengthened when it was found that in another cecidomyid, *Taxomyia taxi,* whose haploid number is 4, the germ-line nuclei contained 40 chromosomes, which was interpreted at that time as a decaploid condition; in *Taxomyia* all the chromosomes are so nearly alike in size and shape that it is not possible to distinguish them cytologically.

Studies on another cecidomyid, *Monarthropalpus huxi,* carried on at Cold Spring Harbor during the months of April and May 1947 have, however, rendered the hypothesis of germ-line polyploidy untenable for that species and hence unlikely in the case of other Cecidomyidae. It now seems more probable that the germ line contains a number of "extra" chromosomes which are not represented at all in the $soma_5$ rather than that the somatic chromosomes are simply present in the polyploid condition in the germ line. If this is so_5 the fact that in *Miastor* and *Taxomyia* the number of chromosomes in the germ line is a multiple of the haploid

number may be merely a coincidence. In future we shall refer to the chromosomes which are present in both germ line and soma as S chromosomes, the "extra" chromosomes which are destined to be eliminated from the soma being referred to as E chromosomes.

SEX DETERMINATION IN THE CECIDOMYIDAE

In *Miastor* and *Oligarces* (subfamily Heteropezinae) and *Mycophila* (subfamily Lestremiinae), pedogenetic reproduction occurs, and has even become the main method of multiplication, sexual generations occurring only at long intervals in nature. Under conditions favorable for growth of these species (which are all fungus feeders), the larvae become sexually mature without undergoing pupation and give rise by parthenogenesis to broods of larvae, which live at first as internal parasites of their own mother, eventually emerging from her dead body to feed for a while on fungal mycelium before entering the reproductive phase. In this type of reproduction only females are produced, and no adult midges ever appear. Under unfavorable conditions, however, "sexual" larvae are produced, and these pupate and develop into adult midges before becoming sexually mature; both males and females are produced, and mating must take place before oviposition.

It had earlier been shown that the pedogenetic reproduction is a true parthenogenesis: the larval ovaries mature precociously and development of the eggs takes place within the maternal body. These eggs undergo only a single maturation division, which is an ordinary mitosis. In *Miastor,* 36 chromosomes are subsequcatly eliminated from the somatic nuclei. **Thus** all these larvae have a diploid soma and all are females. <4SexuaF larvae arise by pedogenesis, In the same way, but are of two kinds, males and females. In the embryonic condition they can be distinguished from pedogenetic embryos only by the fact that some of them (the males) have 6 instead of 12 chromosomes in their somatic nuclei.

Recent work on *Taxomyia* and *Monarthropalpus* has shown that these species (which do not reproduce pedogenetically) have 6 chromosomes in the male soma, 8 in the female soma. Thus they have not established a condition of somatic haploidy such as exists in the male *Miastor,* but their males may be described as somatically semihaploid, since they are haploid for two out of four chromosome pairs. Alternatively, we may designate them as having a complex sex-determining mechanism: $X!X_2O$ (<?), X1X1X2X2 (?). Apparently, in all cecidomyids, sex depends on the number of chromosomes eliminated from the soma during the cleavage divisions, the number in the male and female germ lines being always the same. This condition is very reminiscent of that found in *Sciara* by Metz and his collaborators. Whether genetic factors influence the elimination process, so that a genetical difference exists between male and female embryos before elimination has occurred, is not known, but some species of cecidomyids which have not yet been studied cytologically are known to produce unisexual progenies.

In *Miastor* the elimination of the E chromosomes takes place during the third and fourth cleavage divisions. In male larvae 6 of the 12 S chromosomes must also be eliminated during cleavage, but it is not known whether or not this elimination takes place at the same time as the elimination of the E chromosomes. In *Monarthropalpus,* where we have made a detailed study o£ the elimination process, it takes place at the fifth cleavage division, that is, when there are 16 nuclei in the egg. Four of these nuclei, at the posterior

pole of the egg, do not divide at this division and apparently do not undergo the elimination process; they are the pole-cell nuclei, which will give rise to the germ line. The other 12 nuclei all pass through the elimination division synchronously. The total number of chromosomes present before elimination has not been determined with complete certainty, but is 50 ± 2. In the elimination divisions only 8 of these chromosomes (in female embryos) split and pass to the poles; the rest fail to divide normally and remain in the equatorial region of the spindle. Thus each elimination division gives rise to two nuclei, with 8 chromosomes each, and a mass of "eliminated" chromosomes, which remains in the yolky cytoplasm for a long while, becoming gradually fragmented into smaller masses as the embryo develops.

It is not yet clear whether or not elimination follows the same course in male embryos, two S chromosomes being eliminated along with the E chromosomes at the fifth cleavage division. It is at any rate certain that two S chromosomes are eliminated in male embryos at some stage.

SPERMATOGENESIS IN THE CECIDOMYIDAE

Previous studies had shown that in *Miastor* and *Taxomyia* the sperm carries only a haploid complement of S chromosomes, all the E chromosomes being eliminated at the first meiotic division. Thus, in these species, the egg must be expected to carry all the E chromosomes, but this point has not yet been confirmed by direct observation on the meiotic divisions in the egg. There is no chromosomal pairing in the spermatogenesis of these species, and hence no possibility of crossing over in the males.

In *Kionarthropalpus,* however, the spermatogenesis is of a somewhat different type. During the prophasc of the first meiotic division there are two visibly different kinds of chromosomes in the nucleus: "condensed" ones, which form a crescent-shaped mass of dark-staining bodies to one side of the nucleus, and "diffuse" ones, which are distributed throughout the remainder of the nuclear cavity. At the first meiotic division a spindle is formed, which may be regarded as bipolar, although its two poles are different in nature, one being "active" during the ensuing division, while the other is "passive." As the division approaches, the "condensed" chromosomes become attached to the "active" half of the spindle, while the "diffuse" ones, which are thinner and stain rather faintly, remain in an unoriented tangle at the "passive" end of the spindle. The "condensed" chromosomes are definitely 28 in number and have a considerable range in size, the largest elements being about five times the length of the smallest.

As anaphase proceeds, the condensed chromosomes pass to one pole, the diffuse ones to the other. The latter have not been actually counted, but if there are 50 chromosomes in the germ line and 28 of these are in the condensed group there should be 22 in the diffuse group.

The result of the first meiotic division, therefore, is the production of two kinds of cells, one kind with 28 condensed chromosomes, the other with 22 (?) diffuse ones. The former pass through a second division, which is a simple mitosis, and the resulting spermatids develop into mature sperms; the cells with the diffuse chromosomes do not divide again, and simply remain in the testis as "residual cells" without forming sperms.

The sperms of *Monarihropalpus* thus transmit 28 chromosomes. Since the haploid number is 4, these presumably comprise 4 S chromosomes and 24 E chromosomes; but there are no peculiarities of appearance or behavior which would en-

able one to recognize the S chromosomes at this stage. The fact that the 28 chromosomes are of very different sizes precludes the possibility that the E chromosomes are simply duplicates of the S chromosomes (which are all approximately the same size) and excludes the hypothesis of germ-line polyploidy, so far as *Monarthropalpus* is concerned.

SALIVARY-GLAND CHROMOSOMES IN THE CECIDOMYIDAE

Preliminary studies on the salivary-gland chromosomes of a number of Cecidomyidae were carried out during the summer of 1947. It was found that the general anatomy of the gland varies considerably in the different genera, and that this involves corresponding variations in the cytology of the nuclei. In some Cecidomyidae the salivary gland is of a simple type, as in *Drosophila* or *Sciara*, whereas in others it may have a large basal reservoir or a pair of "supergiant" cells, very much larger than the ordinary "giant" cells of the gland proper. Both polytene and endopolyploid nuclei occur, and the two types may be found in different regions of the same gland. The following are the main conditions that have been found:

1. Gland simple; all nuclei endopolyploid (not polytene). . . . . *Miastor*
2. Gland simple; all nuclei polytene . . . . . *Campiomyia* sp.
3. Gland with basal reservoir; nuclei of reservoir polytene, those of gland proper endopolyploid. . . . . *Dasyneum affinis*
4. Gland with basal reservoir; nuclei of reservoir and of gland proper polytene. . . . *Coniarinta canadensis*
5. Gland with two supergiant cells; nuclei of supergiant cells and of gland proper polytene . . . . . *Cecidomyia seroiinm*
6. Gland with one supergiant cell; nuclei of gland proper polytene, those of supergiant cell showing a combination of polyteny and endopolyploidy. . . . . *Lestodiplosis* spp.

A number of unusual cytological conditions were found in some of the species studied. In *Camptomyia* sp. one of the four chromosomal elements in the salivary-gland nuclei is very much thicker than any of the others and shows peculiar properties. In *Dasyneura affinis* and *Contarinia canadensis* two of the four chromosomal elements bear nucleoli, whereas the other species have only one nucleolar element in the salivary-gland nuclei. Many species of Cecidomyidae show two different kinds of heterochromatin in their salivary-gland nuclei, "compact" and "diffuse." The nucleoli always arise from diffuse heterochromatin, never from regions of euchromatin or compact heterochromatin. With the exception of one species of *Lestodiplosis* previously studied, no individuals heterozygous for inversions have been found in any of the species of Cecidomyidae investigated.

GENERAL SUMMARY AND INTERPRETATIONS

The chromosome cycle of the Cecidomyidae is radically different from that of all other animals hitherto studied, but its genetical implications are by no means clear yet. Basically, all the genera investigated have the same type of cytogenetic mechanism, but *Monarthropalpus* differs from the other genera previously studied in that a considerable number of the E chromosomes is carried by the sperm (in *Miastor* and *Taxomyia* the sperm transmits only a haploid set of S chromosomes).

The significance of the E chromosomes is obscure. In any particular species they seem to be constant in number, so that

there is no reason to believe that they are genetically inert to the same extent as the "limited" chromosomes of *Sciara* or the B chromosomes of maize. It might be suggested that they contain genes which function only in the germ line and up to the time of elimination in the soma (i.e., during the first few cleavage divisions); but it is difficult to believe that their role is so restricted. It is possible that the proteins and nucleic acids of the eliminated chromosomes are made use of as raw materials for the synthesis of S chromosomes in the cleavage nuclei, their role being similar to that postulated by Painter (1940) for the chromosomes of the nurse cells, which also become absorbed into the *egg.* But since the "nurse-cell mechanism" for supplying materials for the synthesis of cleavage chromosomes appears to be well developed in all the cecidomyid eggs that we have studied, it is difficult to see what advantage a second mechanism performing the same function would have. Furthermore, if the functions of the E chromosomes lacked genetical specificity, one would hardly expect them to be so constant in number (the "limited" chromosomes of *Sciara* spp. vary both in size and in number from one individual to another and are totally absent in some species of the genus). It therefore seems probable that the E chromosomes of the Cecidomyidae are not genetically inert and, furthermore, that they possess genetical specificity. It is possible that their genes do not cease to function when elimination occurs, but that they or the genie products to which they give rise may persist for a considerable time in the somatic tissues of the embryo or larva, exerting a delayed effect similar to the "maternal effects" now known in the genetics of many species of organism. Such a suggestion is obviously only tentative and cannot be tested until genetical work has been performed on some species of cecidomyid. Genetical studies are obviously impracticable on gall-making species such as *Taxomyia taxi* and *Monarthropalpus buxi,* which have only one generation per year, but might perhaps be attempted on one of the fungus-feeding or predaceous species, which breed rapidly.

Like *Drosophila,* the cecidomyids lack chiasmata in the males. Whether chiasmata occur in the females, and if so whether they are found only in the S chromosomes or also in the E chromosomes, is still undetermined; preliminary studies on the oögenesis of *Monarthropalpus* did not yield a definite answer to this question.

Whatever the precise genetical significance of the peculiar chromosome cycle of the Cecidomyidae, it is clearly one which is successful in an evolutionary sense, since the group constitutes one of the largest families of the Diptcra (a minimum of 900 species have been described from the United States alone, in spite of the fact that there have been very few students of the group). Furthermore, the Cecidomyidae have been able to "colonize" the most diverse habitats, some species being fungus feeders and others gall makers, while a large number are predators on mites or other insects.

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SPECIAL PROJECTS: BIOLOGICAL SCIENCES

Ross G. HARRISON, Osborn Zoological Laboratory, Yale University, New Haven, Connecticut. *Studies in experimental embryology.*

The grant from the Carnegie Institution has been applied toward the salary of a research assistant, who has been engaged chiefly in making additional models of the regenerating brain and in counting mitotic figures in these brains for comparison with the normal. A considerable amount of time had to be spent in the study of additional cases in order to obtain statistically significant results. This work is now completed and in type for publication in the October 1947 number of the *Journal of Experimental Zoology.* A résumé of the results follows.

Wound healing and reconstitution of the central nervous system after removal of parts of the neural plate. In the course of experiments designed to study the effect of absence of certain portions of the central nervous system on the differentiation of its associated ear vesicles, interesting observations on the regulation and restitution of the nervous system itself were made. The experiments concern regeneration in the brain after removal of portions of the neural plate in the early neurula stage in *Amblystoma punctatum.* The variants include excision of one lateral half and both halves of the presumptive hindbrain, either with or without underlying mesoderm and with the wound covered by grafted ectoderm or left uncovered; also cases in which a lateral half of the entire brain was taken without mesoderm and the wound covered. There are only minor differences In the healing and early behavior of the wounds in the various experiments.

After removal of one-half the hindbrain region of the neural plate, the remaining neural fold develops normally but Inclines across the median plane until it reaches the ectoderm of the opposite side, with which it then fuses. Being thus cut off from the exterior, the nervous tissue in the region of the operation is left as a half-tube, closed by neural crest derived from one side but later distributed to both sides. When the underlying mesoderm is left in, an equal distribution of the neural crest is facilitated and the visceral skeleton is normal in a large majority of cases. When the mesoderm is removed, the movements of the neural crest are often interfered with and the visceral skeleton on the side of operation is likely to be irregular and defective.

After the neural crest moves out, the neural half-tube closes, either directly by the two margins coming together, or indirectly by the formation of a lamina, extending from each border and ultimately closing off the central canal by a thin epithelial curtain. More frequently this appears to be mainly the product of the ventral border. After direct healing, the medulla is left usually with a thick roof and very small central canal throughout part of its extent, and dorsally a thin-roofed passage often interrupted but similar to the normal fourth ventricle. The fiber tracts do not develop normally in these cases. In the closure of the half-tube by the thin certain, a sharp crease is formed in its wall at a varying distance from the ventral margin. This becomes the central longitudinal sulcus and marks the future ventral mid-line of the regenerated medulla. The thin curtain of epithelium which closes the tube Iks at first ventral, and touches the ootochord.

Through rotation on its axis the nerve tube is gradually righted and the sulcus even passes over to the defective side for a short distance. The material thus passed to the defective side is the original and principal contribution to its regeneration.

After bilateral extirpation of the presumptive hindbrain, the gap between midbrain and spinal cord is not filled in.

After extirpation of an entire lateral half of the brain region of the neural plate, regeneration takes place likewise from the opposite side, although a minimal amount of material may come from the spinal region, since the cord in such cases is somewhat thinner on the defective side for some distance into the trunk region. Eyes regenerate from across the mid-line in all the cases in which a lateral half of the forebrain is removed. The retinal layers are complete, but the vitreous body is very defective and no lens has been found.

Further augmentation of the original contribution from the opposite side takes place through hyperplasia, which leads to a mean relative restitution value of 71 per cent by the time the yolk is resorbed. The hyperplasia is significantly greater when the underlying mesoderm is intact than when it is excised. That there is a genuine hyperplasia is shown by the excess weight of the two sides of the regenerating nervous system over the weight of one side of the corresponding part in the normal control, amounting to a mean of 152 per cent in four hindbrain operations and 167 per cent after removal of the entire half-brain. The more rapid cell division which produces the hyperplasia does not begin until some time after the operation, but it persists in a diminishing degree until the larva begins to feed, at which time in the hindbrain of the normal control it has come almost to a standstill.

A deficiency in the hindbrain probably also stimulates greater mitotic activity in more distant parts such as the telencephalon. The figures here are, however, not highly significant, and further investigation is required.

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DIVISION OF HISTORICAL RESEARCH

Cambridge, Massachusetts

A. V. KIDDER, *Chairman*

Success in archaeology, as in war, depends to a large extent upon an effective intelligence service and readiness to seize upon and exploit the "breaks." This is strikingly illustrated by the events of the past season's field work, during which information given by friends of the Division and at once followed up led to two of the year's three most rewarding undertakings.

First among these, perhaps indeed the single most important discovery ever made in the Maya field, resulted from word sent in by Mr. Giles G. Healey, who has long been interested in the Division's activities. In the winter of 1946 Mr. Healey penetrated the rough and practically unexplored jungle west of the Rio Usumacinta in Chiapas, Mexico, to photograph the primitive Lacandon Maya for a documentary film on Maya antiquities and the present-day Indians, which he is making for the United Fruit Company. Having with difficulty gained the confidence of the Lacandon, who are suspicious of all whites and are particularly loath to have them see the ancient temples at which they still conduct ceremonies, he was led by them to a small group of ruins three days' journey from the river. On entering one of the buildings, he was astonished to see that its three vaulted rooms were covered from floor to capstones with brilliant mural paintings,

Mr. Healey notified the Division of his find as soon as he was out of the bush, and at our request returned in July, accompanied by the Division artist, Sr. Antonio Tcjeda. On the latter's report that the paintings far surpassed anything hitherto known, a party fully staffed and equipped to make copies and photographs, financed by the United Fruit Company, and led by Mr. Karl Ruppert, spent six weeks at Bonampak (Maya for "Painted Walls"), as the site has been named by Dr. Morley.

The murals depict processions, ceremonies, warfare. The human figures, nearly life-size, are executed with extraordinary naturalism. Costumes, ornaments, weapons, and musical instruments are reproduced with remarkable fidelity and in great detail. There are long hieroglyphic texts. The walls of this forgotten little temple have yielded fuller data on many aspects of Maya civilization at the height of the Classic period than one had dared hope would ever be recovered. Mr. Ruppert's account of the expedition, with description of the paintings and of the very fine sculptures that also came to light at Bonampak, appears in the body of this report.

The second important find of the season can be traced back to the eruption of the volcano of Santa Maria in 1902, which covered the neighboring slopes from the highlands to the Pacific coastal plain with a meter of white ash. The region is one of the principal coffee-producing areas in Guatemala, but to set out the coffee trees it is necessary to dig through the ash and well down into the underlying soil. Sr. Vitalino Robles, of Quetzaltenango, owns a plantation there, the Finca El Paraiso, which is indeed a veritable archaeologist's paradise. Several years ago, in the course of planting, his workmen uncovered a series of stone slabs, Sr. Robles* an ardent amateur archaeologist, had the area cleared

of ash and, digging under the slabs, came upon a large cache of pottery. Always a most helpful co-operator with the Division, he halted work and sent word to our office in Guatemala City. Sr. Cesar Tejeda went to El Paraiso and assisted in removing the vessels, many of which were of plumbate pottery. This ware is of much archaeological significance because it was very widely disseminated in trade throughout Mesoamerica. It has been the subject of intensive study by Miss Anna O. Shepard (Publication 573). The El Paraiso plumbate proved to be of a type not previously known. For this reason it was desirable to obtain more material; in February Mr. E. M. Shook and the Chairman, at Sr. Robles' invitation, carried on further excavations.

The digging revealed the fact that the pottery cache had been made in a large, low mound, its contours masked by the heavy layer of volcanic ash. On widening and deepening the original Robles pit, we encountered a rectangular tomb, its closely fitted wall and floor slabs painted red. It held two skeletons accompanied by much plumbate pottery and jade. In another part of the mound were burials in great pottery urns.

While work at the mound was in progress, Mr. Shook investigated another outcropping of stone slabs at a spring in a near-by ravine. These turned out to be the outer edge of an extensive pavement which, sloping upward, ended at a narrow masonry-walled, slab-roofed passage that led into the side of the ravine. It was at first believed that this must be the entrance to a tomb^ but when it was followed to its end it proved to open into a round chamber^ 8 m. in diameter,, with two encircling benches and a central pit full of ashes and burned stones$_3$ evidently a communal sweat bath. It is of an entirely new type and was probably of ceremonial significance, for in clearing the frontal pavement we found enormous quantities of fragments of fine plumbate vessels doubtless ritually broken. Mr. Shook's report on the El Paraiso work is appended.

Also adding significantly to knowledge of Maya archaeology were several very important tombs opened by Mr. A. L. Smith in the Department of Quiche, Guatemala, where in 1946 he had excavated a tomb of the Early Classic period in one of a group of mounds in the outskirts of the highland Indian village of Nebaj. Facing that mound was another. Surmising that this might contain other interments, he returned to Nebaj in 1947 and became involved in a most difficult but most highly productive piece of excavation. The mound's frontal platform proved to hold a series of tombs, altars, and ceremonial caches so stratified that their age, relative to one another, could surely be determined. The pottery vessels, incense burners, alabaster and marble vases, pyrite mirrors, gold and copper ornaments, and magnificent carved jades recovered illustrate the development of local arts over a period of some seven centuries; they prove that Nebaj was long the seat of an unexpectedly rich and flourishing community; and they indicate that a lively trade was maintained with the great centers on the Rio Usumacinta. Mr. Smith's report appears below.

The foregoing were the highlights of a most successful season, which included various other field activities.

A. L. Smith, before going to Nebaj, continued his survey of the northern highlands, mapping, noting, and photographing ruins in the Department of Baja Verapaz. Later he visited a number of sites in the Nebaj-Aguacatan-Sacapulas area in the comp'any of Miss Tatiana Proskouriakofif, who gathered material for reconstruction drawings of sites and buildings of the sort contained in her *Album of Maya*

architecture (Publication 558). At Nebaj, Miss Proskouriakoff undertook the essential and in this case particularly difficult task of recording, on plans and sections, the exact location of tombs, caches, and architectural features as they came to light in the excavation of the mound.

E. M. Shook inaugurated a southward-heading survey of archaeological sites on the Pacific slope and coastal plain. He commenced operations in January, excavating at mound groups near Ayutla, on the Mexican border. At the same time Dr. Philip Drucker, of the Smithsonian Institution, began a similar survey on the Mexican side and worked northward. Dr. Drucker and Mr. Shook are keeping in close touch with each other and their combined efforts will open up a region hitherto almost completely neglected and one which not only was densely populated in ancient times, but was certainly always a highway for migration and commerce. Very interesting finds are to be expected.

Shock's investigation at Ayutla was interrupted by the opportunity to dig at Finca El Paraiso, which is also in the zone of his projected survey; and just as that excavation was finished, the United Fruit Company sent word of discoveries at Tiquisate, still farther south on the coastal plain, which had been made in breaking new land for banana farms. Given every facility by the Company, Shook spent several weeks at Tiquisate putting in test trenches and studying material that had come to light during the developmental operations.

The Chairman, as stated, worked with Shook at El Paraiso. He visited A. L. Smith's diggings at Nebaj and made several trips to Huehuetenango, in western Guatemala, where the United Fruit Company is carrying on an extensive project of excavation and repair at the ruins of Zaculcu, the ancient capital of the Mam Maya. Close touch is being kept with this work, which is yielding much information that bears on architectural and ceramic problems of interest to the Division. The technical aspects of the project are being handled by Messrs. S. H. Boggs and A. S. Trikj both former members of the Division staff; this year Mr. Gustav Strömsvik of the present staff was given leave to supervise the restoration of the Zaculeu ball court.

Another archaeological undertaking that keys well with the Division's program is an examination by Dr. Robert Wauchope, also formerly with the Division, of Guatemalan sites occupied at the time of the Spanish conquest. The work is being done by the Middle American Research Institute of Tulane University.

An interesting and important development has been the establishment in Guatemala City of a very fine new anthropological museum. Mr. R. E. Smith, the Division's local representative, has been acting as chairman of the government's committee on planning and installation. This has occupied a large share of his time during the year, an activity justified by the fact that the museum will house the Division's great collections from Uaxactun, Kaminaljuyu, Nebaj, and other sites, as well as by the fact that the ample storage space now become available will permit transference from our office to the museum of the large and extremely valuable lots of potsherds gathered by us from all parts of Guatemala. In order to have more ready access to these materials, the office of the Division has been moved from downtown Guatemala to a building close to the museum.

The Division office has continued to serve as headquarters in Guatemala City for scientific workers from other institutions. This year it has been so used by Dr. L. C. Stuart, of the University of

Michigan, who is making a herpetological survey of the Republic; by Dr. Wauchope, of Tulane University; and by Dr. T. Dale Stewart, physical anthropologist of the United States National Museum. Dr. Stewart's work, under a grant from the Department of State, has been of great value to us. In past years, abundant data have been gathered on the bodily make-up of the Yucatecan Maya, but no comparable information has been available regarding the various Maya-speaking groups of the highlands. Dr. Stewart measured, photographed, and blood-tested series of men and women at Solola and Patzum. He also studied the considerable amount of skeletal material accumulated by the Division in past years, as well as that found during the Zaculeu excavations. He was supplied with a Division car and greatly aided by native interpreters put at his disposal by Professor Antonio Goubaud, Director of the Instituto Indigenista Nacional. Professor Goubaud's assistance furnishes a further example of the hearty cooperation the Division has always received from the governments of Guatemala and Mexico, the latter having granted duty-free entry of the equipment and supplies necessary for the Bonampak expedition and having delegated a staff artist of the Instituto de Antropologia e Historia, Sr. A. Villagra, to accompany the party and work with Sr. Tejeda. For these and many other favors throughout the years, the Division is under deep obligation to Dr. Alfonso Caso, former Director of the Instituto; to Arq. Ignacio Marquina, its present head; and to Dr. Eduardo Noguera, Director of the Institute's Department of Pre-Hispanic Monuments.

In the field of Maya linguistics, Dr. Norman McQuown, by arrangement with the Department of Anthropology of the University of Chicago, is giving half his time to study of the great mass of material gathered by the late Dr. Manuel J. Andrade. In December 1946 he made a trip to the Huastec Indians, a tribe in the Mexican state of Veracruz, who, although speaking a Maya language, are now, and apparently long have been, culturally quite distinct from the main southern group of the Maya.

Desk activities of the Division staff have also gone forward. Dr. S. G. Morley has been engaged in preparation of guidebooks to Chichen Itza and Uxmal, and has made further progress on a dictionary of Maya hieroglyphs. His large and fully illustrated book, *The ancient Maya,* was published during the year in English by the Stanford University Press and in Spanish by the Fondo de Cultura Economica in Mexico. Its wide sale, calling at once for a second printing, indicates how satisfactorily it fills the long-felt need for a work on the Maya suitable for the general reader. Dr. H. E. D. Pollock continued working up the great amount of data on the architecture of the Puuc area in Yucatan gathered by him and Mr. Shook in the years before the war; Mr. Karl Ruppert, before leaving for Bonampak, was occupied with architectural materials collected last year at Chichen Itza. Miss Tatiana Proskouriakoff devoted herself to the intensive study of Maya sculptural art; Mr. J. E. S. Thompson, to that of Maya hieroglyphic writing. Under part-time arrangements with the Peabody Museum of Harvard University and the United Fruit Company's Zaculeu Project, Dr. J. M. Longyear worked on the pottery he obtained at Copan in the winter of 1946; Mr. Stanley H. Boggs, on that from his excavations for the government of Salvador at Tazumal. Mr. E. H. Morris continued preparation of reports on finds of former years made in Arizona caves occupied by early Southwestern agricultural peoples. Miss Anna O. Shepard completed a monograph on plum-

bate pottery and a paper on symmetry in ceramic decoration, both of which are now in press.

Mr. R. L. Roys continued his research on Maya-language documents of the early colonial period. Dr. F. V. Scholes' work on Yucatan in the sixteenth century goes forward, with the assistance of Miss Eleanor B. Adams, at the University of New Mexico, where he is now Dean of the Graduate School. Dr. Robert S. Chamberlain has completed monographs on the conquest of Yucatan and of Honduras. He has accepted a post as Associate Professor of History at the University of Miami. Dr. Sol Tax, of the University of Chicago, has given half time to preparation of reports on the Quiche and Cakchiquel Indians of Guatemala; Sr. Alfonso Villa R., full time to data gathered in former years on the Maya-speaking tribes of Chiapas. The completion of the foregoing historical and ethnological researches will bring to a close the activities of the Division in these fields. Under the respective direction of Dr. Scholes and Dr. Redfield, they have done much to throw light upon the findings of the archaeologists and to render understandable the conditions existing today in Mexico and Guatemala.

As of June 1, 1947, Miss Eleanor W. Ritchie resigned to be married, thus terminating her long, faithful, and effective service as Division secretary.

BONAMPAK EXPEDITION

KARL RUPPERT

Early in 1946 Mr. Giles G. Healey, employed by the United Fruit Company to make a photographic record of the Maya, past and present, was in the eastern part of the state of Chiapas, Mexico, filming some groups of Lacandon Indians, and was directed by them to the site of Bonampak. Here he noted some remarkably well preserved paintings on the walls and vaults of the only standing three-chambered building.

On his return from the bush Mr. Healey reported the find to the Chairman of the Division, who at once arranged for Sr. Antonio Tejeda, Division artist, to go to Bonampak. In July Mr. Healey and Sr. Tejeda spent five days at the site. The paintings, as shown by the sketches made at that time, were so remarkable and so important that it was considered imperative to send an expedition for their complete recording.

In the winter of 1947 such an expedition was undertaken, financed by the United Fruit Company and directed by Carnegie Institution of Washington. Personnel included: Karl Ruppert, in charge; Gustav Strömsvik, engineer; J. Eric S. Thompson, epigrapher; Antonio Tejeda, artist (all of Carnegie Institution); Giles G. Healey, photographer, United Fruit Company; and Agustin "Villagra, artist, Instituto Nacional de Antropologia e Historia, Mexico.

Mr. Strömsvik reached Bonampak January 31, having gone ahead to arrange transportation and establish camp. Messrs. Healey and Thompson arrived February 15 and returned to Tenosique February 28, Mr. Thompson returning to the States, and Mr. Healey again leaving for the ruins on March 6. The remainder of the party, proceeding by plane to Agua Azul on the Usumacinta River and thence by mules, reached the site March 17.

Bonampak lies about 25 leagues south and slightly east of the ruins of Yaxchilan at an elevation of 400 m. In this area Mr. Healey has found a number of previously unreported ruins. The site is relatively small, compact, and carefully laid out, with a main plaza measuring 90 m. by 110 m. and surrounded on three sides by low mounds. The fourth side is defined by a natural hill, 43 m. high, artificially

terraced, up which, from plaza level, a broad flight of six steps rises to a wide landing on which were found Stelae 2 and 3 and their associated altars. From this landing the stairway, now wider by 12 m., continues to a second landing on which are seen two standing buildings. Building i, containing the wall paintings, is of three rooms; the other is a single-chambered structure. A third platform or landing 14 m. higher supports six standing buildings, each with a single chamber. On top of the hill, reached by a well defined stairway, are a number of artificial mounds formed by the collapse of structures. Though the eight standing buildings are in a surprisingly good state of preservation, large trees growing on the roofs will hasten their disintegration.

The buildings in most cases rise from a simple plinth. The lower wall zones are plain; the masonry is of blocks with some slabs. The upper zones are faced with small, regular slabs, rise with a batter, and often show traces of stucco decoration. Only one structure has roof ornamentation; it consists of a perforated roof comb formed by a series of seven transverse walls, 4 m. in height. The vaults show much variation: simple soffit slopes, interrupted slopes, and stepped. The lintels of all standing buildings are of stone, four of them sculptured.

Only one of the five stelae found in the plaza is sculptured. This monument, now broken, had a height of 5 m., width of 2.60 m.,5 and thickness of 20 cm. It carries an Initial Series date of 9.17.?.?.? and is further sculptured with a single human figure. Also in the piaza are a number of plain altars, circular and rectangular, one of the latter resting 00 short wedge-shaped legs. A crudely carved jaguar figure, 2.13 in. long, lies in the northeast sector of the plaza unassoeiated with any structure. The two stelae and two altars on the first landing of the terraced hillside are beautifully sculptured. One of the buildings on the upper landing contains a plain stela; inside four buildings are plain, slightly tapering, columnar altars.

Building 1, with three chambers, contains the wall paintings. The building has an over-all length of 16.50 m. and width of 4.12 m. Its exterior construction is similar to that of other buildings at the site. In the upper zone there remain traces of stucco decoration and niches containing seated figures. The lintels are sculptured. A wide bench is built against the end and back walls of each room; from an offset at the spring line, the vault rises in a slope with a single interruption. Beam holes, in pairs, are seen at two levels.

The recording of the paintings in Room 1 constituted the major project of the expedition. The condition in which the paintings were found and the preparation necessary before they could be copied is described by Sr. Tejeda:

> Growing out of the top of the building were great trees whose roots pierced the masonry. In some parts where they have rotted owing to the action of time or to the separation of the stones, the roots have permitted a constant infiltration of water, which has deposited on the stucco walls a calcareous sediment that in some places is so thick that it is impossible to perceive what kind of decoration existed. This destructive action is evidenced sometimes by petrified bubbles, and sometimes by a calcareous layer, just as though the walls had been painted white. In some places the infiltration is so constant that it has washed away the paintings, making recovery impossible. The humidity has also favored the growth of fungus, green and black. A factor that has contributed greatly to the destruction, especially where the walls are vertical as are the divisions between rooms, is the droppings of a great many bats which have found a comfortable lodging in the upper part of the vault. Finally, it is believed that the most dangerous element of

destruction is the capillary roots that have entered between the wall proper and the plaster surface that carries the paintings. The damage may be seen in places where the roots have wedged out and displaced the painted stucco, now lying on the floor, almost pulverized.

Sr. Villagra, who also made copies of the wall paintings, and Sr. Tejeda began the long and tedious task of cleaning the walls before starting to draw. To obtain greater transparency of the calcareous coating, once we had removed the thickest part, we applied water, but succeeded only in vaguely enlivening the colors. It occurred to Sr. Tejeda to try kerosene, and the result was a great success, as it was possible to observe in the paintings details which previously were not known to exist. The kerosene is applied with a brush, and the action endures approximately eight or ten hours, after which it disappears by absorption and volatilization. It does not hurt the colors, and serves temporarily to impede the formation of fungus.

Never before had such a wealth of Maya wall paintings been available, nor had anything been found comparable in subject matter, detail, and execution. On the walls and vault of this one room thirty-four human figures are portrayed. In the center of the back wall are three figures wearing elaborate costumes and ornate headdresses. To their left is a group of musicians, some blowing long trumpets, some carrying gourd rattles, others carrying turtle shells which are struck or rasped with a forked stick. One man stands behind a vertical drum with a skin stretched over the upper end. The figures to the right bring offerings or are in positions of adoration. The first band on the vault is of hieroglyphs and groups of human figures; above this, on the vault and capstones, are large bold masks.

In the time spent at the site the artists were able to copy the paintings in only one chamber. Although those in the middle room were not recorded, some of the scenes, such as that in which blood is seen dripping from the ends of men's fingers, or those showing processions and probably battles, are of such interest and excellent draftsmanship that their value is equal to if not greater than that of the paintings copied this past season.

GUATEMALA HIGHLANDS

EDWIN M. SHOOK

Mr. Shook resigned from his position with the United States Government and returned to the Division in August 1946. Early in October he began preparation for field work in the southwestern highlands and on the Pacific coast of Guatemala. An intimate knowledge of most of this area and the contiguous region of Chiapas, Mexico, had been gained during three years' service on the government's Cinchona Procurement Program. As complete a record as possible, under the circumstances, had been made of the archaeological remains throughout the zone. The information thus gathered showed that the narrow strip of hot coastal plain from sea level to approximately 300 m. elevation had witnessed the ebb and flow of pre-Columbian Indian culture from the earliest horizons known in Guatemala to the time of the Spanish conquest. Sites ranging from small clusters to great groups of mounds, each over a kilometer In extent, line the banks of the many streams crossing the fertile plain. The site of Itzapa, just across the Mexican border In Chiapas, Is typical o£ the large rules. With a few exceptions, the remains above the 300*111. elevation on the Pacific slope of the cordil* lera are small and widely scattered. Tafiimulco Is typical of these sites. Not until the broad inland ¥a!ky$ and plateaus north of the volcanic mountain range are reached does one encounter ruins of con*

siderable size. An examination of private archaeological collections and surface sherd samples from southwestern Guatemala showed plumbate pottery to be most abundant down the Rio Cusulchima and Naranjo valleys, fanning out over the Pacific slope and coastal plain from these drainage systems.

The first activity of the field season was a reconnaissance of the northern half of the San Marcos Department and the Rio Cuilco valley of southern Huehuetenango, not only to search for the source of plumbate pottery, but to fill the remaining void in the archaeological picture of southwestern Guatemala. A suitable base of operations was established at the United States Government cinchona plantation, Finca El Porvenir, situated on the south slope of the Tajumulco volcano. The trip from El Porvenir to San Marcos and Tejutla was made by automobile on October 23. Thereafter, a ten-day circuit of 200 km. was made on foot and horseback to Sipacapa, San Miguel Ixtahuacan, Antigua Tutiapa, Cuilco, Canibal, Tectitan, Tacana, Ixchiguan, back to Tejutla, and then by car to El Porvenir. Over thirty minor sites were recorded. Each of the modern towns mentioned, with the exception of Ixchiguan, had one or more archaeological ruins within the town or on the outskirts* The most important zone appears to be the Cuilco valley, where remains occur at short intervals on both sides of the river; others are situated in tributary valleys and on spurs of the Sierra Madre directly above the Rio Cuilco. One well preserved hilltop site, Pueblo Viejo, 8 km. southwest of Sipacapa, has exposed masonry of cut semiblock and slab stones laid in mud mortar. At Chilipe, 7 km. south of Cuilco, a well defined open-end ball court was found, the only ball court seen on the trip. The previously known ruins of El Reparo, 10 km. below the town of Cuilco, were visited and a large stone monument and urn burial discovered. The monument, carved in the round and depicting a full standing human figure, stood on the lowest step of the principal pyramid. The burial of a young adult was found below the top floor of the same pyramid in a large red ware urn with another pottery vessel inverted over the lower as a cover. Although surface sherds were examined and samples collected, no plumbate ware was seen at any site visited on the trip. This is of particular significance in the continuing search for the manufacturing center of this most widely traded Mesoamerican pottery.

The second part of the field season consisted of a series of excavations on the Pacific coastal plain paralleling the Guatemala-Mexico frontier. El Sitio, the first site investigated, is an enormous group of mounds formally arranged around plazas with monuments of plain columnar basalt. The ruins lie along the east bank of the Rio Gramal, a small tributary of the Rio Suchiate, 18 km. north of Ayutla, on the highway to Catarina and Malacatan. Five test pits were sunk: four through platforms and mounds from surface to sterile subsoil, the fifth on level ground at the north edge of the site away from ancient construction. This last test produced a mixed lot of material from two distinct occupations of El Sitio. The earlier belonged to the Middle Culture horizon contemporaneous with the Miraflores phase in Kaminaljuyu, whereas the later occupation occurred during the post-Classic period, as plumbate pottery was well represented. The burial of an important personage was found below the floor of a terrace or platform. A huge pottery urn covered by another inverted vessel contained the body, jade beads, and ornaments. Other burial furniture was on the outside, including, a finely carved stone

scepter. The major occupation and greatest architectural activity took place at El Sitio during the Late Middle Culture period.

A small site, La Libertad, on the east edge of the highway, 14 km. north of Ayutla, was next investigated and proved to be contemporaneous with the late occupation at El Sitio. Plumbate sherds occurred in each level of the stratigraphic cut. Similar evidence was recovered at Santa Romelia, where a group of scattered mounds on both banks of the Rio Seco, 10 km. north of Ayutla, indicated a small village rather than a large ceremonial center like El Sitio. Again, plumbate was evenly distributed from top to bottom of the test cut and amounted to 30 per cent of all sherds. Here the results show that plumbate pottery served a utilitarian as well as a ceremonial purpose.

At Ayutla single small groups of mounds may be found anywhere on the plain between the Suchiate and Melendres rivers. During the leveling for a railroad siding, about 75 cm. of the ground surface was cut down and archaeological material equivalent to Santa Romelia and La Libertad was exposed. Just east of Ayutla on the west side of the Rio Melendres another major site, El Jobo, comparable in size to El Sitio and Itzapa, was discovered. Pyramidal mounds up to 15 m. in height and a multitude of lesser structures, arranged in an orderly manner around plazas, extend approximately 1 km. along the riverbank. A finely carved stela of the Itzapa style, and two urn burials accompanied by some forty pottery vessels were found in El Jobo. The burials and furniture belong to the Middle Culture horizon and are contemporaneous with the early occupation of El Sitio. Unfortunately the stela had been disturbed and broken in recent times and lay at the foot of a mound. An unsuccessful attempt was made to locate its base and associate the stela with the ceramic material. The structure with which the monument was associated had been built during the early period, but surface sherds of plumbate also indicated that El Jobo had a more recent occupation. A small site, Buena Vista, just south of El Jobo and possibly an outlying group of that large center, produced from the central fill of a mound a large plumbate burial urn containing the skeletal remains of a child, and a beautiful jar of the same ware.

There are many archaeological ruins on the fertile strip of land from Ayutla to Ocos between the Rio Suchiate and the Naranjo. The major sites are Santa Clara, Los Limones, and La Zarca, 6, 10, and 13 km. respectively below Ayutla. Another plumbate burial urn containing an infant skeleton was found in a mound at Santa Clara, and a ball court of the open-end type was discovered.

On the Hacienda Los Limones there are two sites: one on the east bank of the Suchiate, the other on the west side of the Naranjo. The latter has a type of construction hitherto unknown on the Pacific coastal plain. The substructures consist of a hearting of sandy brown earth encased by masonry terrace walls of small, selected river-worn stones laid in lime mortar and finished with a heavy layer of excellent lime plaster. The lime was derived from sea shells; in many instances the unsuccessfully burned shells or their fragments appear in the mortar. Unfortunately the short stay at Limones produced no pottery to aid in the placement of this site in the cultural sequence.

La Zarca is a major site located on the east bank of the Suchiate. No excavations were undertaken, but a ceramic sample was obtained from the local farmers, who are constantly unearthing archaeological specimens during crop planting. The ma-

terial showed that La Zarca had the same occupational range as El Sitio and what appears to be a postplumbate period. Characteristic of this phase are red-on-cream ware tripod bowls with tall, birdhead-effigy feet. Some of these bowls have striations on the interior similar to grater bowls or *molcajetes* from late horizons in the Valley of Mexico.

The small, briefly investigated site of La Victoria, 17 km. south of Ayutla and 3 km. inland from the ocean, produced a relatively high percentage of solid, hand-modeled figurines of the so-called Archaic type, now assigned to the Middle Cultures. Again the presence of plumbate in the surface levels indicated a more recent occupation.

The third part of the field season, from late January to early March, was spent on Finca El Paraiso, a coffee farm on the Pacific slope at 1000 m. elevation. El Paraiso is located in the Chuva zone of the Department of Quetzaltenango, 10 km. by road north of Colomba. The owners, Srs. Vitalino and Benjamin Robles, during the course of coffee cultivation, have made important archaeological discoveries over a period of many years. The majority of the objects they found came from an insignificant-looking low mound on a level bench of land jutting out from the main mountain range. Undoubtedly, the mound was the principal structure of a small village occupied during Late Classic and post-Classic times. In the upper part of the mound the Robles found two gold disks associated with effigy plumbate pottery; in 1943, assisted by Sr. Cesar Tejeda, they encountered a cache of many vessels without metal at a greater depth. The specimens were made available to the Division for study, and a generous invitation was extended by the Robles to make further Investigations in El Paraiso. Accordingly, Dr. Kldder and Mr. Shook planned to devote from three to six days there, thoroughly recording all data. It actually required six weeks, so rewarding were the excavations.

A north-south trench was dug through the mound's center, disclosing its construction. It was an earth-and-stone-filled platform with vertical exterior walls heavily backed with waterworn boulders. The platform probably once supported a structure of perishable material. Within the platform was found a red-painted, stone-lined, richly stocked tomb sunk through subsoil prior to the platform's construction. It contained the skeleton of an adult seated cross-legged on the floor, backed against the north wall, facing south. Another human skeleton lay diagonally across the floor of the tomb. Around the dead, covering the available floor space, had been placed a wealth of furnishings; the tomb was then filled, and other offerings were piled in a heap above the closed tomb. This was the pottery cache discovered by the Robles in 1943. The tomb and cache contents included jade and shell beads and ornaments, obsidian lancets, an iron-pyrite mosaic mirror, nine pottery bells, three drums, one flageolet, one whistle, three figurines, nine spindle whorls, and over sixty-seven vessels. Plumbate was the most abundant ware found in this tomb.

Near the platform's center, 3.50 m. below the surface, another interment had been made before construction of the mound. Two large pottery urns, each containing an adult body, were found side by side, each covered by an inverted vessel. The furnishings, both inside and outside the urns, included jade beads and ornaments, small black polished pebbles, an iron-pyrite incrusted mirror, pottery spindle whorls, and vessels. Several of the latter are of plumbate ware. Many caches of one or more pots were found throughout the fill of the mound, some having

been put there during construction, others near the surface having possibly been buried after completion of the mound. We believe that the two thin gold disks and effigy plumbate vessels discovered by the Robles belong to the later of these caches.

West of the platform the land slopes sharply to a ravine called La Grata, from the head of which issues a spring of cool, crystal-clear water. Carvings on natural rock outcrops and the abundance of potsherds led the Robles to investigate. They uncovered a line of flagstones and a rich deposit of sherds, and had the fortitude to resist further digging until our arrival. The flagstones proved to be those of a broad paved terrace facing the spring. A stone stairway descended to the terrace from the direction of the village site above. At a right angle to the natural slope of the ravine's north side, an underground passage, large enough to permit a short man to walk erect, led 7 m. Into the hillside from the paved terrace. At that distance a stairway ascended to the interior of a circular structure somewhat resembling a Southwestern Pueblo kiva. It consisted of a central lire pit encircled by two flagstone benches, one above and set back from the lower, like seats of an amphitheater. The maximum inner diameter of the top bench was 5.65 m. The level of this bench averaged 1 m. below the soil surface prior to the 1902 eruption of Santa Maria volcano, which added about 1 m. of pumiceous ash to the Paraiso region. The fire pit of the circular structure was filled with broken metates and unworked boulders, all severely burned. The passage served as a drain as well as an entrance, as far as the terrace below, where a well made, stone-lined, slab-covered drain channeled the low of water along one side of the terrace to the ravine. No conclusive evidence was obtained on the use of the circular structure or on the method of roofing. It is believed to have been roofed and possibly to have served as a ceremonial or communal sweat bath. The ceramic material from La Gruta proved the contemporaneity of the circular structure and the village site at El Paraiso.

The fourth part of the field season, from mid-April through May, was spent in exploration and excavation on the lower coastal plain south of Tiquisate in the Department of Escuintla. Recently the United Fruit Company began clearing this area for new banana plantations, digging deep drainage canals and building roads, in the course of which work a wealth of archaeological material was exposed. Through the kindness of the Company officials and particularly the Tiquisate manager, Mr, A. L. Bump, the opportunity was offered the Division to investigate the area. Excavations were made on Ticanlu, Tacana, Zunll, and Tollman farms, and surface sherds collected at Las Trozas, Huisisil, Ixtepeque, and Pacaya. Many of the ruins bordered on a dry stream bed between the present Nahualatc and Naranjo rivers. If the stream dried up or radically shifted its course during the occupation of these sites, it must have had a profound effect 00 the inhabitants. The excavations in four of the ancient settlements along the dry stream bed proved that they iourished vigorously during the Early and Late Classic periods. Then activities abruptly ended and the area, at least that part investigated* was abandoned. No effigy or Tojil period plumbate or postplumbate material was recovered in the excavations or was seen in any of the private collections in Tiquixatc. Prior to the Early Classic surge in Tiquisate, apparently a thinly scattered population inhabited she zone, as a small amount cif Middle Culture material was found.

Diagnostic of this period are solid, hand-modeled figurines and certain forms of Usulutan ware pottery.

During the field season, visits were made to Copan and Zaculeu to keep abreast with the work of others. Dr. Kidder and Mr. Shook briefly inspected the ruins of San Cristobal, Department of Totonicapan, and Piedra Parada, Santa Isabel, Canchon, and Virginia, Department of Guatemala. They also began the recording of the immense Robles Collection of pottery and artifacts in Quetzaltenango. Mr. Shook continued compiling information on modern sweat baths and on the manufacture of archaeological counterfeits in Guatemala.

GUATEMALA HIGHLANDS

A. L. SMITH

The work carried on during the 1946-1947 field season consisted of the following activities: reconnaissance in the Departments of Baja Verapaz and Quiche; excavations at Nebaj, Department of Quiche; visiting various sites in the Departments of Huehuetenango, Baja Verapaz, and Quiche in order to gather material for reconstruction drawings.

During the first five weeks of the season's work, Mr. A. L. Smith, assisted by Sr. Cesar Tejeda, carried on archaeological reconnaissance in Baja Verapaz. Six sites were visited: Cahyup, Chuitinamit, Pichcc, Toloxcoc, Pachalum, and El Porton. Plans of these sites were made, individual buildings measured and photographed, architectural details recorded, and, where possible, surface collections of pottery recovered. The two most interesting ruins were Cahyup and Chuitinamit in the Rabinal area. Both of these are fortified sites of the conquest period situated on the crests of high hills on the north side of the valley of Rabinal, the former at its east end, the latter northwest about 8 km. down the valley. At the time of the conquest the Spaniards attempted to conquer the valley of Rabinal, but were driven out, and it was not until after the Indian rulers at Cahyup and Chuitinamit were converted to Christianity by Las Casas and Father Angulo that the Spaniards finally occupied the valley.

The ruins of Cahyup lie about 2 km. north of the village of Rabinal. There are five groups. The main group crowns the top of a hill some 250 m. above the valley. The twenty-two structures that form this group are located in and around three plazas and consist of temples placed on high platforms, long single-room buildings with multiple doorways, and altar platforms. The single-room buildings form two or three sides of a plaza and face upon it; temple structures are placed in the plaza and are associated with one or more altar platforms. One of the most interesting structures at Cahyup is a large pyramid supporting two temples, each resting on its own platform. Two other groups are on hills to the north and northeast of the main group; the remaining two groups lie in the depression between the hills. Irregularly placed on the slopes leading down into the depression mentioned above are short terraces which undoubtedly once supported houses of perishable materials. A most unusual construction was found on a high hill about 1.5 km. north of the main group. This proved to be a solid, round masonry structure 240 m. high with five terraces rising to a flat top. It may have been used as a watch tower or signal post.

The ruins of Chuitinamit consist of eight groups extending along the top of a ridge about 300 m. above the valley. The general direction of the ridge is northeast and southwest. The groups are well separated so as to form definite units. With

the exception of two ball courts, a type of construction not found at Cahyup, the two sites have similar structures arranged in much the same way. The ball courts are of typical conquest site design, with end zones enclosed by high walls and stairways leading out at either end. One of the courts had never been completed. Southwest of the most northeasterly group, two high defense terraces protected the rest of the site from attack. The upper slopes of the ridge, close to the various groups, were dotted with house platforms. These, of which there were over 400, were small platforms of stone with a terrace in front of each. Both Cahyup and Chuitinamit have many well preserved standing structures that show a great deal of Mexican influence. A good example of this, which occurs at both sites, is twin temples standing on a common pyramidal substructure.

Pichec, another hilltop site, lies directly across the valley from Chuitinamit. It is a small group comprising a temple and altar and several low platforms. Toloxcoc stretches along a high ridge about 7 km. southeast of Rabinal. There is very little standing masonry left, just low platforms with post holes, small shrines, and considerable terracing. Pachalum is another hilltop site just east of San Jeronimo. Stretching along the crest of a hill about 300 m. above the Salama valley, it is a fairly extensive ruin of the type of Chuitinamit. The main plaza has a temple in its center and several altar platforms, and is bordered by long, low, one-room buildings. There is no ball court, but there are outlying platforms and terracing. Locally the ruins arc known as "Pueblo Viejo," but as this term is often used for sites lying near villages, it seemed best to distinguish the site by calling it Pachalum after the hill upon which it rests. El Porton, a valley site, is on a national plantation about 1 km- out of San Jeronimo on the road to Salama. There is no masonry showing here, only a group of mounds on three sides of a large plaza.

After leaving Baja Verapaz, Smith and Tejeda, accompanied by Miss Proskouriakoff, moved to Nebaj, Department of Quiche, where comfortable quarters in the local pension served as a base for the remainder of the field season. Most of the time at Nebaj was spent in excavating the frontal platform of a large mound in the mam group of the ruins of Nebaj. This mound has the same shape as a mound facing it, in which, during the 1946 field season, Smith excavated a corbel-vaulted tomb of the Early Classic period. Leaving Tejeda to find the entrance of the passageway into a similar tomb, Miss Proskouriakoff and Smith visited other sites to gather material for reconstruction drawings.

The first ruin visited was Chalchitan, a valley site in the Department of Huehuetenango. Here the ball-court group, rather than the whole site, was chosen for investigation. In the Sacapulas area of the Department of Quiche the fortified hilltop site of Chutix Tiox and the valley site of Xolchun were selected. Throughout the season, when opportunity offered, other sites were visited for the same purpose: in the Ixil area of the Department of Quiche, the ball-court sites of Oncap, Hull, Tziquay (see pi. 1), Vicaveval; in the Rabinal area, Cahyup and Chuitinamit, In Sacapulas two tombs were found, one *it* Chutix Tiox, the other at a new site called Xolpacol, about 6.5 km. from Sacapulas on the road to Agoacaun. Unfortunately, both tombs had been robbed, but their shape could be determined; *h* proved to be very different from that of tombs found at earlier sites Chutix Tiu\ and Xolpacol being of the late, conquest tvpe. The tombs, which were in structures, had two chambers e^ch, an inner circular one which \v*<* the *v.\mh* prorer.

and a rectangular antechamber considerably larger in area. The two parts of each tomb were joined by a doorway blocked by a stone slab.

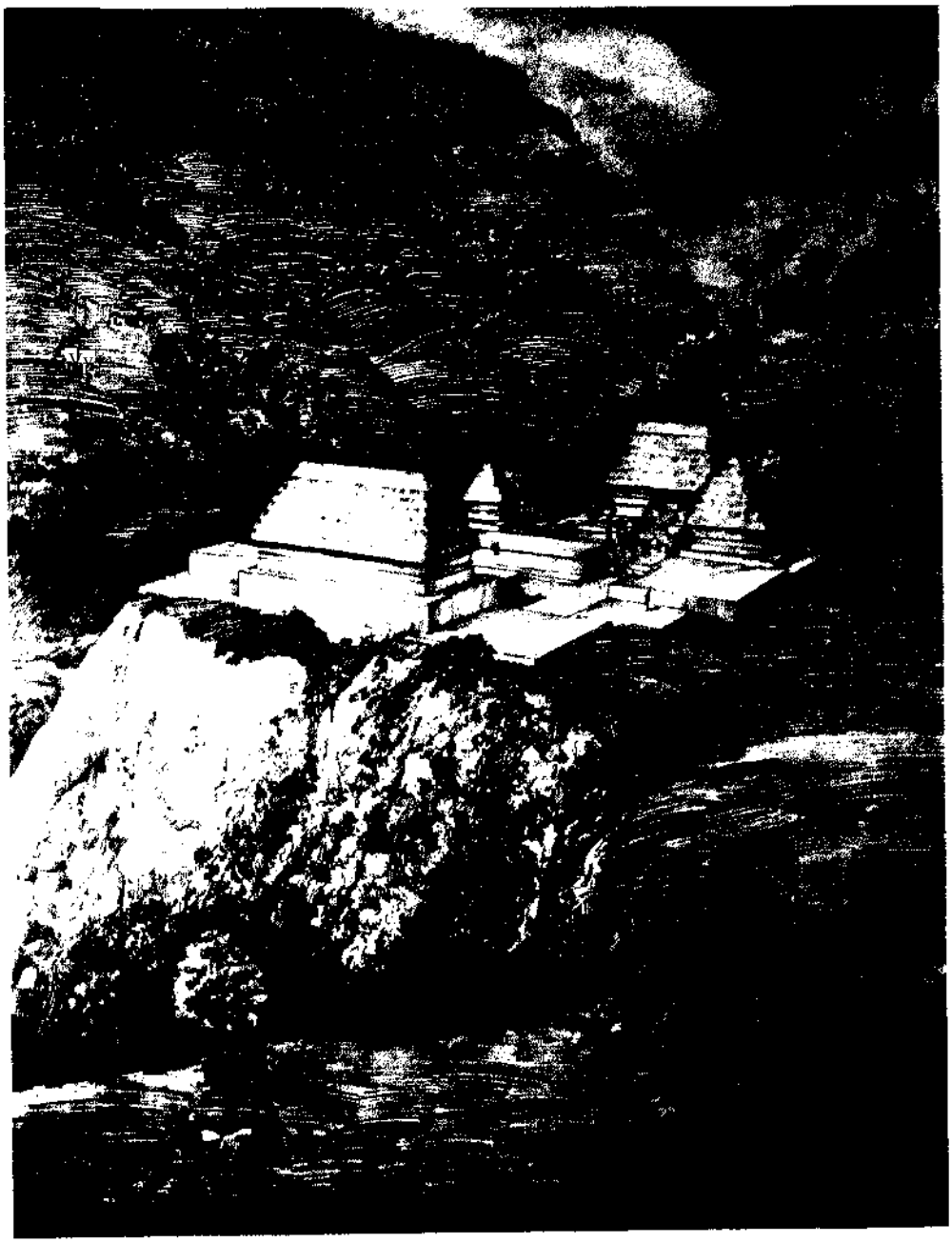
Returning to Nebaj, after their first absence, Miss Proskouriakoff and Smith learned that Tejeda had uncovered an altar below which was a burial of eleven skulls. He also had uncovered a paved ramp leading downward beneath the frontal platform of the mound. At this point Tejeda left Nebaj to resume his studies at the University of Mexico. He was replaced by Mr. Douglas Binney. Further excavations disclosed that the ramp descended to the entrance of a long passageway leading into a corbel-vaulted tomb similar to the one found in the opposite mound in 1946. Unfortunately, the vault had collapsed, and it was necessary to dig down from the top of the frontal platform in order to get into the tomb. This required digging a pit 8 m. wide and 12 m. deep. The tomb, the earliest found, had been placed in sterile ground well below the foundation of the earliest structure.

During the excavation required to get into this tomb, a series of eight tombs and twenty-one caches was found associated with six superimposed stairways belonging to a sequence of platforms, several of which were painted red. Fortunately the tombs and caches were so stratified that their relative positions in time could be established. They cover a span of some 700 years of occupation, from the Early Classic period through the post-Classic period of plumbate pottery. The tombs vary in construction. In Early Classic times large chambers were constructed and roofed with corbeled vaults, whereas smaller and narrower tombs were closed with large stone slabs extending from wall to wall In Late Classic times the large vaulted tombs were abandoned and only long, narrow chambers roofed with large slabs were used. Still later, in post-Classic (plumbate) times, tombs were roofed with wooden beams supporting stone slabs. In all periods multiple burials were the custom.

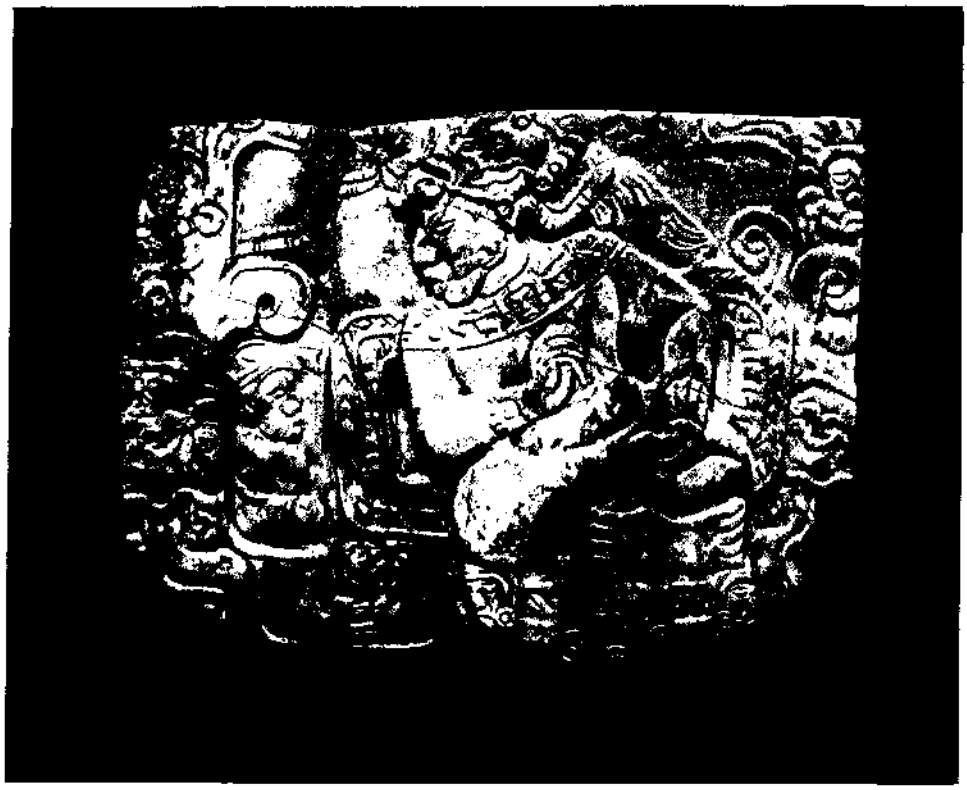
Furniture from the tombs and objects found in caches vary according to the style of the period with which they were associated. Such material consists of pottery, alabaster and marble vessels, pottery whistle figurines, beautiful jades in the form of beads and carved pendants and plaques (see pi. 2), shell ornaments, crystal pendants, pyrite mirrors, flint laurel-leaf blades, copper and gold ornaments, incense burners, and the remains of a codex, part of one page of which depicts a priest or ruler in costume. It is interesting to note that at Nebaj outside influence seems to be from the Maya of the Rio Usumacinta area rather than from the Mexicans.

Unfortunately very little architecture was found. The outer structures had been ruined by agriculture, and the inner structures had been cut through or partially removed to put in late tombs. Throughout the work architectural features that came to light and the positions of tombs and caches were recorded on plans and sections by Miss ProskouriakofT. In May she and Binney had to leave, the former to return to the United States. At this time Mr. Gustav Strömsvik joined Smith and assisted him in the completion of the excavations.

During the operations at Nebaj two new sites were visited, Caquixay and Tuchoc. Caquixay is about a two-hour horseback ride east of CotzaL It is a well preserved site of the Huil type, namely, a ball court and adjoining plaza with an altar platform in the center of the latter. The ball court is of the open-end variety and had the stucco remains of what appeared to be a human head with feathered headdress in the center of cither playing wall



Tziquay, one o£ the sites on the Flnca San Francisco, Department of Quiche, Guatemala. Reconstruction drawing by T. Proskouriakoff.



Jade breast ornament from Nebaj. A $5^{1}/_{4}$-inch plaque, dating from about the ninth century, depicting a priest or ruler. The finest piece of Maya jade carving that has yet come to light.

Tuchoc, about halfway between Caquixay and Cotzal, is a site of the same type. Other new sites were located through the kindness of Colonel Arthur Binney, United States Naval Attaché in Guatemala, who took Smith on several flights over the San Andres Sajcabaja area. This area, which lies about 27 km. northeast of Quiche, consists of a large open plain about 1200 m. above sea level. As a result of the survey six sites, which from the air appear to be in a good state of preservation, were located on the plain.

Owing to the length of time taken in the excavations at Nebaj, several investigations had to be postponed until some future date. Among these are a ground reconnaissance of the Sajcabaja area, the mapping of the fortified site at Xolpacol, and an attempt to find at either Chutix Tiox or Xolpacol an undisturbed late tomb of the type which was noted this season but of which both examples had been robbed. The discovery of such a tomb at one of these conquest-period sites would be of the greatest importance, as it should contain objects in use shortly before or at the time of the conquest.

YUCATAN, GUATEMALA, HONDURAS

S. G. MORLEY

On November 11, 1946, Dr. Morley reached Mexico City, where he remained for a week, most of the time in conference with the Hon. Adrian Recinos, former Ambassador of Guatemala to the United States, who translated his recent book, *The ancient Maya*, into Spanish, and also with the staff of El Fondo de Cultura Economica, the publishers of the Spanish edition, which appeared in the late spring.

During the winter Dr. Morley was in Yucatan. In April he went to Guatemala, where he visited the ruins of Qulrigua, which, thanks to the care given them by the United Fruit Company, he found to be in better condition—better bushed, kept in better trim, and the monuments better marked with descriptive signboards—than ever before.

Some fear has been expressed that the surface of the sandstone monuments at Quirigua has been deteriorating because of exposure to the sun during the past thirty-six years. The high forest in which they were formerly buried in deepest shade was felled in 1911 by the School of American Research, to remove the danger of falling trees' breaking the monuments, which had occurred in several cases previous to that time. A decade ago, Dr. Morley sprayed Stela K with an English preparation intended to protect sandstone buildings from deterioration, by sealing in the surface of the stone, thus preventing or retarding erosion. His examination of the Quirigua monuments this spring convinced him that the spray had been most successful.

The local Fruit Company officials were so co-operative as to carry out Dr. Morley's recommendation that the bushed area in the Great Plaza be extended. As cleared of trees many years ago by the School of American Research, only the western half of the Great Plaza had been exposed. This not only reduced the apparent size of the plaza by half, but also failed to disclose its function as an amphitheater, a large three-sided enclosure surrounded by ascending tiers of stone seats. The Great Plaza now appears in its true character.

The new National Museum of Guatemala was not yet completely installed in April, but sufficient progress had been made in displaying the large amount of stone material, especially the Piedras Negras stelae and altars, to indicate that it would be one of the leading archaeological museums of America when finished.

The trip Dr. Morley made to Copan in late March was his fifteenth. He found the ruins in a better state of conservation than ever before, owing to the extensive excavations, repairs, and conditioning operations of the Carnegie Institution during the past twelve years, and to the supervisory care given them by the government of Honduras.

A fragment of a new Initial Series was deciphered. This was discovered by Sr. Raul Pavon Abreu, Director of the Museum of Archaeology, History and Ethnology of Campeche, in the debris of Mound 7 at the western end of the Court of the Hieroglyphic Stairway. The inscription was very unusual in that its corresponding period glyphs faced to the right instead of to the left as is overwhelmingly the case in other inscriptions, and the corresponding coefficients were also on the right sides of their period glyphs instead of on their left sides. The reason for this inversion of the usual order was aesthetic, arising from the desire to have the hieroglyphs of this inscription face the central axis of the building on which they had originally been carved. Although the introducing glyph and the day and month signs are still missing, this whole Initial Series may be read as (9).8.8.16.10 (6 Oc 3 Kayab).

Before returning to Yucatan, Dr. Morley visited Tegucigalpa, where he called on Professor Angel Hernandez, Minister of Public Instruction of Honduras, and congratulated him upon the splendid care the government of Honduras is taking of the ruins of Copan, perhaps the most spectacular archaeological site of the Maya Old Empire. Dr. Morley returned to Yucatan April 19 and to the United States at the end of May 1947.

Owing to the death of Dr. E. L. Hewett last December, the directorship of the School of American Research and the Museum of New Mexico,, a joint institution at Santa Fe, became vacant. The managing boards of these two organizations had tendered this position to Dr. Morley, who has been associated with both organizations for many years. Dr. Bush gave Dr. Morley permission to accept the provisional directorship, to serve without salary so long as he should be connected with the Carnegie Institution of Washington, from which he retires July 1, 1949. With this understanding Dr. Morley accepted the position offered him by Mr. Paul A. F. Walter, president of the managing board of the School of American Research, to take effect as of June 1,1947, pending final approval at the annual meeting of the joint boards on August 23. It is hoped that an amalgamation of all the scientific organizations in Santa Fe, anthropological as well as historical, may be achieved under plans for reorganization already in course of being carried out.

HIEROGLYPHIC RESEARCH

J. E. S. THOMPSON

During the past year Mr. Thompson has continued work on the introductory volume to his study of Maya hieroglyphic writing. This has entailed many unexpected forays into territories which, at the inception of the study, had been deemed sufficiently known to need no further exploration at this stage of the work, but which, it turned out, had to be probed in order to round out the introductory survey of the subject. Consequently, the first volume is not yet completed, but fuller information on specific problems compensates for the delay. For instance, as our knowledge concerning the subject of the hieroglyphic texts accompanying divinatory almanacs in the Maya codices appeared inadequate even for this initial stage, Mr. Thompson devoted much time to that matter, with the result that he now

feels that he can get the general sense of most of those texts, and can offer specific translations of a number of the constantly recurring glyphs.

The problem of the hieroglyphic writing is not one that can be quickly solved. Progress in the past has been discouragingly slow, but now with each additional year of research, the speed increases slightly. During the past year a number of glyphs have been identified, and one or two additions have been made to the very small list of affixes of known meaning. Work on the illustrative material for the volume continues to be rewarding, and the linguistic side of the work has progressed, largely as a result of the very helpful co-operation of Mr. Ralph L. Roys. A point has now been reached at which the absence of full linguistic material on lowland languages and dialects related to Yucatec is making itself felt. It is not improbable that good dictionaries of such Maya languages as Choi, Tzeltal, and Tzotzil would yield homonyms corresponding to apparent examples of rebus writing in the glyphs, for which homonyms are lacking in Yucatec. The situation is roughly what one might expect were one endeavoring to reconstruct Latin from modern Italian, but without access to full material in Spanish, Portuguese, and French. Members of the Summer Institute of Linguistics, who have much unpublished linguistic material from all lowland Maya groups except Chorti, have proffered their co-operation in this work, a generous offer which should prove most helpful.

One chapter and several appendixes of the introductory volume remain to be written, and, in addition, a very thorough revision will be necessary. The greater part of the glyphs to be used as illustrations have now been drawn, and it is hoped that the illustrative material will be completed by the end of the year.

Mr. Thompson was at Bonampak, Chiapas, in February and made drawings of such glyphs on the frescoes as were then visible. Among the sculptured dates recovered at that site are:

Lintel	4	(9. 8. 9.15.11) or (9.11.2.10.11)	7 Chuen 4 Zotz'
Stela	2	(9.17. 5. 8. 9)	6 Muluc 17 Yaxkin
Stela	2	(9.17.18.15.18)	12 Etz'nab 1 Ceh
Stela	4	9.17.15. 0. o	5 Ahau 3 Muan

There is also an Initial Series on the murals of Temple 1 which Morley has read as 9.13.0.3.4 7 Kan 12 Zee. The lintels of this same temple have yielded two rather uncertain dates, and there is a badly weathered Initial Series of Katun 17 or 18 on the magnificent Stela 1. It is evident that Bonampak was a center of the hierarchic cult for a long period.

MAYA SCULPTURE

TATIANA PROSKOURIAKOFF

The summer and early fall of 1946 were devoted to the preparation of the text which is to be an exposition of the results of researches in Maya sculpture carried on during several seasons. The study deals chiefly with general trends of development in the lowland Maya area as a whole, and these have been briefly summarized in a previous report. Their more detailed statement brings out certain points in regard to the regional distribution of traits which suggest changes in the degree of contact existing between separated sites of the Maya area at different periods of its history.

For the eighth cycle, the material is very meager, and it is not possible to give a clear description of the prevalent styles or their distribution. Strong similarities between Maya sculpture of this period and certain monuments which have been attributed to other cultures on the periphery of the Maya area may be significant. The carving on the Hunac.ib mouth of the

Cave of Loltun, the stela at El Baul which bears a disputed early date, the sculptures of Santa Margarita and San Isidro Piedra Parada in the Department of Quetzaltenango, and certain monuments of Kaminaljuyu exhibit traits characteristic of the earliest phase of the Early Classic period. Since the seventh-cycle and early eighth-cycle dates suggested by the inscriptions on some of these mortuments fall outside the known range of Maya sculpture, stylistic comparison cannot be used to confirm them, but it may in some degree overcome the reluctance to assign these sculptures to an early horizon.

At the end of the Early Classic period (in the first quarter of the ninth cycle) the Maya style appears as an integrated and distinctive entity wherever sculptures of this period are found. This period is followed by a hiatus, and when sculptural activity is resumed, at about 9.8.0.0.0 or 9.9.0.0.0, sculpture shows marked regional differences. Copan retains many characteristics stemming apparently from early Peten, and its style is closely related to that of the Leyden Plate. The most advanced characteristics seem to appear first in the western half of the area and to the north, indicating that the impetus of the new development came from either of these two directions. As the Late Classic period progresses there is a rapid fusion of regional styles, and particularly a spread eastward of Usumacinta traits. Complexes of traits noted at the beginning of the period at Piedras Negras become common in Copan after 9.14,0.0.0. Another group of traits links the Usumacinta and specifically Yaxchilan with the Puuc area of Yucatan. Although such stylistic similarities do not in themselves demonstrate direct contact between sites, they furnish valuable leads for the study of the relations existing between diverse regions.

In the winter of 1947 the study was interrupted by a field trip to the highlands of Guatemala in connection with the survey of that area reported by A. L. Smith. It was resumed in May, when we were very glad to acquire the services of Miss Kisa Noguchi in the preparation of illustrations which will be the basis of the method of stylistic appraisal proposed in the study.

CERAMIC TECHNOLOGY

ANNA O. SHEPARD

The principal activities during the current year have been preparation of material for a ceramics handbook, study of a punch-card system, and preliminary analysis of Usulutan ware. In addition, a section was added to a paper on the symmetry of abstract design, previously considered completed. Early material from the Pueblo region recently published by Dr. J. O. Brew suggested the new section, which is devoted to all-over patterns and a review of evidence of the influence of basketry design on early pottery design.

The purpose of the ceramics handbook is threefold: (1) to present for the archaeologist that part of technical and scientific ceramics which is applicable in our field, (2) to summarize and critically to evaluate methods of archaeological ceramic description and analysis, and (3) to consider the place of ceramic data in archaeology and to examine the basis of our interpretations. There has long been need for an outline of ceramics written expressly to give the archaeologist background for understanding the technical features of pottery, particularly as scientific knowledge of the clay minerals has undergone marked advance in the past twenty years and much pertinent information has appeared only in technical journals. The review of analytical procedures will cover shape and decoration as well as technical features. A

number of methods developed in our own work will be described, and attention will be given to field tests for the archaeologist.

Our ceramic studies have reached the stage at which a comprehensive review has become desirable. Extensive summarizations and comparisons require means of sorting rapidly the accumulated data. The practicability of a punch-card system for hand sorting has been tested in both technical and stylistic work. Immediate application of the system in technological analysis was found in an index of our collection of some 3500 thin sections. A code covering provenience, period, pottery classification, paste composition, and various technical features has been devised, and cards have been printed. Sections of Peten and Copan pottery have been indexed to date, and the advantages of the method have been effectively demonstrated. Punch cards have proved no less applicable in stylistic analyses, particularly of entire and restorable vessels. Revision of method in these studies is desirable because our material is limited in extent and is scattered. To base comparative and distributional reviews on published illustrations is time-consuming and often unsatisfactory. Doubtless the fact that the bulk of archaeological ceramic material Is in the form of sherds has directed and restricted our studies more than we ordinarily realize. We have inevitably been led to give undue prominence to secondary features such as color, texture, and wall thickness because they are easily determined in the fragment, which may give only a hint of vessel shape and design. Consequently ceramics as an aspect of material and artistic culture has been neglected for potsherds used as a tag for place and period. Without depreciating the potsherd, one may point to the desirability of bringing together a record o£ available, significant, entire vessels. A photographic file such as that started in the Cambridge office of the Division of Historical Research is beginning to be recognized as a requisite for comparative work; but with the ordinary indexing system it soon becomes unwieldy, and locating specimens and returning them to the file is discouragingly time-consuming. Punch cards fully meet this difficulty, since with a sound and comprehensive code a wide variety of classes and of specific traits can be sorted rapidly; moreover, filing is eliminated. Considerable time has therefore been given to the development of systematic classifications of vessel shapes, decorative techniques, and design styles to insure a logically consistent ancl comprehensive code. A trial set of cards prepared for Usulutan ware is being used to test the code. It is hoped that when the system is perfected, other institutions will be sufficiently interested to adopt it and thus initiate a cooperative project for exchange of material. A number of archaeologists, including a large group of Mexican authoritïes, have been consulted on the code for cultural regions and have shown a splendid spirit of co-operation.

Usulutan, the principal type of pottery analyzed during the current year, is one of the more widely distributed wares of the Archaic period and therefore affords opportunity for study of contacts and spread of influence on that horizon. Neither the decoration, which is simple and geometric in a technique long misunderstood, nor vessel form, which is varied and elaborate, has so far shed light on centers of production or on volume and extent of trade. The ware occurs mainly in the region of younger volcanic formations of Guatemala and Salvador; most of ït Is tempered with volcanic ash. When these conditions obtain, the feasibility of using paste composition to distinguish pottery from different sources may be qutv

tioned, and the Usulutan study can therefore be considered a test case. The preliminary microscopic examination of a large collection from Miraflores and smaller samples from Copan, a number of localities in Guatemala, and several in Salvador has been encouraging. Eight distinct varieties of ash associated with different types of clay have so far been noted. Their distribution indicates distinct sources, and it is clear even from the preliminary examination that the ware was made in a number of districts and that there was considerable interchange between them. Relations will be plotted in detail as analysis proceeds. Possible local variation in style will also be studied by correlating form and composition. This evidence bears on the question of broad trends in ceramic history. It has appeared that the pottery of the Archaic period exhibits less regional specialization than that of the Classic, a possible difference which suggests a general parallelism with Pueblo ceramic development. But individual styles are less conspicuous among the predominant monochromes of the Archaic than among the polychromes of the Classic, and the fundamental obstacle in testing this generalization has been uncertainty as to amount of exchange and inability to distinguish indigenous from imported pottery by appearance alone, except in the case of a few striking types. There is now assurance that composition will afford a reliable basis for investigating the problem of local specialization in this area as it has in others.

EARLY CULTURES OF SOUTHWESTERN UNITED STATES

EARL H. MORRIS

Early in the year 1946-1947, Mr. Morris completed the study of a group of Basket Maker ceremonial sashes from northeastern Arizona. These textiles were found in a cave which yielded timber dates ranging from A.D. 473 to 478. Despite their age, the sashes were in a perfect state of preservation, and it was possible to recover every detail of the technique employed in their manufacture. The material was dog hair, hand-spun into slender threads which were flat-braided into long, narrow bands adorned with bead-strung tassels and fringes at the ends. The largest is 3 m. long by 6 cm. wide, composed of 119 individual strands. Analysis of these sashes throws additional light on the virtuosity of the early aborigines of the Southwest in the art of weaving.

Some two months were spent in recording and photographing a collection of specimens from a cave near Durango, Colorado. This collection, property of the Mesa Verde National Park Museum, contains the only perishable materials of Basket Maker age that have been found in the region. Results of the study will be incorporated in a report on excavations in the vicinity of Durango conducted by Carnegie Institution in 1939 and 1940.

The remainder of the year was devoted to a detailed analysis of Anasazi cloth sandals from the Four Corners region of the Southwest. The Anasazi developed sandal-making into a fine art which continued to be practiced for a full millennium, roughly from early in the second century of the Christian era to about 1250. Upon the manufacture of their footgear they lavished their utmost in mechanical skill and artistic ability. Certain of the sandals exemplify some of the most complex finger weaving that the world has ever seen. Richness of ornamentation is equally extensive and intricate. It is of two kinds: colored, attained by the introduction of dyed weft threads; and structural, produced by devious manipulations of the weft strands in the uncolored areas.

Of no other early American art in perishable media have so many examples survived. Hence it is felt that a complete record of the life history of this art is both justifiable and important. Work toward this end, which was halted by the war, was resumed by the artist-draftsmen assisting Mr. Morris, as soon as they were released from service. It is expected that this work will continue without further interruption until complete data have been obtained and put in form for publication.

LINGUISTIC RESEARCH

NORMAN A. MCQUOWN

Mr. McQuown undertook the continuation of the work on the Maya Linguistic Project on September 1, 1946. He devoted the first month to familiarizing himself with and making an inventory of the Maya materials collected by the late Dr. Manuel J. Andrade and elaborated by Abraham M. Halpern during the relatively brief period which he was able to devote to this task (see Year Book No. 40, pp. 308-309; No. 41, pp. 274-275). A program of work for the year 1947 was sketched out. In this, Mr. McQuown was guided by the interim report on the state of the project prepared by Mr. Halpern in July 1946, before he left for duty with General MacArthur in Japan. The more important parts of this report are outlined here:

A. The basic aims of the work on the Maya languages:
   1. The glaring deficiencies in the amount and quality of available *primary source material* should be corrected.
   2. A certain amount of the material collected should be synthesized in the form of *grammatical sketches.*
   3. The material should be examined from the point of view of *comparative linguistics,* so that ultimately the general lines of development of the Maya language family could be laid down.
   4. In the course of the achievement of the first three objectives, *special problems* of particular interest, either for general linguistics or for workers in the related fields of Maya archaeology and ethnology, would at least be indicated, if not worked out exhaustively.

B. The general goal of the Maya linguistic research: The research was designed not so much to produce the last word on all problems of Maya linguistics as to complete basic research and arrive at basic conclusions of a sort that would put Maya linguistic research on its feet scientifically.

C. Necessity of the work: That this research was necessary is beyond all possibility of question. The available materials of a descriptive nature were thoroughly antiquated. In the field of comparative Maya linguistics, deficiencies in the descriptive data made it impossible to arrive at conclusions based on anything more than the most superficial kind of inspection.

D. Status of the project at present: Of the objectives mentioned above (A), Andrade went a long way toward realizing the first, the compilation of material. With regard to the second objective, he had, before his death, almost arrived at the completion of a grammar of Yucatecan Maya, but had put nothing on paper with regard to the other languages. For all the languages except Yucatec, the material is in the form of raw field data. With regard to the third objective, Andrade accomplished little or nothing. With regard to the fourth, he called attention to the possibilities inherent in the application of dialect-geography techniques to at least the Guatemalan languages and had begun to collect materials on which such a study could be based, but he had not initiated the work of processing the materials toward this end.

E. Materials collected by Andrade:
   1. *Huastec:* a rather extensive body of text materials, vocabulary and paradigmatic material for the Potosino dialect* and a relatively small body of material of the Veracruz dialect.

2. Yucatan-Guatemala languages: an extensive amount of material on *Yucatec, Mam,* and the Panajachel dialect of *Ca\chiqud;* a moderately extensive amount of material on *Quiche* and *Que\chi;* small bodies of material on *Po\omam,* various *Tzutuhil* and Cakchiquel dialects, *Aguacatec,* and *Jacaltec**
3. Chiapas languages: very small amounts of material.

F. Condition of the materials: Linguistic materials in the form of raw field notes are rarely susceptible to immediate exploitation by anyone other than the original collector. The process of collection of field material is such that every investigator is forced to adopt certain expedients which depart in one way or another from standardized practice, and an investigator rarely leaves a complete record of such departures and the reasons for them. With Andradc's death, a great deal that he knew but had not written down was lost irrevocably.

There are certain inconsistencies in recording. In many cases one cannot be sure which of two or three variant recordings represents the norm for any given word and which are variations from the norm. In some cases, one can decide on the basis of the notes that the balance of likelihood is in favor of one variation rather than another. An unsolved phonetic question of major importance in all the languages is the presence or absence of phonemic length and accent. In most cases of variant recordings, different interpretations are possible, but if one operates entirely from Andrade*s field notes, it is difficult, perhaps impossible, to decide which interpretation best fits the facts.

These difficulties exist if one relies exclusively on the field notes as they stand or *on* the phonograph records, which unfortunately fail one on many of these points. A short period of field work, in which an investigator would have the opportunity of observing the phonetics at iirsf hand, wouM, however, be sufficient to settle all the doubtful points and would even enable the investigator to make use of untranscribed phonograph records.

It is now customary among linguistic field workers to supplement text material by extensive collections of paradigmatic material relevant to the analysis of the texts. Andrade's technique was somewhat different from this. His questions were standardized for all languages in order to facilitate comparison on certain specific points of grammatical structure. This material is extremely useful, but needs some supplementation.

G. Recommendations for further work of compilation:
1. The investigator should have the opportunity to familiarize himself with the *phonetics* of the various languages through direct field work.
2. The investigator should have the opportunity to collect further *paradigmatic material.*
3. The investigator should devote some time to the collection of *folfyloristic texts* where obtainable.

H. Recommendations for further descriptive and comparative work:
1. The *Yucatec grammar* is already well handled, so little or no further work need be done there.
2. A *grammar of the Potosino dialect of Huastec* should be an immediate task.
3. Concentration on *Mam* in the Yucatan-Guatemala area *is* recommended, since the Mam materials are among the most extensive in the collection, and one can expect to find certain archaic features preserved in Mam which have been lost in some of the other languages.
4. If time permits, one of the *Chiapas* languages should be investigated intensively and the others merely surveyed.
5. The *dialect study* of the Cakchiquel and Tzutuhil area should be carried out, but should be treated as a pilot study In which the objective would be

to formulate the types of problems that arise and to indicate the methods which are applicable.

6. The elucidation of the *internal relationships* within the Maya family and the *reconstruction* of Primitive Maya should be prime objectives.
7. It is very probable that in the course of reconstructing Primitive Maya, the scholar engaged on this task will find leads indicating the direction in which *external relationships* must be sought.

Mr. McQuown accordingly devoted the following two months to getting acquainted with Andrade's phonetically and phonographically recorded Potosino Huastec materials, and with the dictionary materials compiled by Halpern from the raw data. It soon became apparent that a small number of fairly important phonological problems and a large number of morphological questions could not be solved on the basis of the available material. Accordingly, a field trip to Las Armas, San Luis Potosi, Mexico, was undertaken; nine days were devoted to the collection of a vocabulary of about 2000 items, a considerable amount of paradigmatic material related to the verb, and a couple of texts. With this material, together with general notions obtained from the survey of the previously collected material, it was possible to work out the sound system and a beginning was made toward working out the morphology and syntax. The elaboration of the materials gathered on this field trip was continued during the first six months of 1947, when the major portion of Mr. McQuown's time was devoted to teaching linguistics in the Department of Anthropology at the University of Chicago. A start was made on the compilation of a Spanish-keyed comparative Maya vocabulary, from which will be drawn the cognate material to be used in working out the sound-correspondence matrix for the various languages of the family, and for reconstructing Proto-Maya.

Mr. S. L. Bradshaw, commissioned by the Institution to prepare the manuscript of Andrade's Yucatec grammar for the printer, completed his work and submitted the manuscript early in 1947.

It is hoped that by 1950, the general outlines of a comparative Maya grammar may be laid down.

ANTHROPOMETRY OF THE HIGHLAND MAYA

T. D. STEWART

The late Dr. Aleš Hrdlička had planned to visit Guatemala in December 1943 to take measurements and observations on the highland Maya, but he died in September of that year. His successor in the curatorship of the Division of Physical Anthropology, United States National Museum, Dr. T. D. Stewart, finally undertook this work during the first three months of 1947. His trip was made in cooperation with the Guatemalan government and under the program for co-operation with the American republics through the State Department and the Smithsonian Institution. In addition to studying the living, Dr. Stewart examined the available prehistoric skeletal remains, especially those recovered at San Agustin Acasaguastlan (A. L. Smith and A. V. Kidder, *Explorations in the Motagua Valley, Guatemala,* Carnegie Inst. Wash. Pub, 546, 1943), at Kaminaljuyu, and at Zaculeu.

The main objective of Dr. Stewart's trip was to obtain information about the highland Maya which would enable him to make comparisons with the lowland Maya of Yucatan* These two groups, although rather widely separated geographically and exhibiting differences in material culture, nevertheless belong to the same linguistic stock. According to J. Alden Mason *(The Maya ami their neighbors,* 1940^ p* 70),

"The Mayan stock is unusually homogeneous both as regards geographical location and linguistic differentiation. It is really too unified for even the major divisions to deserve the rating of 'families/ and many of the so-called languages' differ only dialectically." Since language is fairly resistant to change (more so than material culture), considerable interest attaches to the question whether this linguistic homogeneity reflects a similar status in physical type.

Anthropometric records on the Maya Indians of Yucatan, obtained through the interest of the Carnegie Institution by G. D. Williams and Morris Steggerda, have already been published *(Maya-Spanish crosses in Yucatan,* Papers Peabody Museum, Harvard Univ., vol. 13, 1931; *Anthropometry of adult Maya Indians,* Carnegie Inst. Wash. Pub. 434,1932; *Maya Indians of Yucatan,* Carnegie Inst. Wash. Pub. 531, 1941). For the highland groups of Guatemala, on the other hand, only two anthropometric studies are on record, one by Oliver La Farge and Douglas Byers *(The Year Bearer's people,* Tulane Univ. Middle Amer. Research Ser., Pub. 3, 1931) and the other by Ada d'AIoja *(Sobre la variahilidad de algunos caractcres antropometricos observados en grupos de Indigenas Centroamericanos,* Inst. Panamericano de Geogr. e Hist., Pub. 43, 1939). Neither of these Guatemalan studies, which are themselves not very well known, includes comparisons with Yucatan.

Dr. Stewart undertook the collection of data that would supplement those already available and at the same time allow their fuller interpretation. Since in Guatemala the municipio, being endogamous, is the basic unit for ethnic study, as Dr. Sol Tax has shown *(The municipios of the midwestern highlands of Guatemala,* Amer. Anthropologist, vol. 39, 1937)* Dr. Stewart restricted his study to two municipios within one linguistic subgroup, the Cakchiquel. First at Solola, Department of Solola, and later at Patzun, Department of Chimaltenango, he obtained comparable series of males, 82 and 72 respectively. At Patzun, moreover, he obtained a series of 35 females. All together this is the largest series from one highland linguistic group thus far studied.

In addition to the routine anthropometric measurements, observations, and photographs, the records obtained this season include blood groups (A, B; M, N), taste sensitivity to phenyl-thiocarbarnide, palm- and fingerprints, and hair samples. Arrangements have been made for Dr. William C. Boyd, of Boston University School of Medicine, to analyze the blood groups and taste records, and for Dr. Harold Cummins, of Tulane University Medical School, to analyze the dermatoglyphics.

Preliminary inspection of the anthropometric records indicates that the Cakchiquel are lighter-complectioned, slightly lighter in weight, longer-headed, narrower-faced, and broader-nosed than the lowland Maya of Yucatan. Also, there are some significant metrical differences between the samples frorfi Solola and Patzun, a fact which suggests that, as suspected, inbreeding is producing local varieties in the highlands.

In his examination of the skeletal remains Dr. Stewart gave special attention to evidences of cultural practices, such as artificial deformation of the head and dental mutilation. The former, almost universal in the collections examined, mostly consisted in flattening of the occiput in the vertical plane ("cradleboard deformity") combined with frontal flattening. Previously this type had been reported only from Tajumulco *(Skeletal remains from Tajumulco, Guatemala,* Monogr. School Amer. Research, 1943). In other cases, es-

pecially at Kaminaljuyu, only frontal flattening was present. Also, at Zaculeu some evidence of the so-called "lambdoid" deformity was found in skulls from the most recent tombs.

As for dental mutilations, five examples of filed teeth were observed in the Zaculeu collections. One of these is a new type, or at least not included in the Borbolla key *(Types of tooth mutilation in Mexico,* Amer. Jour. Phys. Anthropol., vol. 26, 1940), whereas the others are types known from elsewhere in the Maya area.

It is regarded as desirable that the experience gained in this successful first season be utilized for the extension of these observations elsewhere. For example, it is important to learn to what extent in the highlands the barrier of language is an aid in the formation of physical types. In this connection the Quiche, neighbors of the Cakchiquel, or the Mam, neighbors in turn of the Quiche, should be more fully studied. If the records are made by one observer, moreover, they will be more uniform and less subject to multiple personal biases.

HISTORY OF THE MAYA AREA

RALPH L. ROYS

During the past year the comparative study of the Books of Chilam Balam has been continued. Especial attention has been given to the Codex Pérez, and a guide to this manuscript has been prepared to accompany the reproduction in the Peabody Museum of Harvard University.

The Codex PeYez consists of extracts which J. Pio Pérez copied from various Maya manuscripts, apparently during the second quarter of the nineteenth century. A large part of it was taken from the lost Book of Chilam Balam of Manl. There have been transcriptions, but only in receat years was Dr. S. G. Morley able to obtain a photograph of the original for the Carnegie Institution of Washington.

The first third of the manuscript is composed largely of Maya translations of European astrological and calendrical material (Year Book No. 45, pp. 220-221), which appealed to the interests of the more Hispanicized element of the Indian population; but most of the remainder is devoted to the native lore. The Codex Pérez covers a wide range of Maya learning and pays much attention to the augural or divinatory aspects of the Maya calendar. Here are predictions of the coming of the Spaniards and the new religion, prophecies for the tuns or years, and others for the 20-year periods called katuns with their valuable historical allusions. Of especial interest are the famous Mani Chronicle, several isolated historical narratives, and a version of the creation story differing in some respects from any that has been published. As in other Books of Chilam Balam, we find indications of the close association between history and prophecy in the Maya mind. One passage presents an important aspect of native Maya astrology, and there are several long explanations of Maya chronology. In spite of some chronological errors, these disquisitions add considerably to our knowledge of the native terminology and the point of vlew of the Indians who were endeavoring to preserve the old traditions. Besides the material not found elsewhere, there are parallels of passages in other Books of Chilam Balam; but in general the Codex Pérez versions are fuller and furnish more details.

In a previous report (Year Book No. 44, pp. 181-183) attention was called to chronological concepts expressed in certain prophecies in the Books of Chilam Balam of Tizimin and Mani. For the better understanding of this aspect of Maya science, a tentative translation has been made of a series of prophecies for the 20

tuns of a Katun 5 Ahau alleged to begin in 1593. In its present form the series is the work of eighteenth-century compilers, and the chronological setting is incorrect; but the greater part of the content appears to have been copied from earlier manuscripts. Although it seems plain that the prophecies really apply to the tuns, more emphasis is placed on the year-bearers. It is true that pessimism predominates in other Maya prophecies, but here the news is almost invariably bad. The language is often symbolic. Mythological allusions are frequent, but only rarely are they to the better-known and more important deities. A number of the names, such as Chac-uayab-xoc ("great demon shark"?) and Chac-mumul-ain ("great muddy crocodile"?), suggest fabulous monsters. Fauna names are sometimes preceded by a numerical coefficient, such as Ah Uucte-cuy ("7-owl") and Ah Uuc-ch*apat ("7-centipede"). These may be mythological personages, but the close association of the name Ah Buluc-am ("7-spider") with Montezuma suggests that it was considered to be the Maya name of the latter.

During this period work has been done on collecting and cataloguing material from sixteenth-century sources for a study of the political geography of the Yucatan peninsula at the time of the Spanish conquest, a joint project of Dr. Scholes and Mr. Roys. Time has also been devoted to reading proof of the history of the Chontal Indians of Acalan-Tixchel.

HISTORY OF THE MAYA AREA

FRANCE V. SCHOLES AND ELEANOR B. ADAMS

Work has been done on collecting and cataloguing material from sixteenth-century sources for a study of the population and political geography of the Yucatan peninsula, a joint project of Mr. Scholes and Mr. Roys. This work has included the study of data previously assembled and the investigation of additional documentary series, chiefly encomienda papers and proofs of services of conquerors, soldiers, and early settlers of Yucatan. The collection of the data is now nearing completion, and during the coming months the final study should begin to take form.

Miss Adams has carried forward her investigations of the foreign corsairs who scourged the coasts of Yucatan in the sixteenth century. The spadework research for this study, which has necessarily included the study of a wide range of supplementary sources in addition to those directly relating to events in Yucatan, is now virtually complete. Miss Adams will spend a considerable part of the coming year in writing up the data as a separate monograph.

These two studies will help to lay the foundation for the general history of Yucatan in the sixteenth century, the major project of Mr. Scholes at present. For this larger work some documentary research remains to be done, but the major series of documents have been rather thoroughly surveyed or extracted. The general plan of the history has also been worked out in some detail, and outlines have been made for several chapters.

Finally, considerable time has been devoted to the reading of proof of the history of the Chontal Indians of Acalan-Tixchel, now in press.

HISTORY OF THE MAYA AREA

ROBERT S. CHAMBERLAIN

Mr. Chamberlain's work has consisted of an investigation of the Spanish conquest period, roughly 1517-1550, in Yucatan, Tabasco, Honduras, Chiapas, and adjacent territories. His writing is based primarily on extensive research in documents existing in the Archivo General de Indias de

Sevilla, the Archivo Histórico Nacional, Madrid, the Archivo General del Gobierno, Guatemala City, and to a lesser degree in the Biblioteca Nacional, Madrid, the Archivo General de Simancas (Spain), and the Archivo General de la Nación, Mexico City. This research has helped to close important gaps in the history of the former Spanish provinces named above, to correct earlier accounts, and to re-evaluate, or evaluate for the first time, the course of events.

Mr. Chamberlain's research has made possible the preparation of two major works, one on the conquest and colonization of Yucatan, and the other on the conquest and colonization of Honduras, for publication by the Carnegie Institution of Washington, and brief monographs and articles for publication by the Carnegie Institution of Washington and by various historical journals. Because of the interlocking nature of much of the documentary source material, the preparation of the manuscripts of the two major studies was carried on concurrently, the manuscripts being completed some months apart.

The principal new contributions to Spanish colonial history resulting from Mr. Chamberlain's work have been:

1. The history of the conquest of Yucatan has been corrected, amplified, and reinterpreted.

2. The history of the conquest of Honduras has been fully told. Five unknown years, 1539-1544, important for the governmental evolution of Honduras and for the extension of the conquest, have been added to the history of the province. The conquest of Higueras, the western and, in the colonial period, the most important part of Honduras, has been more fully told, and new interpretation has been given to the early history of the province as a whole.

3. Four years have been added to the history of Chiapas, 1540-1544, when Francisco de Montejo, who was also Adelantado of Yucatan and Governor of Honduras, was governor of that province. This has been done in a brief monograph which is being published as Contribution 46 in the Contributions to American Anthropology and History (Publication 574).

4. Through the histories of the conquest and colonization of Yucatan and Honduras, Francisco de Montejo has been revealed as one of the truly great Spanish conquistadors and administrators. Montejo's career has hitherto been neglected. He was a man of great stature and vision, an empire builder in the real sense. Mr. Chamberlain is drawing up an outline on which to base a biography, as such, of Montejo.

In addition, on the basis of documents from the Archivo General del Gobierno, Guatemala City, it has been possible for the first time to give an account, even though a very brief one, of the early history of the town and province of San Miguel, now the southern part of the Republic of El Salvador,

During the period which Mr. Chamberlain has had under study, fusion of European culture, as represented by the Spaniards, with native New World cultures, and mixture of European and Indian races not only began but progressed rapidly. Spanish governmental, religious, economic* and social forms, institutions, and attitudes were speedily imposed on the Indians. At the same time the Indians sought tenaciously to cling to their own cultures. It is this continuous and fundamental clash and fusion of European and native American cultures and races which have given most of the Spanish American countries their past, present, and future form and aspect. It scarcely need be pointed out that greater knowledge of the past and present of the countries and peoples of

Latin America is becoming increasingly important in view of the fact that the United States is now forging more closely than ever before its political, economic, military, and cultural bonds with the other nations of the western hemisphere.

HISTORY OF SCIENCE

GEORGE SAHTON

Introduction to the history of science. Most of Dr. Sarton's time was devoted to proofreading of volume III. At present the page proofs of the whole work have been read (xxxv + 1910 pages), but the compilation, editing, and printing of the indexes remain to be done. It is hoped that the whole work may be published before the end of 1947.

Editing of his. Publication of *Isis* by the Harvard University Press was slowed up In 1946 but is now improving. During this year there were published nos. 85, 105-108 of *Isis,* forming the first halves of volumes 32 and 37 and the second half of volume 36. These five numbers comprise a total of 501 pages, with 8 plates and 35 figures, and include 33 main studies, 70 notes, 99 reviews, and about 1000 bibliographic items.

Lecturing in Harvard University. Two courses were delivered this year, dealing respectively with the history of science from the sixteenth to the seventeenth century, and with the history of modern science, the number of students being 212 and 350. Efforts are being made to reduce the size of these audiences.

Ancient science down to Epicures. Work on this project had to be stopped until volume III is finished.

PUBLICATIONS

MARGARET **W. HARBISON**

The long-delayed *Album of Maya architecture* (Publication 558), by Tatiana Proskouriakoff, was distributed in December 1946.

The Maya Chontal Indians of Acalan-Tixchel: a contribution to the history and ethnography of the Yucatan Peninsula (Publication 560), under the joint authorship of France V. Scholes and Ralph L. Roys, is completely in galley proof, and the gravure facsimiles of the Chontal Text are made. It is expected that this book, the second in a series of historical studies, will go to final press before the end of 1947. The manuscript of a third volume in this group, Robert S. Chamberlain's *The conquest and colonization of Yucatan, 151J-1550,* has been prepared for the printer and will shortly be presented for publication. Dr. Chamberlain's next manuscript, *The conquest of Honduras and Higueras,* is now being edited.

Excavations at Kaminaljuyu, Guatemala (Publication 561), by A. V. Kidder, J. D. Jennings, and E. M. Shook, with technological notes by Anna O. Shepard, was printed early in 1947, but lack of binding facilities has delayed its distribution. Delivery is expected in July. In addition to over 300 pages of text, the book contains 207 figures, about half of them gravure, of which four are in color.

Anna O. Shepard's *Plumbate: a Mesoamerican trade ware* (Publication 573) awaits paging. Much of the text is arranged to face the specific illustration being discussed. Of its 44 figures, about two-thirds are gravure.

Volume IX of Contributions to American Anthropology and History (Publication 574), now in galley proof, contains four papers: *An archaeological reconnaissance in the Cotzumalhuapa region, Escuintla, Guatemala* (no. 44), by J. Eric S. Thompson; *Textiles of pre-Columbian Chihuahua* (no. 45), by Lila M. O'Neale, professor of decorative art in the University of California, Berkeley, to which is ap-

pended a chemical analysis of the coloring matter by Michael Kasha, of the university's Department of Chemistry; *The governorship of the Adelantado Francisco de Montejo in Chiapas, 1539-44* (no. 47), by Robert S. Chamberlain; and *The symmetry of abstract design, with specific reference to ceramic decoration* (no. 47), by Anna O. Shepard.

The artifacts of Uaxactun, Guatemala (Publication 576), a 76-page monograph by A. V. Kidder, has been released for final printing. It forms part of the general survey of work at Uaxactun, reports on the architecture and ceramics to be written by A. L. and R. E. Smith, respectively.

Early in 1947 the Division issued a small *Guide hoo\ to the ruins of Copan* (Publication 577), by Gustav Strömsvik, with maps of the site and halftone illustrations of outstanding features. A brief mention of books recommended for a general background of Maya culture is appended.

To the third volume of Notes on Middle American Archaeology and Ethnology fifteen numbers were added during the year. Six papers from members of the staff, Miss Proskouriakoff and Messrs. Kidder, Roys, Shook, Strömsvik, and Thompson, are listed in the bibliography at the end of this report. Authors outside the Institution contributed the remainder; *Some Mexican figurines of the colonial period* (no. 70), *The codex of the Derrumbe del Templo Mayor* (no. 72), *Some exam fits of Yeztla-Naranjo geometric ware* (no. 73), *The "Tortuga" of Coatlan del Rio, Morelos* (no. 76), and *Stone objects from Cocula and Chilacachapa, Guerrero* (no. 80), by R. H. Barlow; *Otomi looms and quechquemitls from San Pablito, State of Puebla, and from Santa Ana Hueytlalpan, State of Hidalgo, Mexico* (no. 78), by Bodil Christensen; *Easter ceremonies at San Antonio Palopo, Guatemala* (no. 81), by Elsie McDougall; *The treble scroll symbol in the Teotihuacan and Zapotec cultures* (no. 74), by Horace Neys and Hasso von Winning; and *Drawings of Tajumulco sculptures* (no. 77), by Antonio Tejeda. The last constitutes an illustrated supplement to *Excavations at Tajumulco, Guatemala* (Monograph 9 of the School of American Research), by Bertha P. Dutton and Hulda R. Hobbs.

John M. Longyear III wrote *Cultures and peoples of the southeastern Maya frontier* as no. 3 in Theoretical Approaches to Problems, a series published by the Division to offer a forum in which tentative solutions and hypotheses are presented to stimulate interest in the final synthesis of Middle American cultural history.

In addition to seeing these publications through the press, Mrs. Harrison is engaged In editing the manuscript of *The Maya chronicles,* by Alfredo Barters Vasqucz and Sylvanus G. Morley. Work on her dictionary of archaeological terms is temporarily halted pending revision of ceramic nomenclature.

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