Brick Clays

As pointed out by the writer,[1] there are in the State tremendous amounts of glacially-transported clays, classifiable as Estuarine Clays, Lake and Pond Clays, Flood-plain and Terrace Clays, Drift or Boulder Clays, and Seasonal or Varve Clays. Their abundance and wide distribution are indicated by the number of brick dwellings in the country, oftentimes in out-of-the-way places, as well as in urban centers.

The largest known deposits are found along the Connecticut River and other streams, but deposits also occur along the lake shores and in former natural depressions which were filled with the clay sediments by streams flowing from the retreating ice sheet.

Brick Yards

Considerable brick yards have been in operation in the past at East Ryegate, Westminster, Putney, and Bennington but, as far as the writer is informed, none of these plants is at present in operation.

THE DRURY BRICK AND TILE COMPANY, INCORPORATED

Office, Essex Junction.

Officers: President, H. D. Drury; vice-president, H. K. Drury; treasurer, M. W. Drury.

Quarries and kilns at Essex Junction.

Products: Sand-struck and water-struck bricks.

Capacity, six million sand-struck and one and one-half million water-struck bricks annually.

An analysis of the clay, made some years ago by the writer, gave the following results:

SiO_2	53.69
Al_2O_3	21.24
Fe_2O_3	8.65
TiO_2	.41
MnO	.02
CaO	2.84
MgO	1.03
Na_2O	1.78
K_2O	3.94
H_2O	5.36
Moisture	.79
	99.75

[1] The Clay Deposits and Clay Industry of Vermont; 15th Rpt. Vt. State Geol. (1925-26).

REPORT

OF THE

STATE GEOLOGIST

ON THE

MINERAL INDUSTRIES AND GEOLOGY

OF

VERMONT

1935-1936

TWENTIETH OF THIS SERIES

ELBRIDGE C. JACOBS
F.G.S.A.
State Geologist

RELIEF MAP OF VERMONT

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FREE PRESS PRINTING CO., BURLINGTON, VT.

STATE OF VERMONT

OFFICE OF STATE GEOLOGIST

BURLINGTON

To the Board of Conservation and Development,
Montpelier, Vermont,

Gentlemen: I herewith present my biennial Report, as State Geologist, for 1935-36.

The Report is late owing to the long time needed for its preparation and to the date of my appointment, May 25, 1937.

In the Report, in addition to information regarding the condition of the mineral industries of the State, I have presented the first fairly comprehensive account of Vermont geology since Hitchcock's Geology of Vermont, of 1861. It is hoped that this account may be helpful to the teachers of Vermont and to many others, whose requests for information show their deep interest in Vermont geology.

In addition to my own work I am very glad to present an article by my colleague, Prof. Charles G. Doll, on an unusual glacial feature of the State.

Besides the preparation of this bulletin, I have attended to the large correspondence connected with this office and have advised with various people on their geological problems.

Respectfully submitted,

ELBRIDGE C. JACOBS,
State Geologist.

Fleming Museum,
University of Vermont.

CONTENTS

ILLUSTRATIONS

Vermont Mineral Industries

The mineral industries of the State, as a whole, are rapidly recovering from the depression. Comparing production in 1935 (the latest available figures for a calendar year) with those of 1933, one finds that the asbestos tonnage has increased 83.8 percent, lime 45 percent, talc 17.7 percent, granite (cubic feet) 16 percent, and fire clay 10.5 percent. Comparative figures for marble and slate are not available.

In the lime industry prices per ton are about the same as in 1933, talc prices have improved 10.6 percent, while granite prices per cubic foot have increased 42.3 percent.

In the last Report references to the geology of the various mineral deposits were given. It is not thought necessary to repeat them here.

Marble

Production

Vermont continues to be the greatest producer of marble in the United States (and probably in the world), exceeding her nearest competitor, Georgia, by about 46 percent in "footage."

The latest available figures from the Minerals Yearbook, United States Bureau of Mines, for 1934 are as follows:

State	Building and monumental (rough and finished)		Other uses		Total	
	Cubic feet	Value	Short tons	Value	Short tons*	Value
Alabama	26,480	$ 95,441	46,070	$ 45,451	48,320	$ 140,892
Arkansas	.....[1]	.....[1]	.....[1]	.....[1]	510	7,356
California	.....[1]	.....[1]	.....[1]	.....[1]	990	12,134
Georgia	236,720	969,140	19,660	20,114	39,740	989,254
Massachusetts	5,470	17,566	360	576	830	18,142
Missouri	70,220	169,519	120	900	5,930	170,419
New York	8,690	26,420	9,410	47,032	10,140	73,452
Tennessee	141,990	518,659	3,090	12,416	15,070	531,075
Vermont	432,170	1,190,249	13,330	17,063	50,060	1,207,312
Other States[2]	43,180[3]	207,888[3]	3,520[3]	32,483[3]	5,690	220,881
	964,920	$3,194,882	95,560	$176,035	177,280	$3,370,917

[1] Included under "Other States."
[2] Arizona, Colorado, Maryland, New Jersey, North Carolina, Utah, Virginia, and Washington.
[3] Includes also States entered as "....[1]" above.
* Approximate.

From these figures it is calculated that of the total dollar value of building and monumental marble produced in the United States, Vermont companies accounted for 37.25 percent; while of the total dollar value of all grades of marble, Vermont companies showed about 35.8 percent.

Marble Companies

THE VERMONT MARBLE COMPANY

Main office, Proctor.
Branch offices in the larger cities of the United States.
Officers: Chairman of the board, F. C. Partridge; president, Redfield Proctor; vice-presidents, S. A. Howard, Benjamin Williams, Mortimer R. Proctor, D. H. Bixler; treasurer, H. V. Smith; secretary, Benjamin Williams; assistant secretary, H. L. Smith.
Quarries at Brandon, Danby, Dorset, Florence, Isla La Motte, Proctor, Rochester, West Rutland, Roxbury, St. Albans, Swanton; also in Alaska, Colorado, and Montana.
Fabricating plants at Florence, Middlebury, Proctor, Center Rutland, West Rutland, and Swanton.
Products: Memorials, mausoleums, exterior building stone, interior finish, lumar, jetmar, garden furniture, gifts in marble, scale tops, imposing stones, electric switch boards, etc.
By-products: Fluxing material, road metal, whiting substitutes, "Vermarco" products.[1]

Research Department

For the past fourteen years the Vermont Marble Company has maintained a Research Department, studying the technical and scientific aspects of the marble business. This study has covered a wide range of subjects, such as: Cement for use with marble, physical and chemical tests of marble, use of bronze and other metals in conjunction with marble, care and cleaning of marble, development of stain removers, the dyeing of marble, weatherproofing methods for stone, new uses for marble and marble waste.

Marble Exhibit

At its Proctor plant the Vermont Marble Company has installed a very beautiful exhibit of its marbles. In this display there are shown over fifty varieties of marble, each arranged in the shape of a three-sided booth. These booths vary from eight to sixteen feet in length and are uniformly six feet, seven inches high. The varieties of the marble include pure white, "Secondary Statuary," "Westland Dark Cream," "Northern Pearl," "Neshobe Gray," "Variegated Champlain," "Royal Red," Verde Antique, "Champlain Black" and many others. Besides the booths there are displays of gifts in marble: carved fireplaces, ornamental mantles, baptismal fonts, bird baths, flower pots, tiled flooring, balustrades, marble baths, the model of a marble building, while the masterpiece is a section of a chapel, with lumar panels and, above the altar, a carving in white marble of Leonardo da Vinci's "Last Supper."

New Products

In times of business depression forward-looking companies lay extra emphasis on research, looking to the improvement of

[1] See under Lime, p. 20.

their products and the development of new ones. Following this rule, the Vermont Marble Company has produced several new types of marble which may be briefly noted.

LUMAR

This is a scientifically developed luminous marble possessing remarkable properties of light transmission and diffusion. It was developed by the company's research staff at the Mellon Institute of Industrial Development, at Pittsburgh, and by Prof. Geo. W. Bain, the company's geologist.

By cutting slabs of suitable marble to thicknesses varying from one-fourth to three-quarters of an inch, in certain crystallographic directions, determined by studies in the crystal structure of the rock, products are obtained of high light transmissibility and wide diffusion, which bring out the sub-surface texture, color, and beauty of different varieties of marble. The name is copyrighted and registered. Among the varieties produced are "Lumar Yule," "Lumar Antique," "Lumar Green Vein," "Lumar Pavonazzo," "Lumar Brocadillo," and "Lumar Red."

JETMAR

This is a black, processed marble, made from lighter colored stone, not by dyeing, staining or impregnation but by a secret process of interfusion, utilizing both vacuum and pressure, in special equipment designed and constructed for the purpose. The product is a uniformly jet black marble giving, when polished, a highly lustrous surface.

A fine display of lumar and jetmar panels has recently been installed in the University of Vermont Fleming Museum of Geology.

Marble Fabricators

TEMPLE BROTHERS, INCORPORATED

Main office, Rutland.
Officers: President, J. R. Temple; treasurer, W. N. Temple.
Products: Monuments made from granite and marble of both local and foreign sources.

KINSMAN & MILLS, INCORPORATED

Main office, Rutland.
Officers: President, W. J. McGarry; vice-president, Mrs. Mary W. Mills.
Products: Monumental and building work in marble and granite.

Granite

The Vermont granite industry in 1935 showed an increase over 1934 of 16 percent in "footage" and 26 percent in value. The estimates for 1936 show a further improvement and the Barre District[1] will probably enjoy the best business it has had since 1931. The problem of unemployment in the district no longer exists—in fact it has been necessary to go outside the district to obtain workmen.

Production

According to the Minerals Yearbook of the United States Bureau of Mines, for 1934, the production of monumental stone by states was as follows:

	Cubic feet	Value
Vermont	740,700	$1,932,954
Georgia	310,090	386,779
Minnesota	100,270	208,281
Massachusetts	61,060	114,005
Maine	26,790	20,592
California	15,260	29,236
Other states	372,800	705,975
Total	1,626,970	$3,397,822

These figures show that Vermont produced over twice as much granite as her nearest competitor, 45.5 percent of the total "footage" and 56.9 percent of the total value.

Production in the Barre District

The following data were furnished by the Barre Granite Association:

[1] In order to stop pirating, the Federal Trade Commission has defined the "Barre District for the Quarrying of Granite" as beginning at the southerly part of the city of Barre, Washington County, State of Vermont, and extending westerly about two and one-half miles, then southerly about four miles to and including Williamstown, in Orange County. All granite quarried elsewhere may not legally be named and advertised as "Barre granite" hereafter. The location indicated comprises the whole of the eminence south of Barre City locally known as Millstone Hill.

Year	Rough stock		Manufactured	
	Cubic feet	Value	Cubic feet	Value
1929	1,268,178	$12,152,174.40	1,014,542.4	$9,721,739.52
1930	1,125,840	9,612,601.00	900,672	7,690,080.80
1931	842,922	5,745,711.00	674,338	4,596,568.80
1932	651,401	4,722,349.00	521,121	3,777,879.20
1933	575,046	4,406,186.00	460,037	3,524,948.80
1934	643,050	4,973,247.00	514,440	3,978,597.60
1935	668,838	6,274,065.92	535,070	5,019,252.74
1936, first six months	363,720	3,728,120.45	290,976	2,982,496.36

ESTIMATED OUTPUT OF MONUMENTAL GRANITE IN BARRE DISTRICT, VERMONT

1935

Total quarry output, rough stock	Cubic feet	668,838
Shipped out of Barre District in rough	Cubic feet	133,768
Manufactured in Barre District	Cubic feet	535,070
Light stock consumed in district	Cubic feet	418,024
Dark stock consumed in district	Cubic feet	250,814
Number of cutters (approximately)		1,240
Average daily wage		$8.00
Number of days worked		225
Total pay roll for year		$2,232,000.00
Estimated overhead		1,116,000.00
Estimated value of light stock		1,358,577.19
Estimated value of dark stock		1,003,257.00
Estimated polishing cost		423,173.80
Output from saws		141,057.93
Total value of granite		$6,274,065.92

ESTIMATED OUTPUT OF MONUMENTAL GRANITE IN BARRE DISTRICT, VERMONT

FIRST SIX MONTHS, 1936

Total quarry output, rough stock	Cubic feet	363,720
Shipped out of Barre District in rough	Cubic feet	72,744
Manufactured in Barre District	Cubic feet	290,976
Light stock consumed in district	Cubic feet	227,325
Dark stock consumed in district	Cubic feet	136,395
Number of cutters (approximately)		1,550
Average daily wage		$8.00
Number of days worked		115
Total pay roll for one-half year		$1,384,600.00
Estimated overhead		692,300.00
Estimated value of light stock		738,806.25
Estimated value of dark stock		545,580.00
Estimated polishing cost		290,125.65
Output from saws		76,708.55
Total value of granite		$3,728,120.45

Members of the Barre Granite Association, Inc.

As of August 1, 1936

BARRE

Abbiati & Fontana
Acme Granite Company
Adams Granite Company
American Granite Company
Anderson-Friberg Co.
Anderson & Johnson
Barre Blue Granite Company
Barre Hickey Mill
Barre Memorial Company
Batchelder Company, E. J.
Beck & Beck
Bianchi & Sons, Chas.
Bilodeau & Company, J. O.
Brusa Brothers
Burke Brothers
Buttura & Son
Caccavo Granite Company
Carroll Brothers
Celente & Bianchi
Cerasoli & Cerasoli
Chioldi Granite Company
Comolli & Company
Cook, Watkins & Patch
Dessureau & Company
Gelpi Granite Company
Giudici Brothers & Company
Gomo Brothers Company
Granite Memorial Shop
Grearson & Lane Company
Harrison Granite Company
Hebert & Ladrie
Herrera & Reales Granite Company
Hinman Company, H. P.
Hoyt & Milne, Inc.
Initial Granite Company
Industrial Granite Company
Johnson & Gustafson
Johnson, E. F.
Jones Brothers Company
Jones Brothers Dark Quarry
Lawson Granite Company
Letter Granite Company
Liberty Granite Company
Littlejohn, Odgers & Milne
Mascetti, Paul
McDonnell & Sons
Malo Granite Company
Marr & Gordon, Inc.
Milne Granite Company, Alex
Modern Granite Company
Morlote Granite Company, S.
Nativi Granite Company
North Barre Granite Company
Novelli & Calcagni
Orlandi Granite Company
Olliver & Company
Parnigoni Brothers
Peerless Granite Company
Pena Granite Company
Pirie Estate, J. K.
Puente Granite Company
Revilla Granite Company, J.
Robins Brothers
Roux Granite Company
Saporiti, William
Shield Company, Inc., Waldron
Sierra Granite Company
Smith & Company, E. L.
South Barre Granite Company
South End Polishing Company
Steele Granite Company
Stewart Turning Works, R. J.
Thurber & Isabelle
Union Granite Company
Usle & Perojo
Usle & Revilla
Valz Granite Company
Veino Granite Company
Wells-Lamson Quarry Company
White Granite Company
Zampieri & Buttura

MONTPELIER

Bonazzi & Bonazzi
Capitol Granite Company
Columbian-Artistic Granite Company
Desilets Granite Company
Everlasting Memorial Works
Excelsior Granite Company
Gill & Company, C. P.
Johnson Granite Company
Jurras Granite Company
Montpelier Granite Works
Riley Brothers
Sheridan & Poole
United Granite Company
Wetmore & Morse Granite Company

NORTHFIELD

Cross Brothers Company
Duprey & Company
Pando Granite Company

WATERBURY

O'Clair Granite Works, C. L.
Union Granite Company

RIVERTON

Provost Granite Company

WILLIAMSTOWN

Williamstown Granite Company

ASSOCIATE MEMBERS—BARRE

Bouffard, Ernest
Jacques Saw Plant
Maxwell, William James
Minnie Polishing Company, Fred.

Active Granite Companies—Barre District

JONES BROTHERS COMPANY, INCORPORATED

Main office, 10 High Street, Boston, Massachusetts.
Officers: President, M. Walker Jones; vice-president, Marshall J. England; treasurer, Seward W. Jones at Boston.
Branch office, 700 Main Street, Barre, Vermont.
General manager, Heber G. England.
Quarries at Graniteville and Websterville, Barre District.
Superintendent, J. A. Healy.
Products: Monuments and mausoleums, rolls for paper companies and chocolate grinding; ornamental sun dials, garden seats, etc.

J. K. PIRIE ESTATE

Main office, Barre.
Trustees and managers, James G. and Fred F. Pirie.
Quarries in South Barre and Williamstown, Barre District.
Fabricating plant: None. The company simply quarries granite.
Products: Mostly dark Barre granite; some light Barre.

ROCK OF AGES CORPORATION

Note.—This corporation is a consolidation of the following old companies: Boutwell, Milne & Varnum, Barclay Brothers, Canton Brothers, E. A. Chase Granite Company, Eureka Granite Company, Grearson & Lane, Lawrence Granite Company, William Milne Company, Perry Granite Corporation, Phillips & Slack, and George Straiton Granite Company.
Main office, 206 Bank Street, Burlington.
Officers: President, Roy L. Patrick; vice-president, Harry A. Way; treasurer, Joseph T. Smith; clerk, Warren R. Austin.
Quarries, sawing and polishing plant at Graniteville.
Fabricating plants at Barre, Montpelier, Northfield, Waterbury.
Products: "Rock of Ages Barre Granite," monuments, mausoleums.

E. L. SMITH COMPANY

Main office, Barre.
Officers: President, Frank M. Corry; vice-president, Donald W. Smith; treasurer, Bernard V. Funk.
Quarries at Graniteville and Websterville.
Fabricating plant: None. The company simply quarries granite.
Products: Light and dark Barre granite.

WELLS & LAMSON QUARRY COMPANY

Main office, Barre.
Officers: President, Marshall J. England; vice-president, Maurice L. Kelley; treasurer, H. Brandon Jones.

Quarries at Websterville.
Fabricating plant: None.
Product: Light Barre granite.

WETMORE & MORSE GRANITE COMPANY

Main office, Montpelier.
Officers: President, Frank M. Corry; vice-president, William F. Corry; treasurer, Edward H. Deavitt; secretary, Frank C. Corry; assistant treasurer, Frank G. Wheaton.
Quarries at Websterville.
Product: Rough Barre granite, light and medium.

Other Active Granite Companies

ADAMANT QUARRY COMPANY

Office, East Montpelier.
Officers: President, Harry Daniels; vice-president, W. E. Patch; secretary-treasurer, R. B. Daniels.
Quarry at Adamant.
Fabricating plant: None. The company simply quarries granite.
Products: Light and medium granite.

PRESBREY-LELAND STUDIOS, INCORPORATED

Main office, 681 Fifth Avenue, New York City.
Manufacturing office, Brattleboro.
Officers: President, C. H. Presbrey; treasurer, F. C. Presbrey; manager of studios, W. S. Martin.
Quarries at West Dummerston.
Studios at Brattleboro.
Products: Private, public, and cemetery memorials.

CROSS BROTHERS COMPANY

Main office, Northfield.
Officers: President, L. T. Cross; vice-president, M. W. Cross; treasurer, G. A. Cross; secretary, J. A. Cross; superintendent, J. F. Cross.
Business: Builders of cemetery memorials, using Barre granite.

Granite Fabricators

THE TEMPLE BROTHERS, INCORPORATED

Main office, Rutland; branch at Pittsfield, Massachusetts.
Officers: President, J. R. Temple; treasurer, W. N. Temple.
Business: Designers and builders of cemetery memorials, both of granite and marble.

KINSMAN & MILLS, INCORPORATED

Office, Rutland.
Officers: President and treasurer, W. J. McGarry; vice-president, Mrs. Mary W. Mills.
Business: Monumental and building work, both of granite and marble.

Structural Granite

JOHN B. HALL & ASSOCIATES, INCORPORATED

Office, Hardwick.
Officers: President and treasurer, John B. Hall; clerk, William A. Sinnott; directors, Albert E. Cox, Guy W. Larrabee, M. J. Sullivan.
Business: General quarrying and manufacturing of Woodbury gray granite for building purposes; also private and public mausoleums from the same stone.

Slate

The severe depression in the slate industry, noted in the last Report, has abated considerably and slate quarriers and manufacturers are encouraged by the increased demand for their products.

According to the Minerals Yearbook for 1936, sales in roofing slate in 1935, in the United States, increased 77 percent in quantity and 43 percent in value, mill stock increased 12 percent and 16 percent, respectively, while total sales gained 40 percent over 1934.

As in the past, Vermont stands second only to Pennsylvania in the amount and value of her slate products. Her chief output is roofing slate, slate granules, and "mill stock" which includes slate used for structural and sanitary purposes, flagging and slate flour.

Slate Companies

Since the last Report several companies have ceased to operate. Those still active are as follows:

Castleton

The large quarries and mill of the Staso Milling Company are located in Castleton, just south of the village. The headquarters are at Poultney.

Hydeville

THE HINCHEY CONSOLIDATED SLATE COMPANY

This company is a consolidation of the P. F. Hinchey Slate Company, the G. R. and J. F. Hinchey Slate Company, and the General Slate Company.
Main office, Hydeville.
Officers: President, James Hinchey; treasurer, M. H. Fain.
Quarries at North Poultney and Fair Haven.
Fabricating plants at Hydeville, North Poultney, Fair Haven.
Products: Unfading green, unfading mottled purple and green slate, sold as roofing slate and mill stock (electrical panels, billiard slabs, flooring, flagging, etc.).

THE HYDEVILLE SLATE WORKS

This partnership has succeeded the old McDougal & O'Day Company.
Partners: J. O'Day and F. D. O'Day.
Quarry at Castleton (north of the village).
Plant at Hydeville.
Products: Panels for switchboards, flagging, etc.

New Haven

HARVEY BUSH SLATE COMPANY

Main office, Fair Haven.
Partners: Joel Griffith, Mrs. Joel Griffith, John R. Griffith.
Quarries at Scotch Hill, Fair Haven.
Products: Unfading green, mottled, purple, gray, sold as roofing slate, and flagging.

THE FAIR HAVEN MARBELIZED SLATE AND VERMONT STRUCTURAL SLATE COMPANY

Main office, Fair Haven.
Officers: President, E. D. Raymond; treasurer, M. A. Owens; manager, A. L. Carpenter.
Quarries at Castleton, Fair Haven, and Poultney.
Products: All unfading colors, except red, made into roofing and structural slate (flooring, electrical slate, etc.). Also marbleized slate.
This company recently celebrated its seventy-fifth birthday and is the oldest slate company in Vermont—and perhaps in the United States.

MAHAR BROTHERS SLATE COMPANY, INCORPORATED

Main office, Fair Haven.
Officers: President, George M. Mahar; vice-president and general manager, Thomas Mahar; secretary-treasurer, Edward F. Mahar.
Quarries in Poultney and Castleton.
Fabricating plants: Roofing slate mill in Poultney; electrical and structural mill in Hydeville.
Products: Unfading purple, unfading mottled green and purple slate, sold mostly as roofing slate, but also for electrical and structural purposes.
This company also leases the Minogue Brothers & Quinn mill at Hydeville.

PEDRO BROTHERS PARTNERSHIP

Office, Fair Haven.
Partners: Joseph Pedro, Rivese Pedro, Tony Pedro, John Foote, Domick Sbardella.
Quarry at Scotch Hill.
Products: Unfading green, mottled green and purple, gray slate sold as roofing slate and flagging

W. H. PELKEY SLATE COMPANY

The proprietor has died and the estate is being settled.

THE SCOTCH HILL SLATE COMPANY

Proprietor, Richard Griffith.
Product: Roofing slates.

VARIEGATED SLATE COMPANY

Office at Fair Haven.
President, Connie Hayes.
Quarry at Fair Haven.
Products: Green and variegated structural slate and flagging.

Poultney

THE AULD & CONGER SLATE COMPANY

This company has been sold to C. R. Beach of Fair Haven.

THE CAMBRIAN SLATE COMPANY

Main office, Granville, New York.
Officers: President, David O. Roberts; secretary-treasurer, Iola San.
Quarry at Poultney.
Products: Sea-green and variegated roofing slate.

LANDSCAPE SLATE AND ROOFING COMPANY

Office at Poultney.
Officers: President, D. O'Brien Owen; vice-president, W. Harry Williams; treasurer, Russell I. Williams; sales manager Geo. W. Sutter.
Quarries at Poultney.
Products: Roofing and flagging.

MONTVERT SLATE COMPANY, INCORPORATED

Office at Poultney.
Officers: President, George Ebel; vice-president, W. Harry Williams; treasurer, Russell I. Williams.
Quarries at Poultney and in New York.
Products: Roofing and flagging.

THE McCARTY SLATE COMPANY.

Office at Poultney.
Officers: President, Michael McCarty; manager, H. D. McCarty.
Products: Unfading green and gray roofing slate.

THE STASO MILLING COMPANY

Home office, Poultney.
Officers: President, John W. Powers; secretary-treasurer, W. F. Krohn; general manager, Charles T. Kett.
Quarries at Castleton and Poultney.
Processing plants at Castleton and Poultney.
Products: Slate granules (green, red and other, artificial, colors) and mineral fillers.
Capacity of plants 700 tons a day.
The company also has quarries and mills in Maryland, Georgia, Missouri, and Michigan.

Wells

NORTON BROTHERS

Main office, Granville, New York.
Proprietor, E. R. Norton.
Quarries at Wells and at Pawlet.
Products: Roofing slate and flagging.

OWEN L. WILLIAMS & SON

P. O. address, Granville, New York.
Office and quarry at Wells, Vermont.
Officers: ————.
Products: Roofing slate and flagstone.
Dealers in all slate products.

Pawlet

OWEN W. OWENS SONS, INCORPORATED

Main office, Granville, New York.
Officers: President, D. O. Owens; vice-president, W. R. Owens; secretary, D. O. Owens, Jr.
Quarries and mill at Pawlet.
Products: Roofing slates.
Note.—The Progressive Slate Company, of Granville, has been merged with the above corporation.

THE O'BRIEN SLATE COMPANY, INCORPORATED

Main office at Granville, New York.
Officers: President and secretary-treasurer, James O'Brien.
Quarries at Pawlet.
Product: Roofing slate

West Pawlet

RISING & NELSON SLATE COMPANY

Main office, West Pawlet.
Partners: S. M. Rising, T. S. Nelson, A. H. Morrill.
Quarries and mills at West Pawlet, Poultney, Fair Haven, and in Maine.
Products: Roofing, flagging, flooring, etc.

Talc

The leading talc-producing states are, in order of tonnage, New York, Vermont, California, and Virginia.

Vermont Production

The talc-producing companies of the State continue to be the Eastern-Magnesia Talc Company, Incorporated, the Vermont Mineral Products Company, the Vermont Talc Company, and the American Soapstone Finish Company.

From data furnished by the companies the following figures have been compiled:

1935		Six months, 1936	
Short tons	Value	Short tons	Value
42,657	$316,134.82	22,253	$166,502.96
Average selling price per ton....	7.41		7.47

The Talc-Producing Companies

THE EASTERN-MAGNESIA TALC COMPANY, INCORPORATED

This corporation is a consolidation of the former American Mineral Company of Johnson, Eastern Talc Company of Rochester, and Magnesia Talc Company of Moretown. Consolidation was effected January 1, 1924.

Main office, Burlington.

Officers: President, John S. Patrick; vice-presidents, Joseph T. Smith, E. W. Magnus; treasurer, Roy L. Patrick.

Mines at Johnson and Moretown.

Grinding plants at Johnson and Moretown.

Products: Ground talc at Johnson; ground talc and talc crayons at Moretown.

THE VERMONT MINERAL PRODUCTS COMPANY, INCORPORATED

Main office, Chester.

Officers: President, Harry F. Douglas; secretary, Walter H. Austin; treasurer-manager, Urban F. Dorand.

Quarry at Chester.

Products: Micaceous soapstone and talc.

THE VERMONT TALC COMPANY

Main office, Chester Depot.

Officers: President, Nathan P. Avery, Holyoke, Mass.; secretary, Giles Blague, Springfield, Mass.; treasurer, John B. Aikman, Chester, Vt.

Quarries at Windham, Vermont.

Grinding mill at Chester Depot.

Product: Finely ground talc.

THE AMERICAN SOAPSTONE FINISH COMPANY, INCORPORATED

Main office, Chester Depot.

Officers: President, Z. A. Edson; treasurer, E. E. Holt.

Quarry, 4½ miles from Chester Depot.

Product: A "mongrel" soapstone and talc, used largely by roofing manufacturers.

Soapstone

Soapstone has been quarried in Vermont at Athens, Chester, Grafton, and Perkinsville since 1850. The uses to which it is put are many, among them being sinks, tanks, table tops, hearth stones, stoves, griddles, foot warmers, radiators for fireless cookers and flat irons and factory dresser rolls.

THE VERMONT SOAPSTONE COMPANY

Headquarters and mill at Perkinsville.
Proprietor, John H. Hicks.
This company also uses Virginia soapstone.

Asbestos

The 19th Report of the State Geologist gave a brief account, with references, of the asbestos deposits of Vermont on Belvidere Mountain, together with a review of the various attempts to establish an asbestos industry in the State.

It was seen that the Vermont Asbestos Corporation had, in 1929, acquired the old workings and mill of the Asbestos Corporation of America. With great effort and expense the property was developed to such a stage of operation that, in 1930, it produced 83 percent of the total United States' output of chrysotile asbestos fiber. Subsequently, the production has been steadily increased so that it now represents almost 100 percent of the total.

Production

Year	Short tons
1929	1,170
1930	3,530
1931	2,980
1932	3,558
1933	4,965
1934	6,507
1935	9,130

The property was held by the Vermont Asbestos Corporation under perpetual leases from the Town of Belvidere, the Lamoille County Grammar School, and the University of Vermont. By the authority of Acts passed by the Vermont General Assembly, held valid by the Supreme Court, the Vermont Asbestos Corporation acquired the fee simple of the property on the eastern slope of Belvidere Mountain from the Town of Belvidere and the University of Vermont.

On February 5, 1936, the Vermont Asbestos Corporation sold its properties, plants and equipment to the Vermont Production Co., Inc., whose name was later changed to the Vermont Asbestos Corporation. This company is owned by a subsidiary of The Ruberoid Co., of New Jersey, one of the largest manufacturers of roofing materials in the world.

This company has purchased the "Gallagher Property," so-called, which adjoins its other properties in the Town of Lowell, Vermont, and now has a combined holding of about 1,800 acres of mineralized lands on Belvidere Mountain.

THE VERMONT ASBESTOS CORPORATION, INCORPORATED

Main office, Hyde Park.

Officers: President, W. B. Harris, New York City; vice-presidents, L. C. Rugen, Bound Brook, New Jersey; F. E. Byrnes, Hyde Park; treassurer, S. D. Van Vleet, New York City; general superintendent, A. E. Parmelee.

Product: Chrysotile asbestos fiber used in the manufacture of shingles, siding, paper, board, roofing paints and plastice, boiler covering cements, brake linings and clutch facings, hot and cold moulded products, etc.

Capacity: The present plant and equipment are capable of producing 15,000 tons of asbestos fiber annually from the serpentine rock, which contains about 10 percent of asbestos. The company now employs 150 hands at Eden and is the main support of the working population of the district.

It would seem a certainty that an asbestos industry of considerable proportions is now well established in Vermont and that the United States has a reliable source of supply of asbestos fiber.

Lime

As already noted, the lime industry of the State has shown a large increase in production over 1933. The product is used in the chemical industries, for building, paper making, agricultural purposes, etc.

Lime is being burned at Swanton, Fonda Junction, Winooski, and at New Haven Junction. Hydrated lime is being produced by the Vermarco Lime Company and the Green Mountain Lime Corporation.

Production

	Short tons	Value
1929	43,923	$362,169
1930	40,648	319,108
1931	31,218	236,508
1932	29,027	194,359
1933	30,753	200,582
1934	38,015	252,731
1935	44,599	286,006
1936 (six months)	20,128[1]	143,543

[1] One plant was out of production for eight months.

Lime Producing Companies

CHAMPLAIN VALLEY LIME COMPANY

Main office, Worcester, Massachusetts.

Branch office, Winooski.

Officers: President, H. D. Brewer; secretary, Frank C. Smith, Jr.; manager, R. W. Foster.

Quarry and kilns, Winooski.

Products: See Green Mountain Lime Corporation.

THE GREEN MOUNTAIN LIME CORPORATION

Main office, Worcester, Massachusetts.

Branch office, Winooski.

Officers: President, H. D. Brewer; secretary, Charles I. Button; manager, R. W. Foster.

Products of both the above companies: Building, chemical, spraying, agricultural limes, etc.

Among the hydrated lime brands produced by the Green Mountain Lime Corporation are: "Chemical Hydrate," "Masons' Hydrate," "Snow Fluff Spraying Hydrate," "Agricultural Hydrate," "Sure Crop," etc.

THE VERMARCO LIME COMPANY

This is a subsidiary of the Vermont Marble Company and produces a hydrated lime for building, chemical, and agricultural purposes.

THE SWANTON LIME WORKS

Main office, Swanton.
Proprietor, John P. Rich.
Quarries and kilns at Swanton.
Products: Lime for paper, leather, building, agricultural uses, etc.

THE FONDA LIME COMPANY

Main office, St. Albans.
Manager, L. F. Willson.
Quarries and kilns at Fonda Junction.
Products: Lime for chemical, building, agricultural purposes, etc.

Fire Clay

One of the most successful of the mineral industries of Vermont has been built up and carried on by the

RUTLAND FIRE CLAY COMPANY

Main office, Rutland.
Officers: President, C. A. Perkins; treasurer, J. C. Flynn; secretary, C. S. Perkins.
Quarries at Rutland, east of the plant.
Manufacturing plant, Rutland.
Products: Stove lining, patching plaster, furnace cement, boiler covering, roofing cement, pipe-joint cement, water-pipe cleaner, water glass.

Production

	Short tons
1929	9,925
1930	9,938
1931	8,570
1932	7,039
1933	8,100
1934	8,288
1935	9,052
1936 (six months)	4,582

Kaolin

The account of kaolin occurrence, geology, and production, given in the last Report may here simply be brought up-to-date.

The only company at present engaged in the kaolin, of China clay, industry, as far as known, is

THE VERMONT KAOLIN CORPORATION

Main office, Bennington.
Officers: President, Sanford C. Lyons; other offices at present vacant.
Mines at South Shaftsbury and East Bennington.
Mill at East Bennington.

At the present time the Georgia Kaolin Company and another large producer in the South are exploring the deposits by core drilling. This exploration has shown the presence of several million tons of kaolin which, however, will need chemical decolorization in order to insure the necessary color.

Brick Yards

THE DRURY BRICK AND TILE COMPANY, INCORPORATED

Office, Essex Junction.
Officers: President, H. D. Drury; vice-president, H. K. Drury; treasurer, M. W. Drury.
Quarries and kilns at Essex Junction.
Products: Sand-struck and water-struck bricks.
Capacity, six million sand-struck and one and one-half million water-struck bricks annually.

Molybdenite

The occurrence of molybdenite (MoS_2, or sulphide of molybdenum) in Granite Hill, on the Wallingford-Shrewsbury line, has long been known. Professor Eggleston[1] has studied and described the syenite stock which makes up the hill (obviously misnamed) and mentioned the occurrence of molybdenite in the syenite, on the west side of the eminence.

In the years 1934, 1935, 1936, prospecting was carried on by James R. Leahy, of Rutland and, as a result, the Cuttingsville Molybdenum Corporation was formed to prospect the promising deposit.

The prospecting showed a mineralized zone over 3,100 feet long and some 125 feet wide, in which molybdenite occurs in characteristic gray flakes, associated to some extent with the yellow molybdite (Fe_2O_3. MoO_3. H_2O). Some of the mineral, at least, is of high grade, analyses showing as much as 30 percent of molybdenum, while the "dump" averaged 1½ percent.

In July, 1936, the property was taken under option by the Molybdenum Corporation of America, one of the three largest producers of molybdenum. It is understood that, if a sufficient tonnage is indicated by exploratory methods, this corporation will erect a concentrator and proceed with the extraction of the mineral.

Molybdenum is finding increased use in the manufacture of alloy steels which are today so largely used in automobile construction, as well as in dyeing, lubricants, etc.

[1] Eruptive Rocks at Cuttingsville, Vt.; J. W. Eggleston, 11th Rpt. Vt. State Geol. (1917-18).

An Account of Vermont Geology

Elbridge C. Jacobs

Introduction

The increasing number, and presumably ready sale, of so-called popular books on geology and kindred out-of-door sciences shows very clearly that the public is becoming more nature minded as time goes on, that many people even in this restless motor age realize that there are indeed "sermons in stone" and "books in the running brooks" and fain would know something of them.

And so, each year, a good many letters reach the State Geologist's office from Vermonters and especially from summer residents in the State and visitors, asking for information concerning the mountains and the lowlands, the rocks and the minerals and the mineral resources of this commonwealth.

Such information is to be found in the various Reports of the Vermont State Geologist, many of which are out of print, and in geological journals, where they are not available to the general reader; while many new facts have come to light and should be recorded.

The last comprehensive work was the Geology of Vermont (two volumes, 1861) by President Edward Hitchcock, of Amherst College. Since then geology has made great advances and the old volumes are of little value—furthermore they are nearly out of print.

It has seemed fitting, therefore, to prepare this rather short article for which the title, Geology of Vermont, would be too ambitious. We also need very much a good geological map of the State. To be sure a great deal of exploration and study, especially in the Green Mountains, remain to be done but, in a large way, a fairly satisfactory map could be prepared if the needed funds were available.

For the portrayal of the physiography of the State (geomorphology is just the word) we are very fortunate in having the relief model, or map, which was built in 1931, under the auspices of the Vermont Commission on Country Life. The model is 85 inches long and 54 inches wide. The horizontal scale is two miles to the inch (approximately twice that of the United States topographical sheets) while, vertically, the exaggeration is four to one, which makes our loftiest mountain, Mansfield (4,393 feet above sea level) one and two-thirds inches high. Many relief

maps suffer from too great vertical exaggerations, which give Alpine appearances to very unalpine elevations. It is believed that we have escaped this error in our Vermont map.

On the model the chief relief features stand out clearly. In the southwest portion are seen the Taconic Mountains which enter the State from Massachusetts. One sees lying east of these the Vermont Valley trending to the north and debouching upon the Champlain Lowland, with its low ridges and shallow valleys, and glorious lake. Then comes the mountain backbone, the Green Mountain system, extending through the State as a great massif, almost uncut by passes to the latitude of Rutland whence, trending somewhat to the northeast, it spreads out fanlike into several separate ranges. East of the mountains lies a plateau-like region very much dissected into hills, low ridges, and deep valleys. This is the Vermont piedmont.

Rivers, lakes, ponds, railroads, trunk highways—all are shown, while county and township lines enable one to locate this or that feature or place accurately.

These relief models are to be found in the Fleming Museum of the University of Vermont, and at Middlebury College, while a third has recently been installed at the State Capitol. A photographic reproduction forms the frontispiece of this volume.

Contents

Area and Boundaries[1]

The area of the State is 9,564 squares miles. The maximum length is about 126 miles, while the maximum width, which is at the international boundary, is about 93 miles.

One or more of the boundaries of Vermont has been in controversy from the date of her admission to the Union, March 4, 1791, until May 29, 1933.

The western boundary seems to have given the least trouble and it was determined before 1791. From south to north it was

[1] Information taken from Boundaries, Areas, etc., of the United States and of the Several States; E. M. Douglas, U. S. Geol. Survey Bulletin 817 (1930).

marked by the western boundaries of the townships of Bennington and Rutland counties as far north as the Poultney River, thence down the channel of the river to East Bay of Lake Champlain and northward through the middle of the deepest channel of the lake to the border. The most westerly point of this "deepest channel" lies off Crane's Point, Addison, in longitude 73° 26.3′. The Vermont-New York line, from the Massachusetts-Vermont-New York corner to the Poultney River, was resurveyed in 1904.

To end the long dispute between the Royal Provinces of New York and Massachusetts Bay, from parts of which Vermont was carved, Kind George Third, on the 20th of July, 1764, decreed that the western bank of the River Connecticut from where it enters the Province of Massachusetts Bay as far north as the 45th degree of north latitude should be the boundary of the said two provinces of New York and New Hampshire, thus fixing the northern boundary of the present State of Vermont at latitude 45°.

In 1767 astronomical observations were made on the east shore of Lake Champlain and a mark was set at the supposed position of the 45th parallel. But later surveys showed that this boundary, for its entire length, was from a quarter of a mile to one and one-tenth miles north of the 45th parallel.

In 1842, by convention between the United States and Great Britain, a line running west from Hall's Stream, a tributary of the Connecticut, to the deepest point in Lake Champlain was agreed upon as part of the northern boundary of the United States. From this survey the northwestern corner of Vermont, and the northeastern corner of New York, falls in Lake Champlain, in latitude 45° 00′ 38.9″; longitude 73° 20′ 38.9″.

The beginning of the line, in the middle of Hall's Stream, is in latitude 45° 00′ 48.7″; longitude 71° 30′ 05.7″. The Vermont-New Hampshire line then runs east for about one and three-fourths miles to the west bank of the Connecticut River, the approximate position being latitude 45° 00′ 50″; longitude 71° 27′ 57″, which marks the extreme northeastern boundary of Vermont. This small area east of Hall's Stream, known locally as "The Gore" is often incorrectly shown as a part of New Hampshire.

The southern boundary of Vermont was the northern boundary of Massachusetts Bay, which was fixed by King George in council under date of August 5, 1740. It was resurveyed and remarked by a commission representing the two states between 1885 and 1898. The southwest corner is in latitude 42° 44′ 45.2″; longitude 73° 15′ 54.9″. From this point the line runs nearly straight, bearing about two degrees south of east for 41 miles, to the south-

east corner of Vermont, marked by a monument on the west bank of the Connecticut River.

The eastern boundary of the State was long in dispute, first between the royal provinces of New York and New Hampshire, later between the independent states of New Hampshire and Vermont. Vermont maintained that the old English common law rule, the *medium filum aquae,* or thread of the stream, delimited her eastern boundary; while New Hampshire maintained that King George's order in council, July 20, 1764, fixed her western limit at "the western banks of the River Connecticut." The controversy dragged down through the years.

Joint resolutions of the Legislature of Vermont, approved November 22, 1912, and February 13, 1913, authorized a suit in the Supreme Court of the United States to settle the position of the boundary line. Vermont asked that the boundary be declared the channel of the Connecticut River (the thread of the stream). New Hampshire, in its reply to the Vermont bill of complaint, asked that the boundary be fixed at the high-water line on the west bank of the river; also that the north boundary of Vermont end at Hall's Stream, instead of at the Connecticut River, one and three-fourths miles farther east. This claim regarding the termination of the boundary at Hall's Stream was later abandoned.

On October 13, 1930, the Supreme Court appointed the Hon. Edmund F. Trabue Special Master to make "special findings of fact and conclusions of law and to submit his findings to this Court with all convenient speed, together with his recommendations for a decree," etc.

As a result of the Master's hearings and recommendations to the Supreme Court, that body decreed (May 29, 1933) "That the true boundary is at the low-water mark on the western side of the Connecticut River, as the Special Master has found. We adopt his definition of low-water mark, which is not challenged here, as the line drawn at the point to which the river recedes at its lowest stage without reference to extreme drought."

Lake Champlain

"Sing a song, a rich refrain,
And let echoes swell the strain,
To our lake, our loved Champlain,
Lovely Lake Champlain."

So sing the students of the University and as they sing, hats come off and they stand at "attention"; it is their college song.

And what more inspiring theme for a song than this noble body of water bordered by low shores and jutting headlands, set with verdant islands, great and small, and encircled by the lofty peaks of the ancient Adirondacks and the graceful ridges of the Green Mountains and the Taconics. On its shores, as Stafford writes, "The delicate beauty of unnumbered springtimes, the flaming glory of unnumbered autumns."

The lake[1] is 107 miles in maximum length and it extends five miles into Canada. The maximum width is ten miles, this in about the latitude of Plattsburg. The lake is about 95 feet above mean sea level. (See p. 74, footnote.)

There are some eighty islands, of which Grand Isle, North Hero, Isle La Motte, and Valcour are the largest.

The area of the lake is, in New York, 151 square miles; in Vermont, 322; in Canada, 17; total, 490 square miles. The combined areas of the twelve largest islands is 55 square miles, leaving the water surface, 435 square miles.

The deepest channel of Champlain which, as already noted, forms the New York-Vermont boundary, runs a sinuous course, first between the New York shore and Isle La Motte and Grand Isle, then nearer the middle of the lake to Split Rock and Thompson's Point, south of which, it trends more towards the New York side as far as the latitude of Port Henry, beyond which it continues south through the narrow part of the lake and up East Bay to Poultney River. The deepest sounding, 399 feet, is a little over two miles north of Split Rock Point.

Now lakes are ephemeral things. They are called into being by various causes, such as dislocations of the earth's crust, damming, etc., and ultimately they are filled up with the sediments of entering streams, or by growing plants, and pass out of the picture—"They have their day and cease to be."

There is evidence that our lake occupies a down-dropped block in the earth's crust, due to a process called faulting, of which more later. If one imagines this block as being hinged on the Vermont side and dropping down near the opposite shore, like a huge, horizontal trap door, he will visualize the situation and the process. It is probable that, before the lake came into being, there was an ancient river which ran south and entered the Hudson.

At about the close of the Great Ice Age, which happened in this part of the world some twenty or thirty thousand years ago, the differential rise of the region impounded the glacial waters and Lake Champlain was formed, a vastly larger lake at that

[1] U. S. Coast and Geod. Survey data.

time whose shores can be traced as far inland as Richmond, where the old shore lines reach the 600-foot contour of the topographic sheets, and can be followed northward to Westford, with the old lake benches showing up clearly on Cobble Hill and Arrowhead Mountain; and southward nearly to Rutland.

There was also a marine invasion in late glacial times, in proof of which is the skeleton of a small whale, shown in the State Cabinet at Montpelier, which was found in 1849, at Charlotte when the Burlington and Rutland Railroad was being built. Furthermore, small marine shells (Saxicava, Leda, Mya, Macoma, etc.) are still to be found along the lake shore, while the smelt which our fishermen angle for through the ice, trace their lineage back to the salt-water period of the lake's history.

And so Champlain was born of the glaciers. It was claimed for a time by the sea god, Neptune, and now, in this more genial age, it remains a thing of beauty and a joy—but not forever.

Fundamentals

"The time has come, the walrus said,
To talk of many things":—If he had been a geologically-minded walrus he might have added—
Of rocks and folds and overthrusts,
Of lakes and streams and springs;
And how the mountains came to rise—
And what the glacier brings.

A wise man has said: "He who would gather the wealth of the Indies must take the wealth of the Indies with him." In other words, we must possess knowledge if we would acquire more knowledge. So let us begin as simply as may be. This is not the place for a treatise on geology, nor is one needed; for of late years numerous books on the subject have been written, many of them of an elementary nature that offer few difficulties to the average reader.

A list of good books will be found at the end of this section.

Our earth is essentially made up of rocks, of many kinds and conditions. To the geologist even sand is included, for he knows that it is merely former rock masses that have been reduced to fine grains by the wearing down processes which we call erosion, and that some day it will become cemented into massive rock again. So he calls sand unconsolidated rock and includes with it gravel and even boulders. Nor does he hesitate to include ice, which covers millions of square miles of the Arctic and Antarctic regions, as a rock even though its melting point be low.

Next, most rocks are composed of one or more minerals, and minerals are naturally occurring elements, like gold, silver, copper, graphite, etc., or definite unions of the elements, called chemical compounds, such as oxides (and ice is the solid phase of oxide of hydrogen, or water), sulphides, carbonates, silicates which constitute a vast division of minerals, etc.

Now nearly all of the minerals have an urge to assume geometric forms: variously shaped plane faces, symmetrically arranged about certain directions known as crystal axes. These we call crystals. Many of these crystals are among the most beautiful things in nature and the science which studies them is crystallography. Crystallographers find that all crystals can be brought within six systems of crystallography, these systems being defined by the number and relative inclinations of the theoretical axes. The six systems are the Isometric, Tetragonal, Hexagonal, Orthorhombic, Monoclinic, and Triclinic. Of these the Isometric is the most, and the Triclinic the least, symmetrical. Here a reference book with illustrations is "indicated."

Crystals are the choice things of the mineral kingdom. They are the "educated" minerals; they have the urge and the opportunity to develop themselves. In other cases the urge is weak or the opportunity, or physical conditions, lacking and we get not crystallized but cryptocrystalline minerals whose true inwardness is revealed by the microscope equipped for polarized light. Massive quartz is a good illustration. These are the poor "students" who just haven't gotten on. Finally, in a vanishingly small number of cases, minerals are simply "dumb"; they are absolutely incapable of making a crystallizing effort. These we call amorphous. Opal is an example and, like other "dumbbells," is often very beautiful.

Those minerals which make up the rocks, we call the rock-making minerals.

Prof. F. W. Clarke, of the United States Geological Survey, calculated, years ago, that of the ninety odd elements known to man, only sixteen are geologically important and make up 99 percent of the earth's crust. These are:

Oxygen	47.33%	Titanium	0.46%
Silicon	27.74	Hydrogen	0.22
Aluminum	7.85	Carbon	0.19
Iron	4.50	Phosphorus	0.12
Calcium	3.47	Sulphur	0.12
Potassium	2.46	Barium	0.08
Sodium	2.46	Manganese	0.08
Magnesium	2.24	Chlorine	0.06
			99.04

A few of the elements, gold, silver, copper, platinum, etc., occur in the uncombined state as minerals, but it is seen that these are insignificant in the great scheme of things. The rock-making minerals are generally combinations of two or more of the above sixteen elements.

It is seen that oxygen, silicon, and aluminum comprise over 80 percent of the crust. The two most common minerals of the earth's crust are quartz (SiO_2), oxide of silicon, and feldspar, a family of minerals of which orthoclase ($KAlSi_3O_8$), a silicate of potassium and aluminum, is the best known.

Rock-making minerals may be divided into two groups, the non-metallic and the metallic. The former are so called because they do not resemble metals; they are transparent to translucent and they have not the peculiar luster of iron, copper, gold, and other metals. The metallic minerals are opaque and do resemble the metals in their luster.

Some Non-Metallic Minerals

QUARTZ

This mineral is to be found practically everywhere in Vermont, mostly in the uncrystallized, or massive form, constituting considerable portions of the mountain schists, gneisses, etc., or the lowland sandstones and sand banks, but sometimes occurring as crystals with beautifully developed hexagonal prisms, surmounted by six-sided pyramids. Quartz varies widely in color. While inherently colorless, it is seen in many colors due to the presence of minute impurities. It is harder than your knife, standing No. 7 in the scale[1] of 10, and has a vitreous or glassy luster. It has a specific gravity of 2.65 (2.65 times as heavy as an equal volume of water).

FELDSPAR

Feldspar is the name of a family of minerals which are, chemically, silicates of aluminum, potassium, sodium, calcium and, rarely, barium. The members of the family are orthoclase, microcline, albite, oligoclase, andesine, labradorite, bytownite and anorthite. Of these, orthoclase, microcline and albite are the most common in our Vermont rocks.

Feldspars crystallize in the monoclinic and triclinic systems, but good crystals are rare in Vermont and the minerals are found

[1] *Scale of Hardness.*—Ten minerals make up the scale. Each will scratch the preceding. 1, talc; 2, gypsum (both scratched by the finger nail); 3, calcite; 4, fluorite; 5, apatite (3, 4, 5, scratched by a knife); 6, orthoclase; 7, quartz; 8, topaz; 9, corundum; 10, diamond. Minerals of the same hardness will scratch each other.

in the massive form, making up parts of the granites and syenites of the igneous rocks, the schists and gneisses and other members of the metamorphics, and some of the sedimentary rocks. Feldspars are differentiated in thin rock sections studied under the microscope in polarized light. The luster (or "kind of shine") is softer and lacks the vitreous quality seen in quartz. This is the best way of telling them apart. The color is most often gray or white and the hardness is six in the scale of 10. The specific gravity varies from 2.55 to 2.76. Note that quartz is about the average of these limits and, furthermore, that the specific gravity of the earth's crust as a whole is about the same. Evidently quartz and feldspar are our fundamental minerals.

KAOLIN

Minerals occur as primary, secondary, and metamorphic. Quartz and feldspar are most often primary, but kaolin is a secondary mineral, formed by the action of chemical solutions in the earth acting on feldspars and other rocks. The following chemical reaction shows how such a change could have been brought about.

Orthoclase + water + carbon dioxide gives kaolin + potassium carbonate + quartz

$$2\,KALSi_3O_8 + 2\,H_2O + CO_2 \rightarrow H_4Al_2Si_2O_9 + K_2CO_3 + 4\,SiO_2$$

In this reaction it is seen that the orthoclase, an anhydrous silicate) has been changed to a hydrous silicate of aluminum, with side products of soluble potassium carbonate, and quartz. Feldspar means field mineral. Its decomposition gives us, largely, our soils and their virgin richness in potash.

Kaolin, formed in place, gives us our rich China clay deposits, such as those at Bennington and, in patches, north as far as Brandon. Impure kaolin, transported by the glaciers, gives us our great deposits of brick and tile clay—enough to make bricks for the nation.

Clay is very soft, has a peculiar odor, and when wet it is sticky, or plastic, which enables the potter to work his will on it. It is widespread in Vermont and woe to the motorist who drives over roads made of it, in wet weather.

MICA

Every year many samples of rock containing shining white or yellow particles are sent to the Geologist for identification. They look promising and the sender secretly hopes that they are gold. Fortunately for him they are not; for if they were he might give

up his dairy and go into gold mining, which would surely spell disaster in this State at any rate.

Mica is the name of a mineral family of complex silicates, whose members include muscovite, or white mica; biotite, or black mica; sericite and several others. Micas are especially characterized by their softness, easy splitting, or cleavage,[1] and by the thinness and flexibility of the cleavage laminae. Sometimes, in veins of pegmatite, micas attain large developments and are used for stove windows, etc. More often, in our rocks, they are of small to microscopic size. The black biotite gives the pepper-and-salt appearance of our best granites; the white muscovite is found in some of the schists; while sericite with its minute scales gives the silvery gray appearance to our mountain schists and gneisses.

AMPHIBOLES

The amphiboles are a family of anhydrous silicates of calcium, magnesium, iron, and aluminum. They crystallize in the orthorhombic, monoclinic or triclinic system and the chrystals tend to be long and often bladed. Well developed crystals are, however, scarce in Vermont. The minerals have many forms and many colors. Their hardness is, on the whole, greater than that of one's knife, while their specific gravity is considerably greater than quartz or feldspar, varying from 2.9 to 3.5.

The chief varieties of amphibole of interest to us are hornblende, whose black, shining blades are seen in hornblende-schists and whose stubby prisms occur in the syenites of Ascutney and Cuttingsville; tremolite, the albino of the tribe, with its white or gray silky appearance, seen at Belmont, in the mountains; and actinolite, in sharp, light green needles, often found penetrating the talc veins in various parts of the State.

It may be noted that true asbestos, whose properties are of course familiar to all, belongs to the amphibole family, but that our Vermont product is a hydrous silicate and has been derived from serpentine. Members of the amphibole family also make up the rock, amphibolite, of which more later.

PYROXENES

Pyroxenes also constitute a family of anhydrous silicates of calcium, magnesium, iron, aluminum, while rhodonite contains manganese. They crystallize in the orthorhombic, monoclinic or triclinic system and are generally more "stubby" than the

[1] Cleavage is the property that minerals have of splitting up into smaller pieces, with smooth surfaces which are parallel to actual or possible crystal faces. Micas possess this property in the highest degree.

amphiboles. The hardness ranges from 5.5 to 6.5 and the specific gravity from 3.1 to 3.7. The colors vary widely, from black augite to nearly white enstatite, green jadeite and pink rhodonite.

Pyroxenes of microscopic size are found in thin sections of diorite, peridotite, and pyroxenite, which occur chiefly in the eastern half of the State, while augite-camptonite dikes are very numerous both east and west of the mountains. Sizeable specimens of pyroxenes are rare, though augite has been reported in Chester and rhodonite in Irasburg, Topsham and Cavendish.

OLIVINE

Olivine is a silicate of magnesium often containing iron, crystallizing in the orthorhombic system. Its colors are varying shades of green, yellowish to olive, and it is characterized by a sugary texture. It seldom occurs as individuals in Vermont, but its presence in the basic intrusives and its alteration have given rise to the extensive deposits of serpentine and talc in the State.

SERPENTINE

Serpentine is used as the name of a mineral and also of a rock, although serpentenite is sometimes used for the latter to distinguish it from the mineral.

Serpentine is a secondary mineral, a hydrous silicate of magnesium ($H_4Mg_3Si_2O_9$), derived from magnesium-containing minerals by a process similar to that which, we saw, changed orthoclase to kaolin. The reaction may be written:

Olivine	+ water	+ carbon dioxide	gives	serpentine	+ magnesite
$2\,Mg_2SiO_4$	$+\ 2\,H_2O$	$+\ CO_2$	$\rightarrow$	$H_4Mg_3Si_2O_9$	$+\ MgCO_3$

Note the similarity of the kaolin molecule to the serpentine molecule.

Serpentine is in some occurences massive, as in our verd antique quarries, and in others fibrous, giving us the hard, splintery picrolite, also found in the verd antique quarries. The color of the massive varieties is typically olive green, but yellowish-greens, blackish-greens, and yellows occur. The hardness is 2.5 to 3, the luster is resinous to greasy and the mineral often has a greasy feel.

Verd antique, which is serpentine veined with calcite or dolomite, occurs in a number of places in the State, notably in the Rochester and Warren valleys, and is one of our most beautiful decorative stones. When polished it is known as verd antique marble which is one of the choice products of the Vermont Marble Company.

ASBESTOS

Asbestos is a word loosely used. We have seen above that it is properly a variety of amphibole, an anhydrous silicate. But the word is used for our serpentine "asbestos" whose real name is chrysotile. The long, flexible, silky fibers in choice specimens, or the short, woolly ones in most of our Vermont material, is characteristic. Its resistance to high temperatures is outstanding and so it finds extensive use in theatre safety curtains, "movie" booths, auto-brake linings, asbestos shingles (which by the way contain only about 15 percent of asbestos) and other things.

Chrysotile asbestos is being extensively quarried on Mount Belvidere, while the great quarries of southern Quebec, to which our deposits are closely related, are the greatest in the world.

TALC

Talc is $H_2Mg_3Si_4O_{12}$, another hydrous magnesium silicate. Its color is white to gray and green and it is the softest mineral known, therefore, standing No. 1 in the scale of hardness. It has a greasy feel and millions of people use it for face powder, of late years wonderfully tinted—to simulate youthful complexions. Talc seldom or never crystallizes.

Talc is a secondary mineral, produced by percolating chemical solutions acting on basic, intrusive rocks. In Vermont it is closely associated with serpentine. Two varieties are found: The beautiful sea-green, foliated talc, which is one of the loveliest of minerals and, like other lovely things, not at all common; and the massive, white or gray variety which is the talc of commerce. A great broken chain of talc deposits (in some places a double chain) extends, north to south, throughout the State. Talc is being extensively mined today at Windham, Moretown, and Johnson. See the article in this bulletin on Mineral Resources.

SOAPSTONE OR STEATITE

Soapstone is made up of a mass of interwoven fibers of talc, chlorite and other minerals. Like talc it is heat resisting and, better than talc, it does not disintegrate under wide ranges of temperature. It is of grayish color, very soft and sectile.

Soapstone was formerly used for foot warmers in the "one horse, open sleigh," for stoves, etc. It is still used for griddles, sinks, flatiron cores, and the like. It is still being quarried at Athens, Chester, and Perkinsville to a small extent, and good specimens can be obtained.

GARNET

Garnet is the name of a family of silicates. The most common is the red to brownish-red almandite, $Fe_3Al_2(SiO_4)_3$—which means orthosilicate of aluminum and ferrous iron. It is a hard mineral, 6.5 to 7.5 in the scale, and it crystallizes in the isometric system, most commonly as twelve-sided, "diamond" shaped (playing card "diamond") crystals, called dodecahedrons, and trapezohedrons (see a text book). You will find many of them in our schists and gneisses, notably up the North Branch of the Winooski River and along the beautiful road through the mountains, leading from Bennington to Brattleboro. It was quarried for a time at Cavendish for use as an abrasive.

EPIDOTE

Epidote is an exceedingly complex silicate of calcium, aluminum and iron. It is a product of metamorphic (see later) changes in igneous or sedimentary rocks and, although it sometimes crystallizes in the monoclinic system, it is most often seen as a fine-grained rock of peculiar green hues, yellowish-green to olive. It may resemble serpentine but is harder (6 to 7 in the scale, compared with 2.5 to 3 for serpentine). It occurs in various parts of the State, but the greatest exposure known to the writer is the ridge in Roxbury on the sides of which verd antique has been quarried for over eighty years.

CHLORITE

Another alteration product of other minerals is chlorite, which really is the name of a family rather than of a single mineral.

As the name suggests it is green in color, usually dark, and its hardness is about 2. Although chlorites do crystallize in the monoclinic system, their urge to do so is not great and they generally occur in thin flakes and leaves. They give the green shade to a great many of our schists and gneisses—along the road, for instance, from Middlesex to Montpelier and in a thousand other places. In the old quarries around Chester they make up chlorite schists, so thinly laminated that they used to hang down like the leaves of an open book. Mineralogically the color of the Green Mountain rocks is due more to chlorite than to any other mineral, except perhaps sericite.

TOURMALINE

Tourmaline is a mineral of various colors, but in Vermont only the black is common. It crystallized in the hexagonal system as long striated prisms, terminated with three-sided pyramids. The

mineral is a complex silicate. It is usually highly lustrous and is hard (7 to 7.5). It is an easily recognized mineral and is found in many places in the State: In the Chester talc quarries, in Guilford, Grafton, Newfane, etc. It is also seen, microscopically, in the schists and gneisses of the State.

KYANITE

Kyanite is Al_2SiO_5, silicate of aluminum. It occurs in long blades, sometimes white but more often of a peculiar steel-blue shade. It is translucent (like ground glass) and hard (5 to 7 in the scale). It belongs to the metamorphic minerals and has been found in Woodstock, while, years ago, fine specimens could be had in Irasburg.

Besides the silicates, simple and complex, which we have been briefly considering, there are two simple non-metallic minerals, calcite and dolomite, that loom large in the scheme of things.

CALCITE

Calcite is $CaCO_3$, calcium carbonate. It is a "salt" of H_2CO_3, carbonic acid—that is, the H_2 of the acid has been replaced by Ca. Now if we add an acid, HCl (hydrochloric acid), for example, to the calcite, the mineral "fizzles" or effervesces, more elegantly, and we get H_2CO_3 given off. But this is unstable and breaks up into H_2, and CO_2 which we call, inexactly, carbonic acid. All carbonates have this property and so can be easily recognized.

Calcite crystallizes in the hexagonal system (in the rhombohedral division of it, more exactly), the crystallizing urge is great and the crystal forms are numerous and beyond the scope of this article. Uncrystallized or massive varieties are common. The mineral has perfect cleavage, breaking up, when struck, into smaller, perfectly shaped duplications of the original. Its hardness is 3, just beyond that of one's fingernail, and its color is colorless to white. The crystals are transparent and lustrous; the massive varieties dull.

Besides being interesting as a mineral, calcite is the stuff of which limestone and marble are made. It is also to be seen filling the cracks of various rocks, where it has been deposited from solution. It is quite soluble in water containing CO_2 and is one of the causes of "hard" water.

DOLOMITE

In this mineral the calcium of calcite has been partly replaced by magnesium and we get $CaMg(CO_3)_2$, calcium-magnesium carbonate. The properties of dolomite are so much like those of calcite that it is difficult, in the field, to tell them apart. Its chief interest for us lies in the fact that it makes up several of our rock formations in the Champlain Lowlands and elsewhere.

Some Metallic Minerals

GOLD

Although decidedly not a rock-making mineral, gold is so inevitably in the mind of man that whenever a geologist is seen working at his trade, breaking rocks to get fresh exposures, or examining the lie of a formation, he is at once suspected of "looking for gold," hence it must be briefly considered here. As already stated gold does occur, though in vanishingly small quantities, in many places in New England but we have yet to find a deposit of profitable extent.

Gold crystallizes in the isometric system, often as octahedrons —come to the Fleming Museum of the University and see some beautiful examples—but is most often found in small grains and scales, sometimes in large lumps or nuggets, of which the famous Welcome Nugget of Australia was literally a shining example. Its color is, typically, golden yellow, quite unlike that of pyrite or even of chalcopyrite, and it is very soft, malleable, ductile, and of very high specific gravity (15.6 to 19.3). It occurs primarily in veins in quartz and in other rocks, generally associated with metallic sulphides; and secondarily, in stream beds forming placer deposits.

Vein gold was discovered in Bridgewater in 1851 but gold winning was never successful. Gold in placer deposits also occurs in the township which are said to have yielded several thousand dollars worth of the metal. How much it cost to obtain this yield was not stated but it is Professor Perry's[1] opinion that gold winning is "hardly more than a holiday diversion at best." Gold has also been "washed" in Stowe and probably in other places in the State.

PYRITE

Pyrite is often called "fool's gold" for obvious reasons. Chemically it is FeS_2, disulphide of iron. Its urge to crystallize is prodigious and we find it widely distributed as cubes, often striated, and octahedrons, or eight-faced crystals, of the isometric system. It also occurs in shapeless masses.

[1] Geology of Bridgewater and Plymouth; E. L. Perry, 16th Rpt. Vt. State Geol. (1927-28).

Its color is generally brass yellow and it is so hard that it will strike fire, hence the name. Many people, attracted by its form and color, bring it to the Geologist secretly hoping that it is "what many men desire," but of course it isn't; it's too hard and brassy-looking to be gold.

Fine cubes of pyrite occur in the chlorite schists around Chester, while the mineral is to be found in our metamorphic rocks pretty much all over the State.

PYRRHOTITE

This is sometimes called magnetic pyrites, since it is attracted by the magnet when pure but not otherwise. It is Fe_7S_8, sulphide of iron, it has a bronze color and is soft (3.5 to 4 in the scale). By these properties it is easily told.

Pyrrhotite occurs in large quantities with the copper ore at South Strafford, Vershire, and East Corinth. It is also disseminated in the rocks in many parts of the State.

CHALCOPYRITE

This is one of the ore minerals, that is minerals from which one or more metals can be profitably extracted. Its composition is $CuFeS_2$, sulphide of iron and copper, and it is one of the great sources of copper. Chalcopyrite is sometimes found as small wedge-shaped crystals but is much more likely to occur in yellow masses which fool people as pyrite fools them. It is much softer than pyrite (3.5 to 4, compared with 6 to 6.5 for pyrite) and this fact together with its golden-yellow color readily places it. Back in the eighteen seventies Vermont was a large producer of copper, which was mined in South Strafford, Ely, or Vershire, and East Corinth. The ore was chalcopyrite mixed with pyrrhotite. Chalcopyrite occurs also in Wolcott, Berkshire and Richford, while small pockets of it were found in the talc deposits of Stockbridge. The occurrence of such ore minerals of gold, silver, copper, lead, tungsten, etc., in alluring but unprofitable quantities all through New England and in the Maritime Provinces has proved very unfortunate for ambitious miners and smelters.

MOLYBDENITE

Molybdenite is MoS_2, sulphide of molybdenum. It crystallizes in the hexagonal system but is generally found in disseminated grains and flakes. It has many of the properties of graphite—softness, greasy feel, rubbing off onto fingers, marking on paper—but its color is blue-gray instead of black. The metal, molybdenum, obtained from it, is in great demand for alloy steels for tools, automobiles, etc., in textile manufacture, and as a lubricant.

In Vermont a deposit of molybdenite has recently been discovered at Cuttingsville and is being developed. Molybdenite has also been reported at Brighton.

CHROMITE

This mineral has the composition, $FeCr_2O_4$, oxide of chromium and iron, and is an important ore of chromium—and chrome steel, used on our automobiles, saves us a lot of trouble because it is rust proof.

The mineral is brownish black in color, is harder than your knife, and may be slightly magnetic. It occurs in small masses in our serpentines, usually in the northern part of the State, at Troy, Lowell, Jay, Westfield, and perhaps in other places.

MAGNETITE

This is magnetic oxide or iron and is a combination of the two oxides of iron, Fe_2O_3. FeO, ferric and ferrous oxides, respectively. It strongly attracts the magnet. Its color is black, its hardness 5.5, it is lustrous, and its specific gravity about 5.

It is another of the minerals with a strong urge to crystallize and occurs commonly as eight-sided crystals, in the isometric system, called octahedrons. It also occurs in great masses and is an important ore of iron in New York State, being mined at Mineville and smelted at Port Henry. It is very widely disseminated through our mountain schists and gneisses and small boys have a lot of fun fishing it out with magnets from stream beds whither erosive processes have carried it.

ILMENITE

Ilmenite is $FeTiO_3$, oxide of iron and titanium. It sometimes crystallizes but is more often found in disseminated grains of microscopic proportions in the mountain rocks. Sometimes, up in the mountains, one finds it in thin plates or small, irregular masses and recognizes it by its black or brownish black color and brownish red streak.[1]

GRAPHITE

Graphite is crystalline, sometimes crystallized, carbon (C) and occurs in small scales and leaves but sometimes in compact masses.

[1] Streak is the color of the powder of a mineral. It is obtained by rubbing the mineral on a piece of unglazed porcelain or a bit of Arkansas stone which may be had at a hardware store.

Its color is black to dark gray, it is very soft, shiny, soils the fingers and marks paper. It is the essential ingredient of lead pencils.

It occurs in Vermont at Ripton, disseminated in the schists, and in the mountain rocks as small scales, forming graphite schists. In Johnson considerable masses of nearly pure graphite are found.

Finally, in this brief summary, we have several minerals of mixed properties which we call sub-metallic. They combine the opaqueness of the metallic minerals with the earthy and lusterless appearance of the non-metallics.

HEMATITE

Hematite is Fe_2O_3, ferric oxide or red iron ore. It crystallizes in the hexagonal system but is more often found in the massive state and in many varieties: lustrous, specular iron ore, kidney ore, massive red hematite, earthy red ocher, etc. Its color varies through several shades of red, to black, but its streak is a constant cherry red. Its hardness varies widely, and its specific gravity is about five.

Hematite is our most important iron ore, occurring in enormous quantities in the Lake Superior district, and furthermore it is perhaps the most widely disseminated of minerals and is one of nature's most abundant pigments, giving the gorgeous colors to the Grand Canyon of the Colorado River, the Garden of the Gods in Colorado, and everywhere giving us rocks of varying shades of red. There is practically no hematite ore in Vermont but the Monkton Hills along the lake shore and farther inland, the slate of eastern New York, and rocks in many places in Vermont are red because of the presence of this mineral.

LIMONITE

Limonite, or bog iron ore, is $Fe_2O_3 \cdot nH_2O$, hydrated ferric oxide. It is a secondary mineral and never crystallizes, although it may mimic the crystal forms of other minerals which have superficially altered to it. Such mimics are called pseudomorphs. Its hardness varies widely (1 to 5.5) and its color may be yellow to brown and to black. But its streak is always yellowish brown, which distinguishes it from the red streak of hematite. Its earthy form is called yellow ocher.

In the early days of the State bodies of limonite were mined at Wallingford, Plymouth, Bennington, and other places, and

smelted for wrought iron in small furnaces both in Vermont and in other states.

Besides being an ore of iron limonite is the yellow pigment of nature, as seen in many of our rocks.

SIDERITE

This is $FeCO_3$, ferrous carbonate and in crystallization it closely resembles calcite and dolomite. Its color is light to dark brown while its hardness is 3.5 to 4.5. The color usually distinguishes it.

Siderite was mined years ago at Tyson Furnace.

PSILOMELANE

Psilomelane (the "p" is silent) is $MnO_2 \cdot H_2O$ plus several other elements. It is another of the "dumb" minerals, with no capacity for crystallizing, and occurs as rather soft, brownish-black masses, often earthy and smearing the fingers when rubbed. It is an important ore of manganese, which is used in the manufacture of alloy steels and other purposes.

In Vermont it occurs, probably associated with other manganese minerals, in Wallingford, Bennington, Bristol, Plymouth and in other localities. At the places mentioned it is associated with kaolin and yellow ocher.

Reference Books

The following books are suggested for those (many it is hoped) who may want to go more deeply into the subject than this rather brief account permits.

Down to Earth; Cronies and Krumbein, University of Chicago Press, Chicago, Ill. This is a book written in a clear, breezy style and profusely illustrated. It is especially well suited to the lay reader.

Textbook of Geology; Part 1, Physical Geology, Longwell, Flint and Knopf, of Yale University; Part 2, Historical Geology, Schuchert and Dunbar, of Yale University, John Wiley & Sons, New York (1933).

An Introduction to Physical Geology; W. J. Miller, of the University of California, at Los Angeles.

An Introduction to Historical Geology; by the same author, D. Van Nostrand Co., New York (1935 and 1937, respectively).

Rocks and Rock Minerals; Pirsson and Knopf, John Wiley & Sons (1908).

Introduction to the Study of Minerals and Rocks; A. F. Rogers, of Stanford University, McGraw-Hill Book Co., New York (1921 or later).

Handbook of Rocks; J. F. Kemp, late of Columbia University, D. Van Nostrand Co. (1923 or later).

Geologic Structures; Bailey and Robin Willis, McGraw-Hill Book Co., New York (1934).

Rocks

The earth is made up of organic and inorganic substances. Organic things are the multitudinous compounds of the carbon atom and include the animal and vegetable kingdoms. Inorganic substances embrace all else, including minerals and rocks.

As already stated, most rocks consist of masses of one mineral (for instance, limestone is made up essentially of the mineral, calcite) or aggregates of several minerals (for example, granite is composed essentially of quartz and feldspar and, nearly always, mica). There are, also, rather exceptional rocks made up of natural glasses, such as the black obsidian of Yellowstone Park and other places. These are, strictly speaking, not mineral substances since they are not homogeneous chemical compounds.

We have also seen that sedimentary rocks may be either unconsolidated or consolidated and that, in the processes of nature, one class changes into the other (Fig. 1). The earth's crust, to a depth of thousands of feet, is made up essentially of solid rock, known as bed-rock, which appears here and there at the surface as

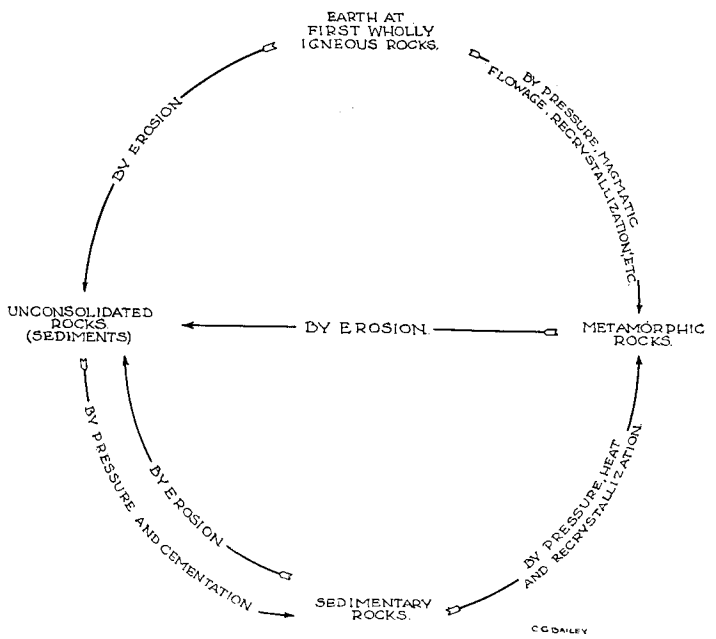

FIG. 1 THE ROCK CYCLE.

outcrops. This bed-rock may be buried under hundreds of feet of unconsolidated rock and its admixture of organic material, which we call soil or the regolith.

THE ROCK CYCLE

Rocks are classified as igneous, sedimentary, and metamorphic. Geologists believe that the earth was once a molten mass which solidified and formed the crust, or lithosphere. If this is true, then all rocks were originally igneous. From these, by erosion, consolidation, alteration, and metamorphism, the sedimentary and metamorphic rocks resulted. Figure 1, modified from an original of, to the writer, unknown authorship, shows clearly the endless rock cycle which is going on in the earth. To illustrate, let us take binary granite, made up of quartz and feldspar. By erosion there result quartz and feldspar, of which the quartz is very stable, while the feldspar alters to kaolin and many other minerals. By pressure and cementation we may get the sedimentary rocks, sandstone and shale, respectively. By metamorphic processes (pressure, heat, recrystallization, etc.), these may be changed to the metamorphic rocks, quartzite and schist, respectively, which by erosion may again be reduced to sediments and so the cycle be completed. Furthermore, igneous rocks, intruding the other classes, may melt them up and "assimilate" them, thus completing the cycle in another way.

Igneous Rocks

The igneous rocks of the earth's crust are those which have resulted from the solidification and, most often, the crystallization of molten material, from within the earth, which is called **magma.** If the magma solidifies within the crust the product is intrusive rocks; if on the surface, extrusive rocks. If the extrusive magma builds up cones, there result volcanoes; if it solidifies in layers the result is lava plateaus. If the extrusive magma solidifies too quickly to become crystalline it forms natural glasses.

The science which studies and describes rocks is petrography. It makes use of rock sections, ground to the thinness of tissue paper, and microscopes equipped with nicol prisms for producing polarized light—and this you will have to look up in Roger's text book, listed above.

In this brief bulletin we may say simply that igneous rocks in this State occur as **dikes, sills,** and **batholiths.** Dikes are those sheets of igneous rocks, relatively thin, often miles long, and of unknown depth, which we see cutting across the **bedding planes** or **schistosity planes** of the other classes of rocks.

Their **dip** is generally high. In Vermont dike rocks are usually brown to black in color and can be easily recognized. There is an excellent example just outside of Barre City on the road to Williamstown, while other good occurrences are to be seen in the city quarry and in the old Phelps quarry, in Burlington. Over fifty dikes have been found in Chittenden County, many on Grand Isle, while others occur pretty much all over the State. Sills are dike-like bodies lying parallel to the bedding planes of the sedimentaries in which they occur (like separate sheets of paper placed in a book). They are less common than dikes but can be found east of Newport, Vermont, on the cliffs of Mt. Pisgah, east of Willoughby Lake, and in other places.

Batholiths are great masses of igneous rock that, as magma, have invaded the earth's crust, without reaching the surface, and have solidified and crystallized. Of course subsequent wearing down of the crust, by the various agencies of erosion, has revealed them.

Our granite quarries are located on batholiths, while similar masses of granite make up a large part of Essex County. The Vermont Mount Monadnock, in Essex County, and Mount Ascutney, in Windsor, are also essentially batholiths, although they are also called **stocks.**

These igneous rocks naturally have no bedding planes because of the manner in which they were formed, but they do break up into larger and smaller units called **joint blocks,** which are bounded by **joint planes** (see later).

Igneous rocks are composed of essential minerals, which are used as a basis of classification, and accessory minerals, which vary widely.

GRANITE

Granite is the most common igneous rock of the continents. In Vermont it occurs for the most part in the Piedmont region, as will be shown later. Essex County is largely made up of one or more granite batholiths.

The essential minerals of granite are quartz, orthoclase, and almost always muscovite or biotite. The quartz is recognized by its glassy, shapeless grains; the feldspar, by its flashing cleavage faces and softer luster; and the mica, by its thin laminae. The accessory minerals are microcline, perthite, magnetite, apatite, hornblende, and others. The predominating accessory mineral gives the variety. Thus, most of our Barre and Woodbury granites are biotite-granite; while the "Bethel-white" is a quartz-monzonite, in which orthoclase and plagioclase are present in about equal

amounts. Barre granite, which is used wholly for monumental purposes, is famous for its beauty and durability. From the "Bethel-white" stone the Union Station and the new Post Office, in Washington, D. C., have been built.

In Craftsbury occurs, not as a batholith, but on the surface, as glacially-transported boulders, a peculiar "pudding granite," "prune granite" or what have you, which is best known as orbicular granite, and is characterized by round nodules of black mica as large as an inch and one-quarter in diameter. It is a sort of freak granite and, like other freaks, most interesting.

SYENITE

Syenites are sometimes described as quartzless granites, the quartz being either wholly lacking or very subordinate in amount. They are vari-colored granular rocks made up essentially of alkali-feldspars with hornblende, nephelite, micas, etc., as accessory minerals. Varieties of the syenite family are hornblende-syenite, a striking-looking rock of white to gray feldspar peppered with short, stubby crystals of black hornblende; nordmarkite, a greenish-gray, fine-grained rock, containing biotite and aegyrite; pulaskite, an olive-tinted, porphyritic nepheline-syenite, containing aegirine-augite, biotite and other minerals, and some others.

In Vermont syenites make up the greater part of Mt. Ascutney, Mt. Monadnock, in Essex County (to be distinguished from its famous name-sake, Mt. Monadnock, New Hampshire), and in the improperly so-called Granite Hill, at Cuttingsville. They also occur in other places, as will be shown later.

Granites and syenites are classified as acid igneous rocks owing to the large amounts of silica (SiO_2) which they contain (generally over 65 percent for granite and over 55 percent for syenite). The other igneous rocks are known as basics and ultra-basics and contain all the way from no silica to around 50 percent. The more common basic rocks are:

DIORITE

This rock is rather on the border line between acid and basic intrusives. As usually found it is a fine-grained "pepper-and-salt"-looking rock, the "pepper" being hornblende, pyroxene, or biotite, any or all, while the "salt" is plagioclase feldspar plus or minus quartz. Diorites are abundant in the eastern half of the State, where they occur as dikes and batholiths.

PERIDOTITE

Peridotite is defined as a non-feldspathic, crystalline rock, consisting essentially of olivine (the French name for which is *peridot*) and generally containing pyroxenes, biotite, magnetite, etc. The color is various shades of green to black. The rock is not easily recognized and so needs to be studied in thin sections with the microscope. If composed of olivine alone, the rock is called dunite; if pyroxene alone, pyroxenite.

It is from such rocks that our serpentines have been derived. Peridotites and pyroxenites are found in Lowell, Eden and Troy, while dunite is found in the sections cut from the serpentines farther south.

There are other igneous rocks in the State, basalts, diabases, aplites, etc., but they are subordinate to those described and space does not permit their discussion.

Sedimentary Rocks

1. Unconsolidated

In the study of sedimentary rocks we may begin with Figure 1, at that part of the cycle marked "Unconsolidated rocks," which are seen to have been derived from any or all of the other three classes. Naturally the sediments will contain many of the minerals which were in the parent rock. Thus on the beaches of the granite coast of New England the sand is made up of quartz grains but often contains also magnetite and garnets, while the clay resulting from the alternation of the feldspar has been carried to greater depths. On some of the Hawaiian beaches one sees the white, foaming waves dash up onto jet black volcanic sand of basalt, which contains olivine, magnetite, feldspar, etc. On other Hawaiian beaches and in Bermuda one can bathe on soft gray, rounded sand derived from the coral reefs, which are biogenic rocks. Along many of our rivers gravel and sand banks form "bars" which the weak current has temporarily deposited, while there are also deposits of muds and clays which are the decomposed remains of feldspars.

Not only have running water and beating waves reduced massive rocks to sands and muds, but the glaciers of the Great Ice Age have ground the bed-rock into boulders, gravel, sand, and clay. This *débris* was transported for longer or shorter distances, and deposited in peculiar glacial forms, of which more later.

Furthermore, it may be noted here that the great sand and clay banks along the shores of Lake Champlain, sometimes hundreds of feet above the present lake level, and banks high above the surface of our streams, notably along the Lamoille at Fairfax, Johnson, and other places, show impressively the regional rise of the land since glacial times.

CLAY

This is the finest grained product of erosion and is found in river beds and lake shore deposits, either ancient or modern. Its principal ingredient is kaolin, which gives it the property of plasticity. Clay is seldom pure but is found mixed with fine mineral fragments of quartz, mica, and feldspar, and often with iron carbonate and other salts solidified from solution. It has resulted from the alteration of feldspars and other silicates, as shown on page 33.

There are two principal varieties of clay, residual and transported. The former, called China clay, is the purer and has been formed by the alteration, *in situ*, of feldspars and other minerals. From it fine porcelains, such as the French Sèvres and the German Meissen, are made. Transported clay is very impure and has resulted from the alteration of feldspathic material transported by the glacial ice sheet of the Pleistocene. It is the material which is used in brick and tile manufacture.

In Vermont the large deposits of China clay in Bennington have been worked for over a hundred years. There are other deposits in Rutland, North Clarendon, South Wallingford, North Dorset, and Brandon.[1] Deposits of transported clay are found in many parts of the State.

MARL

In many small ponds and muck beds of the State there are deposits of a calcareous clay which is called marl. It is used by the farmers for neutralizing the acidity of their soils.

Sorted and Unsorted Rocks

Water in motion exerts a sorting action on unconsolidated rocks, moving the heavier and larger units a shorter distance than the lighter and smaller grains. The coarser products of the sorting action are gravel (unconsolidated) and conglomerate (consolidated); the finer products are sand (unconsolidated) and sandstone (consolidated); the finest, clay muds (unconsolidated) and shales (consolidated). On the other

[1] The Clay Deposits and Clay Industries of Vermont; E. C. Jacobs, 15th Rpt. Vt. State Geol. (1925-26).

hand boulders, gravel, sand, etc., which the continental glaciers carried along in their courses, are not sorted but lie higgledy-piggledy about where the ice sheet dropped them. This material is known as **glacial till** or **glacial drift.** The largest individuals, often of enormous size, are called **glacial erratics.** The whole State of Vermont was once buried under the continental glaciers of the Great Ice Age, some 25,000 or 30,000 years ago, and consequently glacial material is found nearly everywhere.

In the laying down of sedimentary rocks sometimes the deposition of sediments has been continuous and the bedding planes of adjacent formations are parallel even though crustal disturbances may have tilted or folded the strata. The strata in this case are said to be **conformable.** Different sources of supply may result in alternating beds of sandstone and limestone. Such a case is to be seen in the Phelps quarry, at Burlington, where the steep back wall is made up of metamorphosed sandstone (Monkton quartzite) in which are visible a few strata of conformable pink, Winooski dolomite.

Again, after the laying down and consolidation into rock of one series of strata with its typical fossils, uplift may take place, followed by a period of erosion, often lasting for thousands of years, which wears down the surface. Then renewed submergence may occur and new strata containing different fossils, may be formed on the eroded surface of the older. If there is no difference in dip of the two series of strata the relationship is called a **disconformity.** But if the older series, before the renewed submergence, is tilted and eroded so that the dip of the newer strata, following submergence and renewed deposition, differs from that of the older strata, we have an **angular unconformity.** The period of uplift and erosion of the older series of strata may be so long that newer forms of life appear and may be found as fossils in the newer strata, which is consequently of a different age than that of the older. There is no means of measuring the duration of erosion. It is called a **lost interval.**

Basal Conglomerates

The eroded surface of the older formation may reach sea level and on it the tides and waves may distribute rounded stones, gravel, and sand, derived from the more inland parts of the same formation. With further submergence and consolidation this *débris* is consolidated and so marks the basal formation of a new cycle of deposition. The consolidated material is called a **basal conglomerate.**

2. Consolidated Rocks

Sediments with their entombed plant or animal remains have been deposited (and are being deposited) layer upon layer, on the bottoms of bodies of water: the ocean (near its shores), marginal seas like the Gulf of Mexico, epeiric seas such as Hudson Bay, lakes, and in those shallow seas which once covered great areas of the continents. These sediments accumulated slowly, often to vast thicknesses. Pressure, due to deep burial, or pressure combined with the action of natural cementing material, such as oxides of iron, calcium carbonate, silica, colloidal clay, etc., has consolidated these sediments into sandstones, limestones, dolomites, and shales, depending, of course, upon the kind of material deposited. Oftentimes the sediments were not pure, resulting in siliceous limestones, calcareous sandstones and similar rocks.

The outstanding characteristic of sedimentary rocks is its stratification, or occurrence in definite layers or **strata.** Depending upon the varying nature, condition, and supply of the material deposited, and on the cementing media, strata vary in their texture and thickness and present definite, individual members of various colors. A stratum may be a fraction of an inch or many feet in thickness. Strata are separated from one another by surfaces of easy cleavage, called **bedding planes** or **stratification planes.** As originally laid down, strata were approximately horizontal but, owing to the effect of earth forces, they often appear at various inclinations to the horizontal. They may also be folded and faulted. See page 63.

Sedimentary rocks may be interbedded with one another. "A collection of beds, lying concordantly one above another, and deposited during a given geological period, is called a **formation.**" Knopf.)

SANDSTONE

Sandstone has resulted from the consolidation of quartz grains, held together by the various cementing materials already mentioned. It is characterized by its granular nature, various degrees of coarseness, and color. It passes on the one hand into sandy shales, and on the other into conglomerates. Sandstone often contains other minerals such as feldspar, mica, magnetite, clay material, etc. If mica is present in large amount the rock is micaceous sandstone; if clay material, argillaceous sandstone; if iron

minerals, ferruginous sandstone; if feldspar grains predominate, arkose. If the compacted material consists of minute, angular fragments of other rock material, such as feldspar, sand grains, slate, etc., usually dark in color, and strongly cemented together, the rock is called graywacke (German, Grauwacke), from the gray color which often, but by no means always, characterizes it. Sandstones vary widely in color, due to the nature of the cementing material: reds from ferric oxide (hematite), yellows from hydrated ferric oxide (limonite); gray to white, from calcium carbonate, etc.

In Vermont our most extensive sandstone formation is in the Monkton Hills, a broken chain of hills and low mountains which are located either close to, or some miles from, the Champlain lake shore. Its prevailing color is red of varying shades, and it was formerly called the red sandrock. The greater part of the formation, however, is no longer sandstone but its metamorphic equivalent, quartzite, which will be described later. Various other sandstones occur in the State but so extensive has been the metamorphism of the rocks that sandstones are very subordinate. In places the weathered sandstones and quartzites of the Monkton Hills have yielded Lower Cambrian fossils.

SHALE

Shale is often called mud rock, since it results from the consolidation of mud material, which is chiefly clay. It is characterized by its thinly-laminated, weak structure and grains of microscopic size.

Shales often contain other minerals, especially graphite, pyrite, and calcite, of which pyrite is frequently seen as brass-yellow cubes and calcite as concretions of grotesque shapes which brick makers call "clay dogs." That the latter are really $CaCO_3$ is easily proved by applying a drop of acid to a specimen.

Shales or shaly limestones are to be seen all along the lake shore. Here they are often veined with white calcite which has resulted from $CaCO_3$ filtering into cracks and crystallizing. Extensive formations of black shale, often highly folded and contorted, extend along the west shores of North Hero and Alburg. Fossils of Ordovician age are found in the shales of Grand Isle, North Hero, Chimney Point, and other localities.

LIMESTONE

Pure limestone is composed of the mineral, calcite, which is calcium carbonate ($CaCO_3$). It effervesces freely even with such

weak acids as those found in vinegar and lemon juice, or with dilute hydrochloric acid (HCl), prepared by diluting 1 volume of concentrated acid with 25 volumes of water. The microscopic grain size, unlike that in sandstone, causes limestone to present smooth surfaces to the eye. The hardness is 3 and the specific gravity is about that of quartz (2.6-2.8). The color varies from pure white, through various shades of gray (dove gray is very common in Vermont), yellow, brown, to black. Being soluble in water containing carbon dioxide (CO_2) in solution, limestones show widened solution cracks, holes of various sizes, and caverns. The great Luray and Endless caverns of Virginia and, largest and most famous of all, the Carlsbad Caverns of New Mexico, have resulted from this property of limestone. Limestone caves also occur in the islands in Malletts Bay and in Highgate.

Limestone often contains impurities, such as clay, giving argillaceous limestone; sand, forming arenaceous limestone; carbonaceous material, giving graphitic limestone. With increasing amounts of magnesium carbonate ($MgCO_3$) replacing the $CaCO_3$, limestone passes into magnesian limestone and, finally, into dolomite.

Limestone strata are usually thick and break up into rhombic joint blocks.

For the most part limestones have resulted from the assimilation by living organisms of solutions of calcium carbonate in ocean and other waters. At their death the organisms have left vast skeletal remains, such as the coral reefs, for example. These accumulations have been reduced to limy sediments by erosion and these sediments again deposited and consolidated into rock, often leaving no trace of their biogenic origin. Some lime sediments have also resulted from chemical reactions or supersaturation.

In Vermont limestones are found in many places and numerous small lime kilns testify to their extensive use, mostly for agricultural purposes. Very pure limestone formations, of Cambrian or Ordovician age, extend from Swanton south to Leicester Junction. They have been extensively quarried as the basis of high-grade lime products at Swanton, Fonda Junction, Winooski, New Haven Junction and Leicester Junction. Along the lake shore and on the Vermont islands there is much black limestone of Ordovician (some probably Trenton) age. On the eastern flank of the Green Mountains there is a great limestone belt running practically the length of the State. This has been located and described by the late Prof. Charles H. Richardson in his many articles in past Reports of the Vermont State Geologist, as will be shown later.

DOLOMITE

Large masses of the mineral, dolomite, plus admixtures of calcite, quartz grains, and other minerals, make up the rock, dolomite. Dolomite looks so much like limestone in the field that it requires special chemical tests to distinguish the two. We have seen that limestone effervesces freely with dilute hydrochloric acid (1-25). To acid of this strength dolomite does not react at all; but if concentrated acid is used or, better still, if the rock is pulverized and then heated in a test tube with concentrated acid, it will freely effervesce. Boiling with logwood solutions is also used, effecting violet stains with the limestone but none with the dolomite.

The dolomitic formations in the State are the Rutland dolomite which extends from Williamstown, Massachusetts, northward along the Green Mountain front at least as far as Milton; the Mallett dolomite which is exposed in the buffs around Malletts Bay; the Wallingford dolomite, in the township of that name; and others, to be noted later.

CONGLOMERATE

This rock is a mass of more or less rounded pebbles, of varying size, held together by one of nature's cements which we have noted. It may be likened to a pop-corn ball in which the corn represents the pebbles and the molasses, the binding material. Conglomerates are formed from river deposits, from wave deposits on old marine beaches, and from glacial accumulations. They often make up the base of a formation (see p. 50) and mark the transition from an older one. Thus, the Irasburg conglomerate of Richardson, running north to south through the State marks, it is claimed, the transition from the Cambrian to the Ordovician periods The basal nature of this conglomerate has been questioned.

Two other important formations are the Corliss conglomerate and the Mill River conglomerate, in the St. Albans region, to be noted later.

Metamorphic Rocks

As the name suggests these are "made over" rocks, that is rocks which, originally sedimentary or igneous, have been altered in their texture, structure and mineral content by heat, pressure, and chemical action (any or all of these) so that there result rocks of quite different character and appearance. The subject of metamorphism is a formidable one and is altogether beyond the scope of this bulletin. The reference books on physical geology, given on page 43, will provide ample matter for ambitious readers.

Briefly we may say that the metamorphic equivalent of sandstone is quartzite; of shale, slate; of limestone, marble; of various mixed aluminous and silicate material, schist or gneiss. Furthermore schists and gneisses may have been derived from igneous rocks: gneisses from granites; schists and slates from felsites; hornblende-schists from basalts; and serpentines from peridotites.

QUARTZITE

Quartzite has been metamorphosed from sandstone by the infiltration and subsequent crystallization of silica. The structure of the sandstone parent has not been changed but the texture, instead of being finely or coarsely granular, is now impalpable, giving the rock a glazed appearance. Owing to the strength of the quartz cement, the fractures of a piece of broken quartzite run through the sand grains and cement alike, giving sharp, irregular surfaces; whereas, in sandstones, breaking takes place around the mineral grains, in the weaker cement.

The color of quartzite naturally varies: white, gray, various shades of yellow and red, etc. Quartzites are seldom pure but often contain feldspar, mica, calcite and other minerals.

There are two great quartzite formations in Vermont: the light gray to maple sugar-colored Cheshire quartzite, which forms the western front of the Green Mountains and extends, with some interruptions, the length of the State; and the Monkton quartzite, which forms the greater part of the Monkton Hills, as already noted.

MARBLE

Marble is a trade name rather than a scientific one, being loosely used for various rocks which can be polished and used for decorative purposes. Thus we have, aside from the various grades of true marble, verd antique marble, onyx marble, dolomite marble, and even the fine-grained calcareous sandstone of northwestern Vermont which, quarried and fabricated, is called the Champlain marbles.

Petrographically, marble is limestone in which metamorphic action has produced crystallization, changing the lusterless grains of the parent rock to the bright, sparkling mass of crystals which gives the beautiful luster to the metamorphosed product. Pure, crystalline calcite, of fine grain, gives us our finest statuary marble, while various impurities in the stone give hundreds of varieties used for all manner of decorative purposes. By all means you must go to Proctor and see the marble exhibit in all its variety and beauty. It is one of the show places of the State. While there be

sure to see the new "lumar marble," a recent discovery of the Vermont Marble Company, giving most beautiful colors in transmitted light; and the "jetmar," a black, processed marble.

As everybody knows, the famous marble deposits of the State are in Rutland County, at Brandon, Florence, West Rutland, Dorset and Danby. There are also small marble "lentils" in the schists and gneisses of the Green Mountains and in the valley of the White River from Granville south to Stockbridge, Vermont.

Besides the West Rutland marble there are other formations of non-commercial grade such as the Winooski marble, Shelburne marble, Forestdale marble, Plymouth marble, and others.

SLATE

Slate is metamorphosed shale. Metamorphism has produced in it a crystalline texture and an induced structure known as **slaty cleavage.** This slaty cleavage can usually be distinguished from the bedding planes, when both are present, by its thin fissility and by the angle of contact between the cleavage and bedding planes. As a result of slaty cleavage the rock splits easily into large sheets of varying thinness which makes possible its use for roofing purposes, billiard tables, switch boards, and other articles.

Slate is of microscopic grain size and may contain many minerals, especially graphite, chlorite, quartz, mica, crystals of pyrite often of considerable size, and oxides of iron which cause the characteristic green, purple, mottled and red colors. Black slates owe their color to carbonaceous material.

Our best slates, "sea-green," "unfading-green," "purple" and "variegated," are found in the southwestern part of the State, in a belt extending from Sudbury to Rupert, at Hydeville, Fair Haven, Poultney, Wells, Pawlet, while over the boundary, in New York State, occur the red slates of Granville. Another belt, which Richardson has named the Memphremagog slates, extends down through the center of the State to Northfield, and a third occurs along the Connecticut River from Barnet to Guilford. Several formations in northwestern Vermont, the Parker slate, Georgia slate, Highgate slate, are of only geological importance.

PHYLLITE

Phyllite, which means "leaf stone," is a rock intermediate in its metamorphic nature between slate and schist. "It is a compact, lustrous (fine-grained), schistose rock with its microscopic minerals less well defined than a mica schist, the characteristic mineral by which its foliations are controlled being sericite (a metamorphic mica)." Neumann.

Our phyllites are dark gray to black and are characterized by their shiny appearance and easy cleavage. They occur in various parts of the State, in long belts, striking approximately north and south.

SCHIST

Schist is a metamorphic rock whose characteristic structure is seen in its fine foliations. This structure is due to the presence of finely cleavable minerals, such as mica, sericite, chlorite, talc, hornblende, etc., which have been developed by metamorphic action, especially by the stresses set up in mountain folding. Besides these, other minerals, such as quartz, feldspar, calcite, have crystallized in elongated parallel forms rather than in the granular shapes which these minerals would ordinarily assume. Schists are made up of fine foliae which, unlike gneisses, are mineralogically similar. They are lustrous rocks, silvery-white, gray, and various shades of green in color, and are named for the minerals which predominate; thus, mica-schist, sericite-schist, chlorite-schist, garnet-schist, hornblende-schist, etc.

The Green Mountains are made up predominantly of schists, gneisses, and quartzites. Of the schists, the silvery sericite-schist and the red-speckled garnet-schist are most common.

Much work remains to be done on the petrology and structure of the Green Mountains. The schist formations thus far described and named are: the Bethel schist, Vershire schist, Cavendish schist, Gasset schist, Halifax schist, Lunenburg schist, Readsboro schist, Mendon schist, Pinney Hollow schist (Plymouth), Whitingham schist, and the Westford schist which the writer is describing and has named. Readers of this article who are resident in any of the places named may be interested to examine and collect specimens from them. The chlorite schists of Chester are especially interesting because of the fine development of their foliations and of the cubes of pyrite and crystals of tourmaline associated with them.

GNEISS

Gneiss is an old Saxon miner's name for coarsely banded rocks of granite-like makeup. Besides the coarse laminations, or foliations, gneiss is characterized by *alternate bands* of schistose minerals, generally micas, on the one hand and granular minerals, such as quartz, feldspar, hornblende, garnet, etc., on the other. When typically developed, gneiss is easily recognized by this banded

appearance, but in the Green Mountains it is often to be differentiated from schist only by microscopic examination. Gneisses vary widely in the thickness of their bandings and in their color, the latter depending, of course, on the colors and preponderance of certain mineral constituents. White and gray bandings are perhaps our most common combinations. Depending upon the prevailing minerals, there are hornblende-gneiss, garnet-gneiss, epidote-gneiss, etc. Sometimes the gneiss contains irregular "knots" of feldspar and quartz, enclosed by the bands. It is then called "augen gneiss," from the German, meaning eye-gneiss.

The gneiss formations which have been named in Vermont are Bull Hill gneiss, Mount Holly gneiss, Newbury gneiss, Reading gneiss, and Mount Holly granite-gneiss. Other gneisses occur in the mountain massif and may be included for the present under the caption, Green Mountain gneiss.

AMPHIBOLITE

Amphibolites are metamorphic rocks made up essentially of amphibole, a family of minerals whose most common member is hornblende. Much more could be written about the origin and varieties of amphibolites than there is space for here, and so reference books should be consulted. However, let it suffice to say that Vermont amphibolites have a schistose structure and are seen to be composed of needles of black hornblende. The microscope reveals quartz, feldspar, magnetite, chlorite, epidote, pyrite, etc. Owing to their schistose character amphibolites generally split easily into flat pieces. They may have been derived from igneous or from sedimentary rocks. They alter, in Vermont at least, to chlorite-epidote-schists. In this State amphibolite forms the capping of Mount Belvidere, and overlies the serpentine masses in which the chrysotile asbestos has been developed. Elmore Mountain, southeast of Hyde Park, is made up of interbedded amphibolite and schist. Amphibole stocks have been noted in Bridgewater,[1] in Strafford,[2] and in other places.

SERPENTINE

As already seen, serpentine, the rock (sometimes called serpentinite), is made up of the mineral, serpentine, plus admixtures of other minerals: chromite, magnetite, calcite, dolomite and others. It has resulted from the alteration of the magnesian minerals of

[1] Geology of Bridgewater and Plymouth; E. L. Perry, 16th Rpt. Vt. State Geol. (1927-28).
[2] The Strafford Quadrangle; C. H. Hitchcock, 8th Rpt. Vt. State Geol. (1911-12).

ultrabasic, intrusive rocks, as suggested by the chemical equation given on page 35.

Serpentine is a striking-looking rock easily recognized by its varying shades of green (leek, blackish-green, brownish-red, brownish-yellow, etc.), its softness (2.5 to 4, easily scratched with a knife), dull to waxy luster and greasy feel. It occurs as broken chains of lenses or pod-shaped intrusives (sometimes in larger masses) running throughout the State from north to south, and generally within the ranges of the Green Mountains. Deposits are known in Troy, Westfield, Montgomery, Lowell, Belvidere, Johnson, Eden, Waterbury, Duxbury, Fayston, Moretown, Waitsfield, Roxbury, Rochester, Stockbridge, Plymouth, Ludlow, Andover, Windham, Dover, Marlboro and, perhaps, in other townships. To the south serpentine extends into Massachusetts while, in Canada, great deposits occur at Richmond, Black Lake, Thetford, etc., from which the great chrysotile asbestos deposits have been derived.

VERD ANTIQUE

Serpentine as such has little or no commercial use, but when it occurs slashed and veined with calcite or dolomite it forms the beautiful verd antique "marble" which is in large demand for paneling, columns, statuary, and other purposes. Verd antique deposits have been, or are being, worked in Roxbury, Rochester, Warren, Moretown, and Windham.

Fossils

"These rocks, these bones, these fossils forms and shells
Shall yet be touched with beauty and reveal
The secrets of the book of earth to man."

Practically ever since plants and animals appeared on the earth many of their remains became entombed in the sediments, which were later consolidated into rocks. In these rocks the organic remains, or casts, or impressions of them, were preserved as fossils. These fossils tell us of marine, or land, and climatic conditions of the past, give paleontologists a basis for their study of the evolution of life, and help geologists to divide the history of the earth into the eras, periods, and epochs of the Geologic Timetable (see p. 71).

Some fossils are found over a wide range of geological periods, while others are restricted to a single period. The latter are known as **index fossils** and they enable the geolo-

gist, by their presence in sedimentary (rarely in metamorphic) rocks to recognize a given formation, however remote it may be from the **type locality** where it was first described. Thus the Trenton formation, whose type locality is at Trenton Falls, New York, is also found on the Foreland of Vermont, the Vermont piedmont, and in many other parts of North America.

Animal fossils are classified as **vertebrate** and **invertebrate,** based on the presence or absence of a backbone, primitive or well developed. Both divisions are represented in Vermont.

Among the vertebrate fossils may be mentioned the whale skeleton[1] found in Vergennes, in 1849, and now on exhibition in the State Cabinet at Montpelier; elk antlers, found on Grand Isle, a mastodon tusk, discovered in Richmond, Vermont; a tooth of Elephas americanus, dug up at Mt. Holly; and others. All of these are on exhibition in the Fleming Museum of the University of Vermont or in the State Cabinet. They are relics of the late Pleistocene epoch.

The invertebrate fossils are legion and are found in various parts of the State. Among the kinds (phyla) of fossils are Trilobites, Brachiopods, Pelecypods, Bryozoa, Cephalopods, Gastropods and Corals.[2].

Structures

The exposure of bed rock at the surface is called an **outcrop.** The unconsolidated material through which it appears is the regolith, or mantle rock. Sedimentary rocks may appear as parallel strata, either horizontal or inclined to the horizontal plane at various angles. They may appear as folds, either continuous or faulted. In all these strata we find **joints,** or systems of cracks which divide them into blocks without displacing the lines of bedding. Owing to orogenic, or mountain-making, movements there are few horizontal strata in Vermont.

As has already been stated, the compass course of an inclined stratum across the country is called its **strike.** The maximum inclination of a stratum to the horizontal plane is called its **dip** (Fig. 2). From the figure it is seen that the strike and dip of a stratum are at right angles to each other.

[1] Fossil Cetacea; G. H. Perkins, 6th Rpt. Vt. State Geol. (1907-08).
[2] For those who wish to know more about the subject, an excellent elementary text is An Introduction to the Study of Fossils, by H. W. Shimer; Macmillan Company, New York (1933).

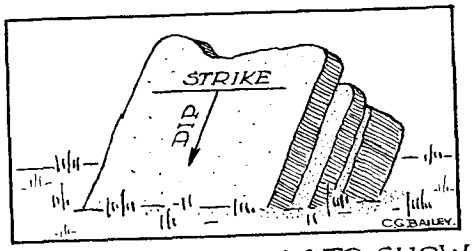

FIG. 2. DIAGRAM TO SHOW DIP AND STRIKE.

Kinds of Folds

The subdivisions of Figure 3[1] show cross-sections of various types of folds. The reader will at once understand that

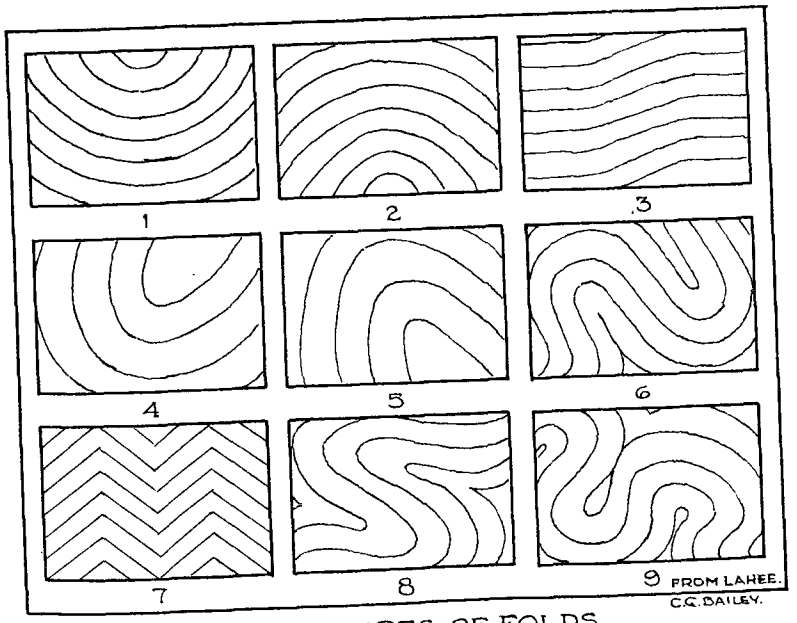

FIG. 3. TYPES OF FOLDS.

1 SYMMETRICAL SYNCLINE. 2. SYMMETRICAL ANTICLINE. 3. MONOCLINE 4. ASYMMETRICAL SYNCLINE. 5. ASYMMETRICAL ANTICLINE. 6. ISOCLINAL ANTICLINE AND SYNCLINE 7. CHEVRON FOLDS. 8. RECUDENT FOLDS. 9. FAN FOLDS.

[1] Reproduced from Field Geology; F. H. Lahee, by permission of the McGraw-Hill Book Co., New York City.

the folds themselves extend longitudinally at right angles to the cross-sections (through the paper), often for long distances. The **crest line** runs along the top of the fold, at right angles to the dip, in Figure 3-2. The compass course of the crest line is the strike of the fold. If the crest line is inclined to the horizontal we have a plunging (or pitching) fold. The "nose" of Mount Mansfield as well as the small folds north of the "chin," are plunging synclines. The "head" of Camels Hump is also a plunging syncline. The flanks of a fold are its limbs. The axial plane is that plane which bisects the fold. If the fold is symmetrically arranged to the axial plan so that, if one-half were turned over onto the other, along the axial plane, it would fit the other half, the fold is symmetrical; if it would not, the fold is asymmetrical. The axial plane may be vertical, as in 1, 2 and 7; or it may be inclined, as in 4, 5, 6, 8 and 9.

In Figure 3-1 the fold is a symmetrical syncline. The dips of its limbs converge downward. Figure 3-2 is a symmetrical anticline. In it the dips of the limbs diverge downward. Figure 3-3 is a monocline. The fold has but one limb and its strata all incline in the same direction. The strata of Mt. Philo, in Ferrisburg, and the other Monkton Hills are monoclines and dip easterly. Figure 3-4 is an asymmetrical syncline, while 3-5 is an asymmetrical anticline. Figure 3-6 shows isoclinal folds; note that the limbs are parallel to one another. There are many folds such as 5 and 6 in Vermont, among them a great, nearly perfect, upright isocline in the limestone quarry at Leicester Junction. The chevron folds shown in 3-7 are rather exceptional. Figure 3-8 is an overturned fold. In it the lower limbs are seen to be doubled under the upper. If the lower limb of such a fold is practically horizontal, we have a recumbent fold. There is a huge fold of this type at Hydeville, near the south end of Lake Bomoseen.

It should be noted that metamorphic, as well as sedimentary, rocks may be jointed, folded, and faulted.

An **anticlinorium** is a composite, up-arched anticlinal fold, made up of minor anticlines and synclines, but anticlinal as a whole. The Green Mountains form an anticlinorium, whose minor folds are overturned to the west.

A **synclinorium,** on the other hand, is a composite, downwarped, synclinal fold, composed of minor anticlines and synclines, but synclinal as a whole. The Taconics represent this type of structure. Besides the larger structure, synclines and anticlines, there occur in the mountain schists and gneisses irregular, small

folding and crumplings which are called crenulations, plications, or crumplings.

Joints and Faults

Tensional and compressional stresses in the earth's crust cause fracturing of the rock masses. The chief results of the fracturing are joints and faults. All three classes of rocks, sedimentary, igneous, and metamorphic, are found jointed and faulted but the phenomena are most plainly seen in sedimentary rocks.

Joints are fractures in a rock mass in which the continuity of each stratum, schistosity plane, or other feature (a vein in an igneous rock, for example), across the break has not been disturbed. To illustrate, let a pack of playing cards represent a mass of sedimentary rock, the individual cards representing the strata. Lay the pack upon a table and cut it, transversely into several rectangular blocks, either touching one another or somewhat separated. The card strata are now jointed: touching, they represent closed joints; separated, open joints. Note that the continuity of each card, across the cut, has not been disturbed. If the cuts are oblique we get rhombic joint blocks, seen especially in limestone and dolomite. Jointing often extends across a region for great distances, forming **master joints.** In Vermont the master joints run roughly east and west. They are responsible for the "nose" on Mount Mansfield and the "face" of the "Lion," unhappily known as Camel's Hump, an animal to which it bears no resemblance. Joints are also seen in the granite quarries, dividing the rock into "beds," which are roughly parallel to the surface, and vertical or oblique blocks, which make quarrying operations easier. A **fault** (Figs. 4 and 5) is defined by a master of structural geology, Prof. Bailey Willis,[1] as "a break or shear in which there has been an *observable displacement* of the two parts of a mass parallel to the plane of the break" (parallel to the "Fault Plane" of Fig. 4.). "The fact of the displacement of one side of the shear past the other side is the distinguishing characteristic of a fault." We may illustrate this definition with Figure 4, which represents a **gravity,** or **normal, fault.** The part, B, has been displaced relatively to the part, A, parallel to the "Fault Plane." The stippled strata are no longer continuous. The **elements** of the fault: strike, hade, foot wall, hanging wall, etc., are correctly marked on the figure, but the dip is wrong, for dip is the angle made by the inclined fault plane with the *horizontal.* Dip plus hade equals 90°. Part, B, may have moved down the fault plane, along it, or

[1] Geological Structures; McGraw-Hill Book Co. (1934).

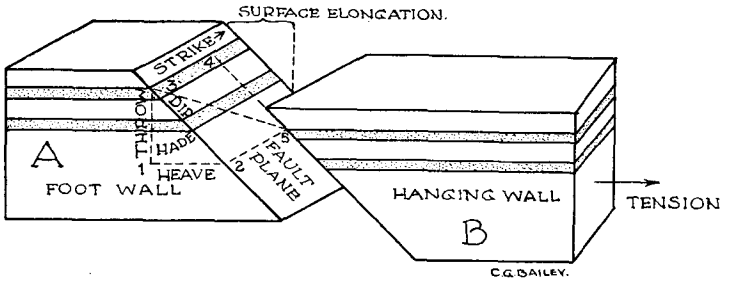

FIG. 4 HIGH ANGLE NORMAL FAULT

both (as in the case of Fig. 4). Furthermore, B may be in contact with A, giving a **closed fault,** or more or less separated from it, forming an **open fault,** and resulting in a widened fault zone between the hanging and foot walls. The fault dip may be 90°, forming a vertical fault, or it may be of various smaller degrees. Figure 4 represents a high angle, **normal** or **gravity fault** and, by the faulting, the strata have been lengthened. It is evident that tension in the crust has produced this type of faulting.

Normal faults are found all over the earth. There are many in the Champlain lowland, especially on the New York side, but they are also found in Vermont, on Grand Isle and along the southern lake shore. In the mountains one is to be seen in Roxbury, on the southern border of the verd antique ridge, and there are many others; for faulting is the rule, not the exception.

Figure 5 represents a **thrust fault,** or **overthrust.** In it, owing to compression in the crust, part B has been forced over, onto, part A and the strata have been shortened. The under part of the overthrust mass, B, is called the **sole** of the fault block. The "elements of the fault" apply equally well here, although they have not been marked. As a result of

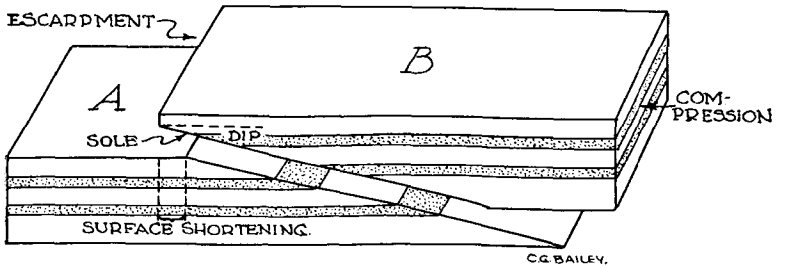

FIG. 5. LOW ANGLE THRUST FAULT.

the thrusting, **escarpments,** often hundreds of feet high, are formed. In Figure 5, the unstippled, top, stratum, is geologically younger than the stippled lying just beneath it. When erosion has carried away the unstippled, top, stratum, we shall have the older, stippled, stratum of B, lying upon the younger, unstippled, stratum of A.

Overthrusts have produced some of the most magnificent mountain ranges, system and chains in the world. The Himalayas, the Alps, Andes, the Northwest Highlands of Scotland, the Northern Rockies, and the Appalachians are all examples of overthrust mountains. Owing to thrust faulting the strata have been shortened, "from a few miles up to twenty-five, thirty, or even forty miles for individual thrusts, while in the Alps the Alpine zone as a whole was made narrower by considerably over 100 miles."[1] The Matterhorn, Mt. Everest, some of the peaks of the Appalachians, etc., are often called mountains without roots, for their "roots" lie often many miles away from their summits. This is also true of the Green Mountain peaks.

Figure 5 shows overthrust horizontal strata, but it is obvious that the compressive stresses may also have thrown the strata into folds, which is the case in all the examples given above.

It will be shown that overthrusting has played a dominant rôle in the development of Vermont.

Fault Troughs, or **Graben,** are defined by Willis as "long, narrow depressions that are bounded on both sides by faults." The English call such depressions **rift valleys.** The rift valleys of East Africa and the graben of the Great Basin, of the southwestern United States, are famous examples of this type of faulting. Some have thought that Lake Champlain lies in a graben. There is a small graben in Roxbury, on the way from the railway station to Mrs. Spaulding's house.

Erosion

Two opposing sets of forces are at work on the earth: one, destructional, tending to degrade the surface; the other, constructional, seeking to build it up. The first includes erosion; the second, diastrophism, which need not concern us here. The earth's surface, as we see it today, is the net result of these opposing forces.

The agencies of erosion are rain, frost, glaciers, temperature changes, and water in motion, whether in the running stream or the beating wave.

[1] Textbook of Geology; Longwell, Knopf and Flint; John Wiley & Sons (1932).

By these degrading agencies, acting over long periods (for nature knows no time) even the mountains were brought low and former seaways and other depressions were filled with sediments, transported by the streams. Then, from these, thousands of feet of sediments, consolidated into rocks, new mountains were raised up by orogenic forces. Such is the endless cycle of nature.

Rivers

Rivers play an important part in this geological drama. Their rôle is threefold: erosion, transportation, and deposition.

In **youth** they run in narrow valleys, at steep gradients, with water falls and potholes (so frequently seen in Vermont), and often with lakes in their courses. Their erosive action is chiefly downward and is due to their "tools," or sand grains, carried swiftly by the streams and scouring the rocks in their courses.

Mature streams have largely finished their down cutting. They widen and flatten their valleys and form flood plains, over which they swing in sweeping meanders. The divides between adjacent water sheds are lowered and frequently the tributaries of one stream "capture" those of another. With time the region takes on a more level aspect. Many Vermont streams, such as the Winooski, Lamoille, and Missisquoi, are in their mature stage and flow in meandering courses.

Finally rivers become **old.** When a river system or, better, several neighboring systems in a region, have done their work, the country has been worn down to the ultimate **base level,** which is sea level, and can be degraded no farther. Mountains and uplands have disappeared and there remains a low, rolling country with here and there an erosion remnant, so resistant to erosion that it has lagged behind the rest and stands out, as a low mountain or smaller eminence, above the plain. It should be noted here that rivers are not young, mature, and old, counted in years, but in the work that they have done or have still to do.

The worn down region, often many miles in extent, is called a **peneplain** and the erosion remnants are known as **monadnocks,** so-called from the typical example, Mount Monadnock, in southwestern New Hampshire.

Few, if any, peneplains are to be seen in the world today at sea level, for we are living in a time of continental uplift and the old peneplaned surfaces, after after having sunken beneath the waves and received thousands of feet of sediments from neighboring high lands, have in the rhythmic processes of mother earth been upraised and dissected into mountains of a new cycle.

In many regions of the world there are to be seen remnants of the old peneplains. In the Appalachians the highest ridges show, by their even skyline, that they were carved from an old peneplain. In southern Canada the Laurentian Mountains show a similar history. In the Grand Canyon of the Colorado, buried under thousands of feet of sedimentary rocks, the remains of the Grand Canyon Mountains are seen worn down to peneplains. New England is an old, mountainous region which has suffered a similar fate and the **New England upland peneplain** now gently slopes upward and northward from Long Island Sound to the foot of the White Mountains. As one drives over the Mohawk Trail to the height above North Adams, Massachusetts, he sees this peneplain extending far to the eastward, with Mt. Monadnock and other eminences standing out as monadnocks on its surface. Peneplaination in Vermont will be considered in due course.

Besides being young, mature, or old, streams are also classified, according to the attitude or "lie" of the rocks over which they flow, as **consequent, subsequent, antecedent,** and **superposed.** Note the descriptive nature of each term.

CONSEQUENT STREAMS

Consequent streams flow *in consequence* of the topography. They are developed on the original slope of a new land surface of unconsolidated rocks or of consolidated rocks. Examples of the former are seen in the streams flowing across the recently emerged coastal plains of the Atlantic and Gulf coasts of the United States, or across the great cover of rock material laid down by the ice sheet of the Pleistocene, or in streams flowing upon an emerged delta surface. Again, a peneplain may be submerged and streams flowing from the *hinterland* may cover it with coastal deposits. Later the region may be upraised and tilted, or perhaps upwarped into a great arch. Consequent streams will be formed and take their courses down the slopes. Streams formed upon volcanic surfaces are also consequent.

An example of streams flowing upon the dip of consolidated rocks is seen in the Sierra Nevada fault-block, down the western dip-slope of which the Merced River, the Tuolumne, and other rivers take their courses. In Vermont the Lemon Fair, Dead

Brook and others, flowing across the Foreland (p. 79) are consequent streams.

SUBSEQUENT STREAMS

Streams of this type adjust themselves to rock structures by taking advantage of any vulnerability of the rocks to attack. This susceptibility to erosion may be due to soft rocks, as limestones, or to exposed edges of strata, due to jointing, faulting, and other causes. Such streams follow along the strike of the soft strata. Streams which have so adjusted themselves are called **subsequent.** Where consequent or superposed streams and subsequent ones are associated they often flow practically at right angles to each other, as the subsequent Browns River and the superposed Lamoille. This forms a trellis drainage pattern.

In our region the Connecticut River is a subsequent stream throughout much of its course. It flows on the strike of the rocks, which is, roughly, north and south. Among the subsequent streams of Vermont may be mentioned the north branches of the Nulhegan, the Coaticook, and Pherrins River, in Essex County; the Passumpsic, in Caledonia County; the Barton and Black rivers, in Orleans County; the Waterbury, Mad, North Branch and Dog rivers, tributaries of the Winooski, in Washington County; the Clarendon and the upper course of the Castleton River, in Rutland County; and the streams flowing *in* the the Vermont Valley.

Rivers (which flow, of course, by virtue of the force of gravity, from higher to lower levels) are often seen cutting across mountain ranges and ridges, apparently in defiance of natural laws. The explanation of their behavior is as follows:

ANTECEDENT STREAMS

These are streams which *antecede* the structure across which they flow. So slowly do mountain-making forces act that the river in question is strong enough to maintain its grade in the face of the rising ridge or mountain range—like a log in a saw mill which rises around the cutting tool. Examples of this type of stream are the Columbia River of the northwestern United States, and the Green River of Utah.

SUPERPOSED STREAMS

It has been shown that an old topography, such as a peneplain, may be buried under a cover of unconsolidated rock material (sand, clay, and the like), may be upraised and perhaps tilted or arched, and that young, consequent streams will then take their courses down the new slopes.

In time the streams will cut down through the cover and "discover" the underlying rock structures. Fixed in their courses, they will erode their deeper channels in the rock, quite regardless of its structure, and so become **superposed** (or superimposed) upon it. At the same time subsequent streams will carve their valleys along belts of soft rocks, the unconsolidated cover will be washed away, and the old peneplain will be dissected into a mountainous region of a newer cycle, cut by the superposed rivers and their **water gaps** which, with the subsequent streams, forms a trellis pattern. Famous examples of superposed rivers and their water gaps are the Delaware River and water gap, and the Potomac River and its water gap at Harpers Ferry. In the latter instance the Shenandoah River is a subsequent stream which has eaten headward along the soft limestones, forming the Shenandoah Valley.

Most of the large streams of Vermont are superposed; they are quite out of harmony with the rock structure on which they flow.

The Winooski River is perhaps the best example. It rises in Cabot, in Washington County, and takes its course across the mountains, nearly everywhere flowing against the dip of the rocks, in which it has carved a great water gap, from Montpelier to Richmond. As already seen, its subsequent tributaries are the Waterbury, Mad, North Branch, and Dog rivers which, with it, form a trellis drainage pattern.

The Lamoille and Missisquoi are also superposed streams and water gaps are seen along their courses.

The Winooski is also superposed upon its emerged delta plain which extends from Richmond to the lake. It flows in a sweeping meander east of Fort Ethan Allen but, at the Limekiln bridge, it has cut a water gap in the Shelburne marble which it "discovered" in its course.

Glacial erosion will be briefly considered later.

Historical Geology

The earth is incredibly old. Rocks are known which modern methods, based on the rate of disintegration of radio-active elements in the rocks into other elements, have shown to be 1,850,000,000 years old. It is probably conservative to place

the age of the earth at, very roughly, two billion years, a span beyond human comprehension.

The essence of geology is change. Tennyson caught the vision when he wrote:

> "The hills are shadows and they flow
> From form to form and nothing stands;
> They melt like mists, the solid lands,
> Like clouds they shape themselves and go."

The Geological Timetable has been devised to set forth the great changes and the lesser ones. It is divided into Eras, Periods, and Epochs.

The eras are the grand divisions and their ends are marked by geological "revolutions," which are mountain-building times—the Appalachian Revolution, at the end of the Paleozoic, for instance, which marked the final uplifting and folding of the Appalachian Mountain Chain.

The periods are subdivisions of the eras and are characterized by the dominance of definite forms of plant and animal life, as well as by smaller, more localized crustal disturbances—the Cambrian Period by "the rise of shell-bearing molluscs and the dominance of trilobites; the Ordovician Period, by the culmination of trilobites, the spread of molluscs, and the rise of fresh-water fishes and corals."[1]

Eras and periods are world-wide in their scope.

Epochs are still smaller sub-divisions and are of more local application, as will be pointed out later.

Vermont geology is, for the most part, vastly old; but her glacial accumulations are relatively modern, since they belong to the Pleistocene, or Glacial Epoch, of the Quaternary Period, which belongs in the Cenozoic Era. During the great lapse of time between the Ordovician and Quaternary periods (439,000,000 years, if the Timetable is correct), Vermont stood above the sea and, as far as is known, with one exception, no rocks of the intervening periods were laid down. The exception is a small area containing the Brandon lignite, whose "fossil fruits" have been assigned to the Tertiary.[2]

The following Geological Timetable shows the divisions of time in order, from the Archeozoic to the Recent. The figures have been kindly furnished by Prof. Adoph Knopf, of Yale University. These figures, naturally, are tentative and very rough estimates based on the study of radio-active elements in many

[1] Textbook of Geology, part 2; Charles Schuchert; John Wiley & Sons, New York (1933).
[2] The Brandon Lignite; G. H. Perkins, 4th Rpt. Vt. State Geol. (1903-04).

The Geological Timetable

Eras	Periods	Duration (In millions of years)	Began—years ago (In millions of years)	Epochs	Vermont formations
Cenozoic	Recent			Pleistocene	
	Quarternary	1*	1		
	Tertiary	59	60		
Mesozoic	Cretaceous	50	110		
	Jurassic	40	150		
	Triassic	50	200		
Paleozoic	Permian	30	230		
	Pennsylvanian } Mississippian }	50	280		
	Devonian	50	330	Upper (Cincinnatian)	Waits River ls.
	Silurian	50	380	Middle (Champlainian)	Canajoharie shale. Trenton ls. Black River ls. Chazy ls.
	Ordovician	60	440	Lower (Canadian)	Beekmantown dolo. Georgia slate. Corliss congl.
	Cambrian	60	500	Upper (Saratogan)	Williston ls. Highgate slate. Gorge formation. Milton dolo. Mill River congl.
				Middle (Acadian)	St. Albans slate. Rugg Brook congl.
				Lower (Georgian)	Shelburne marble. Parker slate. Mallett dolo. Winooski marble. Rutland dolo. Monkton qtz. Cheshire qtz.
Proterozoic (Algonkian)	Pre-Cambrian	550	1,050±		Mendon dolo. Mt. Holly gneiss. Stamford granite-gneiss. Mooslamoo phyllite. Forestdale marble. Nickwacket graywacke.
Archeozoic		950	2,000±		

* To date.

rocks, but they serve admirably to show the vastness of geologic time and the relative lengths of the periods.[1]

It is seen that our Vermont formations, with the exception of the glacial deposits and the Brandon lignites, belong to the Ordovician and Cambrian periods and to Pre-Cambrian time—whether to the Proterozoic or Archeozoic has not been definitely proved.

[1] A great deal of work has been done on the estimation of the age of the earth and its rocks, by radioactive methods. See the Age of the Earth; National Research Council, Bul. 80, 487 pp.; Washington, D. C. (1931).

The formations given, with the exception of Beekmantown, Chazy, Black River, Trenton, and Canajoharie, have been established in Vermont. Some of them extend into Quebec. The list of Vermont formations is by no means complete and reference will be made to most of the others.

Sources of Information

What is known of the geology of Vermont is recorded in the various Reports of the Vermont State Geologist and contributions to the various geological journals of the United States. These contributions should be reprinted in the State Geologist's reports but, unfortunately, funds are lacking.

The Reports of the State Geologists are to be found in the libraries of the University of Vermont, Middlebury College, and Norwich University, as well as in the libraries of many of the towns of Vermont. They are also on file in most of the universities, colleges, and other institutions of this country, as well as in some foreign countries. The reports subsequent to 1925-26 may be had on application to the State Librarian, at Montpelier. The others are out of print.

The United States topographical maps are of the greatest value to all sorts and conditions of out-of-door people, from trampers to the builders of dams. Those interested in geology will find them most helpful. About 80 percent of the State has been mapped to date and the maps may be obtained in book stores of the larger cities or by applying directly to the United States Geological Survey at Washington. Key maps, showing the areas covered by the various topographical sheets, may be had without cost.

Physiography and Structure

The State of Vermont falls naturally into five physiographic divisions: The Vermont Lowland, the Vermont Valley, the Taconics, the Green Mountains, and the Vermont Piedmont. These will be considered in order.

The Vermont Lowland

"The hills
Rock-ribbed and ancient as the sun,[1] the vales
Stretching in pensive quietness between;
The venerable woods—rivers that move
In majesty, and the complaining brooks
That make the meadows green."

One of the striking features of the Appalachian Chain is the Great Valley which runs for over a thousand miles from the St. Lawrence Valley through the Appalachians to Georgia. This great corridor includes, in order, the Champlain Valley, Hudson Valley, the Wallkill or Kittatinny Valley of New Jersey, the Lebanon Valley of eastern Pennsylvania, the Cumberland Valley of southern Pennsylvania and Maryland, the Shenandoah Valley of Virginia, the Valley of Eastern Tennessee, and finally the Coosa Valley in Georgia and Alabama.

The Champlain Valley, or Champlain Lowland, bordered by the Green and Adirondack mountains, is about twenty miles in maximum width and is roughly "V" shaped in plan, widening to the north.

The Vermont Lowland, extending from the Green Mountain border to the lake, varies greatly in width, from about seventeen miles at Chimney Point and thirteen miles in the latitude of Highgate Springs to about five miles in Georgia. It is a rolling country made up of low hills and ridges, with less rugged areas between, flat lake-shore terranes, and delta plains, all dissected by the rivers of the region and their tributaries.

Extending through, roughly, the middle of the lowland is a series of low hills and mountains (these terms are very loosely used) varying in elevation from 700 to 1,400 feet above sea level. The series includes Aldis Hill, St. Albans Hill, Arrowhead Mountain, Georgia Mountain and Cobble Hill. They are thrust blocks with steep escarpments to the west and more gentle slopes to the east.

Then along, or not far from the lake shore, is seen a broken chain of escarpments and low mountains which include Eagle Mountain, 280 feet a. t. (which means 280 feet above mean sea level) in Milton; Malletts Head, 280 feet; Ethan Allen Park escarpment, 300 feet, and Red Rocks, 260 feet (both in Burlington); Pease Mountain 760 feet; Mt. Philo, 958 feet; Mt. Fuller, 920 feet; Shellhouse Mountain, 640 feet; Buck Mountain, 927

[1] This, of course, is poetic license. Neither the hills, nor even the earth itself, is "ancient as the sun."

feet; and Snake Mountain 1,260 feet. Keith has called the southern members of this chain, Pease Mountain to Snake Mountain, the Monkton Hills, since they all belong to the Monkton formation which will be considered presently. The members of this chain, like those of the "series of low hills and mountains" above, are thrust blocks, presenting steep escarpments to the west and more gradual slopes to the east. They mark the position of the Champlain fault seen on the frontispiece and on Figure 7.

West of the Champlain fault we have the great islands, Grand Isle, North Hero, and Isle La Motte, and the Alburg tongue, which are areas of low relief, being not much over 100 feet above the lake level which, in turn, is about ninety-five feet above the datum, mean sea level.[1]

Also west of the Champlain fault are the lake shore terranes, old bottoms of the greater, glacial Lake Champlain. They are flat and afford rich farming lands in west St. Albans, west Swanton, Colchester, Ferrisburg, Panton, Addison, Bridport, Shoreham, Orwell, and Benson.

Drainage and Delta Plains

The lowland is drained by four large rivers: The Missisquoi, Lamoille, Winooski, and Otter, and their tributaries, as well as by numerous smaller streams. The Missisquoi, Lamoille, Winooski, and Otter, superposed streams flowing down from the mountains into glacial Lake Champlain, which once extended as far east as Brandon, East Middlebury, Hinesburg, Richmond, Colchester, Cobble Hill, and Milton, have built great deltas. Upon the recession of the lake these became "fossil deltas" and through them the extended rivers cut their meandering courses. At present these rivers are building newer deltas into the lake.

The fossil delta of the Missisquoi is to be seen in Swanton and Highgate. The modern river has built a great delta which has tied Hog Island to the mainland and is now flowing across the delta in a series of distributaries.

The fossil delta of the Lamoille is in Milton township and the modern delta lies around the river's mouth, chiefly to the

[1] The map of Lake Champlain (War Department, Corps of Engineers, 1933) shows the mean lake level, from 1871 to 1932, inclusive, to be 95.19 feet; the "Standard Low Water (Harbor Improvement Plane)," 92.50 feet.

At Burlington, data compiled by Mr. D. A. Loomis from the U. S. Engineers' gauge, between 1907 and 1936, inclusive, show that the lowest lake stage, 92.04 feet, occurred on November 23, 1908; the highest stage, 100.89 feet, on March 28, 1936.

The proposed Canadian Remedial Works project in the Richelieu River seeks to hold the lake stages as far as possible during the navigation season, between the upper limit of 95 feet and the lower limit of 92.50 feet. In the non-navigation season the water level may drop to 92 feet.

June, 1937.

north. Lake currents have formed a shoal from this material and on this is built the Sand Bar bridge and the highway to Grand Isle.

The fossil delta of the Winooski forms great plains in Colchester, South Burlington, and eastward to Richmond. The fine drill field of Fort Ethan Allen is a part of it and the city of Burlington is built partly upon it, partly on the old lake shore terraces and partly on the red Monkton quartzite. The modern Winooski is building a delta into the lake. Bristol village stands on the fossil delta of the New Haven River.

The ancient Otter Creek (more properly the Otter River) formed deltas, now fossil, in Brandon, Leicester, Salisbury, etc., while the modern stream and the Little Otter are building extensive deltas into the lake, off Ferrisburg township.

These rivers are very ancient, probably as old as the modern Green Mountains.

Along some of these rivers, notably the Winooski, we find flights of terraces showing that, with the rise of the land, following the recession of the Pleistocene ice sheet, the rivers were rejuvenated and cut more deeply into their channels, reaching bed rock in places and forming inner gorges, of which the gorge of the Winooski in Middlesex and at the Winooski bridge at Burlington are fine examples.

Lakes

Scattered over the Vermont lowland are numerous lakes and ponds (here again the usage of these words is loose), of which the largest are Shelburne Pond; Sunset Lake, in Benson; Bomoseen, in Hubbardton and Castleton; and Lake St. Catherine, in Poultney and Wells. These lakes are of glacial origin, being due to the damming of natural valleys and other depressions by material brought down by the ice sheet of the Pleistocene.

Structure

The structure of the greater part of Vermont is predominantly overthrusting to the northwest, caused by tangential pressure in the earth's crust, coming from the southeast, which piled up the rock strata of the lowland into a series of overlapping members, like the courses of shingles on a roof in which the "courses" represent the strike and the thick, butt ends of the shingles represent the escarpments facing the west. The results of this thrusting in a series of faults, of which the Champlain fault and the Moun-

tain Border fault are outstanding and are to be seen clearly marked on the frontispiece and on Figure 7.

The working out of the structure and stratigraphy of the lowland has involved many years of patient labor by eminent geologist, among whom may be mentioned Sir William Logan, the first director of the Geological Survey of Canada; Charles D. Walcott, formerly director of the United States Geological Survey; Arthur Keith, also of the United States Geological Survey; Prof. Charles Schuchert, of Yale University; Prof. Benjamin Howell, of Princeton University; and others. To Mr. Arthur Keith[1] belongs the credit of finally solving the problem and distributing the various strata involved in a series of sequences, "each prevailing in a distinct belt and each exhibiting important differences from the other belts." Each sequence, in turn, is made up of a number of formations whose geological ages have been determined, chiefly by the fossils found in the strata.

In his work in western Vermont, Keith finds three major tracts in the lowland, a fourth in the Taconics, and a fifth in the mountain massif. Each sequence is separated from the others by major thrust faults. He divides the lowland into a Western, a Central, and an Eastern sequence. The Champlain overthrust separates the Western from the Central sequence; the Mountain Border thrust is the dividing line between the Central and the Mountain sequences; while his Monkton thrust (not shown on the frontispiece) which runs from "west of Middlebury" and "gradually traverses the valley with a trend north and northeast until it joins the main (Mountain Border) fault at the border of the valley and the Green Mountains, about ten miles southeast of Burlington, separates the Central and Eastern sequences."

The Champlain Overthrust

The Champlain fault is a great thrust which has been traced from the Gaspé Peninsula up along the course of the St. Lawrence River to Quebec City, thence southwesterly through Quebec Province and through western Vermont, into Cornwall. In Charlotte it runs along the base of Pease Mountain and Mt. Philo. South of Philo it skirts the base of Shellhouse and Buck mountains and is seen on the western face of the Snake Mountain escarpment, "about thirty or forty feet from the top" (Cady). It dies out in Cornwall township. (See the frontispiece and Fig. 7.)

[1] Cambrian Succession in Northwestern Vermont; Am. Jour. Science, 5, February, 1923. Stratigraphy and Structure of Northwestern Vermont; Jour. Washington Acad. of Sciences, 22, July, 1932, and August, 1932. International Geological Congress Guidebook 1.

To the west of the fault, in Vermont, are Ordovician shales and limestones, on the mainland and on the islands; to the east, and forming the fault escarpments, are Lower Cambrian formations.

THE ROCK POINT OVERTHRUST

The most striking topographical feature of the Champlain fault, striking because of its commanding position on the shore of the lake and its full exposure, is the Rock Point overthrust which lies just north of Burlington Bay and Lone Rock Point. It is one of the finest examples of overthrusting in the United States and has been visited by geologists from many lands. It is situated on the property of the Episcopal Diocese and is reached by a gully leading down from the higher land to the lake shore.

From the shore a cliff rises some eighty feet above the lake (Fig. 6a). About thirty feet from the bottom one sees a sharp line of demarcation which divides the massive, lighter colored rock above, from the shaly, darker rock below. The lower member is a black, shaly limestone of Ordovician (probably Trenton) age, much contorted and veined with white calcite. Above the shale rises a bold, overhanging escarpment of massive dolomite, rather pinkish in color, showing great jointing planes and jagged surfaces. This is the Winooski marble formation (really dolomite), of Lower Cambrian age. We, therefore, have an overthrust of (older) Cambrian dolomite upon (younger)Ordovician shale.

On the under side, or sole, of the thrust-block there is seen a series of flutings (Fig. 6b), worn into the rock by the thrusting, while between the two formations there is a thin bed of rock flour, or gouge. The axes of the flutings show by their strike (northwest) the direction of the thrusting and by their dip (about ten degrees southeasterly) the inclination of the fault plane.

This is, therefore, a low-angle thrust fault, as illustrated by Figure 5.

From the cliffs great blocks of dolomite have fallen, the largest of which suggested the name, Lone Rock Point, to the settlers of Burlington 160 odd years ago.

On the higher land, east of the escarpment, the dolomite has been compressed into a series of anticlines and synclines such as commonly accompanies thrusting. Along the shore the thrust is seen extending to the north for about one-eighth of a mile, where it disappears under the lake shore sands.

Some distance north and east of the Rock Point thrust, the Winooski marble cliffs of Ethan Allen Park mark the extension

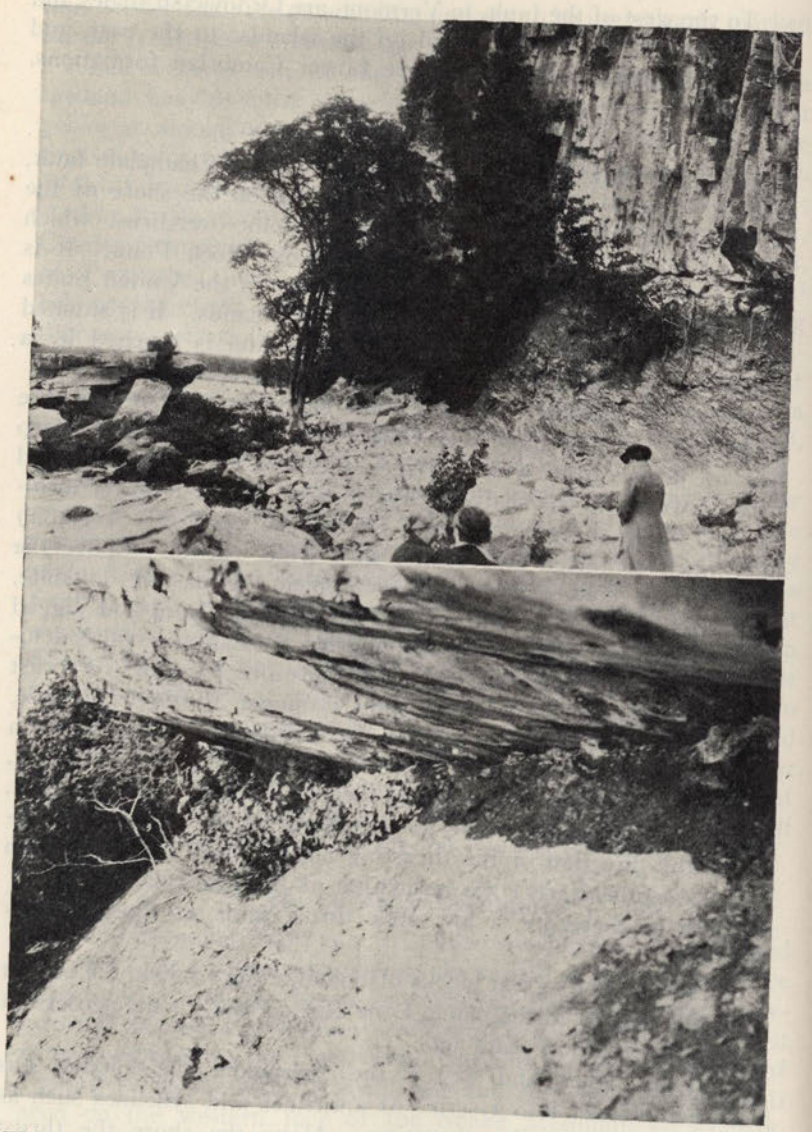

FIG. 6a, ABOVE; FIG. 6b, BELOW. THE ROCK POINT OVERTHRUST, BURLINGTON, VT.

of the fault. To the east the rock dips down and disappears under the sediments of the Winooski River.

The continuation of the fault to the north is seen at Malletts Head and on the north side of Malletts Bay, where again the Winooski marble rests by thrust on the Ordovician shale. The east shore of the bay, however, is made up of the next lower member of the Lower Cambrian, the Monkton quartzite, a dark red rock, whose high escarpment, to the west, and long dip slopes, to the east, add a striking feature to the landscape.

Farther north, in Milton, Eagle Mountain is another block of the Winooski marble thrust onto the Ordovician shale, while, as already noted, a line of lower escarpments marks the course of the fault through Georgia, St. Albans, Swanton, Highgate and into Quebec where, at Phillipsburg, another large thrust block is to be seen on the lake shore.

The Western Sequence

In Europe the Alps massif has been carved by erosion out of a great mass of overturned strata which, once lying far to the south, was thrust northward onto the worn-down strata of what is now northern Switzerland. Geologists call this worn-down region onto which the northward-moving mass came to rest, the Foreland (German, Vorland); the region where it originated, the Hinterland, for which there is no adequate English equivalent.

The situation is essentially the same in Vermont, where the overthrust slices of the mountain sequence and the central sequence, taken as a whole, have been thrust onto the western sequence, which is our **Foreland**. The hinterland lay far to the eastward—how far we have no means of knowing.

The western sequence extends from the Canadian border, along the lake shore to western Orwell. It includes the western parts of Highgate (Fig. 7), Swanton, St. Albans, all of Grand Isle County, embracing Grand Isle, North Hero, Alburg peninsula, Isle La Motte, and the smaller islands of this part of the lake, the western parts of Burlington, Shelburne, Charlotte, Ferrisburg, Panton, Addison, Bridport, Shoreham, and Orwell.

Its width at Isle La Motte, eastward, is about thirteen miles. South of this latitude it becomes narrower, being only a few rods wide in Milton and at Rock Point, where its shales peep out from under the thrust masses of the Winooski formation of the central sequence. The sequence widens to seven or eight miles in Ferrisburg and Addison and then gradually narrows to its end in Orwell.

Of all the divisions of Vermont the western sequence, or Foreland, was the least affected by folding and thrusting, its rocks are the least metamorphosed, and its strata are the most highly fossiliferous.

The region is essentially flat, with only a few northward-trending ridges, and its surface, which was once covered by the waters of the glacial Lake Champlain, is thickly mantled with the Champlain clays and with the glacial accumulations of the Pleistocene. The underlying rocks and the outcrops are made up of limestones, dolomites, and shales of Lower and Middle Ordovician age.

Grand Isle County includes the islands of South Hero-Grand Isle, North Hero, Isle La Motte, and the smaller islands, Providence, Stave, Butler, and others, as well as the Alburg peninsula.

The relief is low, only a few ridges reaching 150 or 160 feet above the lake. Folding is at a minimum but is to be seen especially on the west shore of Grand Isle where low cliffs of limestone and shale show synclines and anticlines. A good deal of the land is swampy, while lake clays and glacial accumulations are much in evidence.

Many dikes cross Grand Isle from east to west, varying in width from a few inches to four feet. Some of them are composed of unusual igneous rocks, called monchiquites. The dikes were studied and described by H. W. Shimer.[1]

The Champlain lowland in New York is cut by many systems of normal faults which trend in two chief directions, north-south and northeast-southwest. Some of these faults cross the lake and cut Grand Isle, North Hero, and Alburg. By their "throws" (Fig. 4), they are responsible for the eastward tilting of the strata. G. H. Hudson[2] and A. W. Quinn[3] have studied and described these faults. An interesting question is whether the normal faults cut the Champlain overthrust (and so are younger than the thrust) or are cut by it (and so are older than the thrust). Quinn has been unable to decide the matter, but Keith says that "a very few (normal) faults are known to cross the Champlain overthrust into the region of the Central sequence," which would seem to settle the matter.

THE NORTHERN PART

Years ago the geology of Grand Isle County was worked out by the late State Geologist, George H. Perkins,[4] assisted by the

[1] The Dikes of Grand Isle; 3rd Rpt. Vt. State Geol. (1901-02).
[2] Fault Systems of the Northern Champlain Valley; 13th Rpt. Vt. State Geol. (1921-22).
[3] Normal Faults of the Lake Champlain Region; Jour. Geology, Vol. 41 (1933).
[4] Geology of Grand Isle County; 4th Rpt. Vt. State Geol. (1903-04).

late Prof. H. M. Seeley of Middlebury College. Reference to their work shows two colored plates giving the locations and extents of the formations. They found the county to be made up of Beekmantown, Chazy, Black River, and Utica beds of the Ordovician Period. Later investigations have shown that there is no Utica present but that the shales are of Canajoharie (Trenton) age.

Much later, Prof. E. J. Foyles[1] made a study of Providence Island which he showed to be made up of Chazy and Trenton beds.

THE SOUTHERN PART

The southern part of the Vermont lowland (Keith's Western sequence) is, as Foyles notes, "a gently rolling country made up of Champlain clays and glacial accumulations, with some northward-trending ridges which are due to the ice movements (of the Pleistocene) and to the attitude of the underlying rocks." The eastern part, west of the Champlain thrust, is hilly, with Barber Hill, in Charlotte, rising to 420 feet above sea level; Marsh Hill, in Ferrisburg, 320 feet; Cream Hill and Sisson Hill, in Shoreham, 405 feet and 517 feet, respectively; and Mt. Independence, in Orwell, 300 feet.

Several islands belong in this sequence: Juniper, Rock Dunder, Cedar, Gardner, as well as several islets.

The region is drained by the Otter Creek, Little Otter, Dead Creek, the Lemon Fair, and smaller streams.

In this southern part of the lowland there have been found considerable folding and faulting of the strata so that the geology is more complicated than in Grand Isle County.

A great deal of geological work has been done in this region. Edward Hitchcock issued his report on the Geology of Vermont in 1861, in two volumes, but his work is now largely out of date, owing to the advances which have been made in the science. In 1886 R. P. Whitfield[2] was working in the region, while Brainerd and Seely[3] established a famous section in east Shoreham and showed, on faunal evidence, that it was made up of various members of the "Upper Silurian" which we now call Ordovician. Seeley[4] also contributed an article on the geology of Addison County, while Gordon[5] made contributions to the knowledge of that region.

[1] Geology of Providence Island; 13th Rpt. Vt. State Geol. (1921-22).
[2] Notice of Geological Investigations Along the Eastern Shore of Lake Champlain; Bul. Amer. Mus. Nat. Hist. (New York City), Vol. 1, and Observations on the Fauna and Rocks at Ft. Cassin, Vt., *ibid*, Vol. 2.
[3] The Calciferous Formation in the Champlain Valley; Bul. Am. Mus. of Nat. Hist., Vol. 3 (1890). Same title; Bul. Geol. Soc. of Am., Vol. 1, (1890).
[4] Preliminary Report of the Geology of Addison County; H. M. Seeley, 7th Rpt. Vt. State Geol. (1910).
[5] Studies in the Geology of Western Vermont; C. E. Gordon, 12th Rpt. Vt. State Geol. (1919-20).

In later years Professor Foyles[1] has mapped a large part of the southern lowland, while Keith[2] has shown that, west of the Champlain thrust, at Snake Mountain, there is a small area, four or five miles long and less than a mile wide, of Upper Cambrian Potsdam quartzite.

As the result of these investigations we know that the southern Vermont lowland is made up, almost wholly, of Ordovician strata, including Trenton, Canajoharie, Chazy, and Black River, and in this order of abundance.

STRATIGRAPHY

Juniper Island and Rock Dunder are made up of shales. Whether they are Trenton shaly limestone or Canajoharie shales has not, the writer thinks, been determined. They are evidently erosion remnants of the formation which once was continuous, eastward, to the mainland.

West Shelburne and Charlotte, west of the Champlain thrust, are Trenton limestone, bordered on the lake shore by Trenton shale.

In Ferrisburg and Panton there are northeast-trending, alternating beds of Trenton limestone and shale, and Chazy limestone, with the former largely predominating. The dips of these strata suggest synclinal and anticlinal folds, but Professor Foyles gives no cross-sections to indicate them. By the dam, in Vergennes, the Chazy is faulted over onto the Trenton shaly limestone. There are small exposures of Black River limestone southeast of North Ferrisburg, at Fort Cassin, and on the north shore of Button Bay. Canajoharie shale extends along the lake shore in a narrow strip from Arnold Bay to Button Bay.

The greater part of Addison is made up of Trenton limestone, with a smaller belt of Chazy, extending from Vergennes to the southern part of the township. Here a narrow belt of Black River lies between the Chazy and the narrow strip of Potsdam sandstone which lies just west of the Champlain thrust at Snake Mountain. Bridport, west of the Champlain thrust, which runs through the eastern part of the township, is shown by Foyles to be made up of three northeastward-trending beds of the Trenton: from west to east, "calcilutite" (which is Grabau's term for a calcareous shale); limestone, and "argillutite," (which is the same author's word for an argillaceous, or clayey limestone).

[1] The Geology of Shoreham, Bridport, and Fort Cassin, Vt.; E. J. Foyles, 14th Rpt. Vt. State Geol. (1923-24).
The Stratigraphy of the Townships of Addison, Panton, and Southwestern Ferrisburg; 15th Rpt. (1925-26). The Stratigraphy of Ferrisburg; 16th Rpt. (1927-28).
[2] Cambrian Succession in Northwestern Vermont; Am. Jour. of Science, Vol. 5 (1923).

The Champlain thrust runs through about the center of Shoreham, from north to south. West of the thrust Foyles shows the township to consist, geologically, of Trenton limestone, in the northwest corner and at Larrabee's Point; Trenton "argillutite," which predominates in the central part of the area, and a small belt of Chazy limestone in the northeastern corner.

Orwell, Benson, and West Haven have not been mapped in recent times. Hitchcock's old map showed the region, from west to east, to be made up of "calciferous sand rock" (a limy sandstone), Trenton limestone, and "Hudson River shales," which may mean "calcilutite" or "argillutite."

FOSSILS

As has already been stated, the Foreland, or Western sequence, contains the largest number of fossils of any part of the State. These fossils are all of Ordovician age and include trilobites, brachiopods, bryozoa, cephalopods, gastropods, graptolites and ancient corals. They are to be found in many localities, some of them famous, and in varying degrees of abundance.

Many trilobites have been obtained from Grand Isle County.[1] They are mostly fragmentary but large, perfect specimens of *Isotelus* are still to be had.

On Isle La Motte, Prof. P. E. Raymond, of Harvard University, has discovered (in the Goodsell quarries, on the eastern part of the island) and described the Oldest Coral Reef.[2] This reef consists of ancient corals of an hitherto undescribed species, which Raymond has named *Lamottia heroensis,* surrounded by stromatoceria and bryozoa. The coral heads are from an inch to twenty-four inches in diameter and are found overlying the Trenton limestone.

Another locality yielding ancient corals is on Button Island, where R. J. Foyles[3] has described an old reef of *Stromatocerium rugosum* and *Columnaria halli. Stromatocerium lamottense*[4] is also known here.

Now corals are marine organisms requiring warm, clear, salt water for their existence. Consequently their occurrence on the shores of Lake Champlain points significantly to the ocean waters and milder climates which once prevailed in this region.

At Thompson's Point, Charlotte, many fossils have been found and it is still a good collecting ground. At Chimney Point, Addi-

[1] 4th Rpt. Vt. State Geol.
[2] 14th Rpt. Vt. State Geol.
[3] 14th Rpt. Vt. State Geol.
[4] 15th Rpt. Vt. State Geol.

son, Chazy and Black River fossils abound; while on Larrabee's Point, Seeley[1] reported Trenton and Black River fossils in abundance.

But nowhere on the Foreland has such an abundance and variety of Ordovician fossils been discovered as at Fort Cassin, an old Revolutionary earthwork, dating from 1812-14, built on a small promontory which juts out into the lake in Ferrisburg. Here a multitude of trilobites, cephalopods, gastropods, bryozoa, and brachiopods have been studied and described by geologists, among them Augustus Wing,[2] R. P. Whitfield,[3] H. M. Seeley,[4] P. E. Raymond[5] and, more recently, by R. J. Foyles.[6]

Besides these ancient fossils one finds along the lake shore, from the Canadian border southward, at least as far as Button Bay, small pelecypods of more recent times—fossils which tell us by their presence of a marine stage in Lake Champlain and, by their occurrence at elevations several hundred feet above the present lake level, of the upraise of the region since the waning of the Pleistocene ice-sheet. Among these fossils may be mentioned *Mya, Saxicava, Macoma, Leda, Mylitus,* and *Yoldia.*

The Central Sequence

This division of Keith's classification lies between the Champlain thrust and the Mountain Border fault. Its southern boundary is Keith's Monkton thrust. The sequence is made up of long, narrow belts of formations, striking generally north and south, and of Cambrian and Ordovician ages.

These strata, once of far greater lateral extent, have been crowded together by the westward advance of the Green Mountain massif till they have overridden one another and lie, like the shingles on a roof, with escarpments facing the west and with long dip slopes to the east. There is evidence of folding, but the westward thrusting has largely concealed it.

The formations are Lower Cambrian: Monkton quartzite, Winooski marble, Mallett dolomite, Parker slate, Shelburne marble; Middle Cambrian: Rugg Brook conglomerate, St. Albans slate; Upper Cambrian: Milton dolomite, Mill River conglomerate, Gorge formation, Highgate slate, Williston limestone; Middle Ordovician: Corliss conglomerate, Georgia slate (see page 71).

[1] Am. Jour. Science; 3rd Series, Vol. 13.
[2] Am. Jour. Science; 3rd Series, Vol. 13.
[3] Bul. Am. Museum of Natural History; Vol. 1.
[4] 7th Rpt. Vt. State Geol. (which contains fossil lists and many fine plates).
[5] 13th Rpt. Vt. State Geol.
[6] 13th, 14th, 15th Rpts. Vt. State Geol.

Lower Cambrian

THE MONKTON QUARTZITE

This formation was named by Keith for its type locality in the town of Monkton. It is dense, fine-grained rock and, the microscope shows, contains in addition to the sand grains, a large amount of carbonate. This indicates the limy content of the seas in which the sand was deposited. The rock is of varying shades of red, the dark predominating, and forms a striking feature of the landscape as one travels south from Burlington, along the Shelburne Road. The formation is sparingly fossiliferous. Good specimens of *Olenellus, Ptychoparia,* and other trilobites, have been found in the weathered beds of Colchester.

The Monkton is the oldest Cambrian formation in western Vermont but, since it rests by thrust upon Ordovician formations, its total thickness is unknown. Its apparent thickness is given by Schuchert as 300 feet.

The most northern-known exposure of the Monkton is on the northeast shore of Malletts Bay, but it is possible that it occurs east of Highgate Springs, where interbeds of a red quartzite have been reported.

The formation extends southward from Burlington, in a broken belt two to four miles wide, along the western border of which Pease Mountain, Mt. Philo, Buck, Shellhouse, and Snake Mountain form the escarpments of the Champlain overthrust. No exposure of the Monkton is known south of Snake Mountain.

In Burlington the Monkton quartzite was found 170 feet below Winooski Avenue, where a driven well encountered it.

Along Ledge Road, in Burlington, the Monkton rises to the eastward like a flight of stairs, with the "treads" dipping easterly at angles of ten or twelve degrees. On the floor of the old Phelps quarry, on the Shelburne Road, are rain prints, ripple marks and worm trails, which show that the formation was laid down as sand on an old sea shore, while similar impressions at higher levels tell us that the shore was sinking.

The same red quartzite also appears at Oak Ledge, and at Red Rocks Park which rises as a headland some 160 feet above the lake. The underlying limestone or shale is not seen here but it appears just across the bay at Shelburne Point.

From a line drawn from Oak Ledge across the city to the Winooski bridge, northwestward to the outcroppings of Winooski marble on North Avenue, beyond Lake View Cemetery, no outcrops are seen, most of the western part of the city being built

upon the shore of the ancient lake, with the principal north-south streets marking the old strand lines, while the eastern part lies on the old Winooski delta, which makes Centennial Field such an admirable playground.

THE WINOOSKI MARBLE

This formation, which is really a dolomite, takes its name from its exposures in the old quarries along the Winooski River, near Burlington. It is a fine-grained dolomite, in places but little metamorphosed; in others, highly crystalline. The colors are gray, pink and red. In places these are mottled and give the rock, when polished, a very pleasing effect. As Keith[1] remarks: "the characteristic feature of the dolomite is a very marked wavy, lumpy surface . . . . which makes possible the use of the stone as ornamental marble." Schuchert thinks[2] that "The mottling of the marble was due to the shallowness of the sea and the rippled nature of the bottom, which caused the white, magnesium limestone to form in the hollows or to be torn up by the storm waves."

The Winooski marble extends in a narrow, broken belt along the western side of the Central sequence, about 400 feet in maximum thickness[3] (twelve miles north of Burlington), from Canada to Weybridge, where it is seen along the east side of Snake Mountain, "probably less than 100 feet thick." In Milton great cliffs of the marble extend along the lower course of the Lamoille. Near St. Albans Bay the marble is quarried by the Vermont Marble Company. As already noted the Winooski marble forms Eagle Mountain, in Milton, Malletts Head, the eminence north of Malletts Bay, and the islands in the bay where it was formerly quarried. Bureau and washstands tops were made of it in the old Victorian days. Around Burlington it appears at Rock Point and Ethan Allen Park (parts of the Champlain thrust). The Monkton quartzite cuts it out largely in the city but it is seen as a few pink strata in the face of Phelps quarry, east of which it gradually replaces the quartzite and crops out in many places on the links of the Burlington Country Club.

"Walcott, in 1883, found fossils in the pink marble and referred them to the Lower Cambrian." (Keith.)

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From the above descriptions of these two Lower Cambrian formations, it is seen that the westward thrusting has been dif-

[1] Cambrian Succession in Northwestern Vermont, *op. cit.*
[2] Cambrian and Ordovician Stratigraphy in Northwestern Vermont; Am. Jour. Science, Vol. 25 (1933).
[3] The thickness of strata is measured at right angles to their bedding planes and so does not refer to their areal extent which, with low dips, may be very great.

ferential in character, in some places bringing the Monkton quartzite to the fault line; in others, the Winooski marble.

THE MALLETT DOLOMITE

This formation now exists as fragmentary areas of a probably once continuous belt. It is known in southern Quebec, from which province it extends southward through western Highgate, east of the Champlain thrust, for a distance of about seven miles, to the Missisquoi River. South of the river smaller areas are known in St. Albans township and in Georgia. The type locality of the formation is in the ridges just north of Malletts Bay, where Keith described it in 1923. The southernmost exposure, as far as the writer knows, is south of Burlington, on the Williston Road.

Keith describes the formation as massive, light- and dark-gray dolomites, containing interbeds of white quartzite, cross-bedded and ripple-marked (which, like similar structures in the Monkton, indicates an old seashore) and other beds of sandy dolomites, whose rounded, glassy grains of quartz stands out strikingly on the rock surfaces. These grains, however, are not a good diagnostic, since subsequent formations also contain them. Schuchert[1] thinks that these grains represent "wind-blown sand derived from Pre-Cambrian lands." Keith notes that "The beds of this formation are very hard and tough and resist erosion so as to make ridges wherever the formation appears. . . . The Mallett dolomite is between 700 and 800 feet thick, where all numbers are present."

The few fossils, found by Walcott in Georgia and Highgate years ago, place the age of the formation as Lower Cambrian.

THE PARKER SLATE

This formation extends in a discontinuous belt from southern Quebec to Monkton, "where it is cut off against a thrust fault." . . . "South of that point its position in the Eastern sequence is taken by a formation of similar aspect but with less shale and more dolomite." It lies generaly east of, and conformably on, the Mallett dolomite and forms a narrow belt in Highgate, Swanton, and Georgia, after which place it appears farther east in Colchester, where Keith named it the Colchester formation, later changing the name to the Parker slate. It is probably represented by the slate west of Colchester Pond and, extending southward, appears east of the Champlain Valley Fair grounds, in Colchester, crosses the Williston Road, near the Linsenmeir house, runs along the western base of Brownell Mountain, and south through St. George

[1] *Op. cit.*

and into Monkton. "Its estimated thickness is from 20 to 500 feet, in northern Vermont, and from 200 to 250 feet at the south." (Keith.)

To quote Schuchert[1]: "The Parker formation is dominantly one of dark blue micaceous-slate with some flaggy sandstone present in the lower part. In the upper Parker there are also local zones of dolomite, the thickest one, about thirty feet, capping Parkers Cobble." . . . "In addition, the Parker slate has local reef limestones" which, Keith[2] notes, 'consist of massive blue marbleized limestone sharply separated from the slate. They are best shown two miles southeast of Swanton, where two of them are surrounded by gray slate. The lenses measure 100 by 60 feet and 100 by 75 feet.' "

Schuchert states that "The thickness of the Parker slate is highly variable from place to place, because it is the terminal formation of the Lower Cambrian and has undergone much erosion during the following land intervals."

Perhaps the most famous fossil locality in Vermont is at the Parker Cobble which Schuchert locates "two miles N. 60° W. of Georgia Center." On the old Parker farm, now owned by a Mr. Montcalm, Noah Parker first discovered, in a quarry at the base of the hill, specimens of a trilobite which has come to be known as *Olenellus thompsoni*, after the Vermont naturalist and one-time professor at the University of Vermont. This is a type fossil for the Lower Cambrian. In later years C. D. Walcott,[3] collecting in this quarry, obtained a large number of fossils: trilobites, brachiopods, gastropods, and graptolites. Schuchert also notes that, "In a road-metal quarry, one mile N. 15° W. of Highgate Center, was found, in the uppermost Parker slate, the oldest known graptolite, *Dictyonema schucherti* (Ruederman)."

As a result of Walcott's work the Lower Cambrian was for years known as the Georgian. Later the named was changed to Waucobian, after Waucoba Springs, in Nevada.

It may be noted that none of the slates of northwestern Vermont is of commercial quality.

THE SHELBURNE MARBLE

This formation was named and described by Keith, in 1922. He says of it: "Outcrops of this formation are mainly in a wide belt between the town of Colchester and the town of Hinesburg.

[1] *Op. cit.*
[2] *Op. cit.*
[3] Fauna of the Lower Cambrian, or Olenellus Fauna; 10th Ann. Rpt. U. S. Geol. Survey, 18. Also in Bul. 30, U. S. G. S.

Two much smaller parallel strips of marble are found in the town of Shelburne, in addition to the main belt. The name of the formation is taken from its many exposures in Shelburne. The marble there follows next above the Milton dolomite. The formation is composed almost entirely of marble, always light colored and for the most part white. Other colors are light buff or cream bluish-white, and various beds are mottled with cream and white or blue and white." . . . "No contacts are known between the Shelburne marble and the Milton dolomite, which is the next underlying formation. Where the formations cross the Winooski River, nearly three miles east of Burlington (at the Winooski gorge) the Milton dolomite and Shelburne marble are conformable in dip, but their outcrops are separated by the width of the river." "The Shelburne marble contains no fossils as far as is known, but it is uniform and is a regular unit in the Lower Cambrian succession of the eastern part of the valley. It also occupies the same position in the Lower Cambrian Eastern sequence. Assignment of the Shelburne to the Lower Cambrian is also supported by the presence of white marble boulders in the conglomerates of the Upper Cambrian in most of their exposures."

Middle Cambrian

RUGG BROOK DOLOMITE CONGLOMERATE

The lower member of the Middle Cambrian is the Rugg Brook dolomite conglomerate, a thin formation, 0 to 20 feet thick, which occurs along Rugg Brook, about three miles southwest of St. Albans City. Following the uplift and long-continued erosion, which took place at the end of the Lower Cambrian, in this region, the sea again advanced, reworking the old dolomites of the Parker or Mallett formations and forming the basal conglomerate of the late Middle Cambrian. This conglomerate is made up, according to Schuchert, of dolomite blocks up to two feet across, set in a matrix of sand grains, cemented by dolomite mud. It probably represents a once more extensive formation. No fossils have been found in it.

THE ST. ALBANS SLATE

This upper member of the Middle Cambrian "Consists almost wholly of blue-black, sandy, micaceous slate; rarely a bed is very limy, making impure limestones, and there are also thin layers and lenses of sandstone and an occasional dolomite, up to six feet thick. The greatest thickness, 250 feet, is in the Mill River-Rugg

Brook area, three miles southwest of St. Albans. . . . In Adams pasture the thickness appears to be greater than 200 feet. . . . The varying thicknesses (of the formation) are due to the erosion interval following the deposition of the St. Albans slate." . . . "The St. Albans slate is underlain basally in at least three places by the Rugg Brook conglomerate." (Schuchert.)[1]

The formation extends, in a narrow belt, from the Canadian border, lying east of the Lower Cambrian formation, southward through central Highgate, Swanton, St. Albans, and south at least as far as Georgia Plains. South of this it has not been reported.

The type locality is in Adams pasture on the outskirts of St. Albans. To quote farther from Schuchert: "It was for the strata of this place and the wider area about St. Albans that Marcou (1861) founded his St. Albans group." Prof. B. F. Howell, of Princeton University, found in Adams pasture, in the summer of 1922, over a hundred specimens of Middle Cambrian fauna while, two years later, Keith, Prindle, and Schuchert found two other localities. "The first of these was about one and one-half miles southwest of St. Albans on Martin Conner's land, and the next four miles northeast of the city, near the Rockledge estate. This, then, fixed the presence of Middle Cambrian beneath the Upper Cambrian (Highgate) slate, in northwestern Vermont." (Schuchert.)[1]

Upper Cambrian

The Upper Cambrian, in Vermont, is represented by the Mill River conglomerate, Milton dolomite, Highgate slate, the Gorge formations, and the Williston limestone. It extends in a belt of varying width from southern Quebec to the Monkton fault. It lies generally next east of the Mallett dolomite, Winooski marble, and Parker formation and extends through Highgate, Swanton, St. Albans, Georgia, Milton, Colchester, South Burlington, Shelburne, Charlotte, and Monkton. Its most easterly reported occurrence is in the longitude of Highgate Center, in Highgate, and Cobble Hill, in Milton. As with the other formations of the Central sequence, a great deal of mapping remains to be done in order to delimit its boundaries.

THE MILL RIVER CONGLOMERATE

Prof. B. F. Howell[1] named and described this formation in 1929. It forms the base of the Upper Cambrian and, probably once

[1] *Op. cit.*

more widespread, is known in only three localities. To quote Schuchert: "At three widely spaced localities the Mill River limestone conglomerate is seen to overlie the fossiliferous beds of the Middle Cambrian (St. Albans slate) directly but with an erosional unconformity. The typical locality makes a bluff to the east of the Mill River about three and one-half miles southwest of St. Albans. Another place is Adams pasture on the western outskirts of St. Albans, and a third is to the west of the Rockledge estate, four miles north of the city."

The conglomerate is "composed almost wholly of angular fragments of the bluish-white limestone lentils that formed in the Lower Cambrian (Parker slate). Some of these blocks ("lentils") are twenty feet across. There are also, rarely, small angular pieces of Mallett or some other dolomite of the same nature, up to eight inches long. Fossils of St. Albans and even of Lower Cambrian age have been found in this conglomerate, in Adams pasture, and at this place there are also white basal sandstones made up of the usual reworked, wind-blown sand." This means that the older formations were eroded, during a period of uplift, and their *débris* was later consolidated, forming the basal conglomerate in Upper Cambrian time.

The thickness of the conglomerate is from five to fifteen feet.

THE MILTON DOLOMITE

Keith[1] named this formation in 1923. He describes it as follows: "The beds of this formation are practically continuous from Canada to Monkton. They are best exposed in a wide belt passing through the town of Milton, about three miles west of Milton village. The formation consists almost entirely of massive dolomite both fine and coarse-grained. Most of the beds are thick (from one to four feet), especially in the lower part of the formation and, as a rule, the bedding is difficult to determine." . . . "A peculiarity of the Milton is its considerable content of black chert. This forms small, irregular patches and pockets, much broken during the rock movements, and is very seldom found in layers. This chert weathers out in black spots which readily catch the eye." . . . "Another peculiarity of this dolomite is its large content of dolomitic conglomerate." Keith gives the maximum thickness of the Milton as 700 feet.

Fossils, found by Ulrich, fixed the age of the dolomite as Upper Cambrian. In 1932 Schuchert and his associates found fossiliferous Milton dolomite "three and one-half miles in a straight

[1] *Op. cit.*

line southwest of Milton village and about three-fourths of a mile west of the landmark, Cobble Hill." These fossils included trilobites, brachiopods, and gastropods. "In another locality, four and one-fourth miles in a straight line southwest of Milton village and one-fourth mile east of Allen Brook" an abundance of the Upper Cambrian brachiopod, *Lingulepis acuminata,* was found by Schuchert and others. Schuchert writes that "these upper Milton strata are very sandy through a thickness of at least 150 feet, with interbedded sandstone in beds up to ten feet thick, along with horizons of brecciated dolomite and sandstone in which the angular pieces range up to eighteen inches across. This is evidence of shallow waters and of storm waves tearing up the bottom." "Above these dolomites and sandstones there follows, to the east, a long sequence of Highgate slate which passes beneath Cobble Hill, with its capping of older dolomite, and then reappears along the eastern base of the hill."

THE WILLISTON LIMESTONE

This formation, also named by Keith, succeeds the Shelburne marble. "It outcrops in a single belt seven miles long beside the Shelburne marble in the towns of Williston, Burlington, and Shelburne." . . . "It is made up of light or dark blue limestone and marbleized limestone." . . . "The prevailing blue color and notably thinner bedding of this formation distinguish it readily from the underlying Shelburne marble." Fossils, found along Muddy Brook, South Burlington, fix the age as Upper Cambrian. The Williston is also found in the Eastern sequence in and around Brandon.

THE HIGHGATE SLATE

This formation, which represents the highest Cambrian in Vermont, forms a belt lying just east of the Lower and Middle Cambrian beds and extends from Quebec through eastern Highgate, Swanton, St. Albans, and into Milton, a distance of some twenty-five miles. South of Georgia Center it is seen underlying the Milton dolomite. It makes up the base of Arrowhead Mountain and, south of this mass, it appears in the lower Milton gorge where it forms a low ridge, across which the Lamoille River has cut a small water gap. As already noted, the Highgate also forms the base of Cobble Hill. From south of Highgate village to the border, in a belt a mile or so wide, the formation shows some especially interesting features.

The Highgate was named and described by Keith, in 1923, and has also been studied and written about by Schuchert.

Keith writes that it "consists mainly of dark slate, in places black, and usually banded. This banding is in most places regular, sharp and clear and strongly resembles the bandings of glacial deposits." Schuchert found that the banded slate was best seen on the road going up a little hill from the South Gore school, where "it shows in a very striking manner the extraordinary banding, consisting of thin, yellowish-white laminæ of fine silt or clay."[1] Mr. W. H. Bradley, of the United States Geological Survey, thinks that this banding is not due to glacial action but to storm waves or current action. The Highgate is not made up wholly of slate but includes also thin-bedded limestones and dolomites. In the railroad cut, a short walk north of Highgate Center, there is a fine exposure of finely banded limestone, some thirty-five feet thick. In these thin limestone strata Keith found trilobites, in 1921, which fixed the age as Upper Cambrian.

LIMESTONE REEFS OR BIOHERMS

In the Highgate formation and especially in its thinly bedded limestone member, are found enormous "marble-like oval or mound-shaped growths, usually varying in longest diameter from fifteen feet to upward of 100 feet, and in thickness up to ten feet or more. They are often conspicuous white objects in the landscape. One on the Rockledge estate measures 170 x 110 x 8 feet; and another mass, 90 x 50 feet, may be a part of it; four miles southwest of St. Albans there are four in close association, the smallest 15 x 10 feet and the largest 140 x 120 x 10 feet; nearby one in the forest is 200 feet long and 80 feet wide; and one and one-half miles north of Highgate Center is the largest example, about 600 feet long." . . . "All are homogeneous masses of a light blue limestone that show no bedding. They appear to be algal growths in thin sheets or in vertical columns, and in the hollows of a reef there may occur comminuted trilobites." (Schuchert.)[1]

GORGE FORMATIONS

In the north bank of the Missisquoi River, at Highgate Falls, is to be seen another manifestation of the northwestward thrusting for which Vermont is noted, a nearly horizontal thrust fault in the dolomites, limestones and slates of the Highgate formation. Space is lacking to do more than point out the geological significance of this locality. To quote again from Schuchert's work: "Downstream (on the south bank of the river) and structurally beneath

[1] *Op. cit.*

the upper dolomites, occurs the most varied and most highly fossiliferous and, therefore, the most interesting, Upper Cambrian exposure, not only of northwest Vermont but of all eastern North America." Schuchert has divided the beds of dolomite, limestone, shale, slate, intraformational conglomerates[1] and "sandy beds" into Upper Highgate, Lower Highgate, Upper Gorge, Middle Gorge, and Lower Gorge, subformations, and described each in detail, together with the fossils belonging to each other. He gives it as his opinion that, "in the near future it (the Upper Cambrian of Vermont) will become the type area for interareal correlations in all eastern North America, because of its many fossils, not all of which by far have been collected or described."[2]

The Vermont Disturbance

In northwestern Vermont, along a belt extending from near Georgia Center, about N. 15° E. into Canada, near Phillipsburg, Quebec, we have evidence that, at the close of Upper Cambrian time, there was uplift of the region, tilting of the strata, and Keith thinks "perhaps even some folding." During the time of emergence of the land from the sea the uptilted strata were eroded so deeply that, in places, the Upper and Middle Cambrian beds were removed and Lower Cambrian strata exposed. Schuchert has called this period of uplift the Vermont disturbance. It marks the oldest crustal disturbance in Vermont of which there is a record.

With the resubmergence of the region a basal conglomerate, the Corliss, followed by a slate formation, was laid down across the eroded edges of the Cambrian strata. Fossils prove that these newer formations belong to the Ordovician period. Such a relation of the older strata to the newer is called, as has already been noted (p. 50), an *angular unconformity*.

Keith[3] was first to call attention to this angular unconformity in 1922, on the Oliver Grandge farm, "four and one-half miles N. 10° E. of Highgate Center and one-half mile south of the Canadian border." (Schuchert.)

Schuchert[4] states: "Five miles south of Highgate Falls the basal Ordovician conglomerate (Corliss) lies on the Upper Gorge formation, with its higher part and all of the Highgate series eroded

[1] An intraformational conglomerate is one, the fragments of which were derived from the same formation in which they occur. It is due to some interruption, as the action of storm waves, in the orderly process of deposition and consolidation. In basal conglomerates, on the other hand, the fragments, usually rounded from wave action, were derived from an *older* formation which had undergone erosion.

[2] *Op. cit.*

[3] *Op. cit.*

[4] *Op. cit.*

away, prior to the introduction of the sea that laid down the Georgia sequence."

The same author writes that "Probably the best place to see this unconformity is one mile west of Georgia Center, where there is a low arch of the Highgate formation (here there is slate both above and beneath a thick, local dolomite) trending north-south and made at the close of the Cambrian (Vermont disturbance). It was then eroded and the Corliss conglomerate laid down across the different beds of the Highgate, indicated above. Accordingly, the Georgia slate and the Corliss conglomerate rest on different beds of the Upper Cambrian and the conglomerate has fossiliferous pieces of the older formations." The Corliss is, therefore, a basal conglomerate.

Ordovician

THE CORLISS CONGLOMERATE

This dolomitic conglomerate marks the beginning of the Ordovician Period in Vermont. It was at first called the Swanton conglomerate by Keith (1924) but was later changed by him to its present name in 1932.

The formation is fragmentary, owing to the age-long erosion which it has undergone. It is found at various localities along a belt extending from a mile west of Georgia Center, northeasterly through Georgia, St. Albans, Swanton and Highgate (near Highgate Falls), and into Quebec. The type locality is the Corliss ledge, five miles north by east of St. Albans.

The conglomerate consists of large and small masses of limestones and dolomites whose fossil contents prove that they were derived from the Middle and Upper Cambrian formations, set in a matrix of limestone and dolomite paste. In this paste are also found rounded, wind-blown grains of glassy quartz, such as also occur so prominently in the Mallett dolomite. Some of the masses making up the conglomerate are of enormous size, one at the Corliss ledge is a "lenticular mass of light blue limestone 140 feet long by 15 feet thick." (Keith.)

THE GEORGIA SLATE

With the exception of the Quaternary (Pleistocene) glacial deposits, which occur widespread throughout the State, the Georgia slate is the youngest known formation in northern Vermont. Between the laying down of the Georgia slate and the advance of the ice sheet from Canada there is an hiatus marked by over 400,000,000 years (see the Geological Timetable, p. 71), during

which the region was undergoing erosion and also during which, in various parts of the continent, strata of the intervening periods were being laid down.

The Georgia slate occupies a wide, continuous belt extending from northern Georgia (six miles south of St. Albans, according to Keith) through central St. Albans, eastern Swanton and Highgate townships and into Quebec. The belt is some twenty miles long while its maximum width, about three miles, is found in Swanton, from which township it narrows northward and southward. The belt lies generally next east of the Highgate (Upper Cambrian) slate and the Corliss conglomerate, where present, lies at its base.

According to Keith[1] "The formation consists almost entirely of slate, as a rule, of a dark-gray or bluish-gray color. Much of it is banded, a character which is easily seen on the weathered outcrops." . . . "The Georgia slate lies in synclines, and its upper part has been removed by faulting or erosion. Its original thickness is therefore, unknown and even that of the portion remaining can only be estimated." . . . "Its precise age was not determined until September, 1922, when two localities were found in Highgate which settled the matter. At the Oliver Grandge farm the slate was found by the author, lying unconformably on the Highgate slate and separated from it by a little lens of the Swanton (now Corliss) conglomerate." . . . Later, "the author found another locality, a mile S. 20° E. of the above, where substantially the same fauna, but of other species, was more plentiful." . . . "The fossils from these localities, according to field determinations by Schuchert, were at least as young as Black River and possibly as young as Trenton." (See the Geological Timetable, p. 71.)

The Mountain Border Fault

On the eastern border of the Central sequence an abrupt change in the topography is noted. Eastward-dipping escarpments rise, in places, as east of the Drury Brick Company plant, near Essex Junction, only a few tens of feet high; in others, notably on the west slopes of Brigham Hill, Essex township, multiple escarpments aggregate some 700 feet; while again, in Monkton and Bristol, in Chittenden township, in Wallingford, Bennington and other localities, mountains of two to three thousand feet elevation rise above the lowland, or, south of Brandon, the Vermont Valley.

This break in the topography constitutes the Mountain Border fault. It extends north and south throughout the State and marks

[1] *Op. cit.*

the thrusting of the mountain mass onto the terranes to the west. (See the frontispiece.)

The Eastern Sequence

Keith's Eastern sequence includes the region between his Monkton thrust and the Mountain Border fault, "From Middlebury north to Essex on Winooski River. Thence northward to Canada the Eastern sequence forms a narrow belt along the Mountain Border fault. The Eastern sequence cuts across the Central sequence for thirty miles and, south of the latitude of Middlebury, is in contact with the Western sequence, the Middle sequence having been entirely overridden."[1]

THE CHESHIRE QUARTZITE

The Cheshire quartzite, with two interruptions, runs along the Mountain Border fault the entire length of the State. Southward, it extends into Massachusetts to its type locality, the town of Cheshire. The first interruption extends from a point one and one-half miles east northeast of Fort Ethan Allen, southward for about fifteen miles. In this stretch the mountain gneisses are in contact with the sedimentaries of the lowland. The second interruption, according to Keith, extends from the vicinity of Rutland northwards for about twelve miles.

The Cheshire makes up Hog Back Mountain, in Monkton and Bristol, and is also well exposed at the gorge of the Middlebury River, in East Middlebury. It underlies the Lake Dunmore region and rises in Mt. Moosalamoo. Farther south, east of Rutland and along the Vermont Valley, the Green Mountain front is made up of the quartzite, which also occupies a wide area some distance east of Williamstown, Massachusetts.

The Cheshire quartzite is a fine-grained rock, white to light gray and dark gray in most localities, but in places it resembles maple sugar. Thin sections studied under the polarizing microscope, show, predominantly, clear white quartz grains with much smaller amounts of turbid orthoclase, plagioclase, microcline, and occasionally a zircon. Scattered fragments of sericite and limonite are noted.

Fossils found at various localities fix the age of the quartzite as Lower Cambrian. It is, therefore, correlative with the red Monkton quartzite but is radically different in its composition, since the Monkton contains much carbonate and possesses a far

[1] *Op. cit.*

higher iron content. Both formations show cross-bedding here and there, which indicates that they are of shallow water origin.

Keith estimates the thickness of the formation at 800 feet in Wallingford and at over 1,000 feet in Hogback Mountain

Below the Cheshire there is found in many places a basal conglomerate. This, Keith notes: "Usually consists of white and blue quartz pebbles an inch or less in diameter, closely sprinkled through a siliceous matrix. In places the pebbles are much coarser, and boulders as much as three feet in diameter are known." . . . "In most places the (Cheshire) quartzite is sharply defined from the overlying Rutland dolomite."[1]

THE MENDON DOLOMITE

From the western slope of Mt. Moosalamoo (Brandon topographical sheet), Sucker Brook flows into Lake Dunmore. In the bed of this brook, about 200 feet upstream from the bridge, one comes upon the basal conglomerate of the Cheshire quartzite resting unconformably upon the eroded surface of a light gray dolomite. A small cliff of the quartzite rises above the brook. Since the dolomite lies unconformably beneath the Lower Cambrian quartzite it is evidently Pre-Cambrian in age. It is the most northerly proved occurrence of Pre-Cambrian rocks in Vermont. It was named the Mendon dolomite by Whittle,[2] in 1894. Another locality showing the same rock relationship is to be found about two and three-quarter miles north of Pittsford, east of Coxe Mountain (Castleton sheet).

THE RUTLAND DOLOMITE

This formation, named by Keith in 1923, is described by him as lying along the eastern margin of the Champlain Valley, practically coextensive with the preceding Cheshire quartzite and with the same interruptions. "It is very well developed in the valley around Rutland and received its name from that place." Fossils found in numerous localities prove its Lower Cambrian age.

Large exposures of the Rutland are found in Milton west of the mountain front, in Bristol and Monkton and Middlebury, west of Lake Dunmore, west of Nickwaket Mountain and on the slopes of Blueberry Hill. In the Rutland Valley it forms a great open syncline whose western limb, according to Keith, "is found in Pine Hill while the eastern limb, which is locally faulted off, appears along the front of the Green Mountains."[3] Farther south it occupies the Vermont Valley, around Bennington, and in Massachusetts it underlies Williamstown. The Rutland dolomite is a fine- to medium-grained rock of which there are two principal phases: one, light gray to dove color, the other, dark steel-blue. Besides these, in lesser abundance, there is a variegated phase of pinkish and greenish hues weathering to yellow. This is a striking-looking rock and is easily recognized. It occurs west of Lake Dunmore and in Milton. Keith estimates the thickness of the Rutland at about 1,000 feet.

[1] *Op. cit.*
[2] Occurrence of Algonkian Rocks in Vermont; C. L. Whittle, Jour. of Geol., Vol. 2 (1894).
[3] *Op. cit.*

In Milton, extending from the Mountain Border fault westward for about one and one-half miles, into the gorge of the Lamoille River, and northward for several miles, the writer has found a formation which, based on close lithologic similarity, is probably the Rutland dolomite. Unfortunately no fossils have been discovered to confirm it. The dolomite in question shows the same texture and variety of colors that characterize the Rutland. It is best observed in the gorge where the river has cut downward through eighty or a hundred feet of the dolomite and carved the small water gap in the underlying Highgate slate, mentioned on page 92.

In the gorge, near the power house, a bed of Cheshire quartzite, seven or eight feet in thickness, is seen resting along a sharp thrust plate upon the bedding of the Highgate slate, which dips 30° easterly. The quartzite is followed upward by about fifteen feet of dark blue dolomite, intercalated with two shaly layers, above which massive dark blue dolomite rises for thirty or forty feet. This, in turn, is followed by light buff dolomite which makes up the top of the cliff, by the dam. Farther upstream, on the north bank, the "variegated" dolomite appears.

In Milton village, above a single outcropping of Highgate slate, there is a series of westward-facing low escarpments, in turn, of dark blue, light variegated and, again, dark blue dolomite.

Farther east, in the field of the Coutermarsh farm, appear low hillocks of the three dolomite phases, for about 1,000 feet, east of which, across a field, the Cheshire quartzite (here folded, rusty, and much fractured) of the Mountain Border fault appears, followed by a graywacke.

In the road quarry, about two miles north of Milton bridge, along the pavement, the light colored dolomite lies below, and the dark blue rock above, in reversed order to that found in the gorge. Between the two phases is a sheared belt. Evidently thrusting has been responsible for this reversed order.

In excavating on the Pinegrove Farm, in Milton village, some years ago, a vein of foliated talc was found beneath the dolomite. The talc deposits of the State occur in the schists and gneisses of the mountains, hence we have evidence that these "crystallines" lie at no great distance below the rocks of the lowland.

THE BRIGHAM HILL GRAYWACKE

In Milton, Westford, and Essex townships the Mountain Border fault is not sharp but rather a fault zone, some two miles wide, in which several escarpments rise to the eastward, each higher than the preceding. These escarpments culminate in Brigham Hill, Essex, at an elevation of 1,032 feet. The rock of this region is a graywacke which the writer has named for its exposure on Brigham Hill.

West of this hill the formation descends in a series of three escarpments to the lowland where, east of Colchester Pond, it lies by thrust on a slate. Whether this slate is the Parker or the Highgate has not been determined. The graywacke forms a broken anticline on the top of the hill and under it, conformably, is seen a dolomite which is probably the Rutland.

The graywacke also makes up Bald Hill and Hardscrabble Hill, to the north, crosses Georgia Mountain and Aldis Hill (north of St. Albans) and extends northward through the State and into Quebec, where Clark[1] has called it the Gilman quartzite. In it he has found fossils of Lower Cambrian age. The rock is not, however, a quartzite but a graywacke. A single fossil, found on the west slope of Bald Hill, Westford, was identified by Professor Howell as an Hyolithid, of Lower Cambrian age, thus confirming the age of the graywacke.

Southward the graywacke has been followed by the writer to the point, northeast of Fort Ethan Allen where, as already noted, the Cheshire quartzite is cut out as far south as Monkton. In this intervening break, however, the graywacke appears here and there along the Mountain Border fault and is seen on Monkton Ridge, in the gorge at East Middlebury and, at least, as far south as Lake Dunmore.

The graywacke is intimately associated with the Cheshire, overlying it along the fault in East Milton and being infolded with it at the East Middlebury gorge, as it is on Monkton Ridge.

In East Milton it extends easterly from its contact with the Cheshire for about one and three-fourth miles and forms folds

[1] The Lowest Cambrian of Quebec; T. H. Clark, Bul. Geol. Soc. of America, Vol. 42 (1930).

overturned to the west. In Milton village the graywacke makes up the most easterly of the low escarpments mentioned above. It crosses the river, under, and west of the bridge, and forms the ridge which trends northward, just west of the pavement. It also crops out at the gasoline station south of the bridge and overlies the Rutland dolomite for some distance along the banks of the Lamoille River.

Most strikingly, it makes up Arrowhead Mountain, which rests by thrust upon the Highgate slate. Evidently the graywacke was once continuous from East Milton to Arrowhead. The mountain is, therefore, an outlier of Lower Cambrian graywacke resting by thrust upon Upper Cambrian slate. Such an erosion remnant is called by the Germans a "Klippe." Due to the stripping off of the graywacke east of Arrowhead, one looks down upon the underlying Rutland dolomite as through a window. Again the Germans (not the Greeks) "had a name for it," a "Fenster," or window. The dolomite underlying the graywacke on Brigham Hill is also a "Fenster."

Cobble Hill, a prominent landmark in Milton township, is a second "Klippe," but here a dolomite (probably the Rutland) is found thrust onto the Highgate slate.

The Brigham Hill graywacke is a very fine-grained, yellowish to dark gray rock, often with thin bandings of argillaceous material. It has a striking appearance and so is easily recognized. Microscopically it is seen to be made up of fine fragments of quartz, orthoclase, plagioclase, microcline, and perthite, firmly cemented by argillaceous material. It also shows grains of magnetite, ilmenite, leucoxene, a few tourmalines and fragmentary limonite. Sericite is extensively developed in some of the sections. The rock was formed from a sediment which had not been exposed to the abraiding action of the waves.

The Brigham Hill graywacke is not a separate formation but a phase of the Cheshire.

Addison County

It has been seen (p. 79) that the Foreland, west of the Champlain fault, in Charlotte, Ferrisburg, Panton, Addison, Bridport, Shoreham, Benson and Orwell, is made up of Ordovician formations of Beekmantown, Chazy, Black River and Trenton ages, with some Upper Cambrian quartzites.

The region between the Champlain fault and the Green Mountain front is also very largely Ordovician with Lower Cambrian quartzites on the east and west borders.

In this part of the State the overlapping, shingle-like slices, characteristic of northwestern Vermont, give way to open folds. In the third quarter of the last century the Rev. Augustus Wing, whose masterly investigations of the rocks of Addison County brought him lasting fame as a geologist, conceived a great open syncline, broadening and pitching to the south and lying between the "Red Sandrock" (which we now know as the Monkton quartzite) of Snake and Buck mountains, on the west, and the Cheshire quartzites at the foot of the Green Mountains, on the east. Brainerd and Seeley[1] later restudied the region and mapped the Beekmantown, Chazy, Black River, Trenton, and Utica beds.

Recently Mr. W. M. Cady, of Middlebury, a graduate student at Columbia University, has investigated this area between the two mountain uplifts and from Monkton to Brandon. From the abstract of his paper presented to the Geological Society of America, at its Cincinnati meeting, December, 1936, and from private communications, the following results of his work are taken: "The axis of a synclinorium in (Lower) Cambrian quartzites and dolomites, and Ordovician limestones and slates, plunges southward beneath Middlebury, Vermont. The west limb of the structure is bordered by an overthrust on the west slope of the Red Sandrock range (the Monkton Hills), dipping 10° to 30° easterly; 600 feet of red quartzite (Monkton) rest on and dip subparallel to, the thrust. Overlying beds, occupying the center of the synclinorium, are: 800 feet of interbedded quartzites and dolomites, 3,000 feet of interbedded limestones, dolomites, and marbles, and 400 feet of slates. On the east limb, these beds are subvertical and in many cases overturned. A key horizon, the striped, sandy limestones, 1,000 feet below the slate, can be traced northward on the west limb, from Orwell, through Shoreham, Cornwall, and Weybridge into New Haven, where it crosses the nose of the structure and follows the east limb through Middlebury, Salisbury, Leicester, and Brandon; passing around secondary synclines that reflect the form of the major structure. Major thrusting does not disrupt the synclinorium."

Mr. Cady, finds, further, that Middlebury College stands on Trenton limestone. "Below the falls (below the bridge in Middlebury) the Chazy marble is pushed up from the east over the Trenton limestone at a thrust fault, which extends northward along Otter Creek onto the United States Morgan horse farm west of Beldens Falls. Southward this fault extends beneath

[1] Preliminary Report on the Geology of Addison County; 7th Rpt. Vt. State Geol. (1909-10).

Porter Field and is lost in the river gravels. The Chazy marble is seen on both sides of the road to Burlington as far north as New Haven Junction, and forms the river bed at Middlebury, Beldens, Brooksville, and Huntington Falls. Near the covered bridge, just north of Middlebury, it forms the east bank of the river but the Trenton, up over which it is thrust, forms the west bank and the river bed below." 'The Beekmantown limestone crops out on both sides of the road south of Middlebury for three or four miles. Here, on the east side of the syncline, the limestone has been largely metamorphosed to marble; but on the west side, where the road to Bridport drops down over the Cornwall ledges, the limestone remains unmetamorphosed and is more or less fossiliferous.'

A striking feature of the Middlebury landscape is Chipman Hill, which rises 450 feet above the town and is made up of glacially accumulated boulders, sand and gravel. Geologists call a hill of such accumulations a kame.

In discussing the marble deposits of Middlebury, Professor Seeley[1] wrote: "A line drawn from a quarry on the southern border of the town to the Gibbs quarry on the New Haven border will pass directly over or very near eight marble quarries, each of which has been, in times past, the center of active work." . . . "The deposit of marble at the river edge (presumably below the bridge in Middlebury) is of historic interest. Here the marble industry (in Middlebury) has its origin. Here Dr. E. W. Judd had discovered marble and, as early as 1806, he introduced the method of sawing marble by use of sand and gangs of toothless saws."

The marble belt extends northward through Hinesburg and Shelburne and reaches to somewhat north of the latitude of Burlington. Marble was quarried some seventy-seven years ago, near Shelburne Pond but without success.

Other Formations

THE SUDBURY MARBLE

This formation of Keith[2] is found in the town of Sudbury at the northwestern end of the Taconic Range. It "appears to be of Chazy age although it has no fossils. It rests upon the Beekmantown and it underlies limestone of Trenton age, being only separated from the latter by a heavy bed of dolomite. The marble

[1] *Op. cit.*
[2] Stratigraphy and Structure of Northwestern Vermont; Arthur Keith, Jour. Washington Acad. of Sciences, Vol. 22, No. 13 (1932).

is, for the most part, snow white but contains a few colored beds of fine dolomite." Keith thinks that it may belong to the Central sequence, instead of to the Western.

THE HYDE MANOR LIMESTONE

This is also Keith's formation and he locates it near the northern end of the Taconic Range. It "contains a good brachiopod fauna of Trenton age, entirely different in aspect from that of the shales of the same age at the west and southwest." . . . "This limestone has a decided blue color and consists of massive beds interlayered with thin slabby strata. Considerable schistosity is evident in this limestone and it is strongly folded, which facts support an assignment to the Central sequence. Fossils are rather common, however, which tends in an opposite direction towards the Western sequence."

THE HORTONVILLE SLATE

Keith describes this formation which lies above the Hyde Manor limestone, as "a dark or black slate with portions which are sufficiently altered to be called phyllite." "There are also in the slate a few small seams of silicious material giving a local banded appearance. As a rule, the bedding is obscured by the cleavage. This (slate) is well exposed around Hortonville and, though unfossiliferous, is correlated with the Snake Hill formation of New York."

Economics

At the present time the principal mineral industry of the Vermont lowland is the quarrying and burning of limestone, which is considered in the article on Mineral Industries of this Report. Besides the lime, the Vermont Marble Company is quarrying the Winooski limestone west of St. Albans, for decorative purposes and, to some extent, the dark Isle La Motte semi-crystallline limestone. St. Paul's Church and the curbings in Burlington are made of this dark stone. Clay is being dug by the Drury Brick & Tile Company of Essex Junction. The Court House and many foundations of Burlington dwellings are built of the Monkton quartzite from the old Phelps quarry, on Shelburne Road.

The Vermont Valley

"The scenes our earliest dreams have dwelt upon:
Each dale and hill, each deepening glen and wold."

In about the latitude of Brandon the Taconic Mountains rise and they extend through southwestern Vermont and western Massachusetts. These mountains divide the southern extension of the Vermont lowland into two branches, of which the first continues into New York while the second, the Vermont Valley, trends southward between the Taconics and the Green Mountains. As Prindle and Knopf[1] state: "Along the Massachusetts-Vermont boundary the valley is interrupted for a short distance by an east-west ridge, but north of Williamstown, Massachusetts, the valley reappears. Where the western front of the Green Mountains swings eastward, at North Adams, the lowland between the Taconics and Green Mountain plateau widens out into the Stockbridge Valley, which has a width of five to eight miles. The Stockbridge Valley is interrupted by short northward-trending ridges that are included by local usage in the general term, Berkshire Hills. Farther south, in Connecticut, the continuation of the valley is known as the Canaan and Sharon valleys, and in New York it is called the Pawling Valley."

The valley is five to six miles wide, between Brandon and Rutland, whence it gradually narrows, in places to less than a mile, with the mountains rising abruptly on either side. From Manchester southward to the Massachusetts border it gradually widens.

Drainage

The principal river of the valley is the Otter, which rises north of the divide in East Dorset and flows generally northward and westward, as a subsequent stream, till it cuts across the Monkton Hills, between Snake and Buck mountains, and reaches the lake at Ferrisburg. This is the longest river in the State.

South of the East Dorset divide the Batten Kill flows along the Vermont Valley as a subsequent stream to Arlington, whence it turns sharply westward and flows across the Taconics as a superposed stream. (Equinox topographical sheet.) It is probable that the ancient river had its head waters in the mountains to the eastward, in Roaring River, and was superposed throughout its length, but that its "subsequent" tributary, eroding headward along the softer dolomites, carved out its valley and reduced Roar-

[1] Geology of the Taconic Quadrangle; Am. Jour. Science, Vol. 24 (October, 1932).

ing River to a tributary. Farther west the Green River is another subsequent tributary to the Batten Kill.

The Walloomsac River (Bennington sheet) is a superposed stream whose "subsequent" tributaries, Furnace Brook, Jewett Brook, South Stream, have etched out the main valley, in the neighborhood of Bennington.

Structure

The valley floor is made up of the Rutland dolomite (Lower Cambrian in age) and other dolomites. Onto these sedimentaries the Green Mountain mass has been thrust, with the resulting Mountain Border fault (frontispiece). The dolomites lie in open folds of which the largest, according to Keith, is a syncline whose western limb rises in Pine Hill, northwest of Rutland, while "the eastern limb, which is locally faulted off, appears along the front of the Green Mountains." West of this syncline and extending from Brandon to Rutland, are shallower synclines.

According to Professor Bain,[1] who has been geologist for the Vermont Marble Company for many years, a thrust, of Lower Cambrian quartzite and Pre-Cambrian schists, lying on phyllites of possible Ordovician age, "cuts across the strike of folded Cambrian and Ordovician limestones on Pine Hill, between Proctor and Center Rutland. The outcrop of the thrust begins east of Brandon, follows the west crest of Pine Hill, and continues south with an irregular course to the vicinity of Wallingford, where it crosses to the east side of the valley, but can be recognized east of Danby. Other thrust faults appear farther south at the eastern margin of the limestone belt."

The marble belt lies mostly along the western border of the valley dolomite and extends from Brandon southward into Massachusetts. The width of the belt varies. It is about three and one-half miles to Brandon township, while in the western part of Rutland the intensity of folding is so great that "the entire marble zone is compressed into sixty feet." (Bain.) In Dorset township the marble belt increases in width to about five miles.

A excellent map of the Vermont Valley and its marble accompanies the late T. Nelson Dale's extensive account of the marble industry.[2]

[1] *Op. cit.*
[2] The Commercial Marbles of Western Vermont; 9th Rpt. Vt. State Geol., pp. 1-224 (1913-14).

Economics

As everybody knows, the valley is the seat of the marble industry in Vermont. Marble has been, or is being, quarried at Brandon, Florence, Proctor, West Rutland, Danby, and Dorset. The stone at Brandon, Proctor, and Dorset belong, according to Keith, to the Shelburne marble belt of the Eastern sequence (Lower Cambrian), while the West Rutland marble is of Middle Ordovician age.

Marble has been quarried in the valley for probably 150 years. The industry appears to have begun in Tinmouth. The first large enterprise was the Rutland Marble Company which, in 1860, was operating twelve "gangs" and producing 150,000 cubic feet annually. In 1870 Redfield Proctor organized the Sutherland Falls Marble Company which, by 1880, was operating sixty-four "gangs" and was the dominant factor in the marble industry of the State. Later, the consolidation of many smaller companies resulted in the Vermont Marble Company, which is the greatest producer of marble in the United States and, probably, in the world. The present status of the industry is given in this Report, under Vermont Mineral Industries. The late State Geologist, G. H. Perkins,[1] devoted a large part of his last Report to a consideration of the marble industry and its history. He describes the many varieties and their trade names, the machines used in the fabrication of the stone, and gives many illustrations of edifices built of Vermont marble.

In East Bennington there are extensive deposits of kaolin which have been worked intermittently for over a hundred years. (See under Mineral Resources.) The deposits have been described by Burt,[2] who concludes that the kaolin is a residual deposit derived from feldspathic phases of the Cheshire quartzite which makes up the Green Mountain front.

In the Vermont Valley, extending from Colchester, on the north, to the Massachusetts line, there are scattered deposits of kaolin, ocher, iron and manganese and lignite.

Burt[3] has studied the ocher deposits and found that they have resulted from "rock decay during the Tertiary period." The deposits are residual and are cut by veins of iron and manganese ores. At one time the manganese was prospected in the town of Griffith but was not found in amounts sufficient for commercial production.

[1] The Marble Industry of Vermont; 18th Rpt. of the Vt. State Geol. (1931-32).
[2] Origin of the Bennington Kaolins; F. A. Burt, 16th Rpt. Vt. State Geol. (1927-28).
[3] The Geology of the Vermont Ocher Deposits; F. A. Burt, 17th Rpt. Vt. State Geol. (1929-30).

The Taconics

"Come, take the climbing mountain road,
And leave the world behind."

The Taconic Mountains rise in Sudbury and Brandon and extend southward and westward for some seventy-eight miles to Pownal, whence they pass into Massachusetts and eastern New York and continue southward for over 100 miles, finally merging into the highlands of the Hudson.

They consist of several roughly parallel ridges, which generally increase in height to Dorset Mountain (3,804 feet), Mother Merrick (3,320 feet), and Equinox (3,816 feet). In Massachusetts the highest peak is Greylock (3,505 feet).

Drainage

The Taconics are cut by the deep valleys of several westward-flowing streams: The Castleton River, west of Rutland, is a tributary of the Poultney. The Poultney River, which forms part of the western boundary of Vermont, flows into East Bay of Lake Champlain. The Mettawee River rises in the Mettawee Mountain, of Dorset, and flows northwestward through that township, Rupert and Pawlet, and finally into Lake Champlain, north of Whitehall. The Batten Kill River, the longest of these streams, as already noted, rises in the Green Mountains and in the Vermont Valley and flows in a sinuous course through Dorset, Manchester, Arlington and Sandgate to its confluence with the Hudson near Schuylerville. Its tributary, the Green River, drains the western slope of Equinox Mountain. The Walloomsac River, which rises in the Green Mountains, in Glastonbury, flows across the Vermont Valley, in Bennington township, thence northwestward across that township to its junction with the Hoosic River. Finally, the Hoosic River, whose valley, in Massachusetts, separates the Hoosac Mountains (the continuation of the Green Mountains in Massachusetts) from the Taconics, crosses Vermont in Pownal and joins the Hudson near Mechanicsville. All of these rivers are, in the Taconics, superposed.

Very beautiful motor trips may be taken along these streams: From North Bennington down the valley of the Walloomsac; from Arlington along the course of the Batten Kill; from Dorset along the Mettawee; from Poultney along the Poultney River, etc.

There are two large lakes, of glacial origin, in the Taconics: Bomoseen, in Hubbardton and Castleton, is about seven and one-half miles long and drains into the Castleton River. St. Catherine, in Poultney and Wells, is some five miles in length and empties into the Mettawee.

Geology of the Taconic Mountains

The structure of the Taconics is one of great geological complexity. It has been a matter of stormy controversy and has taken nearly a century to unravel.

The rocks of the mountains are shales and limestones, dolomites, marbles, slates, phyllites, quartzites and schists. In the early days of American geology it was thought that they were all of what we now call Ordovician age and that they overlay one another in normal superposition—the oldest at the bottom, the younger above.

But when the New York Geological Survey was established, back in the 1830's, and Ebenezer Emmons was appointed geologist of the eastern district and began to study the mountains which form the eastern boundary of the state, he found that this simple explanation would not do, for there were rocks in the Taconics of greater age than those which we now know as Ordovician. After years of field work, in southern Vermont and in Massachusetts, he believed that he had established a new rock system and for this, in 1842, he proposed the name, Taconic System. This system, he maintained, was independent of the "Primary," or Archean, rocks, below, and the "New York System," which we now call Ordovician, above. He correlated it with the Lower Cambrian System which Sedgwick had developed in England.

As Walcott[1] wrote: "Emmons[1] was not a collector of fossils and did not have a critical knowledge of faunas with which to identify the strata."

Like many another new idea, Emmons' Taconic System aroused intense opposition as well as support, and opponents and proponents, both at home and abroad, rushed into the literary fray, largely on the basis of fossil evidence. The Taconic controversy raged for years and its echoes are heard even today.

Since Emmons' time the problem has been attacked by eminent geologists: J. D. Dana, T. N. Dale, Raphael Pumpelly, C. D. Walcott, Arthur Keith and, perhaps, others. Recently L. M. Prindle and Eleanora Bliss Knopf,[2] by their masterly work, have apparently cleared up the whole matter.

[1] The Taconic System of Emmons; C. D. Walcott, Amer. Jour. of Science, Third Series, No. 133 (1887).
[2] *Op. cit.*

They find that the Taconics are not made up of rocks of the same period, as Emmons thought, but of both Cambrian and Ordovician ages. Further, that the schists, shales, grits, etc., of Lower Cambrian to Ordovician age, which make up the upper part of the Taconics, in Massachusetts, belong to a series of argillaceous rocks which have been thrust westward onto the Lower Cambrian shales and Ordovician slates which now "peer out beneath the Lower Cambrian shales in the Kinderhook Valley" to the west. To quote them further, "It is now reasonably well established that the main structure of the Taconic Mountains is an overthrust mass that has been packed into tight folds in a general synclinal structure."

The authors, further, see the possibility that this overthrust mass of argillaceous rocks had its origin on the *eastern flank of the Green Mountains,* far to the eastward, and was carried westward *over* the Green Mountains to its present position by a series of recumbent folds "rolling one above the other and intensified by low angle thrusts"—a sort of geologic leapfog.

This paper is of absorbing interest and should be read by those having a considerable knowledge of geology, who are interested in this phase of Vermont-Massachusetts geology.

In writing of his Taconic sequence in Vermont, Keith states[1]: "The rocks of this sequence are found only in the Taconic Range and they form a striking contrast with the beds of the same age which form the lower ground on the east and west. The sequence consists almost wholly of slates, but it has also one thin formation of limestone and one of quartzite. By means of these two formations in the Lower Cambrian and one of the red slate in the Ordovician, the order and structure of these formations can be disentangled. The limestone (Beebe) contains a good Lower Cambrian fauna, and one of the slates has Middle Ordovician fossils. Owing to the intense folding and faulting of this sequence, it has been necessary to follow out individual beds wherever they could be recognized." . . . "The entire section is exposed south of Stiles Mountain, near the north end of the Taconic Range." Keith names and describes the following formations: Brezee phyllite, Stiles phyllite, Hubbardton slate, Parker quartzite, Bull slate, Beebe limestone, Hooker slate, Poultney slate, Indian River slate, and Black slate. Of these, Keith places the first seven in the Lower Cambrian, and the last three in the Ordovician. The Brezee phyllite "outcrops around the north and northwest margins of the Taconic Range and is in contact with

[1] Washington Academy; *Op. cit.*

the underlying limestones and marbles at more places than any other formation. It thus forms the sole along which the Taconic overthrust block moved in coming to its present position." . . . "The Bull slate is the principal horizon which is worked for purple and unfading green slates of the slate industry." . . . "The Beebe limestone is the most important formation of the entire Taconic sequence. It is named for its exposure (five to twenty feet thick (near Beebe Pond, in Hubbardton." The Indian River slate "is of such a brilliant red that it is quarried a mile southwest of Poultney for use in making red paint."

The limestone quarry at Leicester Junction, with its fine isocline, does not belong in the Taconic sequence but is of Chazy age.

Economics

Of the four slate belts in the State the only commercially important one lies on the west border of the Taconics and extends from Lake Bomoseen to West Pawlet. On this belt Hydesville, Castleton, Fair Haven, Poultney, Wells, and West Pawlet are the centers of the slate industry. The many pits and enormous waste piles along the belt testify to the importance of the slate industry, which is second only to that of Pennsylvania.

Dale[1] has very fully described the slate belt and its activities. He shows that the slate is of Lower Cambrian and Ordovician ages.

The Green Mountains

"On and up, where Nature's heart
Beats strong amid the hills."

The Green Mountains, which are a part of the great Appalachian Chain, are the outstanding physiographic feature of Vermont and extend throughout the length of the State. Their southern extension, in Massachusetts, is called the Hoosac Mountains; while their northern continuation, in Canada, makes up the Notre Dame Mountains.

The Green Mountains, as outlined on the frontispiece, have the form of a distorted hourglass whose southern base extends from the Vermont Valley to the Connecticut River, a distance of some thirty-six or thirty-seven miles. The top of the hourglass lies along the Canadian border, in Franklin, Berkshire, Richford, Jay, and Troy, with a width of perhaps twenty miles. The con-

[1] Geology of the Slate Belt in Eastern New York and Western Vermont; T. N. Dale, 19th Ann. Rpt. U. S. Geol. Survey (1899).

striction of the hourglass is north of Mt. Pico, in Chittenden and Pittsfield, where the width is about eight miles. North of this point the mountains spread out, fanlike, into three principal ranges. Of these the first, or Front Range (the most westerly) extends from Brandon into New Haven and Bristol townships. The second, or Main Range, extends the length of the State and contains the highest peaks. An offset of the mountain mass, northeast of Mt. Mansfield, is called the Stirling Range. The third range begins in Rochester and runs through Roxbury, Worcester, Eden, Lowell, and Newport to the border. In different parts of its course the third range is known as the Rochester Mountain, Braintree Mountain, and Worcester Range. There is also a fourth, poorly defined, range of low hills which extends from Randolph through East Roxbury, East Northfield, Berlin, Montpelier, Calais, West Woodbury, and dies out in Hardwick. One section of it is called the Northfield Mountains.

The valley between the main range and the third range is very narrow in Rochester but widens northward to some six miles in Morristown and Johnson, beyond which it narrows to the border.

The highest peaks of the Green Mountains, from south to north, are: Glastonbury Mountain, 3,767 feet above sea level; Stratton Mountain, 3,869; Shrewsbury, 3,737 feet; Killington, 4,241; Pico, 3,967; Lincoln, 4,013; Ellen, 4,135; Camels Hump, 4,083; Mansfield, 4,393; Belvidere, 3,360; and Jay, 3,861.

The southern part of the Green Mountains is the most massive and is least cut by cross-valleys, or passes. The highway from Bennington to Brattleboro climbs through a steep valley in the mountain front and crosses a wild upland region, giving the motorist one of the most beautiful rides in the State. East of Manchester, a road runs through a pass in the mountains in Winhall and reaches a broad basin in Peru and Londonderry. The Rutland Railroad climbs through a pass in Clarendon and Shrewsbury, crosses the mountain upland in Wallingford and Mt. Holly, at a maximum elevation of about 1,500 feet, and then transverses another pass on the border of Mt. Holly and Ludlow.

East of Rutland the road through Sherburne Pass and along the Ottauquechee River to Woodstock again takes the traveler through the heart of the mountains.

Farther north the cross-valleys are lower and more numerous. They include Brandon Gap, Ripton Gorge, and Bristol Notch. Still farther north, the great water gap of the Winooski River, extending from Montpelier to Richmond, cuts quite through the mountain mass. Smugglers Notch separates Mt. Mansfield from

Stirling Mountain, while the Burlington & Lamoille Railroad crosses a low gap in Underhill and reaches Cambridge "and points east."

The Lamoille water gap crosses the mountain ranges between Milton and Hyde Park and through it runs the St. Johnsbury and Lake Champlain Railroad. Finally, the Missisquoi water gap cuts through the mountains between Enosburg Falls and East Richford. Hazens Notch, south of Jay Peak, is one of the beauty spots of Vermont.

The Long Trail

For those of robust physique and trained muscles, the Long Trail offers unparalleled opportunities to see the Green Mountains in all their ruggedness and wildness. The trail extends from border to border, over 260 miles, running now through heavy woods and, anon, gaining the bare crestline and affording magnificent views of the Adirondacks and the White Mountains. In the nearby valleys are various shelters, camps and lodges, well supplied with fuel, cook stoves and bunks. The trail is well cared for and hundreds of young men and women, from various parts of the country, cross the whole, or parts of it every summer. The Long Trail is maintained by the Green Mountain Club, Incorporated, which was founded by Mr. James P. Taylor, in 1910, and has a membership of over 1,500. The headquarters of the club are in Rutland, where excellent guide books can be purchased.

Drainage

The rivers which drain the Green Mountains belong to the Champlain-St. Lawrence, the Connecticut, and Hudson drainage basins.

To the Champlain-St. Lawrence belong the Missisquoi, Lamoille, and Winooski river systems, all of which are undoubtedly superposed streams. The Missisquoi rises in the mountains, in Lowell, Westfield, and Troy, flows into southern Quebec and then, refusing to become permanently expatriated, returns to the State in Jay and, flowing across the lowland, enters Missisquoi Bay, in which it has built the great delta already mentioned. The Lamoille rises in Greensboro, Waldon, and Woodbury and, cutting through the mountain ranges, enters Lake Champlain south of the Sand Bar bridge. Its sediments were instrumental in forming the sand bar. The Winooski rises far east of the mountain mass, in Cabot, flows through its water gap in the mountains, and reaches the lake south of Colchester Point. It is some seventy miles long.

Farther south the New Haven and Middlebury rivers have cut gorges in the western front of the mountain mass and made their way across the lowland to the Otter Creek.

To the Hudson drainage belong the Batten Kill and the Walloomsac, which have their sources in the Green Mountain massif and in the Vermont Valley.

Belonging to the Connecticut drainage area are the Black River, rising in Plymouth; the Ottauquechee, having its head waters chiefly in Stockbridge; the Williams River, in Windsor County; Saxtons River, which rises in Grafton and flows southeasterly to its confluence with the Connecticut near Bellows Falls; the West River, whose upper branches are found far within the mountain mass in Londonderry, Peru, and Weston; and the Deerfield which rises in Stratton, flows southward through the Green Mountains in Windham County and into Massachusetts, where it joins the Connecticut at Greenfield.

From his rather hurried examination of most of these rivers the writer believes that they are superposed streams which have been let down upon the mountain mass from a cover of sediments which has been washed away.

Lakes

There are numerous small ponds and a few lakes lying within the Green Mountain massif. They are all probably of glacial origin. Lake Dunmore, about two and one-half miles long, in Salisbury and Leicester, is the largest of these. The artificial lakes formed by damming the Deerfield in Somerset and Whitingham are each about five miles long.

Structure and Petrography

As already noted, the Green Mountains make up an anticlinorium whose folds are overturned to the west. The long, easterly dip-slopes and steep western folds and escarpments are reflected in the grades of the roads which cross the mountains. The mountain mass has been thrust to the northwest along the Mountain Border fault. This thrust follows closely the mountain border in the southern two-thirds of the State but, north of Williston, it lies several miles west of the mountain border and has involved the Cheshire quartzite and Brigham Hill graywacke of the Eastern sequence. There is a sharp offset in the thrust, along a flaw fault, which Clarence G. Bailey, while a graduate student at the University of Vermont, located in Williston. It is about two and one-half miles long and strikes N. 79° E.

The thrusts and thrust escarpments along the mountain border have been noted. Besides these there are thrusts within the mass. In Chittenden County, besides the famous Rock Point overthrust, Mr. Bailey discovered in Mechanicsville, in 1936, a large overthrust of the Brigham Hill graywacke (Lower Cambrian) lying on the Williston limestone, of Upper Cambrian age. Bailey has named it the Mechanicsville overthrust. The writer noted a small thrust in northern Worcester, by the highway, ten and four-tenths miles north of Montpelier.

The Green Mountains are made up of a complex of metamorphic rocks: schists, gneisses, phyllites, quartzites, and marbles. There are also several graywacke formations, which are sedimentaries rather than metamorphics. The rocks of the Green Mountains are intruded by igneous masses: the acid, or granitic, and the basic dunites, saxonites, and others, which were the "parents" of the serpentines, talc, and asbestos deposits which occur within the folds of the mountains. Some of the igneous magma did not reach the surface but is probably not far beneath, for some of the minerals (tourmaline for instance) found microscopically in the metamorphics require magmatic emanatations in their making. Furthermore, the metamorphics are, in places (by the highway leading east from Essex Junction, for instance) intruded by sheets of igneous quartz and feldspar, forming "lit-par-lit" bodies.

In the past geologists have worked chiefly on the Vermont lowland and, to a lesser extent, on the Vermont Piedmont. Laterly more and more attention has been paid to the rocks of the Green Mountains but a very large amount of work remains to be done.

Geologic Age

The original Adirondack Mountains, across the lake, date back to the Archeozoic and Proterozoic Eras, the oldest known. But no mountains can withstand the forces of erosion over many geologic periods; they wear down, are often uplifted, and new mountains are etched out of the old roots by further erosion.

In the Green Mountain region the oldest known uplift took place at the close of the Cambrian period. Schuchert calls it the Vermont disturbance and it is recorded in the rocks in the northwestern part of the State (see p. 94).

The main Green Mountain uplift came a period later—about 380,000,000 years ago, according to our Geological Timetable (p. 71). To quote Schuchert,[1] "Early in the late Ordovician the northern half of Appalachia (this was the old land mass which once lay east or along the present Atlantic coast line, and whose sediments formed the material of which the Appalachian chain was made) experienced the first throes of a disturbance that became ever more marked towards the close of the period and culminated in a chain of fold mountains that extended along the New Brunswick axis from central Newfoundland through Nova Scotia, New Brunswick, and the New England States at least as far south as the present coastal belt of New Jersey. This was the *Taconian disturbance*. It resulted in the close-folding and westward overthrusting of the older rocks of the disturbed belt along the southeastern side of the present St. Lawrence and Hudson valleys."

This was the orogony which produced the original Green and Taconic mountains, of which the latter are the younger. Undoubtedly the Green and Taconic mountains were involved in the Appalachian Revolution, which occurred at the close of the Permian Period, according to our timetable, over 200,000,000 years ago.

Peneplanation

It was shown that the Lamoille and Winooski rivers flow across the Green Mountain ranges as superposed streams and that many other streams of the mountains also give evidence of being superposed. If our theory (p. 68) for the development of this class of streams is true, we may logically maintain that the mountains have been peneplaned at least once, covered with the coastal deposits of an ancient sea, warped up into a great arch, on the slopes of which these rivers took their courses and, in due time, reaching the old peneplaned rock formations beneath, became superposed upon them, quite regardless of their structures. Subsequent removal of the cover, and age-long erosion resulted in rejuvenated mountains and a new cycle of erosion.

If this is a true picture the west slope of the old dome lay far to the east of the present mountain axis, since the divide between the Champlain and Connecticut drainage runs through Greensboro, Cabot, Northfield, Roxbury, Granville, Hancock, Chittenden, and other towns. The suggestion of a former peneplain is seen on the even skyline of the mountains east of the Vermont Valley. Furthermore, a projected profile, drawn upon those topographical

[1] Textbook of Geology, Part 2; John Wiley & Sons (1933).

sheets which include the main range of the Green Mountains, and connecting level areas of the same elevation on the mountain slopes, indicates a possible peneplain at 1,680 feet above sea level. Bain[1] finds a similar suggestion east of the Green Mountain wall (probably in the upland over which the Rutland Railroad passes, in Mt. Holly), where "a gently rolling surface, from one to six miles wide, slopes upward at an increasing gradient to the backbone of the Green Mountains. The surface has an average elevation of about 1,600 feet."

It is not improbable that, in their long history, the mountains have been peneplaned several times.

Detailed Work on the Green Mountains

For several years the writer has been at work on the structure and petrology of the Green Mountains, in about the latitude of Burlington. In this work he has carried a section across the mountains from Milton to Morrisville, which is as far as topographical sheets are available. This is the first traverse of the mountains since the work of Edward Hitchcock, in 1861, and is the most northerly work done in the mountains in recent years. Many more traverses are needed in various parts of the ranges.

A full account of the writer's work along the traverse is planned for the next Report of the State Geologist. In the present article some of the results obtained may be noted.

Years ago geologists were over generous with the Pre-Cambrian, assigning to it many rocks which later investigations showed did not belong there. Even the Guidebook of the International Geological Congress, of 1933, states that "The rocks of the high scarp to the east (of Arrowhead Mountain) are pre-Cambrian." The writer has found no proof of this statement.

Since Pre-Cambrian rocks are practically unfossiliferous and since, in Vermont, the mountain rocks are nearly destitute of fossils, the only way in which the age of our rocks can be determined is by their relation to formations of known age. The Cheshire quartzite and the Brigham Hill graywacke, both of proved Lower Cambrian age, are the only horizon markers in northern Vermont along the Mountain Border fault. It has been shown that the Cheshire extends nearly the entire length of the State and that the Brigham Hill graywacke has been followed from southern Quebec to Lake Dunmore.

In Milton the graywacke extends easterly for one and one-half miles. Beyond it there is a belt of fine-grained schist which

[1] International Guidebook, Part 1, p. 76.

stretches eastward to the eastern part of the township of Westford. The contact of the graywacke with this schist still awaits discovery. The writer has named this formation the Westford schist and has studied it from Fairfax Falls southward to Essex Junction. It is a gray, fine-grained, thinly-foliated rock, with an average grain size of 0.55 by 0.29 millimeters. Under the microscope it is seen to be made up of a mesh of sericite enclosing grains of quartz, orthoclase, plagioclase and some perthite. A great deal of titanite is present and there is an extensive development of leucoxene. A few zircons, a small amount of magnetite and some carbonate are seen, while iron oxide is much in evidence. The metamorphism is of low grade (chlorite zone) as shown by the very large amount of chlorite in minute scales and larger grains.

This fine schist gradually merges into the complex of schists, gneisses and quartzites of the mountains, a group of metamorphics which the writer has called the Green Mountain series. This series extends across the mountains to Morrisville. In Hardwick it gives way to phyllites of Ordovician age. In Elmore a belt of amphibolite appears and, with interbedded mica schists, makes up Elmore Mountain. The amphibolite which caps Mt. Belvidere, to which reference has been made, lies to the north along this belt.

Now in this traverse across the mountains the writer has found no unconformities to justify the recognition of Pre-Cambrian rocks. Further search may, of course, do so. Keith states[1] that his Pre-Cambrian Nickwaket graywacke, whose type locality is north of Rutland, extends to Canada, but the writer did not find it in his traverse. Tentatively, therefore, the rocks from the Cheshire quartzite and Brigham Hill graywacke to the phyllites of Hardwick are held to be Lower Cambrian in age.

Mount Mansfield

This is the culmination of the main range of the Green Mountains and lies along the border of Underhill and Stowe. It makes up a long northward-running ridge whose profile suggests the "caricature of a face," with its forehead, nose, lips, chin and even its Adam's apple. The ridge is about two miles long and the maximum elevation (at the chin) is 4,393 feet above sea level.

Stirling Mountain was once a part of the Mansfield massif but headward erosion of the Brewster River, from the north, and a branch of the Waterbury River, from the south, has divided the mountain into two and carved out the pass known as Smugglers

[1] Stratigraphy and Structure of Northwestern Vermont; Jour. Wash. Acad. Science, Vol. 22, No. 14 (1932).

Notch. It may be noted that the Pleistocene ice sheet crossed the mountain from the northwest to southeast, as shown by the groovings near the hotel, and not along the axis of Smugglers Notch.

A study of the rocks of Mansfield and Stirling show that originally they made up a series of anticlines and synclines, striking roughly north and pitching to the south. The crest of an anticline lay above the notch. Being in tension, it was more susceptible to erosion than the synclines and so it wore down and formed an anticlinal valley. On the other hand, the "nose" of Mansfield is a pitching syncline, much eroded, and one easily walks up over the upturned edges of the schists which are like a pile of saucers, with each saucer smaller than the underlying. As one descends Mansfield by the trails he crosses these saucer-like beds and realizes that once the mountain extended far to the westward in anticlinal and synclinal folds. Undoubtedly it was also much higher. It is a synclinal mountain. The precipice of the "nose" is due to erosion along joint planes, in which the ice-sheet played its part. Similar joint plane erosion is found in the series of smaller escarpments under Mansfield's "chin." The rocks of Mansfield and of the Stirling Range are sericite-schists of silvery color, gneisses, and quartzites. West of the pond on Stirling Mountain there is a large lens of talc, the continuation of which, westward, is found along the Hellbrook Trail, on the eastern slope of Mansfield—an added proof of the former unity of the two eminences. All in all, these mountains are most interesting and well worth tramps and study along the many trails.

The writer has found no evidence that their rocks are older than Lower Cambrian.

Camel's Hump

Camel's Hump to which Champlain, in 1609, at once saw the resemblance to *Le Lion Couchant* and so named it, lies about ten miles to the south, on the Huntington-Duxbury border. It has much the same structure and petrography as Mansfield. The face of the Lion is, again, due to erosion along the east-west master joints.

Farther South

From Lake Dunmore southward evidences of the occurrence of Pre-Cambrian rocks are ample. Along Sucker Brook, which flows into Lake Dunmore, is seen the Cheshire quartzite, in which Dale[1] discovered Lower Cambrian fossils, resting unconformably upon the eroded surface of a light gray (Mendon) dolomite. This dolomite is, therefore, surely Pre-Cambrian in age and is referred

[1] The Cambrian Conglomerate at Ripton; T. N. Dale, Am. Jour. Sci., 29-30 (1910).

to Algonkian (Proterozoic) time. A similar occurrence is to be seen in the valley of Sugar Hollow Brook, east of Coxe Mountain, in Pittsford.

In 1894 Whittle[1] studied the region from Weston to Chittenden townships, lying between the Plymouth and Rutland valleys, an area of some 240 square miles. Here he found Pre-Cambrian rocks which he grouped in two divisions: an upper, or Mendon series, and a lower, or Mt. Holly series. "The Mendon consists of an orderly sequence of dark, chloritic mica-schist, micaceous quartzite, crystalline limestone, flinty quartzite, and well developed, highly metamorphosed, gneiss conglomerate." This series he described as "prevailingly schistose and of undoubted sedimentary origin."

Below the Mendon, Whittle found a "chaotic occurrence of still older, more metamorphosed and variable stratified rocks of Algonkian age, together with gneisses, schists, and abundant metamorphic equivalents of older, basic, igneous rocks." This he named the Mt. Holly series.

Keith,[2] working on the mountain rocks of Rutland County, found a series of formations which grade down through the Lower Cambrian and through the Proterozoic (Algonkian) into the Archeozoic (Archean) granite and granatoid rocks.

In the Algonkian he places his Nickwaket graywacke which "extends in the Green Mountains from the Canadian Border to a considerable distance south of the latitude of Rutland." It is named for Nickwaket Mountain, five miles southeast of Brandon. "The formation consists entirely of schistose rocks with a large percentage of graywacke and feldspathic quartzite." . . . "The graywacke beds at the top of the formation are coarse and in many places conglomeritic, while at its base there are important conglomerates." . . . "The upper graywacke beds are seen in contact with the overlying marble at Forestdale." This Forestdale marble is "massive and greatly metamorphosed in most localities, with growth of many silicate minerals." Keith found that the marble is perhaps 200 feet thick in the district northeast of Brandon, several times as thick, southeast of that town, and becomes thinner east of Rutland. "Northward it is fairly continuous to the Canadian border. At Forestdale, five miles northeast of Brandon, there is an excellent section from the upper graywacke conglomerate of the Nickwaket to the basal conglomerate of the Cambrian."

Keith's Mooslamoo phyllite is found on Mooslamoo Mountain.

[1] Algonkian Rocks in Vermont; C. S. Whittle, Jour. Geology, Vol. 2 (1894).
[2] *Op. cit.* (Washington Academy).

It is "a fine-grained black rock, and consists mainly of quartz and muscovite, with a little biotite and disseminated iron ore." It ranges in thickness from nothing at Lana Falls to probably 500 feet on the south and east slopes of the mountain. "There is an unconformity between the three Algonkian formations and the Lower Cambrian, Cheshire quartzite, so that in many places the Mooslamoo phyllite is removed and the (Forestdale) marble forms the top of the Algonkian. As the unconformity is followed northward the (Mooslamoo) phyllite becomes much thicker, but southward the phyllite, marble and graywacke all disappear and the Lower Cambrian (Cheshire quartzite?) rests directly upon the Archean granite. This unconformity, accordingly, is one of the greatest, if not the greatest, in the region."

The late Professor Foye,[1] of Wesleyan University, worked on the geology of the Rochester quadrangle, in 1917. He did not complete this work and realized that more time was necessary.

The quadrangle lies chiefly in the watershed of the White River, between the second and third ranges of the Green Mountains. As the result of his investigations Foye concluded: (1) "The rocks of this area are mainly the continuation of Whittle's Mendon series (Algonkian in age), from the Rutland quadrangle northward." (2) "The Ripton conglomerate is not of Cambrian age (as claimed by Dale) but is the basal layer of the Mendon series." (3) "The structure of the second range is a geanticline overturned to the west. The core of the anticline is formed, in part, of the Ripton conglomerate metamorphosed to schist; and, in part, of the Mt. Holly series." (4) "The Mendon series occurs on the eastern side of the second range, of which Hancock Mountain forms a part, immediately east of the White River Valley."

Prindle and Knopf,[2] in their paper on the Taconics, describe the Mt. Holly gneiss which they have followed from the Massachusetts border to Glastenbury Mountain (Latitude 43° N. Longitude 73° W.). This gneiss is "a formation of high-grade metamorphism, in part of sedimentary origin and in large part a migmatite."[3] The rock is "a light and dark pinkish gneiss with highly biotitic layers that sporadically carry blue quartz." The formation is of early Pre-Cambrian age.

The same authors also describe the Stamford granite-gneiss, an area lying west of Stamford, Vermont and, also, in Massa-

[1] Report of Geological Work in the Rochester Quadrangle; W. G. Foye, 11th Rpt. Vt. State Geol. (1917-18).
[2] *Op. cit.*
[3] Migmatites are "composite rocks, such as gneisses, produced by the injection of granitic magma between the foliæ of a schistose formation." (Holmes.)

chusetts, occurring on Hoosac Mountain. It is "a coarse-grained, massive, porphyritic rock of striking appearance. It is made up of large perthitic microcline crystals scattered through a finer-grained granitic groundmass carrying abundant quartz of a brilliant blue color." Like the Mt. Holly gneiss, it is of early Pre-Cambrian age. Resting unconformably on the Stamford is the schistose or conglomeratic base of the Cheshire quartzite, "at the classic locality discovered by Wolff[1] one and one-half miles southwest of Stamford."

In the southern part of the Green Mountains, Professor Hubbard[2] and his students have studied the area included in Whitingham and Readsboro townships. They find the area to consist, structurally, of a series of anticlinal and synclinal folds, striking north and northeasterly and pitching to the south. The largest anticline, in the western part of the area, in Readsboro, is ten to fifteen miles broad and has within its width several short, pitching anticlines and synclines. The area is made up of metamorphic rocks, marble and schists. They describe the Sherman marble, Whitingham schist, Hartwellville schist, Readsboro schist, and Halifax schist. These they tentatively correlate with the formations which Emerson[3] has described in Massachusetts, as follows:

Vermont	Massachusetts
Halifax schist	Savoy schist of Cambrian age
Readsboro schist	Chester amphibolite of Cambrian age Rowe schist of Cambrian age Hoosac schist of Cambrian age
Hartwellville schist	Greylock schist of Cambrian age
Whitingham schist Sherman marble	Bellowspipe limestone[4]

On the eastern flank of the Green Mountains, in Bridgewater and Plymouth, Professor Perry[5] of Williams College, finds the region to be "a maturely dissected upland, with a relief of about 1,000 feet." It lies, therefore, on the western border of the Vermont piedmont.

In this area Perry concludes that Whittle's Mt. Holly and Mendon series are present, and he divides this Pre-Cambrian area

[1] Pumpelly, Wolff and Dale; U. S. Geol. Survey, Mono. 23 (1894).
[2] Geology of South Central Vermont; G. H. Hubbard, 14th Rpt. Vt. State Geol. (1923-24).
[3] Geology of Massachusetts and Rhode Island; B. K. Emerson, U. S. Geol. Survey, Bul. No. 597.
[4] Professor Perry, in a letter to the writer, states: "The Bellowspipe limestone now has no independent standing whatever, but is thought to be part of the Ordovician limestone caught up from below and enfolded with the overthrust schists making up the main mass of Greylock (Mountain)." If this is so it of course cannot be used for purposes of correlation.
[5] The Geology of Bridgewater and Plymouth; E. L. Perry, 16th Rpt. Vt. State Geol. (1927-28).

into two parts: "An eastern group (probably the Mendon) of highly metamorphosed sediments; and a western group, of dolomite, coarsely banded, schistose quartzites, and chlorite-sericite-quartz schist, which he places in the Mt. Holly series.

Perry also finds rocks of probably Cambrian age, which he divides into an older and a younger group. To the older he refers several varieties of quartz, a conglomerate, a dolomite, and a dark albititic mica-schist. These occur at the western base of Morgan Peak, in northern Plymouth, and in the vicinity of Solitudus Mountain, in the central part of the township. In the younger Cambrian group he names and describes the Pinney Hollow schist, whose type locality is east of Plymouth village, and whose presence he discovered in Ludlow, to the south, and in Stockbridge, to the north; and the Ottauquechee phyllite and quartzite, which overlies the Pinney Hollow schist and occurs extensively in Bridgewater and Plymouth.

Furthermore, in this area Perry finds Richardson's Bethel schist and Missisquoi group (Cambrian) and Waits River limestone, of Ordovician age.

Richardson's Work

The geological work of the late Prof. C. H. Richardson (formerly of Syracuse University) in Vermont, his native State, covered a period of over forty years and carried him from Quebec southward along the border of the Green Mountains and the Vermont piedmont practically to Massachusetts. This border may be seen as a broken red line in the frontispiece and on Figure 7, but Richardson left this line west of Mt. Ascutney and continued southward through Cavendish, Chester, Grafton, Athens, Westminster, Brookline and, in an as yet unpublished manuscript, through Halifax and Guilford. This is the most extensive work that has been done in Vermont since the two-volume Geology of Vermont by Edward Hitchcock, in 1861. Richardson's articles, which run through the Reports of the Vermont State Geologist, from 1901 to 1918 inclusive, have been criticized by some geologists for their lack of accuracy but they have at least blazed a long trail and brought to light a vast amount of information.

In the northern part of Vermont, in Irasburg, Richardson discovered an erosional unconformity[1] between the Green Mountain formations and the terranes to the east. This, in the course of his long investigations, he followed southward through the State. In

[1] The Terranes of Irasburg; 8th Rpt. Vt. State Geol. (1911-12).

the bed of Lords Brook he found a limestone conglomerate, carrying pebbles and large boulders of granite, diorite, porphyrite, and quartz, which he named the Irasburg conglomerate and considered it to be the basal conglomerate of the Ordovician in Vermont, separating the Ordovician formations on the east from the mountain formations on the west, which he assigned largely to the Cambrian. Richardson found his Irasburg conglomerate, with some interruptions, running through the State as far south as Springfield.

Several geologists have doubted the basal nature of the Irasburg conglomerate. But the Ordovician age of the formations which Richardson has mapped, east of the erosional unconformity, is proved by the many beds of crushed fossils found by him—fossils which Ruedermann, of the New York Geological Survey, has declared to be Ordovician graptolites.

In the eastern foot hills of the Green Mountains and west of his erosional unconformity, Richardson established several formations which may be briefly considered.

The Missisquoi group of sericite schists extends, north to south, throughout the State. Of them Richardson wrote: "They everywhere flank the Ordovician terranes on the west and form the eastermost member of the Cambrian group." Adjoining this group on the west, Richardson found a belt of Cambrian quartzites which, with some interruptions, extend from the International boundary to Massachusetts.

The Bethel schist extends from Bethel to Massachusetts. Richardson regarded this formation as forming the base of the Upper Cambrian in Vermont.

The Cavendish schist was followed from Cavendish to Massachusetts. Richardson believed it to be Upper Cambrian in age.

The Gassett schist extends from Reading southward through Cavendish, Chester, Grafton, and Westminster. It is also placed in the Upper Cambrian.

In Sherburne and at Windham Four Corners, Richardson found a conglomerate which he regarded as forming the base of the Cambrian.

The age of all these formations is based on their stratigraphic relations and is unsupported by fossil evidence.

As regards the presence of Pre-Cambrian rocks in the areas which Richardson studied, the following information may be summarized from his numerous papers. In the summer of 1910 Richardson, accompanied by Dr. J. A. Dresser, of the Canadian Geological Survey, "traversed the area westward in the valley of the Missisquoi River to the highly feldspathic core of the Green

Mountains. There appeared to be no evidence available that the westermost sedimentaries of Hardwick and Woodbury are as old as the Algonkian."

Richardson believed that Pre-Cambrian rocks are present in the extreme western part of Northfield, as "a highly feldspathic mica-schist," and that they may be present in the extreme southwestern part of Braintree.

In the southwestern part of Stockbridge, in Sherburne and Plymouth, he recognized the presence of Pre-Cambrian rocks—the Mt. Holly and Mendon series which Perry encountered in Bridgewater and Plymouth. East of this series Richardson found his Sherburne conglomerate which, as already noted, he placed at the base of the Cambrian in this part of the mountains. Richardson believed, further, that Pre-Cambrian rocks occur in Ludlow, Andover, and Windham.

It appears, therefore, that with the exception of Keith's Nickwaket graywacke, there is small evidence of the outcropping of Pre-Cambrian rocks in the mountains north of Northfield. It goes without saying that such rocks do occur at depth.

Intrusives and Economics

Within the mountain mass, and chiefly between the second and third ranges, there are several broken chains of basic igneous rocks which have given rise to the talc, soapstone (steatite), serpentine, verd antique, and asbestos deposits of the State. These chains, in the aggregate, run from north to south through the length of the State.

Talc deposits[1] are known in Berkshire, Enosburg, Waterville, Cambridge, Johnson, Moretown, Fayston, Waitsfield, Granville, Rochester, Stockbridge, Plymouth, Reading, Ludlow, Cavendish, Andover, Chester, Windham, and Dover. Talc is being mined and milled today at Johnson, Moretown, Chester, and Windham. There are sufficient talc reserves in Vermont to last for centuries. Steatite deposits are known in Braintree, Chester, Grafton, and Athens.

The serpentine deposits are chiefly in Jay, Troy, Westfield, Lowell, Eden, Belvidere, Waterbury, Duxbury, Moretown, and Windham. Verd antique has been, or is being, quarried in Roxbury, Warren, Rochester, Stockbridge, Waterbury, and Windham. Chrysotile asbestos[2] is being extensively quarried and milled on Belvidere Mountain.

[1] The Talc and Serpentine Deposits of Vermont; E. C. Jacobs, 10th Rpt. Vt. State Geol. (1915-16).
[2] Chrysotile Asbestos; G. W. Bain, Econ. Geology, Vol. 27 (April, 1932).

Richardson reported other basic igneous rocks, diabase, peridotite, proxenite, and diorite, in Northfield, Braintree, Randolph, Bethel, Barnard, Pomfret, Woodstock, Reading, Springfield, Grafton, Rockingham, Westminster, Putney, Vernon, Guilford, and Halifax. He found gabbro in Woodstock, Westminster, and Vernon.

Very little granite is found in the Green Mountains. There is an outcropping in Pleasant Valley, Cambridge, but granite occurs chiefly in the eastern foothills of the Green Mountains and in the Vermont piedmont.

Marble

In an extensive article the late T. D. Dale[1] described the calcite and dolomite deposits of the central and eastern parts of the State. Many of these occur within the mountain mass. Those which appear to have commercial possibilities are found in Richford, Rochester, Plymouth, Cavendish, Weathersfield, Jamaica, and Athens. As far as the writer knows, none of these deposits has been exploited.

The Vermont Piedmont

"My heart is where the hills fling up
Green garlands to the day.
'Tis where the blue lake brims her cup,
The sparkling rivers play."

East of the Green Mountains lies a plateau-like region which slopes gently downward to the lowland of the Connecticut River. It is maturely dissected, being made up of a maze of hills, some high enough to be called mountains, between which are short, steep-walled valleys, trending in all directions. Here and there considerable mountains rise above the even skyline. Essex County, in the northeastern part of the State, is decidedly more rugged and is made up of a mountainous mass which extends into New Hampshire. The broken red line on the frontispiece and the "Line of unconformity" on Figure 7, show the boundary between the Green Mountains and the region under discussion.

Dr. Isaiah Bowman[2] first noted that this region bears the same relation to the Green Mountains that the Piedmont Plateau of the Southern Appalachians bears to the mountains which flank it on

[1] The Calcite Marble and Dolomite of Eastern Vermont; 9th Rpt. Vt. State Geol. (1913-14).
[2] Forest Physiography; J. Wiley & Sons, New York (1911).

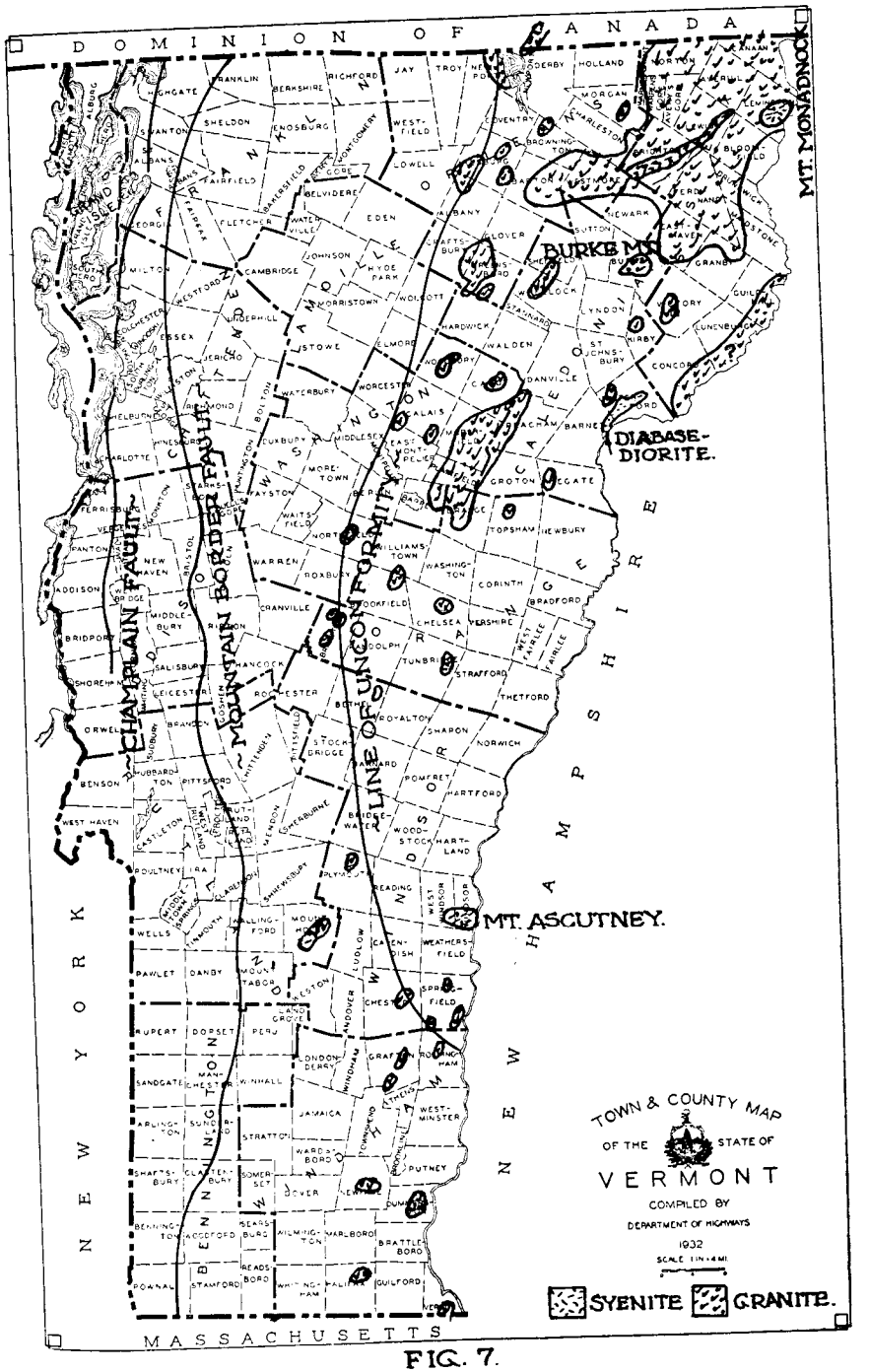

FIG. 7.

the west. The Piedmont is a peneplaned, rolling upland surface extending eastward from the base of the Blue Ridge Mountains, which are made up of Pre-Cambrian and Lower Cambrian metamorphics and sandstone.

Similarly in Vermont, the Green Mountain are composed of Pre-Cambrian and Cambrian metamorphics, flanked on the east by the sloping, maturely dissected surface which is a **peneplain.** This fact was first clearly seen on the completion of the relief model of Vermont in 1931. On looking across the surface of this model one notes the even skyline of the hills, above which rise as erosion remnants the monadnocks of Mt. Ascutney, in Windsor County, Burke Mountain and the Vermont Mt. Monadnock, in Essex County, as well as lesser monadnocks here and there.

In view of the close similarity between the two regions, it seems to the writer fitting to call that part of the State lying east of the Green Mountains the Vermont piedmont.

Profiles projected across the topographic sheets, in the latitudes where they are available (the most southerly in Bennington, Wilmington, and Brattleboro; the most northerly, across Brandon, Rochester, Randolph, Stafford, and Mt. Cube), show accordant levels at 1,400 feet in the northern section and 1,200 feet in the southern. The peneplain, therefore, slopes gently to the south, as well as to the east.

It has already been seen (p. 67) that the New England upland peneplain slopes gently northward and upward to the base of the White Mountains. Lobeck,[1] studying the northern part of this peneplain, found it in contact with the base of the New Hampshire Mt. Monadnock, at an elevation of about 1,100 feet, and ending abruptly at the foot of the White Mountains, at about 1,000 feet above sea level. It seems probable, therefore, that the Vermont piedmont is the extension of the New England upland peneplain, which Johnson[2] demonstrates to be an extension, in turn, of the Schooley peneplain of the Appalachians, in New Jersey and Pennsylvania. The Schooley peneplain, according to Johnson, is of Tertiary age.

Bain,[3] projecting profiles on the topographic sheets for the region west of the Green Mountain axis, from Ferrisburg to Brandon, found evidence of a "mid-Tertiary" peneplain (presumedly the Schooley) at elevations ranging from 1,150 feet, on the north, to 1,000 feet on the south.

[1] Position of the New England Peneplain in the White Mountain Region; A. K. Lobeck, Geog. Review, Vol. 27 (1917).
[2] Stream Sculpture on the Atlantic Slope; Douglas Johnson; Col. Univ. Press (1931).
[3] Geological History of the Green Mountain Front; G. W. Bain, 15th Rpt. Vt. State Geol. (1925-26).

Drainage

The streams of the Vermont piedmont are included in three watersheds: the Champlain-St. Lawrence, the Memphremagog-St. Lawrence, and the Connecticut. To the first belong the Lamoille and Winooski rivers; to the second, the Clyde, Barton, and Black; to the third, all the rest. The north branches of the Nulhegan, and the Coaticook, Passumpsic, Barton, and Black rivers are, as already noted, subsequent streams. The Lamoille and Winooski are superposed.

In regard to the Wells, Waits, White, Ottauquechee, Black (the more southern Black River), Williams, Saxtons, and West rivers, far too hurried investigations by the writer seem to show that they are superposed streams, a classification which is consonant with their occurrence on a peneplain. Meyerhoff and Hubbell[1] agree that the White, Ottauquechee, Williams, Black, Saxtons, and West rivers are "superposed across the underlying structure for ten to twenty miles upstream from their confluence with the Connecticut" . . . . but that "Practically all the tributary streams (to the Connecticut) head in subsequent valleys and many of them (no names are given) continue as subsequent streams from source to mouth."

Lakes and Ponds

"A lake is the landscape's most beautiful and expressive feature."

The northern Vermont piedmont is the lake region of the State, containing over 100 large and small bodies of water: Memphremagog, about one-fifth in Vermont; the Averill lakes and Maidstone Lake, amid the granite hills of Essex County; Willoughby, wild and beautiful in its glacial trough[2]; Crystal Lake, in Barton; Caspian Lake, in Greensboro; the numerous lakes and ponds in Hardwick, Woodbury, and Calais, and many others—beautiful sheets of water, sparkling in the summer sun like jewels amid the hills of this favored region.

These bodies of water are of glacial origin, due to the damming of hollows and valleys by the *débris* of the Great Ice Age.

Vermont lake shores are coming more and more to be occupied by summer residents and boys' and girls' camps, while, in season, fishermen flock to the waters in increasing numbers.

[1] Erosional Landforms in Eastern and Central Vermont; 16th Rpt. Vt. State Geol. (1927-28).
[2] The Geology at Lake Willoughby; E. C. Jacobs, 12th Rpt. Vt. State Geol. (1919-20).

Stratigraphy and Structure

Since Pres. Edward Hitchcock's Geology of Vermont, in 1861, less geological work has been done in this part of the State than in any others, except in the Green Mountains. C. H. Richardson has contributed far and away the most to our knowledge, while R. A. Daly, E. C. Jacobs, R. A. Schroeder, and C. G. Doll of the University of Vermont Geological Department, have done detailed work here and there.

As already noted Richardson traversed the State, north and south, from border to border, along the line of his erosional unconformity and, in his earlier work, embraced large areas in Orange, Caledonia, Washington, and Windsor counties, but a great deal of detailed work remains to be done.

East of the mountain schists, quartzites, and gneisses, the Vermont piedmont is made up overwhelmingly of limestone which is interbedded with north-south-running belts of phyllite, slate, schists, and gneisses, intruded by great batholiths of granite, in Essex County, and by smaller granite bodies in many places, as well as by the syenites of Mt. Ascutney and Mt. Monadnock, Vermont. Basic intrusives: diorite, diabase, pyroxenite, peridotite, and gabbro, are also numerous.

The erosion of the piedmont to a peneplain was, of course, due to the easy erodibility of the sedimentaries and metamorphics, while the more resistant granite and syenite were responsible for the monadnocks.

According to Hitchcock's cross-sections, confirmed by Richardson's numerous sections, the formations exist today as eroded anticlines and synclines, generally with steep dips and with little evidence of faulting. The natural inference that this part of the State was somewhat involved in the westward thrusting of the strata, which culminated in the mountains and in the Vermont lowland, is confirmed in those parts of the piedmont which the writer has examined.

The Waits River Limestone

The most extensive formation in Vermont is the great limestone member which extends, with some interruptions in southern Vermont, from Quebec to Massachusetts and from the Green Mountains to, in some latitudes, the Connecticut River.

Edward Hitchcock mapped this formation and called it the Calciferous-mica-schist, an unfortunate name which is misleading, since only a subordinate part of the formation is schistose, while

the great mass of the rocks is massive limestone and marble. Richardson realized this and,therefore, divided the Calciferous-mica-schist into two members: the Washington limestone (1895) which, since this name was preoccupied, he changed to the Waits River limestone (1905); and the Bradford schist which, for a similar reason, he altered to the Vershire schist in the same year.

Richardson further divided his Waits River limestone into three phases: a light, banded variety (to which he gave no specific name) which occurs near Lake Willoughby, possibly in Greensboro, in Montpelier, Bethel, and Bradford; a dark, steel-gray Washington phase, which is found in Washington township, Montpelier, Derby, Brownington, Irasburg, Greensboro, Bethel, and Woodstock; and a still darker, graphitic Coventry phase, which appears to be of small extent. In his later articles, dealing with the southern part of the piedmont, Richardson did not differentiate his Waits River limestone into these phases.

The Waits River limestone is divided into two branches by the Reading gneiss, in the latitude of Hartford. The westerly branch extends to Cavendish while the easterly branch continues, with interruptions in Chester, Springfield, Grafton, and Rockingham, into Massachusetts.

Richardson described the Waits River limestone as a siliceous rock containing uncombined carbon. In Washington it is a crystalline rock of fine texture and was once extensively worked for marble.[1]

The age of the Waits River limestone is definitely fixed as Middle Ordovician (Trenton) by Richardson's discovery of crushed graphtolites (confirmed by Ruederman of the New York Geological Survey) in some thirty townships extending from Newport to Reading.

The Memphremagog Slate

In the piedmont there are three belts of slate, interbedded with the Waits River limestone, which traverse the State from north to south. Richardson named the largest of these belts the Memphremagog slate and he traced it, with some breaks, from Quebec to Massachusetts. Its maximum width is about three miles. From the international boundary it extends continuously through Newport, Coventry, Irasburg, Albany, Craftsbury, Walcott, Hardwick, Woodbury, Calais, East Montpelier, Berlin, to Northfield. South of here it appears in Randolph, Woodstock, Reading, Springfield,

[1] The Terranes of Orange County; C. H. Richardson, 3rd Rpt. Vt. State Geol. (1901-02).

Rockingham, Westminster, Putney, Dummerston, Brattleboro, and Guilford.

The slate is described as a bluish-gray to black rock, with perfect cleavage and, in some places, well suited for commercial purposes. It was once extensively worked at the Sabin quarry, in Montpelier, and in several quarries in Northfield, but the quarries were abandoned many years ago.

The most westerly belt, as shown by Hitchcock's map of 1861, is narrow and extends from Quebec through Troy, Lowell, Eden, Hyde Park, Morristown, Worcester, to Moretown where it disappears—to reappear, however, in Rochester, Stockbridge, and Bridgewater. In Morristown, at least, it is a phyllite rather than a slate.

Richardson named the most easterly belt the Waterford slate, because he was not sure of its identity with the Memphremagog slate. It runs along the eastern border of the State, at or near the Connecticut River from Burke, with some interruptions to the Massachusetts border. It is described as a slate grading into a fine grained phyllite; dark gray and often studded with staurolite and pyrite. In several localities the slate was at one time worked for roofing material, flagging and road "metal."

The fact that these slates are intercalated with the Waits River limestone, and the discovery in some of them of beds of crushed graptolites place them in the Middle Ordovician.

Phyllite

Lying in, or on the borders of, the Waits River limestone are several broad belts of phyllite which, although they have not been followed, probably extend throughout the length of the State.

The writer has investigated the phyllite of Orleans County[1] and found that it covers the northern half of Westmore, all of Charleston, the greater part of Brownington, and extends northward through Derby and Holland into Quebec. On the west it is in contact with the Memphremagog slate while, eastward, it merges into the Waits River limestone. A few strata of the limestone are intercalated with the phyllite. In Westmore, Mt. Pisgah and Mt. Hor on opposite sides of Willoughby lake, are made up of phyllite and limestone strata (the light gray, banded phase) intruded and domed by granite, which underlies the whole region and crops out in many places. The writer named the formation the Orleans phyllite in 1921.

[1] The Geology of Westmore and Brownington; 13th Rpt. Vt. State Geol. (1921-22).

The phyllite varies in color from dark gray to black and shows good slatey cleavage, apparently parallel to the original bedding planes. The cleavage planes are often covered with fine scales of biotite and crystals of this mineral are often widely disseminated through the rock. Sections of the typical phyllite show a fine, sericitic ground mass with rhombs of ottrelite cutting the schistosity. A good deal of pyrrhotite is in evidence.

Much of the phyllite, and especially that just north of Willoughby Lake, is of a more sandy phase and was once quarried by the Norton-Pike Company, of Littleton, New Hampshire, for the manufacture of scythe stones. Sections of this rock reveal a mass of fine quartz grains and feldspar (the quartz predominating) shot through with fibers of sericite in the planes of schistosity and with bleached biotite, which is the more abundant mica. The sections are thickly sprinkled with graphitic dust which is responsible for the dark color of the rock. Pyrrhotite, garnet, some titanite, and a few stubby tourmalines constitute the accessory minerals. A chemical analysis shows a considerable content of potash, which is responsible for the fertility of the soils in this rich farming region. Some phases of the phyllite are calcareous.

From its relation to the Waits River limestone the phyllite is undoubtedly of Ordovician age.

Farther south, a traverse eastward along the highway from Morrisville through Walcott, Hardwick, Walden, and Danville shows closely folded synclines and anticlines with steep dip, of dark gray phyllite interbedded with black limestone, perhaps the Coventry phase of the Waits River limestone. In Danville it terminates in the light, banded Waits River limestone. The continuation of this belt is found in East Montpelier, Barre, and Orange.

In Randolph Richardson found a phyllite, which he named for this township,[1] lying within his Waits River limestone. He followed it through Bethel, Royalton, Barnard, Woodstock, Reading and Cavendish. He described it as a fine-grained, even-textured, bluish-gray rock which microscopic study showed to be made up of sericite and quartz grains, with accessory minerals of magnetite, pyrite, garnet and limonite, and abundant graphitic dust, giving the dark color. Its association with the Waits River limestone placed it as Ordovician in age.

East of this phyllite belt Richardson found another belt extending from Windsor through the eastern half of Weathersfield and Springfield, making up the greater parts of Rockingham, Westminster, Putney (here it is divided by a narrow belt of Waits

[1] 13th Rpt. Vt. State Geol. (1921-22).

River limestone), and practically all of Halifax, Guilford, and Vernon (the most southerly tier of townships). Richardson named this belt the Brattleboro phyllite[1] in 1915. It is a dark gray, lustrous, schistose rock which the microscope shows to be made up of fine quartz grains with subordinate sericite, some bleached biotite, a few tourmalines, and a good deal of leucoxene, probably derived from ilmenite which has entirely disappeared. It thus resembles, in mineralogy, the "sandy phase" of the Willoughby region. It is evidently of Ordovician age. There is probably no need of three names for the Vermont phyllites. Orleans phyllite for the typical rock, and Brattleboro phyllite for the sandy phase, will be retained.

The Vershire Schist

As already stated, Richardson named the non-calcareous member of Hitchcock's Calciferous-mica-schist the Bradford schist[2] in 1898 but, since this name was preoccupied, he changed it to Vershire schist.

This schist extends along the eastern part of the State in a belt of varying width, from Burke to the Massachusetts border. The Waterford slate adjoins it on the west. In Bradford, the type locality, the belt is about seven miles wide. It is a complex formation consisting of quartzite, gneiss, and staurolitic, amphibolitic, ottrelitic, and garnetiferous schists. Richardson placed it in the Ordovician.

The Reading Gneiss

Hitchcock's map, accompanying his Geology of Vermont, in 1861, shows a great lens-shaped area of gneiss in the southeastern part of the State, extending from Hartford to Halifax, with a maximum width of about seven miles, in Chester. Richardson gave the name, Reading gneiss, to that part of the area lying in Reading, western Windsor, Cavendish, western Weathersfield, Baltimore, Chester, and southwestern Springfield, in 1927. He described it as an ortho-gneiss derived from biotite-granite. The gneiss occurs in synclines and anticlines of steep dip. The other parts of the gneiss area have not been studied.

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In the course of his studies, Richardson also named and described various minor formations: Woodstock schist, Bethel schist,

[1] The Geology and Petrography of Reading, Cavendish, Baltimore, and Chester; C. H. Richardson, 16th Rpt. Vt. State Geol., p. 208 (1927-28).

[2] Areal and Economic Geology of Northeastern Vermont; 5th Rpt. Vt. State Geol. (1905-06).

Blue Hill gneiss, Springfield conglomerate, and others, for the discussion of which there is no space in this article.

Granite

Granite is the most common igneous rock of the continents. In Vermont it is more abundant than any other igneous rock and it occurs, on the surface at any rate, almost wholly within the piedmont district.

Here its resistance to erosion causes it to stand out above the peneplain as monadnocks, such as Burke and Umpire mountains and other eminences of Essex County; Mt. Wheeler, in Orleans County; Millstone Hill, in Barre, and other mountains and hills farther south. On the Town and County Map, Figure 7, it is seen that granite crops out in over fifty townships east of the Green Mountains. One or more granite batholiths underlies a large part of Orleans County.

The northern part of Essex County is a wilderness of granite with mountains rising to 2,972 feet above sea level and with Big Averill and Little Averill lakes lying picturesquely in granite basins formed by the ice movement of the Pleistocene glacial epoch. The only recorded geological work that has been done in the county, since 1861, is that of Schroeder who wrote a short article[1] concerning the area immediately adjacent to the Averill lakes. Schroeder finds that the rocks of this area are granite intruding muscovite-biotite-schist. The granite here is a pink rock made up of feldspar (dominantly microcline) and quartz, with hair-like rutile and possibly zircon as accessory minerals. Small dikes and sills of pegmatite also occur.

Burke and Umpire mountains are granite stocks which have intruded the phyllite of northern Vermont. Large masses of the phyllite, in places indurated to hornfels, have been broken off and caught up in the rising granitic magma and are to be seen on the slopes and summit of Burke Mountain as one walks up the fine road which has recently been completed. Such fragments of rock which are foreign to the igneous rock in which they occur are called xenoliths.

Mounts Pisgah and Hor, as already noted, are domed mountains of limestone and phyllite, up-arched and intruded by granite. Mt. Wheeler is a stock of granite which has been smoothed and glaciated by the ice movements of the Pleistocene. In Barton, Crystal Lake lies in a granitic glacial trough.

[1] A Contribution to the Geology of Essex County; R. A. Schroeder, 12th Rpt. Vt. State Geol. (1919-20).

The commercial granites of the State have been fully described by Dale,[1] who classified them as biotite-granite and quartz-monzonite. His third classification, "hornblende-augite granite" of Mt. Ascutney, is a misnomer since the rock is syenite. Biotite-granite is found in Barre, Woodbury, Ryegate, and Newark; quartz-monzonite in Derby, Calais, Bethel, Hardwick, Groton, Kirby, Randolph, Rochester, and Dummerston. This is a very valuable ariticle and should be consulted by those interested in the subject.

In the Barre district, Millstone Hill, with its many active granite quarries, is the center of the granite industry in northern Vermont. Findlay[2] has described the geology of this area and found that the granite batholith intrudes schists and phyllites which form the country rock. The quarried rock is a fine-grained biotite-granite which, in addition to the biotite, is made up of "abundant microcline and quartz, with lesser amounts of plagioclase and muscovite as the essential constituents of the rock. Some orthoclase is also present." Apatite, magnetite, titanite, tourmaline, and epidote form the accessory minerals. Chemical analyses of the granite are also given. Pegmatite, containing tourmaline, is also found. The fine, even grain, pleasing appearance, and enduring qualities of the rock have made Barre granite famous as a monumental stone.

The biotite-granite of Woodbury was extensively quarried, until a few years ago, for structural purposes. Recently some of the quarries have been reopened.

In Windsor the "Bethel-white" granite is a beautiful, mottled, light-colored stone which has found extensive use for monumental and structural purposes. As already noted the Union Station and new Post Office in Washington, D. C., are built of it. The capital at Madison, Wisconsin, is constructed of Bethel and other stone. Bethel-white is a quartz-monozonite, whose feldspars are made up of approximately equal amounts of orthoclase and plagioclase, together with colorless or bluish quartz and many accessory minerals, practically none of which is dark.

Professor Balk, now of Mt. Holyoke College, has contributed a very valuable article[3] dealing with the relation of the rising granitic magma to the structure of the country rock, in Barre, Woodbury, and Bethel. The article is technical and not intended for the lay reader.

[1] The Granites of Vermont; T. N. Dale, 6th Rpt. Vt. State Geol. (1907-08).
[2] The Granite Area of Barre, Vermont; G. I. Finlay, 3rd Rpt. Vt. State Geol. (1901-02).
[3] A Contribution to the Structural Relations of the Granite Intrusions of Bethel, Barre, and Woodbury, Vermont; Robert Balk, 15th Rpt. Vt. State Geol. (1925-26).

In the southern part of the State granite is being quarried only in Dummerston. Dale described this under two varieties: "White, West Dummerston" which is "a quartz-monozonite of very light gray shade, speckled with bronze colored mica, and of even-grained, medium texture," and a "dark blue granite which is also a quartz-monzonite inclining to medium bluish-gray color and even-grained fine, inclining to medium, texture." The granite is quarried and fabricated by the Presbrey-Leland Studios, Incorporated, of New York City.

Richardson, in his numerous articles, has located pegmatite in Reading, Cavendish, Baltimore, Chester, and Grafton.

The orbicular, or prune granite, boulder-train of Craftsbury, has already been noted. Orbicular granite, in place, occurs in Brownington.

Age of the Granite

Since eruptive rocks do not contain within themselves evidences of the time of their intrusions, their age is given in terms of the youngest rocks which they cut, or of contiguous rocks. The youngest rocks of the piedmont are Ordovician but, in Quebec, granite is found cutting Devonian strata. Hence Vermont granites are usually considered to be of post-Devonian age, though some geologists consider them to be post-Carboniferous.

Syenite

The two largest monadnocks of the Vermont piedmont are Mt. Ascutney, 3,320 feet, and Mt. Monadnock, Vermont, 3,140 feet above sea level.

In his monumental work Professor Daly, of Harvard University, has made an exhaustive study of Ascutney Mountain.[1]

This he finds to be a stock of syenite and the closely allied nordmarkite and pulaskite, intruded by biotite-granite and cut by dikes of aplite, diabase, camptonite, and paisanite. To the west Little Ascutney "is held up by a strong rib of intrusive syenite-porphyry, associated with other eruptives." "The shapely cone north of Little Ascutney, which has been named Pierson Peak (by the author) is strictly controlled in form by a small, elliptical stock of alkaline syenite, cutting the softer diorites."

The eruptives have intruded tilted Bradford schist (now called Vershire) and the overlying phyllite, of Lower Trenton (Ordovician) age, beneath which is a series of schistose rocks, consist-

[1] The Geology of Ascutney Mountain, Vermont; R. A. Daly, Bul. 209, U. S. Geol. Survey (1903).

ing of mica-gneiss, epidote-gneiss, amphibolites and crystalline limestone.

Daly states that the intrusives are probably post-Carboniferous and pre-Cretaceous in age.

The nordmarkite was once quarried by the Norcross Brothers, of Boston. The beautiful, dark green columns of the library of Columbia University were wrought from this stone. Quarrying has long since been abandoned.

The Geology of Mt. Monadnock, Vermont, so-called for its famous namesake of southwestern New Hampshire, has been studied by Professor Wolff,[1] formerly of Harvard University. The mountain "lies on the west bank of the Connecticut River, mainly in the township of Lemington and opposite Colebrook, New Hampshire."

It is a syenite stock, composed of microperthite, albite, quartz, hornblende, and accessory minerals. Essexite, a variety of gabbro, occurs in the syenite and along the southwestern side of the mountain.

Besides these syenite stocks Richardson has reported nepheline-syenite in Braintree, Randolph, Bethel, Reading, Chester, and Brattleboro.

Basic Intrusives

Besides the extensive occurrence of acid igneous rocks there are many intrusions of basic rocks in the piedmont.

On the west border of Lake Memphremagog is a belt of basic rocks made up of diorites, gabbros, and others, cut by granite. Against these the slates and limestone members present a fault contact.

At Fifteen Mile Falls, in building the dam which crosses the Connecticut River from Barnet, Vermont, to Munroe, New Hampshore, the rock used for the concrete aggregate was taken from an extensive intrusion of diabase and diorite. Mr. Irving B. Crosby, of Boston, the geologist of the project, has kindly furnished the following information: "The intrusive on the Vermont side of the Connecticut River, at Fifteen Mile Falls, extends north-northeasterly at least five miles from the dam. The northwest side of it passes about four-fifths of a mile east-southeast of the southeast end of Stile's Pond. Its southern end is at the dam where it fingers out, and stringers of this igneous rocks were found in

[1] Mt. Monadnock, Vermont—a Syenite Hill; J. E. Wolff, 17th Rpt. Vt. State Geol. (1929-30).

the excavation for the dam. A short distance north of the dam, however, it becomes a definite belt, about a quarter of a mile wide. From here northward it averages nearly three-quarters of a mile in width." The location of this belt is shown on Figure 7.

"The intrusive rock is of four (?) varieties: The oldest is a coarse diabase; and next, two varieties of diorite, a fine-grained diorite and a dense trap, the latter being the older and the fine diorite the younger. All of these are cut by dikes of fine granite. The country rock is (Vershire) schist and phyllite. The schist is rather massive and is shown by petrographic analysis to have been formed from a rhyolite. Apparently there were alternating lava flows and sedimentary deposits at the time the schist and phyllite were laid down. Another belt of similar intrusives reaches the river about one-third of a mile west of the dam."

Years ago Dr. O. P. Hubbard, then of Dartmouth College, discovered large boulders of olivine-basalt in Thetford. The late Dr. O. E. Hovey, formerly of the American Museum of Natural History, studied them and referred them to the limburgite division of basalts. Later C. H. Richardson found a dike of limburgite, six to ten feet wide near the old copper mine at Corinth.

On the road from Barre to South Barre there is a Camptonite dike, five feet wide, cutting the phyllite of that region.

Richardson, in his articles, contained in the Eleventh to the Eighteenth Reports, inclusive, of the Vermont State Geologist, describes a diabase dike, fifteen feet wide, in Roxbury; and diorite, diabase, camptonite, peridotite, pyroxenite, and gabbro (several of all) in Braintree, Randolph, Bethel, Barnard, Pomfret, Woodstock, Cavendish, Baltimore, Reading, Chester, Brattleboro, Springfield, Grafton, Rockingham, Athens, Brookline, and Westminster. In his last, and as yet unpublished, article on Halifax, Guilford, and Vernon, he notes amphibole, diorite, and gabbro.

Volcanics

In spite of the statement in a current textbook on geology that: "In northern Vermont and New Hampshire are groups of (other) volcanic vents, the nature of which is clear but the geological date is uncertain," it is exceedingly doubtful that there were ever volcanoes in Vermont. But the statement, above, that the schists of the country rock on the Vermont side of Fifteen Mile Falls are shown to have been derived from rhyolite flows indicates that lava material, probably water borne, has entered the State.

On the southern slopes of Bear Mountain, in northwestern Newport, pillow lava[1] has been reported but there is no evidence that the volcanic vent was in Vermont.

NEIGHBORING VOLCANICS

In Littleton, New Hampshire, Professor Billings,[2] of Harvard University, has described along the Ammonoosuc thrust, his Ammonoosuc volcanics, consisting of bedded schist and soda-rhyolite volcanic conglomerates and tuffs. These were probably derived from ancient volcanoes far to the eastward. Billings thinks that these schists may cross the river and extend into Vermont in Thetford. Anyone finding thinly-laminated schists of light greenish-gray color should report the exact location and send a sample of the rock to the State Geologist at Burlington.

In southern Quebec the eight Monteregian Hills which extend in an arc from Montreal (which is built on the slope of one of them, Mt. Royal) to the east and southeast are thought by some geologists to be old volcanic necks, although rocks derived from volcanics, such as those at Fifteen Mile Falls, have never been found.

In the Boston, Massachusetts, district the volcanic nature of certain felsites, tuffs, and ash-agglomerates has been established at Medford, Melrose, South Natick, and other places. In eastern New York, at Northumberland, near Schuylerville, there is a small extinct volcano, called Starks Knobb, which was within the fighting area in the Battle of Saratoga.

Economics

The chief economic mineral product of the piedmont is granite, which has already been considered.

Old Copper Mines

In the eastern part of Orange County, lying conformably within the Vershire schist, is a chain of copper deposits,[3] in the form of elongated lenses, or pods, which extends from South Strafford northward through Vershire and Corinth. The continuation of this chain is found in the copper deposits of Capleton, Quebec. The mineral is chalcopyrite ($CuFeS_2$) associated with pyrrhotite (Fe_7S_8).

[1] Pillow lavas are those volcanic flows which were laid down upon the floors of water bodies, either marine or fresh. They are so called because of their resemblance to a pile of pillows.

[2] Geology of the Littleton and Moosilauke Quadrangles, New Hampshire; M. P. Billings, N. H. State Planning and Development Commission (1935).

[3] Copper Mining in Vermont; E. C. Jacobs, 10th Rpt. Vt. State Geol. (1915-16).

Back in the 1870's mines in these townships were important producers of copper but they were long since abandoned because of the increasing cost of mining at depth, the sulphurous fumes from the roasting beds which made a desert of the farm lands, and poor management. The Elizabeth mine, in South Strafford, the Ely mine in Vershire, and the Union mine in North Corinth were the best known.

During the Great War attempts were made to rehabilitate these mines,[1] using the flotation process of concentration, but copper could not be extracted cheaply enough to compete with the great western mines and, although it is said that much copper mineral still exists in them, the mines will probably not be reopened.

Mineral Springs

Throughout Vermont there are a good many mineral springs, some containing salts of iron, calcium and magnesium; some, arsenical salts; and at least one, iodine (at Highgate Springs). The Geology of Vermont, of 1861, describes many of these in more or less detail. The list includes the springs at Brunswick, Williamstown, Chester, Newbury, Warren, Clarendon, Quechee, Williamstown, and Vergennes. Besides these, there are mineral springs near Willoughby Lake, at Gassetts, in Hardwick, and probably in other places.

The oldest known of these springs are probably those of Clarendon Springs village which were discovered in 1776 and were credited with wonderful curative properties. Highgate Springs were discovered in 1820. The Franklin House was built in 1840 and had accommodations for "sixty boarders." In recent years efforts were made, repeatedly, to exploit the mineral springs at Brunswick. Pools and walks were constructed and hotels built, but repeated destruction of the buildings, probably by arson, caused the failure of the enterprise.

The Connecticut River Clay Deposits[2]

Along the Connecticut River there are great deposits of varve[3] clays, many of them suitable for brick manufacture. Brick yards

[1] Progress in Copper Mining; E. C. Jacobs, 11th Rpt. Vt. State Geol. (1917-18).

[2] The Clay Deposits and Clay Industries of Vermont; E. J. Jacobs, 15th Rpt. Vt. State Geol. (1925-26).

[3] Varve, or seasonal, clays are those derived from glacial accumulations by streams which sorted out the fine clay and silt material and deposited it in standing bodies of fresh water, lakes, ponds and what not. To quote Antevs: "The silt and part of the clay dropped to the bottom rather soon, but for the most part the finest particles remained suspended for a long time, and settled during the late fall and winter." The result was that each double layer, the coarser below and the finer on top, represented one season's deposit. By counting the number of double layers in a given clay bank, long emerged from the water, one can estimate the number of years that were involved in the formation of the bank.

were once in operation at East Ryegate, Putney, and Guilford but have not been active for some years owing, it is said, to high freight rates and probably to the decline in the use of this material of construction.

On the Vermont side of the Connecticut, Dr. Ernst Antevs,[1] in his glacial studies from Connecticut to New Hampshire and Vermont, has located some twenty of these varve clay deposits.

Glaciology

Vermont, together with the rest of the States as far south as Long Island and the courses of the Ohio and Missouri rivers, once lay in the embrace of the Pleistocene, or Great Ice Age, an ice-sheet thousands of feet thick and bearing within its bulk and on its surface unnumbered tons of rock *débris*. This ice-sheet endured for perhaps a million years and, shod with rock fragments frozen into its under surfaces, like carbonado set in the bit of a diamond drill, moved irresistibly to the south from its home land in Canada, gouging out the rocky troughs of Willoughby Lake, Crystal Lake, the Averill lakes, and others, snubbing off mountain spurs, smoothing, gouging, striating, and polishing rock ledges, overriding the highest mountains, and forming a lifeless desert of ice and snow.

With the coming of warmer climates (but be it remembered that the Ice Age is by no means over: Witness Greenland and Antartica still ice capped; deciduous trees in Alaska and Labrador, where semi-tropical vegetation used to grow, as proved by fossil plants which shows that this north country has not yet returned to its pre-glacial climate)—with this coming the ice sheet rotted away and dumped its load of rock *débris,* which so changed the face of the old Vermont that we can have but small idea of what it looked like before the ice age. Glacial erratics, many of enormous size, some of local origin; others, "outlanders" from Canada, appear on the mountain tops as well as in the lowlands. Glacial till, or drift, lies to varying depths upon the old bed-rock surfaces, damming the valleys and making basins for hundreds of lakes; forming moraines, where the ice movement halted for a breathing spell; diverting rivers to temporary new courses, as in the case of the Dog and Mad rivers, in Warren and Northfield; making up great sand and gravel hills, called kames, such as Chipman Hill, in Middlebury, already mentioned, the great hill at Newport, and hundreds of others; appearing as low, sinuous ridges, called eskers,

[1] The Recession of the Last Ice Sheet in New England; Ernst Antevs; Am. Geographical Soc., Research Series No. 11, New York (1922).

winding down the valleys, such as those in Burke; and covering the lowlands with deposits of sour soil which add so much to the woes of the farmer.

Streams from the melting ice flowed with a volume and an erosive force they had never known before and left old valleys far too large for the brooks that flow in them today—note such valleys on the road south from Burlington. Some of the streams, impounded by glacial *débris* formed glacial lakes whose old shore lines are still to be seen (note especially the old lake terraces which extend upstream from Cavendish to Ludlow and Plymouth). The lakes overflowed and the water sought new outlets, sometimes across rock ledges, and eroded the post-glacial gorges of Quechee Gulf, Gaysville, Cavendish, Bolton, and many other places.

During the great Vermont flood of 1927, in a single night the old glacial stuff which had diverted the stream was washed away and the old, pre-glacial course of the Black River was revealed at Cavendish; while at Gaysville the White River, leaving wreck and ruin in its train, returned to its old course from which it had been driven in the long ago.

As the ice melted, in its early stages, streams running from it helped to grind out pot holes even on the mountain tops, where Professor Doll describes one in the last article of this Report. Other streams, of a later stage, sorted out the clay and silt from the glacial till and deposited them in lakes forming laminated (varve) clays, which were described above. By correlating these varve clay deposits along the Connecticut River, as well as in more widely separated areas, Antevs has established a wonderful chronology, by far the most accurate ever made, which enables him to state that the melting back of the ice-sheet from Hartford, Connecticut, to St. Johnsbury, Vermont, took about 4,300 years, or at an average rate of recession of 238 feet a year. It may be said that Antevs' researches have not been confined to New England but have taken him to many other areas of the United States.

Much more could be written about the Pleistocene glaciation in Vermont, did space permit. It is hoped that, in a later biennial Report, the subject may be more thoroughly discussed.

REFERENCE BOOKS ON GLACIOLOGY

The Ice Age in North America; G. F. Wright; D. Appleton & Co., New York (1889).
Earth Features and Their Meanings; W. F. Hobbs; Macmillan Co., New York (1923).
The Geology of New Hampshire; J. W. Goldthwait; Rumford Press, Concord, N. H. (1925).

Ice Ages, Recent and Ancient; A. P. Coleman; MacMillan Co. (1926).
The Changing World in the Ice Age; R. A. Daly; Yale University Press, New Haven, Conn. (1934).

The Piedmont in General

The piedmont is an old, worn-down mountainous region. The monadnocks of today were intrusions into the old crust which once covered them and were probably of an even greater elevation. The wearing down of the piedmont to the present peneplain enables us to look down into the old mountain mass and realize to how great an extent igneous forces were instrumental in upraising it. The domed mountains, Pisgah and Hor, arched up by the granite which underlies and intrudes them, the granite batholiths of Essex County, the syenite stock of Mt. Ascutney, etc., are impressive examples of the part played by igneous forces in mountain building.

It has been noted that granite undoubtedly also underlies the Green Mountains, for although it seldom reaches the surface, its "juices" and emanations were essential to the formation of quartz, with its liquid inclusions, the primary micas, apatite, tourmaline, and other minerals, which the study of thin sections with the petrographic microscope reveals in the schists and gneisses of the mountains. Since the Green Mountains have been thrust to the northwest, for a distance which is indeterminate, it is quite possible that the intrusives of the piedmont today are the sheared off "roots" of igneous bodies whose upper parts lie within the mountain mass.

A Glacial Pothole on the Ridge of the Green Mountains Near Fayston, Vermont

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During the summer of 1934, the occurrence of a pothole on the ridge of the Green Mountains about a third of a mile south of the summit of Burnt Rock Mountain, in the town of Fayston, was brought to the attention of the writer by Professor George V. Kidder of the University of Vermont. The pothole is situated at the base of a cliff approximately seventy-five feet west of the Long Trail. Its discovery was made by Mr. Henry Webster of Moretown, Vermont, while hunting in the vicinity. In October, 1935, the writer made a journey to the locality and made the following observations.

The elevation of the pothole as determined by an aneroid barometer, is 2,820 feet above sea-level and so far as the writer is aware, it is, probably, the highest known *in situ*[1] pothole occuring in New England. High elevation potholes have been reported from various localities by writers in the past. Jackson[2] gives an account of several potholes at Orange, New Hampshire, at an elevation of more than a thousand feet. Hitchcock[3] describes high elevation potholes in southeastern Vermont, in the townships of Newfane and Wardsboro, at elevations of about 2,600[4] and 1,500 feet above sea-level, respectively.

Where still intact, the Burnt Rock Mountain pothole (Fig. 1) has a diameter of four feet at the rim and, when measured from the lowest lip of the rim, tapers very gradually toward the bottom to a depth of thirty inches. A gradually widening, winding, semi-cylindrical channel extending upward from the pothole, in the face of an east-west trending, vertical cliff, suggests the direction from which the "moulin" torrent came. If this channeled, upward

[1] Potholes on Mt. Jefferson; Irving B. Crosby, Appalachia, Vol. 17, pp. 44-45 (1928-29). This article describes several potholes at an elevation of nearly 4,000 feet, but it appears that they occur in a glacial erratic and not in bedrock, to which the term *"in situ,"* above, refers.
[2] Geology of New Hampshire; C. T. Jackson, pp. 113-114 (1844).
[3] Geology of Vermont; Edward Hitchcock *et al.*, Vol. 1, p. 216 (1861).
[4] An examination of the U. S. G. S., Wilmington and Brattleboro quadrangles, has shown this figure to be much too high. The highest elevation in the town of Newfane is 1,840 feet above sea-level.

extension of the pothole be considered the remnant of a once complete structure, it would seem that its original depth must have been in the neighborhood of fifteen feet, since the height of the cliff at this point is twelve feet. This winding channel, or pothole remnant, curves upward in an east-northeasterly direction upon reaching the top of the cliff, which, in turn, is toward the ridge of the main range. The crest-line of the ridge is about forty feet higher than the present pothole. From the above observation it might be inferred that the stream which made this pothole came from a general easterly direction.

FIG. 1. THE POTHOLE ON BURNT ROCK MOUNTAIN

When first discovered the pothole was filled with soil and a few angular rock fragments derived from the cliff above. This material was removed by the discoverer who reported that it contained no rounded pebbles or boulders. Because of protection by this soil-fill, the walls of the pothole have retained their original smoothness of surface. The lower lip on the downslope side of the rim has been smoothly grooved by the overflowing waters.

The pothole has been drilled approximately along the planes of schistosity in a green, epidotic, micaceous schist, the strike and dip of the schistosity being N20E and 50NW, respectively. Intercalated with the contorted schists are thin lenses or veins of quartz. The cross-sectional plan of the pothole does not appear to have been affected by the foliated structure of the rock, for its diameter is quite constant.

About fifty feet west of the pothole, on the vertical east-west cliff, is a small polished area displaying thin glacial striae with an east-west direction and a pitch of 18° to the west, which would be down the slope. A second smoothed and polished surface, with a shallow striated groove a foot in width, occurs on the same cliff higher up on the slope, about fifty feet to the east of the pothole. This glacial groove and its striations give the same directional readings as the striae previously mentioned. A shallow vertical channel in the face of the cliff at another place, leads the writer to believe that there may be more potholes buried beneath the soil at its base.

It has long been an accepted fact that potholes have their origin in moving water laden with sufficient sediment to serve as grinding tools. This moving water may be wave action or a stream current. Waves striking against a cliffed headland may be so directed by the contour of the rocks as to acquire a swirling motion; when, with the aid of rock tools, a pothole is gradually worn in the bedrock. Since the force which gives the grinding sediments a rotary motion is not applied from above, but rather from the side at a very low angle, the depth of the pothole must necessarily be exceedingly shallow. It is generally saucer-shaped with circular groundplan. Along marine coasts most effective work is accomplished during high tide by both the powerful advancing waves and the strong receding undertow. Coastal potholes are occasional occurrences in the rocky portions of a shoreline. An excellent example of this type of pothole was seen by the author several years ago, at the base of the famous Cliff Walk at Newport, Rhode Island, not far from Easton's Beach. At the time of its discovery this depression contained several well-rounded boulders.

The great majority of potholes, however, are the result of a stream current falling over a precipice. They may be divided into two groups, the subaerially and subglacially eroded. Subaerial potholes are common in rapids and below waterfalls of rivers and streams, and since this paper describes a pothole belonging to the latter group, a discussion of the ordinary stream-worn pothole will not be included. The mechanics involved in the production of potholes connected with both groups, is the same; namely, a current of water plunging from an abrupt elevation, either at a high angle or vertically. They differ, however, in their topographic locations with respect to existing stream courses, the potholes of glaciofluvial origin showing no relationship to present stream courses.

That the pothole in question has a glacio-fluvial origin is seen in its topographic position relative to elevation and remoteness from existing streams. Additional evidence is apparent in the glacial striae in close proximity to the pothole, already described.

Upham[1] describes the moulin hypothesis in the following way: . . . . "the German and Scandinavian term, giants' kettles, may be restricted to the class of holes, bored in the bed-rock beneath glaciers or an ice-sheet by torrents of water falling through deep moulins. The name 'moulin' coming from the French and meaning a mill, is applied to a vertical tunnel, melted at first by the waters of the surface trickling into some very narrow crevasse that has just begun to open, until, after enlargement by this dissolving action, it receives sometimes a large stream . . . . pouring . . . . down a cylindric shaft to the rock floor under the ice."

The hypothesis quoted above considers superglacial streams flowing from the surface of the glacial ice into crevasses and drilling a hole in the bedrock immediately at the bottom. In his article Upham[2] refers to Mr. T. T. Bouvé and Professor George H. Stone as pointing out . . . . "that the subglacial waters, after falling down the crevasses and moulin shafts, would flow rapidly away upon the surface of the bedrock, and then might sweep past the mouths of the potholes during the process of their erosion, supplying all the current needed for their further deepening by the whirl thus given to the water and stones at the bottom." This citation assumes further deepening of "moulin" potholes by subglacial streams flowing past them over the bedrock beneath the glacier.

Concerning the position of "moulin" with respect to its pothole, Upham[3] states: "For the largest and deepest of the giants' kettles, however, to be here noted as discovered in many localities of glaciated countries, I can not doubt that the pothole was cut down exactly at the foot of a great and very deep moulin by its powerful descending torrent." While this supposition is readily conceivable, it is also possible for subglacial streams to be the direct agents of pothole erosion independent of a "moulin" shaft. Where a subglacial stream falls over a rock cliff, a pothole may be formed in the rock at its base, and which may extend upward as a cylindrical boring whose circumference consists of the wall of the cliff on one side and the contacting ice on the other. Upham[4] explains the origin of some of the potholes and channeled cliff faces

[1] Giants' Kettles Eroded by Moulin Torrents; Warren Upham, Bul. Geol. Soc. Am., Vol. 12, pp. 27-28 (1900-01).
[2] *Loc. cit.*, p. 28.
[3] *Loc. cit.*, pp. 28-29.
[4] *Loc. cit.*, p.32.

at Taylor's Falls in Interstate Park, similarly, to wit: "For the explanation of their erosion I can only suggest that here, as in places of moulin torrent action in Massachusetts and New York, effective erosion nearly as in a pothole of the largest size took place on a mural surface, with only ice, as we must suppose, to form the other side of the moulin. It is quite sure that they were worn as half-holes instead of having undergone demolition and removal of the wanting part. On a smaller scale such mural segments of cylindric water-wearing are seen in other places within this little area."

Barker[1] describes a similar occurrence on Towner Hill, where "At the foot of the cliff is the remnant of a still larger pothole that now forms a shallow niche in the face of the cliff." In his description of its origin Barker[2] presents the hypothesis . . . . "that it was bored in solid rock, and that, subsequently, the greater portion of it had been eroded away."

The writer is inclined to the opinion that the Fayston pothole, herein described, was bored in the solid rock and that the missing portion was later eroded away. In support of this opinion the east-west trending glacial striae previously mentioned in this paper, are evidence of glacial erosion. The plane of the face of the cliff containing these striations, if extended to meet the eroded pothole, would cut its circumference. According to this observation it would appear that the pothole was not only glacially made, but, probably, also glacially eroded.

Further, it might be supposed that the smooth water-worn channel in the cliff above the present pothole, was the result of ordinary current channeling on the surface of the rock by a subglacial stream. But when the depth of the existing pothole at the base of the cliff is compared with the diametral depth of the upward-trending channel, and, along with this the vertical attitude of the cliff is taken into consideration, it is difficult to understand this origin for the pothole. That is, with the force of the current directed mainly downward from this twelve-foot vertical cliff, a greater depth for the still extant pothole might be expected when its proportions are contrasted with those of the channel. This channel, then, appears to have been at some time in the past a part of a complete pothole, the product of eddying currents.

Further observations at this locality tend to show that this pothole was probably not formed by a straight fall of water, but,

[1] Glacial Pot-holes at Crown Point, New York; E. E. Barker, Jour. Geol., Vol. 21, p. 463 (1913).
[2] *Loc. cit.*, p. 463.

rather, by a subglacial stream flowing from the general direction of the ridge not far away. This belief is based on the observed fact that, in its upper portion, the pothole remnant curves toward the ridge. Thus, it can be seen that the fall of water, in this case, was not introduced directly from above, as is assumed in the general "moulin" hypothesis which has been quoted above from Upham.

The "moulin" hypothesis presents a difficulty when one attempts to conceive a "moulin" remaining long enough in one place to allow a well-formed, single pothole to be bored in the bedrock. Alexander[1] refers to this difficulty, and in commenting upon potholes . . . . "as reforming in the same manner and at the same spot often enough to account for the work accomplished," he says farther on that it . . . . "rather strains the theory of probability." Upham whose work preceded Alexander's by about thirty years, advanced the theory that "moulin" formation occurs before the ice motion has acquired a definite current to move the crevasse, "moulin," and waterfall away from the spot where they were first formed. He goes on to say that when the ice was given motion because of its increased thickness and consequent pressure, pothole-making ceased. Manning[2] cites a theory of Agassiz, that a crevasse does not move forward with the advancing ice sheet because it is made by the physical features of the underlying surface, and although the glacial mass moves forward, the crevasse remains near or at the place of origin, at least for a sufficiently long time.

In view of the objectionable features associated with the "moulin" hypothesis presented above, the writer suggests that the importance of subglacial streams be given more consideration in an analysis of pothole erosion; at any rate, in those cases in which the potholes are located at the bottom of cliffs, of which there are many. However, the writer's concept does not account for potholes otherwise located. In this connection Gilbert[3] has written, "After the water of the moulin has reached the rock bed it must escape along some course beneath the ice. In flowing away it may accomplish erosion of the ordinary type, and the sculpture resulting from stream erosion may therefore be associated with moulin sculpture." It seems reasonable to suppose that the elevated pothole under discussion was formed by a subglacial stream flowing through an ice tunnel and plunging over the precipice, below which the

[1] Pothole Erosion; H. S. Alexander, Jour. Geol., Vol. 40, pp. 310-11 (1932).
[2] Glacial Pot-holes in Maine; P. C. Manning, Proceedings Portland Soc. Nat. Hist., Vol. 2, pp. 185-200 (1901).
[3] Moulin Work Under Glaciers; G. K. Gilbert, Bul. Geol. Soc. Am., Vol. XVII, p. 319 (1906).

pothole lies. The conditions best suited for subglacial stream action prevail in the marginal area of the glacial ice where ablation is marked. Here the melt-water enters a crevasse, at the bottom of which the subglacial stream has its beginning.

Alexander[1] has found that many of the high elevation potholes . . . . "are associated with cols through which mighty streams may have flowed from temporary glacial lakes. Such are often bounded by rock ridges on the southern side and where the waters overflowed the ridge rapids would form and the conditions for the erosion of eddy holes would exist." The pothole described in this paper is situated in a col and may well have had an origin similar to that pictured in the above quotation but, owing to the nature of the topography and the great difference in elevation between the pothole and adjoining valleys, a rock ridge dam on the south side to impound lake waters, would seem unlikely. In explaining the possible origin of this pothole the writer finds himself in accord with Alexander's hypothesis of a stream crossing the divide in the col, but would postulate a more or less shallow temporary lake, filling a depression in the westward-sloping ice surface on the east side of the ridge, spilling over the ridge, and flowing upon the very uneven surface of the western slope in a series of rapids and waterfalls. In this explanation emphasis is placed on the assumption that the ridge was exposed by the melting of the ice during the waning stages of the Glacial Period.

[1] *Loc. cit.*, pp. 311-12.

INDEX

(Asterisks refer to illustrations)