GEOLOGICAL SURVEY OF NEW JERSEY

HENRY B. KÜMMEL, STATE GEOLOGIST

BULLETIN 16

Annual Administrative Report

OF THE

STATE GEOLOGIST

For the Year 1914

AND ACCOMPANYING REPORTS

BY

J. VOLNEY LEWIS

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Geological Survey of New Jersey

BOARD OF MANAGERS.

His Excellency, James F. Fielder, Governor and *ex officio* President of the Board, ... Trenton.

MEMBERS AT LARGE.

Alfred A. Woodhull,	Princeton,	1919
Frank Vanderpoel,	Orange,	1919
T. Frank Appleby,	Asbury Park,	1915
William Libbey,	Princeton,	1916
John C. Smock,	Trenton,	1918

CONGRESSIONAL DISTRICTS.

I.	Stephen Pfeil,	Camden,	1916
II.	P. Kennedy Reeves,	Bridgeton,	1917
III.	Stephen R. Applegate,	Toms River,	1919
IV.	Washington A. Roebling,	Trenton,	1918
V.	Frederick A. Canfield,	Dover,	1915
VI.	George W. Wheeler,	Hackensack,	1916
VII.	John H. Cannon,	Paterson,	1918
VIII.	George F. Reeve,	Newark,	1918
IX.	E. H. Dutcher,	East Orange,	1919
X.	Herbert M. Lloyd,	Montclair,	1917
XI.	Clarence G. Meeks,	North Bergen,	1915
XII.	Joseph D. Bedle,	Jersey City,	1918

STATE GEOLOGIST.

HENRY B. KÜMMEL.

Letter of Transmittal

TRENTON, N. J., January 19, 1915.

Hon. James F. Fielder, Governor and ex officio President of the Board of Managers of the Geological Survey:

SIR—I have the honor to submit my administrative report summarizing the work of the Geological Survey for the year 1914. This report is made in accordance with Chapter 46 of the Laws of 1910. The manuscript of several reports setting forth the results of the scientific work of the Survey are nearly completed and their publication will be requested in the near future.

Respectfully submitted,

HENRY B. KÜMMEL,

State Geologist.

Administrative Report

HENRY B. KÜMMEL, STATE GEOLOGIST.

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- Drainage.
- Marked chemical or mineralogical features.
- Soil series and types.
- Soil mapping.
- Soils of the Camden area.

Archæology.

- Area surveyed.
- Principal districts.
- Village sites.
- Rock shelters.
- Burial places.
- Trails.
- Raw material.

Publications.

ADMINISTRATION.

Scope of Report.—This Annual Report of the State Geologist covers merely the administrative work of the Survey, and does not discuss, except in outline, the scientific work of the department. The results of this work are published from time to time as maps, bulletins, and final reports, which can be obtained upon application to the State Geologist.

Organization.—The organization of the department has not been changed. The general oversight and direction of the work is vested in an unpaid Board of Managers appointed by the Governor. The State Geologist, in whose hands is the immediate control of the department, is appointed by the Board, and holds office at their pleasure. The work of the department, and that of the Forest Commission, of which he is *ex officio* the executive officer, demand and receive his entire attention.

At the last session of the Legislature a bill was introduced, but was not passed, which proposed to establish a department of conservation, in which were to be merged a number of existing departments, among them the Geological Survey. The chief objection to the proposed consolidation was that it included departments which had nothing in common, and it did not clearly establish the principle that the technical and scientific bureaus of the State should be under the charge of experts trained in their respective professions.

No one can take exception to the broad proposition that the State departments should be organized on a basis of efficient management and economical expenditure. In the application of this principle to the Geological Survey, it should be recognized that the organization of the Survey has always been along lines advocated by the Economy and Efficiency Commission, namely, a non-partisan board of public-spirited men, serving without compensation, who exercise general direction and determine the broad lines of policy, and a geologist as the active head, with a corps of trained assistants, to direct the technical work and carry out the details. The State Geologist is held responsible for the entire conduct of the Survey under the plans adopted by the Board, and this responsibility is made real by the fact that he is appointed by the Board and holds office at their pleasure. Tenure of office under these conditions is given the security which is necessary in a position where personal knowledge of the resources of the State is essential to effective work. This is proven by the fact that since 1864, when the Survey was established, there have been but three incumbents of the office. Frequent changes in the personnel of a scientific bureau are destructive to continuity of work, and extravagant in the resultant loss of knowledge and experience. No file of published reports, however voluminous, no system of records, however detailed, can entirely supersede the personal knowledge and experience of a trained worker. The Board of Managers of the Survey is appointed by the Governor and confirmed by the Senate. Each congressional district is represented and a number are appointed from the State at large. Politics have never entered in any way into any of the discussions or business of the Board. The total expenses of the Board have probably never exceeded $100 per annum, and have usually been less.

Although called a Geological Survey, the work of the department has from the beginning been broader than the name implies. In many respects it has been a department of natural resources and of engineering. Repeatedly, of its own initiative, or in response to commands of the Legislature, investigations have been undertaken and reports have been made on subjects more or less removed from geology. The surveys which resulted in the publication of an accurate topographic map of the State; the investigations of the forest resources and of the losses caused by forest fires, which resulted in the establishment of the present Forest Park Reservation Commission; the plans for the reclamation of the Hackensack and Newark tide-meadows, which have largely directed attention to the improvement of these waste lands so close to large centers of population; the surveys for the inland waterway from Bay Head to Cape May, for the carrying out of which project the Legislature created a separate department; the testing of road materials for the State Road Department; the analysis of coal for different State institutions; the carrying out of a soil survey, in co-operation with the State Agricultural Experiment Station and the United States Bureau of Soils, in which the different types of soils are carefully mapped and analyzed; all these are but a few of the lines not strictly geologic in which the Geological Survey has forwarded the interests of the State. But while it has been engaged in these outside matters, work along strictly geologic lines has not been neglected. In the earlier days of the Survey, when the greensand marls of south Jersey and the iron ores of north Jersey were of great importance and were actively mined at many points, the Survey reports carried information of inestimable value to those industries, and within recent years the demand for information regarding our active iron mines, as well as the possibilities of these ore reserves, has necessitated the publication of a more comprehensive report upon the iron industry of the State. The clay report of 1878, which set the mark for similar publications among state surveys, was supplemented by a report on the clays and clay industry, published in 1904, in which the geology of the clay deposits and the technical phases of the industry were treated at length, and a valuable contribution made to our knowledge of our refractory clays. Investigations of the water supply and water resources of the State were begun at an early date, and a voluminous report issued dealing with the run-off of our streams, the areas of the catchment basins, the value of the water-powers, and the sources of public water supplies. In this report an effort was made to analyze the laws which govern stream flow, and to deduce formulæ by which the flow of the New Jersey streams may be computed from the rainfall. It is interesting to note that although this method of procedure and these formulæ, published twenty years ago, have not received in some quarters in this country the wide acceptance which is their due, they have recently been commended in high terms by one of the foremost English experts in hydraulic engineering. But it is not possible to enumerate here all the activities of the Survey, or the various investigations which it has undertaken. Emphasis must be placed, however, upon the fact that the Geological Survey under its present organization has for half a century served the people of the State economically, and it is believed efficiently.

With the Forest Park Reservation Commission coöperation has been close and intimate, since by law the State Geologist is a member and the Executive Officer of that commission. Hence, in the work of these two boards there has certainly been no duplication of work, and no unnecessary multiplication of paid officials.

It is not easy to see how a great saving can be effected by the abolition of a Board which costs the State less than $100 per year, if the work done by the scientific workers under that Board is to be continued. But if the interests of the State, or political expediency, appear to demand that the Geological Survey be consolidated with the Forest Commission and other boards dealing with the natural resources of the State, it is to be hoped that it will not be done in such a way as to imply that the Managers of the Survey have been "unprofitable servants", or to destroy or diminish the effective scientific organization of the department.

During the year the following appointments to the Board of Managers were made by the Governor: A. A. Woodhull, Princeton, Member at Large, Reappointed; Frank Vanderpoel, Orange, Member at Large, Reappointed; E. H. Dutcher, East Orange, IX District, Reappointed; Stephen R. Applegate, Toms River, III District, in place of Henry S. Washington, whose term had expired and who had removed from the State.

The Board lost by death David E. Titsworth, Plainfield, and Harrison Van Duyne, Newark, both Members at Large.

The following changes on the Survey staff must be recorded: Henry Jennings, assistant in the soil survey, resigned in February to accept a position as county agricultural adviser in Vermont, and in July was succeeded by C. C. Engle, formerly connected with the soil survey in New York State; in June Miss Sara Cooley was appointed clerk and stenographer in place of Miss Henrietta L. Kruse, transferred to the office of the State Tenement House Commission. During the year the Survey staff comprised the following persons, those in the first group being employed continuously:

Henry B. Kümmel, State Geologist; M. W. Twitchell, Assistant State Geologist; R. B. Gage, Chemist; Henry Jennings, Assistant in Charge of Soil Mapping; C. C. Engle, Assistant in Charge of Soil Mapping; Henrietta L. Kruse, Clerk and Stenographer; Sara Cooley, Clerk and Stenographer; John S. Clark, Assistant; R. W. Wildblood, Stenographer and Laboratory Assistant.

C. C. Vermeule, Topographer and Consulting Engineer; J. Volney Lewis, Professor of Geology, Rutgers College, Geologist; D. W. Johnson, Professor of Physical Geography, Columbia University, Geographer; Max Schrabisch, Assistant, Archæological Survey; John G. Baumann, Janitor at Laboratory.

In addition to the above, one or more clerks of the U. S. Geological Survey at Washington, D. C., rendered some service, and several of Mr. Vermeule's assistants were employed, either in the office or in the field, on the revision of topographic maps and inspection work at Shark River Inlet.

Publications.—Publications during the year were as follows:

Bulletin 12. Administrative Report of the State Geologist for 1913, by Henry B. Kümmel, and Including a paper on Recent Storm Effects on the

Northern New Jersey Shoreline and their Supposed Relation to Coastal Subsidence, by Douglas W. Johnson and Warren S. Smith.

New editions of Atlas sheets Nos. 21, 27, 29, 37, scale 1 mile=1 inch; Newark and New Brunswick, 2,000 feet=1 inch.

Raritan folio, Geologic Atlas of New Jersey (prepared and published in co-operation with the U. S. Geological Survey).

Geologic Map of New Jersey, scale 4 miles=1 inch.

The texts for three other bulletins were completed during the year, and their publication authorized by the State Printing Board early in the summer. One of these was a report by Mr. Schrabisch describing the rock shelters of Sussex County once inhabited by the aborigines. The field work on which this report was based was done during the summer of 1913. Another is a summary description of the geologic formations of New Jersey, an outline of the geologic history of the State, and a condensed statement of the mineral resources with reference to the different reports in which their full descriptions may be found. This bulletin was prepared to accompany the geologic map of the State issued in the early part of the year, and its prompt publication is extremely desirable. The third dealt with the mineral production during 1913.

Distribution.—The demand for maps of the Survey was somewhat less than for the years immediately preceding:

	Sheets Sold.		
	1912.	*1913.*	*1914.*
Maps on scale of 1 mile per inch.	1718	1422	1472
Maps on scale of 2,000 feet per inch,	1658	1809	1585
Geologic folios,	69	60	101
State Geologic map,	....	....	253

The demand for the reports of the Survey was a large one. The total number sent out was 7090, of which over 1000 were reports antedating 1909, some of them issued many years ago. A number of the most valuable of the reports, as that on "Clays and the Clay Industry", and the one on "Physical Geography", are no longer available for free distribution, the few remaining copies being held, under the rules of the Board, for sale at cost. A list of all the reports heretofore published, with those still in stock, accompanies this report.

Library.—Accessions to the Survey library, both by gift, exchange and purchase, continue. The least used portion of the library has been deposited in the library of Rutgers College at New Brunswick, where it is really more accessible than when packed away in boxes in the vaults of the State House.

Need of more room.—In common with many other departments, the work of the Survey is in some respects hampered by inadequate accommodations. This is most marked in the case of the laboratory, where increased work due to the necessity of testing all road materials is rapidly approaching, if it has not already exceeded, the limits of the space available. As stated in last year's report, it is necessary for one assistant to work in New Brunswick at the State Experiment Station owing to lack of room in the Survey offices at Trenton. The Assistant State Geologist is compelled to have his desk in the office of the Curator of the State Museum. The loss of efficiency due to inadequate facilities is considerable. A laboratory with the necessary offices, weighing, testing, and store rooms, is the greatest need, and should be provided as soon as possible, particularly as the Survey is a tenant in its present quarters (the second story of a building originally built as a stable and now used as a garage) only by the courtesy of a public-spirited citizen of the State.

Expenditures.—The expenditures of the Survey for the fiscal year ending October 31 were as follows:

FINANCIAL STATEMENT.

	Credit.
Regular Appropriation,	$16,500 00
Supplemental Appropriation,	1,000 00
Testing Road Material Appropriation,	5,000 00
Archæological Survey Appropriation,	500 00
	$23,000 00

Expenditures—Expenses of Board of Managers, $80.33; Salaries, Clerical force, $2,247.89; Salaries, Scientific force, $13,529.84; Traveling expenses, $1,369.91; Office furniture, $96.45; Office supplies, $307.61; Laboratory equipment, $380.62; Laboratory supplies, $638.41; Other scientific apparatus, $9.61; Library, $63.60; Postage, $485.59; Express and freight, $81.63; Telephone and telegraph, $131.23; Engraving and printing maps, $2,550.67; Sundries, $16.28; Unexpended balance, $1,010.33; Total, $23,000.00.

CASH ACCOUNT.

Balance on hand November 1st, 1913,	$87 00	
Receipts from sales of maps and reports,	878 92	
Receipts for services in obtaining marl,	2 00	
Disbursements—Paid State Treasurer,	......	$893 77
Balance on hand October 31, 1914,	......	74 15
	$967 92	$967 92

TOPOGRAPHY AND ENGINEERING.

Mr. C. C. Vermeule, as Consulting Engineer, has continued to advise concerning the topographic and engineering work of the Survey. Messrs. Staats, Lufburrow, and others of his assistants have been engaged on State work, and during such times have been paid by the State.

Bench Marks.—Owing to the necessity of spending a large part of the appropriation in revising and printing new editions of the several sheets of the topographic atlas, it was impossible to set aside any funds for resetting old bench marks throughout the

State or for establishing new ones. In many of the counties new lines of exact levels should be run and additional bench marks established, since many of those set in 1883–1888 during the progress of the topographic survey have been obliterated in the natural course of improvements and alterations. Some work of this character was done in 1912–1913 in the northern counties, and it is desirable that it be extended to other parts of the State.

Revision of maps.—It is the policy of the department to revise and bring to date the topographic atlas whenever the need for new editions of its various parts gives opportunity, and changes in culture render it necessary. In pursuance of this policy, sheets 21 and 27 were brought up to date in the vicinity of the larger towns but the entire area was not traversed; sheet 29, covering the greater part of Monmouth County, was more extensively revised, particularly along the coast; extensive revision of both the Newark and Hackensack sheets was needed, and this work, commenced in the preceding year, was carried to completion in the field, while in the office the necessary drawings were prepared for the engraver. The new edition of the Newark sheet was printed during the year, but the publication of the Hackensack sheet was delayed until early in November; the New Brunswick sheet was also revised and a new edition published. Just before the end of the year work was commenced on the Chester sheet, some parts of this needing extensive revision.

Shark River Improvement.

Progress of work.—The construction of reinforced concrete jetties at Shark River to fix the position of the inlet and prevent it meandering, has progressed slowly but without long-continued interruption, although severe winter storms hindered the contractor greatly, and an equipment which was not adequate at first prevented the completion of the work within the time limits. The task of sinking the heavy concrete piles, some of which are 28 feet in length and which weigh over 4½ tons apiece, proved much more difficult than had been anticipated, particularly since a thick bed of tough marly clay was encountered in which the hydraulic jets made slow progress.

In February the Bay Dredging and Contracting Company requested permission of the Board of Managers of the Survey to sublet to the New York and Panama Canal Wrecking Company that part of their contract relating to the driving of piles, on the ground that the latter company had an equipment particularly designed to place piles of this character, and that by means of a boring device the difficulty met with because of the clay could be readily overcome. At a special meeting held January 30, 1914, the Board of Managers adopted a resolution permitting this to be done in accordance with the original contract specifications.

Although it had been anticipated that the sub-contractor would install his plant at once, the severe weather conditions which prevailed during the latter part of the winter caused great delay and he was not able to get his scows and machinery on the work until April 4. The time from this date until May 20 was spent in setting machinery on the scows, building derricks and installing the cutter, and May 20 he began removing the old piles of a wooden bulkhead which interfered with driving the concrete piles. Nearly three weeks were spent in this work and it was June 11 before he commenced to sink new piles. During the next five weeks only 47 piles were sunk. The cutter, from which so much was expected, proved to be undependable since its cutting blades were frequently broken by striking some buried obstructions in the clay. Finally, on July 18, from some unknown cause, the scows belonging to the sub-contractor sank in the inlet and all work was of necessity stopped until they could be raised. This consumed over two weeks and it was August 3 before they were afloat again. Apparently, the sub-contractor was then in financial difficulties for no further work was done by him.

The Bay Dredging and Contracting Company had continued to set piles until May 20, when the sub-contractor's plant was supposed to be in shape to take over this work, and up to that time had succeeded in putting in 246 of the total of 1356 piles required. As the sub-contract covered only the setting of piles, the Bay Dredging and Contracting Company continued with other phases of the work, chiefly the manufacture of additional piles.

On July 31, the Committee of the Board in charge of the work notified the Bay Dredging and Contracting Company that a meeting of the whole Board had been called for August 10 to consider whether the bonding company should not be called upon to complete the work, and that their action at that time would be determined in large measure by the actions of the Bay Dredging and Contracting Company in the immediate future. The Board of Managers met August 10 at Belmar, and, after inspecting the progress of the work, directed the State Geologist to notify the contractor that unless by September 10 such progress was made in the sinking of piles as to render probable the completion of the contract within a reasonable period, the bonding company would be notified without further warning to take over and complete the contract. The Board also directed that a similar notice be sent to the bondsman.

On September 10 the Committee of the Board in charge of the work found that the contractor had completed his plant and false work and was then driving piles at such a rate as to warrant his being permitted to continue the work so long as such progress was maintained. Since that date the work has progressed steadily and at an increasingly rapid rate. During October more piles were set than during any previous month, and reports for the first two weeks of November show that 70 per cent. as many piles were set as during the entire month of October. This result was achieved in spite of the fact that high tides or heavy surf compelled its temporary stoppage. At the close of the fiscal year, October 31, the work done was as follows:

Piles manufactured, 1280, 91 per cent.; Piles set, 383, 28 per cent.; Caps and beams, 1,783 cu. ft., 9 per cent.; Removing old piles, 61, 61 per cent.

In September, the Engineer in Charge recommended certain changes in construction. Since these changes are such as to increase greatly the strength and stability of the jetty, and since the additional cost does not exceed the unexpended part of the appropriation, they were approved and ordered made.

The oversight of the work at Shark River is vested in a committee appointed by the Board. This committee originally consisted of Messrs. Van Duyne, Meeks and Appleby, the first named being chairman. On Mr. VanDuyne's death in May, Mr. Meeks was appointed chairman, and Mr. Libbey chosen as the third member.

GEOLOGY.

Geologic map.—In march the department issued a new geologic map of the State, compiled from published geologic folios and manuscript data by Prof. J. Volney Lewis and the State Geologist. The scale (about 4 miles to an inch) is sufficiently large to permit a great amount of detail, while the size of the sheet (2 feet by 4 feet) is not so large as to be unwieldy. The compilation of the data, the preparation of copy, the engraving of a new base map and the preparation of the color plates took a long time, but the excellence of the product, artistic, cartographic and scientific, warranted this care and attention. The map shows in colors the location of the different varieties of rock, clay, sand, etc., within the State, and the different periods of geologic history to which they belong and during which they were formed. By means of 18 colors and various patterns of dots and lines, 57 different rock formations are distinctly represented and their location shown. Similar patterns of like colors are printed on the margin of the map and under each is the name of the formation and a brief description of its lithologic character. Identification of the colors and patterns of the map with those printed in the margin is aided by letter symbols printed on each, these symbols being commonly made up of the initial letter of the geologic period and the initial letter of the name of the formation. On the margin the descriptive legend and color patterns are arranged in general in the order of age, those of the younger rocks being placed at the top. It is therefore possible to determine by a study of the map and legend not only the geographic distribution of the various rock formations, but also their lithologic character, their relative age, and the economic products for which each is valuable.

At the bottom of the map are several cross-sections, showing the rock structure beneath the surface. That is, they represent the slants and folds of the rock layers as they would appear if we could view them in the walls of a deep canal cut from 150 to 1200 feet below sea level across the State along certain lines represented on the map. In making these cross-sections it was, of course, impossible to take into account every minor fold and bend, many of which are unknown, but the cross-sections accurately represent the major structures as interpreted after a careful study of all surface outcrops of the rock, supplemented by the evidence of mines and deep well borings.

The new map is a distinct advance, both artistic and scientific, over the earlier geologic maps of the State, the last of which was issued in 1888. The advance in geologic knowledge during the quarter of a century is indicated by the increase in the number of rock formations shown—from 24 on the old map to 57 on the new. This has necessitated many changes in the geologic names formerly used and the addition of new ones.

Teachers and students of geology in colleges and teachers of geography in normal and high schools will find this map of great educational value. Those interested in the development of our mines, the opening of quarries, the digging of clay, and the search for underground waters will wish to consult it frequently, and the intelligent man in every line of occupation will find it helpful to a better understanding of the natural resources of the State.

Summary of the geology of New Jersey.—In the early part of the year Professor Lewis and the State Geologist completed the manuscript of a bulletin describing the geologic formation of New Jersey, and giving a summary of the geologic history of the State. Since this bulletin describes the formations at much greater length than was possible in the legend on the geologic map, it will be of great assistance to the better understanding of that map. The bulletin will also be of assistance to teachers, students, and others who wish a short and comprehensive account of the geology of the State. A series of references to more technical papers will point the way for those who desire further information.

Mineral production.—The statistics regarding the mineral production of the State for 1913 were collected early in the year in co-operation with the U. S. Geological Survey, this work being in direct charge of Dr. M. W. Twitchell, Assistant State Geologist. His report on this work is in part as follows:

"Among the places visited were the zinc mines of Franklin Furnace and near Ogdensburg, iron mines near Wharton and at Oxford Furnace, cement plants and quarries near Alpha and New Village, slate quarry near Newton, limestone quarries and kilns near Carpentersville, Andover, Clinton, Annandale, Hackettstown, Stewartsville and Franklin Furnace, serpentine quarry and grinding mill near Phillipsburg, trap rock quarries and crushing plants near Lambertville and Pennington, sandstone quarries near Wilburtha and Stockton, gneiss quarry near Mt. Arlington, several potteries at Trenton, marl pits near Vincentown, glass sand pits and washeries at South Vineland, and a sand and gravel pit and washery at Cape May Point." A third phase of this work was the preparation of the Bulletin of the Survey on "The Mineral Industry of New Jersey for 1913", which, though finished as early in August as last year and at once placed in the printer's hands, has not yet been printed.

Underground waters.—Dr. Twitchell has also been engaged on work connected with the underground waters of the State. This has involved work upon the well records, both in improving the data already on hand and in devising better methods of obtaining new records, revising and bringing up to date the list of well drillers, making occasional visits to obtain well records of special importance, interviews with officials and talks before meetings of citizens of towns considering putting in underground supplies, numerous letters in reply to requests for information regarding probable underground water conditions at specific localities (many of which involve several hours' study before the answer can be given), and, finally, work upon the report on "The Underground Waters of New Jersey", which he is preparing.

Mineralogical investigations.—During the fiscal year ending October 31, 1914, Professor Lewis spent such time as he had available in a further investigation of various features of the trap rocks of the Newark (Triassic) formation. A condensed statement of the principal results and conclusions arrived at in both of these lines of work is published as a part of this report (p. 45). It is expected that a fuller statement of his investigations and their results will be made in a future Bulletin of the Survey.

Raritan folio of the geologic atlas of New Jersey.—In co-operation with the United States Geological Survey, the State Survey is publishing a geologic atlas of New Jersey. This conforms in plan to the geologic atlas of the entire country which the National Survey, either of itself or in co-operation with the surveys of other states, is preparing. In this joint work the two organizations have shared, to a degree which has varied in different regions, the expense of the field investigations, and of the preparation of the manuscript for text and maps. The expense of engraving, typesetting, and printing has been borne by the National organization, except that the State Survey has paid the actual cost (or less) of paper and presswork of the special edition prepared for it. The editions for the State and for the United States Survey are the same except for the covers and title pages.

Five of these folios have been issued to date, namely, the Passaic, Franklin Furnace, Camden-Philadelphia, Trenton, and Raritan. Each contains topographic, geologic and structure-section maps of the area surveyed, and a descriptive text. Some folios have also an economic-geology map, and some a special sheet showing the surficial formations as distinct from the underlying rock formations. Nearly all are illustrated. The text is designed to give a full description of the region surveyed. In each folio the introductory chapter sets forth the general geographic and geologic relations of the area in relation to the larger region of which it is a part, and gives also a summary of its geologic history. Then follow chapters headed "Topography", "Descriptive Geology", "Geologic History", and "Economic Geology". Under "Topography" there are paragraphs describing the relief, drainage and culture. Under "Descriptive Geology" the character, relations, thickness, and distribution of the different rock strata are fully described and their structure given. Here is set forth also the succession of events in the long course of earth history during which the rock strata were formed. In most regions these events have involved great changes of geography and topography. Many of the sedimentary rocks now exposed to view were formed beneath the sea. Subsequently they were raised above sea level, perhaps forming high plateaus; in some instances they have been tilted or folded to make great mountain ranges of which only the roots now remain, the upper portions having been removed by the unending attack of the agents of weathering and erosion. A careful study of the rock strata demonstrates that not infrequently after prolonged erosion and perhaps the removal of hundreds, or even thousands of feet of strata, the land has been depressed and covered again by the sea, with the result that new formations have been laid down upon the eroded edges of the older. So long has been the lapse of geologic time that in some regions not only has this happened once, but several times, and the geologic history as recorded by the sediments formed is incomplete. In the geologic folios, under the head of "Geologic History", all of these changes are enumerated in so far as they relate to the region under discussion.

From the standpoint of many business men, perhaps the most valuable part of these folios is the portion relating to the economic geology, for under this heading is given full information regarding the mineral resources of the region. These include the mines and ores, quarry products of all classes, sand, gravel, clay, soils, and water supplies—both surface and underground. The terms under which the folios can be obtained are stated on page 43.

Relations of the Kittatinny Limestone.

General statement.—The name Kittatinny limestone was given a number of years ago to the great mass of bluish and gray limestone which forms several belts in Kittatinny Valley and underlies considerable portions of the inter-Highland valleys of the South Branch of Raritan River, of Musconetcong River, Pohatcong Creek and others. The thickness of these beds has never been determined accurately owing to a somewhat complicated structure, but it approximates 3,000 feet. At the base of the limestone and between it and the underlying pre-Cambrian crystalline rocks are a few feet of quartzite and arkose sandstone, which grade upward into calcareous shales and sandstone. Lower Cambrian fossils have been found in these calcareous beds, hence the base of the overlying limestone has been assumed to be Lower Cambrian or later. Upper Cambrian fossils have been found at a few widely separated localities in the middle portion of the formation, and a Beekmantown fauna in the upper part. For these reasons the Kittatinny limestone was for a number of years regarded as ranging in age from the Lower Cambrian to the lower part of the Ordovician (Beekmantown). Of recent years work in the adjoining states of New York and Pennsylvania has raised a question as to the correctness of this conclusion.

Subdivisions in Pennsylvania.—In northeastern Pennsylvania, Miller and Wherry, working in the Lehigh Valley, have divided the Kittatinny limestone into three parts, a basal portion believed to be the correlative of the Tomstown (Lower Cambrian) of southern Pennsylvania, a middle portion called the Allentown, and an upper part correlated with the Beekmantown (Ordovician) of New York. The Ordovician age of the upper part has been well established by fossil evidence and harmonizes with the determinations made in 1900, in New Jersey, although the thickness of beds referable to the Ordovician is much greater than was then supposed.

Subdivisions in the Phillipsburg region.—During the past field season the writer spent such time as could be spared from other duties in a detailed study of the Kittatinny limestone in the vicinity of Phillipsburg, N. J., and Easton, Pa., to determine whether the subdivisions established by Wherry and Miller could be carried across Delaware River, and if so, to trace their limits. The results of this work were on the whole satisfactory. The three divisions were recognized and it was found possible to map their boundaries with approximate accuracy, particularly along the Delaware and Lehigh rivers where numerous quarries, frequent railroad cuts and the river bluffs gave excellent exposures. Away from the narrowly incised trenches of the rivers and their tributaries, rock exposures are often lacking for considerable distances, and the formation boundaries can be located only approximately.

Tomstown limestone.—Overlying the basal sandstone and quartzite (Hardyston) is a considerable thickness of blue and bluish-gray dolomitic limestone with more or less yellowish and silvery shale, which is apparently to be correlated with the Tomstown limestone of southern Pennsylvania. The beds present two somewhat contrasted phases, one an extremely thick-bedded massive limestone, in which the stratification planes cannot everywhere be readily determined; the other, a thin-bedded limestone intercalated with layers of silvery damourite shale, which ranges in thickness from thin films to layers several inches or even feet in thickness. The rock varies in color from dark blue-black to bluish and yellowish-gray. Much of it is crystalline but the crystals are usually so minute that the texture is finely granular. In some layers they are too fine to be distinguished with the naked eye. The preponderating occurrence of damourite shale at certain horizons, particularly in the lower portion of the formation, and its presence as thin films at all but a few horizons is the most striking characteristic of these beds. So far as known, they are not fossiliferous. They are correlated with the Tomstown limestone of southern Pennsylvania because of their stratigraphic and lithologic character. If this correlation is correct, they are Lower Cambrian in age. Their thickness has not been determined but it is probably several hundred feet.

Allentown limestone.—The middle portion of the Kittatinny limestone consists of beds of medium thickness averaging 6 to 18 inches. Where shown in artificial exposures or those which are slightly weathered, the beds are alternately light and dark in color, so that the formation can often be easily recognized even at a distance. On fresh surfaces the rock ranges in color from almost black to blue-gray and light-gray. It is uniformly dolomitic in composition.

Layers of quartz sandstone, usually less than 2 inches in thickness but occasionally thicker, occur at intervals throughout the formation, and indicate shallow water conditions and proximity to a land area from which clastic sediments were occasionally derived. Thin films of shale, ripple marks, and cross-bedded structures are also present and testify as to shallow-water conditions. At some horizons thin laminæ of calcareous and siliceous silt alternate so frequently as to form a so-called ribbon limestone. On exposed surfaces the ribbon structure is accentuated by the differential weathering of the more soluble limestone laminæ. At a few horizons the shale layers are highly carbonaceous, while at others the mineral damourite is an abundant constituent. Layers of oölite occur not infrequently, and at some horizons a pisolitic structure has been observed. Beds of conglomerate composed of angular flat fragments of limestone inclosed in a calcareous or a siliceous matrix, which in some instances is cross-bedded, have been noted at several horizons. In all cases the fragments lie with their flat sides parallel with the bedding planes. This type of conglomerate has been designated *edgewise conglomerate,* and was probably formed by the breaking up and redeposition by shallow wave action of thinly bedded lime sediments. Along many of the bedding planes the rock on opposite sides interlocks in a manner suggesting the suture joints of a skull.

Upper Cambrian trilobites were found in these beds near Carpentersville, by Weller[1] in 1899. Much more conspicuous, however, than these forms are many impressions of colonies of marine algæ, *Cryptozoon proliferum* and allied forms. These consist of closely grown heads, each made up of minute plicated laminæ with wavy cross-section and concentric horizontal section. The smaller heads are an inch or less in diameter but increase with the accumulation of concentric layers and by coalescing with adjacent heads until they attain a width of 2 or 3 feet, and in cross-section form arches, which make a series of domes on the surface of the layer.

The presence of the Cryptozoon heads, the frequent occurrence of oölite and edgewise conglomerate, the alternate light and dark banding, and the comparatively uniform thickness of the beds are the chief characteristics which serve to differentiate these beds from the Tomstown limestone below and the Beekmantown beds above.

The thickness of the Allentown division has not as yet been accurately determined. Neither its base nor its top has been recognized with certainty in any exposure. There is some evidence, not as yet conclusive, that its top is a surface of erosion and that the overlying beds rest upon it non-comformably. Measurements of a portion of those beds made where repetition by folding or faulting can probably be eliminated show thickness of 760 to 1,125 feet with a possible maximum of 2,000 feet.

Beekmantown limestone.—The Beekmantown limestone is a thin to thick-bedded limestone, gray, light blue, or dark blue in color on fresh surfaces and generally weathering to a lighter tone. It is frequently minutely crystalline in texture and many beds are not unlike the Allentown beds in general appearance, except that so far as observed in New Jersey it is not characterized by Cryptozoon heads. The greater part of the formation so far as seen in this State is dolomitic, but some beds relatively low in magnesia and high in lime occur. These are of a dark-blue color, dense texture, in some layers minutely crystalline, and on weathered surfaces they are usually a bluish-gray color. Irregular discontinuous films and thin layers of siliceous silt occur in these purer limestones and on weathered surfaces give the rock a mottled appearance. Many of the dolomitic beds are also somewhat mottled both

[1] Geo. Surv. of New Jersey. Report on Paleontology, Vol. III, 1, 13.

on weathered and fresh surfaces. Oölite and edgewise conglomerate occur, but less abundantly than in the Allentown, whereas chert and flint, both white and black, are much more abundant. These occur both minutely disseminated and in large lenticular masses which may coalesce to form continuous layers. At some horizons the chert so impregnates the dolomite as to form honeycomb masses where the more soluble carbonate has been weathered out. The abundance of black flint, the presence of numerous weathered masses of honeycomb chert, the preponderance of irregular, discontinuous siliceous layers at certain horizons, and the occurrence of beds low in magnesia, are the most easily recognized lithologic characteristics of the formation. Fossils occur very sparingly, and chiefly in the beds low in magnesia, and when found are of great value in correlation, but for the most part the geologist has to rely on the petrographic character of the beds themselves.

In the quarries of the Edison Portland Cement Company, south of New Village, beds of fossiliferous limestone low in dolomite and 40 feet thick occur about 640 feet below the top of the Beekmantown. Similar beds, probably of the same horizon, are exposed in the railroad cut about midway between Washington and Changewater, and are the same distance below what is probably the top of the formation. In the quarries at Penwell, between Washington and Hackettstown, beds of this type occur only 300 feet below the top. Here the beds certainly referable to the Beekmantown are apparently 600–700 feet thick, whereas at several other points the thickness seems to be about 1,000 feet. It has long been recognized that the top of the Beekmantown, that is, the top of the Kittatinny limestone as heretofore described, is an erosion surface on which was deposited with slight unconformity the conglomeratic basal beds of later Jacksonburg limestone. The above data as to the thickness of the Beekmantown and the position of the non-dolomitic layer as regards its top, throw further light on the extent of this erosion interval.

JACKSONBURG LIMESTONE.

New cement rock locality.—In the Annual Report for 1900 it was pointed out that the Jacksonburg limestone, the upper beds of which are the cement rock of Warren County, occurred as a narrow band between the black slate and the blue limestone in Musconetcong Valley, although no outcrops of it had been found except two very narrow exposures, one at Penwell and the other near Asbury. Its location was, however, shown on the geological maps of the Raritan folio recently published. It is interesting to note here that excavations for the stone road from Hackettstown to Washington laid bare a fine exposure a mile north of Stephensburg in practically the exact location indicated on the geologic map several years ago.

CHEMICAL LABORATORY.

General statement.—The chemical work done during the last year has been in charge of R. B. Gage, Chemist, who is assisted by F. H. Baumann and R. W. Wildblood.

The chief lines of work have been the testing of materials used in road construction, the preparation of specifications for the purchase of various kinds of materials, the inspection of the equipment and methods used in the preparation and laying of bituminous pavements, and the testing of samples of coal received from the several State institutions.

Testing of road materials.—The road materials tested include the asphalt and road oil used in state-aid road work for both improvement and repair, the bituminous binders which were used in repairing and reconstructing county roads without state aid, pavement samples of various kinds, sands used in bituminous pavement and Portland-cement aggregates, stone aggregates for pavements of all types and for Portland-cement concrete, and lignin and other inorganic binders.

Over 240 samples of asphalt and road oil have been examined during the past fiscal year. In most cases the sampling has been done by a member of the laboratory force, in order that no error might be made and assurance might be had that the sample represented the material purchased. This has necessitated trips to the points where these materials are prepared, and has usually taken the best part of a day. If the two distributing points for these bituminous materials in the East, namely, Bayonne and Marcus Hook, were not so situated that it is possible to leave Trenton in the morning, sample eight or ten cars of asphalt, and be back in Trenton the same afternoon, it would be necessary to hire extra inspectors to secure the samples. If the volume of work increases much over what it has been for the past year, inspectors will have to be stationed at these two points in the same manner as is now being done by several Eastern States.

The endeavor has been to sample all bituminous material before shipment. Samples are taken from each car and the car sealed. The tests are then generally completed before the car arrives at its destination. The inspector on the road is then advised whether the material contained in the car shipped to the work which he is inspecting is satisfactory or not. By this method of inspection the contractor's work is not delayed awaiting the results of these tests. In a few cases where only one or two cars of material have been required, the road inspector has sampled the material when it arrived at its destination, for an inspector is never sent from the laboratory to sample fewer than three cars.

At the beginning of each year a standard set of specifications is prepared giving the tests which must be met by the various grades of bituminous materials to be used during that year. Samples of material actually used on each contract are then tested to see whether they comply with the requirements. The time required to complete the tests on a given sample is usually two or three days. If the sample is unusual or is intended for some particular experiment, additional tests are made. In such cases the time required is from three to five days.

In order to avoid an immense amount of routine work which would have to be done if contractors were allowed to submit with their bids samples of the materials which they proposed to use, official samples have been secured, tested, and when found satisfactory, given filing numbers. Representative samples have thus been secured from practically all of the firms which supply the road materials used in this State. A contractor desiring to use specific material need only to insert the filing number of that material in his proposal.

The preparation of this official set of samples was a long task, since, in order to determine the merits of the samples, especially of the bituminous materials, many more tests were made than those actually required by the specifications. However, now that this set of samples has been prepared, a standard degree of quality can be maintained for several years with a few changes each year.

The maintenance of state-aid roads rests on the respective counties and is met in part by the automobile-license money which is allotted by the State Commissioner of Public Roads. In making such repairs, a large quantity of road and dust oil of different grades is used each year. Samples are usually sent to the laboratory by the county supervisor for examination. The results of the chemist's analyses are reported to the supervisor, with instructions how the oil should be applied to secure the best results. Since these oils are seldom bought under specifications, it is necessary to determine their quality and merit for the use intended. This is more difficult than it is to determine merely whether an oil or asphalt conforms to a given set of requirements. The expense of this repair work is met in part by state funds, and therefore the examination of these samples is regarded as proper.

During the construction of a bituminous pavement, samples are cut daily from the pavement and sent to the laboratory by the inspector. These are examined to determine whether the pavement is of the proper thickness, and whether it was rolled at the right time and in a manner to give it the required density. A part of this sample is analyzed. The bitumen, filler, and stone content of the pavement is thus secured. After the separation of the bitumen, the mineral aggregate is carefully sieved in order to determine whether or not it is of the proper composition. The county engineer, the inspector, and the contractor are then advised of the results of this examination. By this method it has been possible to keep close check on the manner in which a pavement is being constructed. Since contractors do not lay on the average over 1000 square yards of pavement per day, at least 10 pavement samples must be tested for each mile of road constructed. During the past year, 180 or more such samples have been examined. It seems probable that during the coming season Mr. Gage and his assistants may be called upon to test two or three times this number of samples, and it is a serious question whether they will be able to do so in our present crowded and inadequate quarters. Not to make frequent tests of the pavement as it is being laid, is to invite the possibility of poor work.

In the analysis of a pavement sample, the bitumen is extracted by the use of carbon bisulphide. The fumes of this solvent are poisonous when continuously inhaled. Being exceedingly heavy, they are very difficult to remove except by forced ventilation. Inasmuch as the present laboratory is not equipped with such a system of ventilation, these fumes at times permeate the whole building and compel the operators to discontinue work of every kind for the balance of the day. With the present equipment it is possible easily to make from 10 to 15 extractions per day, provided there is no interruption to the work. On account of the lack of proper ventilation, the force can seldom make more than three or four extractions per day.

Sand for use in a bituminous pavement must be clean, fairly sharp, and well graded. Most sands either contain some loam or clay, or else the grains are too uniform in size to make good aggregates. Since the life of a bituminous pavement depends in large measure upon the character of the sand used, it is very important that this be of the proper quality. For this reason, the attempt is made to test the sands used in bituminous pavements before they are incorporated into the pavement. Sand samples are taken at random from each car shipped unless the sand is known to be uniform in character. Each sample thus secured is carefully sieved and the analysis reported. On an average, from three to five sand samples are tested for each mile of pavement constructed.

The quality of stone used in road work is generally determined by comparison with the sample adopted. Since practically all stone used in this State for road-building purposes is trap rock, there is little trouble in securing a good quality of stone. However, in many quarries the soil which overlies the stone is not properly removed before quarrying. The screenings shipped from some quarries often contain a large percentage of soil or clay, which makes them very objectionable for bituminous work, but apparently does not injure them to any great extent when used as a binder in a macadam road.

The sizes of stone required for bituminous pavements are the most expensive produced by a quarry, and therefore a constant guard against adulteration with undesirable sizes is necessary. Samples from shipments must therefore be regularly secured and sieved. Not infrequently it has been necessary to reject carload lots on account of the percentage of improper sizes contained in the stone. However, after a few cars have been rejected on any one job, there is seldom any more trouble in securing for the balance of the work the grade of stone required.

During the last year or two lignin binders have been used on gravel roads in considerable quantities, and several applications have been made on macadam roads. Numerous samples of these lignin binders have been tested and a set of specifications prepared to which samples must conform when purchases are made on competitive bids. The analysis of these binders is a tedious operation. They are the soluble part of certain woods used in the manufacture of paper. This soluble portion is extracted by digesting the wood with a hot alkaline solution. The insoluble fibre is separated from the solution by filtering off the latter. The solution is then concentrated to the desired degree and sold as a road preservative. It contains both mineral and organic constituents. The mineral constituents evidently are of little value for road purposes, yet are determined since they are indicative of the method of preparation and the nature of the organic ingredients present.

Testing coal.—A number of the state institutions have been purchasing coal and other supplies under sets of specifications that require these materials to conform to a given set of requirements. In this connection numerous samples of lubricating oil, grease, and coal have been sent to the laboratory by different state institutions for examination. Thirty-five or forty samples of coal have been received and tested. The sampling was done by representatives of the institutions and in some cases the methods pursued were not such as to secure samples which properly represented the shipments. That this was actually the case was conclusively shown in one instance where two samples taken from the same carload of buckwheat coal and supposed to be representative, showed a difference of approximately 5 per cent. in the amount of ash content. The samples received at the laboratory have to be crushed, quartered, and ground before any tests can be made. On account of the crowded condition of the laboratory, the preparation of these coal samples for analysis is a longer task than making the analyses themselves. Unless the coal is properly sampled at the beginning and quartered down to a small quantity which shall be truly representative of the entire shipment, further work in the laboratory in grinding and analyzing the material is a waste of time and money, since the results obtained are not representative, and any payment for the coal based on the analysis of such samples may do injustice either to the buyer or to the seller. If the road work increases as seems probable, and no better facilities for the laboratory can be provided, it will not be possible to continue these coal analyses for the state institutions.

Preparation of specifications.—Mr. Gage is frequently called upon to prepare or correct specifications for bituminous materials and pavements. Many of these are for specific contracts for county work done with the aid of the motor-vehicle money. The specifications are generally drawn to meet some particular condition and have to be gone over very carefully. While this work has consumed considerable time, it is really as important as testing the materials themselves, for unless the qualifications imposed and the tests prescribed in the specifications are such as to insure high-grade materials, nothing is gained by making the analysis afterwards.

In addition to preparing specifications for road materials, Mr. Gage has also, at the request of some state institutions, prepared specifications for lubricating oil, grease, illuminating oil, and gasoline. In this work it may be necessary to spend several days in experiments to determine the amount of a single ingredient which should be present.

Inspection of equipment.—Experience has demonstrated conclusively that a contractor cannot construct a good pavement without proper equipment. During the past season the State Commissioner of Public Roads has withheld his approval from contracts, especially those relating to bituminous pavements, until the equipment which the contracor had or intended to use had been inspected and found satisfactory. This inspection, so far as it relates to the equipment used in mixing or applying the bituminous and other binders, is usually made by Mr. Gage in company with the Division and Resident Engineers in charge of the work. When a contractor begins to lay a pavement, Mr. Gage again inspects the equipment and the initial output of the plant. Samples are taken and tested at once in order to correct immediately any defects in the composition of the paving mixture or the manner in which it is to be laid. The local inspector is then instructed what materials to sample and the proper method to follow in taking samples. He is also told what phases in the preparation and laying of the pavement will demand his closest attention. Experience has shown that it is far better to help the contractor at the initial stages of the work to prepare his material and lay the pavement properly, than to condemn later a pavement which is deficient, and to require it to be relaid. Unnecessary delays and much trouble are thus avoided.

Filing records.—A filing system has been installed which will enable us to have a record of all samples tested so that the analyses can be easily and quickly located at any time in the future. Requests by long distance telephone are frequently received for results of certain tests. It is therefore important that these data be in such a shape that the results can be secured without delay.

Lack of room.—The laboratory is located in the same building occupied by it for over ten years. As stated in previous reports, this building was never intended for this use and has few if any of the modern improvements possessed by buildings constructed for laboratory purposes. The inconveniences and disadvantages under which all work has been done for several years gradually become more pronounced and objectionable as the amount of work increases. A point has now been reached where it is almost impossible to do any greater quantity of work than that which has been done during the past year. It has already been necessary to limit the tests of road materials to those of certain grades and types, although in the interest of good work all materials should be tested. The department now has most of the apparatus needed to test the materials used in road construction, yet it is impossible to use this apparatus advantageously through lack of the necessary floor space in which to install some of it.

Portland cement now enters largely into the constructution of roads, both in the concrete foundations and in the surface layer. Concrete, into which Portland cement enters so largely, has almost entirely replaced stone in bridge foundations. The absolute necessity for applying the standard tests to all Portland cement used on important work is recognized by every engineer. The tests are not difficult, but they take time, and certain forms of apparatus are necessary. They cannot be performed in a laboratory every corner of which is full of apparatus for other lines of work.

The need of an enlarged and properly designed laboratory cannot be over-emphasized.

SOIL SURVEY.

The study and mapping of the soils of the State has continued in coöperation with the Bureau of Soils at Washington, D. C., and the State Agricultural Experiment Station at New Brunswick.

Area surveyed.—During the season of 1914 work has been carried on in the region covered by the State Survey atlas sheet 31. This area includes Camden County, the eastern part of Salem County, the eastern two-thirds of Gloucester, and the western portions of Atlantic and Burlington counties. It lies between parallels 39° 60″ and 39° 32″ north latitude, and between meridians 74° 46″ and 75° 12″ west longitude. The northern boundary passes a little to the south of Cinnaminson, the southern boundary is just a little to the south of Newfield, the eastern line is about 2 miles east of Mount Holly, and the western line 3½ miles west of Woodbury. The area measures 700 square miles, of which about 310 square miles were mapped in detail up to November 1, 1914.

The field party consisted of A. L. Fatrick, of the Bureau of Soils, Washington, D. C., in charge; C. C. Engle, of the State Geological Survey; and L. L. Lee, of the State Agricultural Experiment Station, New Brunswick. Mr. Patrick commenced work early in June, Mr. Engle in July, while Mr. Lee was with the party from the end of June to September 12. Work was still in progress at the close of the fiscal year.

Purpose of the soil survey.—The purpose of a soil survey is to map, classify, and correlate soils, to determine and describe their field characteristics, to report on the actual use being made of the soils and their adaptation to various crops so far as can be determined, and upon the relative productiveness of the several soil types. Its primary function is to accumulate and make available knowledge concerning the soil, the soil's relation to crops, and the actual agricultural conditions obtaining on the soils of the region surveyed.

Methods of work.—The soil survey may comprise three distinct functions: first, the making of a base map; second, the identification of the different soil units within the area surveyed; third, the delineation of the boundary lines separating these soil units upon the base map. In regions where reliable base maps are to be had, as is the case in New Jersey, the soil survey embraces only the two last-named functions.

The identification of the soil types in a specific area is based upon the general character of the soil and subsoil material, the general character of the topography and the physiographic situation, the source and derivation of the material, and the agencies through which the material has been accumulated. Certain characteristics of the soil must be determined in the field.

In the work of identifying soils, it is necessary to examine the material from the surface downward through a vertical section of from 3 to 6 feet. This examination is usually made with a 1½-inch wood auger welded to the desired length of pipe with a T-shaped handle bar. On pulling the auger out after boring to a depth of two or three inches, a section of the soil material is obtained in much the same condition as it existed when in place. By repeated borings the desired depth of 3 feet or more is reached.

To ascertain the character of, and variations in, the material from the surface downward, it is necessary to bore only a few inches at a time—not to exceed 6 inches in even the lighter soils, in order that important changes of color may not be overlooked. The number of borings that must be made in any given area depends upon the complexity of the soils of the area.

Color.—In identifying soils, color is of prime importance, since it is not only one of the most conspicuous features, but it reflects physiological and chemical differences, as in the amount of organic matter and of minerals which are, or may be made, of determining agricultural importance. Color as used in classifying and describing soils does not refer merely to the surface coloration, but to the color of the soil as deep as it extends, and of the subsoil to a depth of 3 feet or more. The principal soil colors are white, black, red, yellow, gray, and brown, with shades and variations produced by different combinations, particularly of yellow and red.

Texture.—By texture is meant the size of the particles of which the soil and subsoil are composed, and the proportions in which they are present. Soil particles have been divided into the following classes on the basis of their size: Fine gravel, coarse sand, sand, fine sand, very fine sand, silt, and clay. The texture of the soil is determined by the relative proportions of each of these sizes in the soil. In the field it is judged by rubbing small samples between the thumb and finger or in the palm of the hand. The range of texture arbitrarily adopted in soil-survey work divides the material into twelve classes, viz.: coarse sand, sand, fine sand, very fine sand, sandy loam, fine sandy loam, loam, silt loam, sandy clay, clay loam, silty clay loam, and clay. These are dependent on the various admixtures of the different grades of sand with silt and clay, and are determined accurately and finally by mechanical analyses in the laboratory.

Structure.—The structure of the soil and subsoil has a very marked influence on the ease of cultivation, the requirements of tillage operations, and also upon the water-holding capacity and drainage of the soil. It is important, therefore, that a field man note whether the material is loose and porous, or compact and impervious; if a clay, whether it is friable, plastic, or stiff; in the case of a sand, whether it is loose and incoherent, or whether it is relatively tight. A silt loam may present the appearance of floury material, or it may have an exceedingly compact and impervious structure. Some soils may exhibit a stickiness which causes them to adhere to the auger or to the hand, or they may be of a more powdery nature. Soils derived from highly micaceous rocks exhibit a smooth, greasy feel when rubbed between the fingers, a quality due to the presence of a mass of exceedingly fine mica flakes. All such structural peculiarities associated with the soil material may have an important bearing upon the economic use of the soil.

The variations noted may occur not only at the surface, but at different points in the soil profile, the subsoil frequently being tighter and more impervious than the soil, a difference which must be taken into account in determining the agricultural value of the soil.

Drainage.—A study of the soil material includes the relation of the material to drainage. Lack of drainage is usually apparent upon boring in the soil from the excess of moisture and water encountered, but in this connection, consideration must be given to the climatic conditions which have prevailed at the time of the survey.

Marked chemical or mineralogical features.—Not infrequently soils show some marked chemical or mineralogical features. The occurrence of highly ferruginous material, either distributed through the soil or in the form of concretions on or near the surface, or the occurrence of the green mineral glauconite, may be of importance. The presence of unusual amounts of iron or titanium materials; of mica, quartz, or feldspar; of gypsum, or iron pyrites; or the occurrence of alkali salts, must be noted. The presence of considerable calcium carbonate, or of marked acid conditions must not be overlooked, since all such marked chemical or mineralogical features unquestionably may have important agricultural bearings.

Soil series and types.—The division of soils into various series is determined by the range of color of surface soils and subsoils, the relative character of the subsoil materials, particularly as regards structure, the character of the relief and drainage, and the origin of the material—whether it is material derived from the disintegration of sandstone, shale, etc., or has been deposited by moving water, or has been accumulated by moving ice, or through wind transportation and deposition. A soil series, therefore, represents material possessing a uniformity in general character, origin, and mode of formation, but of different texture. A series is usually designated by the name of the locality where first encountered and classified.

The variation in texture of the soils comprising a series gives rise to a further arbitrary classification into 12 soil types, as coarse sand, sand, loam, etc., and it is important that these types be correctly determined in order that the agricultural value and special adaptations of the soil in any particular area may be ascertained.

Soil mapping.—In preparing a soil map, the areas indicating the different soil types are located with reference to cultural features, such as land lines, roads, railroads, and houses, and to topographic and physiographic features, such as hills, valleys, and streams. These areas are outlined and lightly colored, and are numbered, the same color and number being used for the same soil type wherever it occurs in the area, as well as upon a block in the legend on the map. Where differences are noted which are not sufficient to justify a new series, such as a slight difference in the character of material and drainage, important variations in topography and depth of soil, and important differences in the native vegetation, these are expressed in the mapping as a phase, the same color and conventional sign being used to indicate such phase.

If the change in character of material from one type to another is sharp and distinct, as is the case with any marked change in topography, the boundaries can be accurately located without difficulty, but if one type merges gradually into another, the line of separation is less easily established and frequent examinations of the soil are necessary to correctly outline the types. The smallest unit that it is practicable to show upon a map on a scale of 1 mile to an inch is 5 acres.

Soils of the Camden area[1].—In the Camden area about 400 of the 700 square miles will be mapped before the close of the field season. Ten series have been recognized and about fifty types have been mapped. This number may be slightly increased as the work is extended over the entire area. Most of these have been previously recognized in other areas of the coastal plain region. The correlation of soils of one region with those of another is regarded as one of the chief values of the survey. The important series of this area are the Sassafras, Collington, Moorestown, Elkton, Portsmouth, Taunton, and Muck.

[1] Mr. C. C. Engle is authority for the following statements regarding the soils of the Camden area.

The Sassafras series is the most important one in the area. Its lighter members, such as Sassafras sand, fine sand, and loamy fine sand, are especially adapted to early truck crops. These occur in the region of Moorestown, Camden, Gloucester to some extent, to the west of Woodbury, around Glassboro, Clayton, Williamstown and Berlin. Probably the most important type is the Sassafras fine, sandy loam. This is a moderately light fine sand loam on the surface, grading into a heavy clay to sandy clay subsoil. This type is adapted to medium early truck. The heavier members, such as the Sassafras loam and silt loam, which occur chiefly in the region of Moorestown, Camden and Merchantville, are admirably adapted to late truck and general farm crops.

The Elkton soils are found associated with the Sassafras. They occur in low, poorly-drained areas. The surface color is gray to light-brown, grading into a subsoil of a gray and yellow-mottled color which indicates its need of drainage. This type is somewhat extensive. It is adapted to the production of cabbage, potatoes, hay and grain, and for pasture. It should make a good corn soil when well drained.

The soils of the Collington series are derived from the greensand or marl-bearing formations, and by their physical and chemical constitution they are good soils. They are usually well drained and in color are brown with a greenish cast, containing varying amounts of glauconitic sand. Chief among these are Collington sand, fine sand, and sandy loam. The first two are best developed in the region of Mount Holly, Medford and Marlton. They are well adapted to sweet potatoes, peaches, asparagus and early truck. The Collington fine, sandy loam is one of the best general soils of the area and is found closely associated with the other Collington types. It is well adapted to late tomatoes, potatoes, apples, and truck crops in general. The heavier members of this series are also very well adapted to late trucking and general farm crops. Such heavier members as loam and silt loam are not very widely distributed in the area.

The Moorestown series bears the same relation to the Collington that the Elkton does to the Sassafras, namely, it is less well drained. The surface color is brown to black, containing considerable organic matter in some places. This surface color grades into a green and brown-mottled, sticky subsoil quite heavy in nature. This type is pre-eminently adapted to the production of hay. It is rather extensive in distribution.

The Portsmouth series includes those soils of the Atlantic Coastal Plain region which contain large accumulations of organic matter in the surface layers. Beneath this is usually found a white or light-colored sand. These soils occupy depressions which are more or less saturated with water. It is somewhat widespread. The most important type is the Portsmouth sandy loam, which is adapted to cabbage, tomatoes, spinach, lettuce, celery, onions, and cranberries.

The Taunton series is composed entirely of sands of the Cohansey formation. The surface of the sand is gray to white to a depth of 6 to 15 inches, underlain by a reddish-brown or brown sand. This type is largely non-agricultural.

Muck is not an extensive type but occurs in numerous small areas. It consists of black, partially decayed organic matter, ranging from 8 inches to several feet in depth. When properly drained it is adapted to cranberries, celery, spinach, carrots, parsnips, lettuce, and similar crops.

ARCHÆOLOGY.

The appropriation available for this work during 1914 was only $500, hardly enough to keep Mr. Max Schrabisch in the field for three months and allow a small honorarium for the preparation of the report. The detailed record of the season's work has not yet been prepared, but Mr. Schrabisch has submitted a preliminary report from which the following paragraphs are taken almost verbatim.

Area surveyed.—The archæological survey of Warren County under the direction of the State Geologist during the months of June, July and August, 1914, proved to be quite successful in the number of sites found. Notwithstanding the limited time and money available, nearly all of the county was covered by the investigator, the only section omitted being the southwesterly one comprising Phillipsburg and vicinity. More than 350 sites have been located as against 234 in Sussex County found during the survey of 1913. Most of these were small camp or lodge sites, *i. e.,* localities occupied only for a short time and by single families, while the more permanent sites or villages were noted only in those regions which offered special advantages both as to natural protection and facilities for hunting and fishing. Numerous rock shelters were found, but no one of them was of great size or showed traces of long occupation. Burial places, both large and small, were noted in different parts of the county, particularly along Delaware River.

Principal districts.—While aboriginal sites are scattered all over the county, with the exception of the mountainous regions such as the high slopes of Kittatinny, Jenny Jump, and Upper Pohatcong mountains, there are certain areas which have evidently been frequented far more than others. Of these there are three, namely, Paulins Kill valley between Blairstown and Walnut valley, the Delaware valley in the vicinity of Belvidere, Columbia, and Calno, and, lastly, the region around the Great Meadows. The reasons why these districts were favored are obvious in that they offered many advantages in the matter of fishing and easy communication. The last-named section was probably resorted to as winter quarters because of its sheltered position, being protected from the north winds by Jenny Jump Mountain.

Village sites.—As is but natural, most of the large sites, probably villages, were situated in the favored regions mentioned above. Altogether 25 of these were located, distributed as follows: 4 along Paulins Kill valley, 15 along the Delaware River, 2 near the Great Meadows a short distance north of Vienna, 1 at the northern end of Green Pond, 1 at the junction of Beaver Brook and Pequest River, 1 on the east bank of Beaver Brook north of Sarepta, and 1 on the west bank of Mud Run less than a mile south of Mt. Herman. These sites are believed to have been villages, since they show traces of long-continued occupation both with respect to the great variety and to the number of artifacts left behind.

Rock shelters.—Numerous rock houses were found, that is, overhanging rocks giving evidence of having been inhabited by the redmen. Of these 12 lie between Shuster Pond, near the Sussex County line, and Hainesburg, mostly among the limestone ledges flanking the Paulins Kill, and 7 are in the hilly country south of the Paulins Kill, notably in the neighborhood of Johnsonburg and Ebenezer; 2 are east of Hope, 2 at the Great Meadows, and 2 north of Pequest Furnace on Mount Mohepinoke. All of them were insignificant shelters, and were little used if we are to judge by the scarcity of remains left there. As a majority of them yielded nothing but potsherds and a few bones, they were probably so-called squaw shelters, that is, places tenanted by women only. In others only a few arrow heads were found buried in the debris along with some chips and bones, a fact bespeaking the former presence of hunters at these spots. In the matter of rock shelters, then, Warren County compares but poorly with Sussex, for of a total of 25 Indian rocks located there in 1913, 4 were of great archæological importance, and yielded a rich harvest of implements of different kinds, a fact which indicated either prolonged or frequent occupation. Nearly all of the Warren County shelters lay among the limestone ledges with water always close at hand. It may seem strange that all overhanging slate ledges which were examined—and there were at least half a dozen of these—were devoid of aboriginal remains, although in every instance near some water supply and well protected.

Burial places.—Thirteen localities were noted where Indian interments had been made, six on Delaware River, the others in the interior of the county. Probably the largest prehistoric burial ground was on the farm of the late Andrew Ribble, at Calno, in Pahaquarry Township, on the western slope of Kittatinny Mountain, about a mile east of Delaware River. This site has been known since the Civil War. Another large cemetery lay at Dunnfield, on Delaware River, but it was unknown until the year 1882, when the New York, Susquehanna and Western Railroad was built. In laying the tracks through a sand bank many bones, with fragments of pottery and other relics, were laid bare. A third cemetery was at Delaware, on a low hill east of the river. A single grave was discovered at Shoemaker's Ferry, on Delaware River, in 1912. During the flood of October, 1903, bones and various prehistoric objects were washed out of the bank at a point where Stony Brook empties into Delaware River. Many years ago, when the cliffs which rise abruptly from the river between Columbia and Delaware were being blasted to make room for the railroad tracks, many Indian bones were blown out of a fissure where they had lain for ages, deeply buried.

The following information has been obtained regarding Indian remains in other parts of the county: an aboriginal cemetery south of Catfish Pond, a few hundred yards up the slope of Kittatinny Mountain; one a short distance north of Walnut Valley on a sandy upland field not far from a prehistoric camp site; another on the top of Jenny Jump Mountain near a line between Sarepta and Green Pond. Human remains of undoubted Indian origin were accidentally discovered under a large flat rock near a limestone kiln between Shuster Pond and the Paulins Kill. Indian bones were found many years ago on the west bank of Pequest River, about 1 mile south of Danville. A single skull was discovered near Kalarama about 1882, lying in a cleft amid a heap of limestone bowlders. Another skull was dug up north of Pequest Furnace, on George Wildrick's farm, along with 12 stone hatchets. The skull and hatchets are now owned by Dr. Hoagland, of Oxford Furnace.

Trails.—From a study of the distribution of sites and the topography of the county, some clue may be obtained with respect to the probable location of prehistoric highways. Thus, it may be assumed that a trail skirted Delaware River from Belvidere to Calno, connecting the numerous fishing places along this water course. Again, it is probable that a trail followed the banks of Paulins Kill between Marksboro and Columbia. Since most of the sites hereabouts are on the north bank of the stream, where the land is more level and accessible, the presumption may be justified that this trail lay for the most part on the north bank, if, indeed, there was not a trail on both sides of it. A trail is believed to have crossed Kittatinny Mountain somewhere between Calno and Catfish Pond, and thence to Jacksonburg and Kalarama. Another probably flanked the western slope of Jenny Jump Mountain, circling it both north and south. There are indications that a trail crossed this mountain southeast of Shiloh in the direction of the Great Meadows. It is quite sure that another wound around the Great Meadows, connecting the numerous camp sites in that vicinity. Moreover, a trail probably passed through the Pequest Valley and another through that of the Musconetcong. The distribution of sites seems to indicate this.

Raw Material.—The aborigines of Warren County made use of every available kind of material suitable for the manufacture of their stone tools. Good raw material is plentiful over all the county and there was no lack of flint and chert, the minerals that could best be worked into knives, scrapers, spearheads and arrow points. In addition to these, jasper, quartz, slate, hematite, and crystalline limestone could be secured without much difficulty. As flint and chert were most commonly used, it was necessary for the Indian always to have an ample supply of these highly prized minerals at hand or to know where to get them. Several localities have been noted where they abound. The country north of Blairstown, and that between Hope and Shiloh is underlain by beds of limestone, many of which contain masses of chert and flint. As the limestone weathers, the less-soluble masses of chert and flint are left in the soil. Much flint was noticed in the section of country around the Great Meadows and in the vicinity of Johnsonburg, but above all at the eastern base of Mount Mohepinoke, half way between Townsbury and Pequest Furnace. It would seem, in fact, that the Indians quarried much of it at this spot, since for many years rejects, broken points, and split fragments of raw material were scattered about the base of the ledges in such numbers as strongly to suggest the site of an aboriginal quarry. Jasper, of which material many of their finest arrow points and other tools were fashioned, may have been quarried at the northwestern slope of Scott's Mountain, south of Belvidere, where this mineral occurs in sufficient quantities.

Publications.

The appended list makes brief mention of all the publications of the present Survey since its inception in 1864, with a statement of the editions now out of print. Most reports of the Survey are distributed without further expense than that of transportation. Single reports can usually be sent more cheaply by *mail* than otherwise, and requests should be accompanied by the proper postage, which is now determined by parcel post rates. The amounts given in the following lists apply to all points in the first and second zones from Trenton, which include all parts of New Jersey. Applications from more distant points should be accompanied by the proper amount of postage, based upon distance from Trenton. If not so accompanied, reports may be sent *express collect. When the stock on hand of any report is reduced to 200 copies, the remaining volumes are withdrawn from free distribution and are sold at cost price.*

The maps are distributed only by sale, at a price of 25 cents per sheet, to cover cost of paper, printing and transportation. In order to secure prompt attention, requests for both reports and maps should be addressed simply "State Geologist," Trenton, N. J.

CATALOGUE OF PUBLICATIONS.

GEOLOGY OF NEW JERSEY. Newark; 1868, 8 vo., xxiv+899 pp. Out of print.

PORTFOLIO OF MAPS accompanying the same, as follows:

1. Azoic and paleozoic formations, including the iron-ore and limestone districts; colored. Scale, 2 miles to an inch.
2. Triassic formation, including the red sandstone and trap-rocks of Central New Jersey; colored. Scale, 2 miles to an inch.
3. Cretaceous formation, including the greensand marl beds; colored. Scale, 2 miles to an inch.
4. Tertiary and recent formations of Southern New Jersey; colored. Scale, 2 miles to an inch.
5. Map of a group of iron mines in Morris County; printed in two colors. Scale, 3 inches to 1 mile.
6. Map of the Ringwood iron mines; printed in two colors. Scale, 8 inches to 1 mile.
7. Map of Oxford Furnace iron-ore veins; colored. Scale, 8 inches to 1 mile.
8. Map of the zinc mines, Sussex County; colored. Scale, 8 inches to 1 mile.

A few copies can be distributed at $2.00 per set.

REPORT ON THE CLAY DEPOSITS of Woodbridge, South Amboy and other places in New Jersey, together with their uses for firebrick, pottery, etc. Trenton, 1878, 8vo., viii+381 pp., with map. Out of print.

A PRELIMINARY CATALOGUE OF the Flora of New Jersey, compiled by N. L. Britton, Ph.D. New Brunswick, 1881, 8vo., xi+233 pp. Out of print.

FINAL REPORT OF THE STATE GEOLOGIST. Vol. I. Topography. Magnetism. Climate. Trenton, 1888, 8vo., xi+439, pp. Out of print.

FINAL REPORT OF THE STATE GEOLOGIST. Vol. II. Part I. Mineralogy. Botany. Trenton, 1889, 8vo., x+642 pp. Unbound copies, postage, 8 cents. Bound copies $1.50.

FINAL REPORT OF THE STATE GEOLOGIST. Vol. II. Part II. Zoology. Trenton, 1890, 8vo., x+824 pp. (Postage, 8 cents.)

REPORT ON WATER-SUPPLY. Vol. III. of the Final Reports of the State Geologist. Trenton, 1894, 8vo., xvi+352 and 96 pp. (Postage, 7 cents.)

REPORT ON THE PHYSICAL GEOGRAPHY of New Jersey. Vol. IV. of the Final Reports of the State Geologist. Trenton, 1898, 8vo., xvi+170+200 pp. Unbound copies, $1.00; cloth bound, $1.35, with photo-relief map of State, $2.85. Map separate, $1.50.

REPORT ON THE GLACIAL GEOLOGY of New Jersey. Vol. V. of the Final Reports of the State Geologist. Trenton, 1902, 8vo., xxvii+802 pp. (Postage, 9 cents.)

REPORT ON CLAYS AND CLAY INDUSTRY of New Jersey. Vol. VI. of the Final Reports of the State Geologist. Trenton, 1904, 8vo., xxviii+548 pp. (Price, $1.60.)

REPORTS ON IRON MINES AND MINING in New Jersey. Vol. VII. of the Final Reports of the State Geologist. Trenton, 1910, 8vo., xv+512 pp., with two maps in a separate envelope. (Postage, 8 cents.)

BRACHIOPODA AND LAMELLIBRANCHIATA of the Raritan Clays and Greensand Marls of New Jersey. Trenton, 1886, quarto, pp. 338, plates, XXXV. and map. (Paleontology, Vol. I.) (To residents of New Jersey, postage 10 cents; to non-residents, $1.50, charges prepaid.)

GASTEROPODA AND CEPHALOPODA of the Raritan Clays and Greensand Marls of New Jersey. Trenton, 1892, quarto, pp. 402, Plates L. (Paleontology, Vol. II.) (To residents of New Jersey, postage, 10 cents; to non-residents, $1.40, charges prepaid.)

PALEOZOIC PALEONTOLOGY. Trenton, 1903, 8vo., xii+462 pp., Plates LIII. (Paleontology, Vol. III.) (Price, $1,00.)

CRETACEOUS PALEONTOLOGY. Trenton, 1907, 8vo., ix+1106 pp., Plates CXI. (Paleontology, Vol. IV.) (Price, $2.70.)

ANNUAL REPORTS.

REPORT OF PROFESSOR GEORGE H. COOK upon the Geological Survey of New Jersey and its progress during the year 1863. Trenton, 1864, 8vo., 13 pp. Out of print.

THE ANNUAL REPORT of Prof. Geo. H. Cook, State Geologist, to his Excellency Joel Parker, President of the Board of Managers of the Geological Survey of New Jersey, for the year 1864. Trenton, 1865, 8vo., 24 pp. Out of print.

ANNUAL REPORT of Prof. Geo. H. Cook, State Geologist, to his Excellency Joel Parker, President of the Board of Managers of the Geological Survey of New Jersey, for the year 1865. Trenton, 1866, 8vo., 12 pp. Out of print.

ANNUAL REPORT of Prof. Geo. H. Cook, State Geologist, on the Geological Survey of New Jersey, for the year 1866. Trenton, 1867, 8vo., 28 pp. Out of print.

REPORT OF THE STATE GEOLOGIST, Prof. Geo. H. Cook, for the year 1867. Trenton, 1868, 8vo., 28 pp. Out of print.

ANNUAL REPORT of the State Geologist of N. J. for 1869. Trenton, 1870, 8vo., 57 pp., with maps. Out of print.

ANNUAL REPORT of the State Geologist of N. J. for 1870. New Brunswick, 1871, 8vo., 75 pp., with maps. Out of print.

ANNUAL REPORT of the State Geologist of N. J. for 1871. New Brunswick, 1872, 8vo., 46 pp., with maps. Out of print.

ANNUAL REPORT of the State Geologist of N. J. for 1872. Trenton, 1872, 8vo., 44 pp., with map. Out of print.

ANNUAL REPORT of the State Geologist of N. J. for 1873. Trenton, 1874, 8vo., 128 pp., with maps. Out of print.

ANNUAL REPORT of the State Geologist of N. J. for 1874. Trenton, 1874, 8vo., 115 pp. Out of print.

ANNUAL REPORT of the State Geologist of N. J. for 1875. Trenton, 1875, 8vo., 41 pp., with map. Out of print.

ANNUAL REPORT of the State Geologist of N. J. for 1876. Trenton, 1876, 8vo., 56 pp., with maps. Out of print.

ANNUAL REPORT of the State Geologist of N. J. for 1877. Trenton, 1877, 8vo. 55 pp. Out of print.

ANNUAL REPORT of the State Geologist of N. J. for 1878. Trenton, 1878, 8vo., 131 pp., with map. Out of print.

ANNUAL REPORT of the State Geologist of N. J. for 1879. Trenton, 1879, 8vo., 199 pp., with maps. Out of print.

ANNUAL REPORT of the State Geologist of N. J. for 1880. Trenton, 1880, 8vo., 220 pp., with map. Out of print.

ANNUAL REPORT of the State Geologist of N. J. for 1881. Trenton, 1881, 8vo., 87+107+xiv pp., with maps. Out of print.

ANNUAL REPORT of the State Geologist of N. J. for 1882. Camden, 1882, 8vo., 191 pp., with maps. Out of print.

ANNUAL REPORT of the State Geologist of N. J. for 1883. Camden, 1883, 8vo., 188 pp. (Price, 50 cents.)

ANNUAL REPORT of the State Geologist of N. J. for 1884. Trenton, 1884, 8vo., 168 pp., with maps. (Postage, 5 cents.)

ANNUAL REPORT of the State Geologist of N. J. for 1885. Trenton, 1885, 8vo., 228 pp., with maps. (Postage, 6 cents.)

ANNUAL REPORT of the State Geologist of N. J. for 1886. Trenton, 1887, 8vo., 254 pp., with maps. (Postage, 6 cents.)

ANNUAL REPORT of the State Geologist of N. J. for 1887. Trenton, 1887, 8vo., 45 pp., with maps. (Postage, 5 cents.)

ANNUAL REPORT of the State Geologist of N. J. for 1888. Camden, 1889, 8vo., 87 pp., with map. (Postage, 5 cents.)

ANNUAL REPORT of the State Geologist of N. J. for 1889. Camden, 1889, 8vo., 112 pp., (Postage, 6 cents.)

ANNUAL REPORT of the State Geologist of N. J. for 1890. Trenton, 1891, 8vo., 305 pp., with maps. (Postage, 6 cents.)

ANNUAL REPORT of the State Geologist of N. J. for 1891. Trenton, 1892, 8vo., xii+270 pp., with maps. Out of print.
ANNUAL REPORT of the State Geologist of N. J. for 1892. Trenton, 1893, 8vo., x+368 pp., with maps. (Price, $1.55.)
ANNUAL REPORT of the State Geologist of N. J. for 1893. Trenton, 1894, 8vo., x+452 pp., with maps. (Postage, 7 cents.)
ANNUAL REPORT of the State Geologist of N. J. for 1894. Trenton, 1895, 8vo., x+304 pp., with geological map. (Postage, 6 cents.)
ANNUAL REPORT of the State Geologist of N. J. for 1895. Trenton, 1896, 8vo., xl+198 pp., with geological map. (Postage, 5 cents.)
ANNUAL REPORT of the State Geologist of N. J. for 1896. Trenton, 1897, 8vo., xxviii+377 pp., with map of Hackensack meadows. (Postage, 6 cents.)
ANNUAL REPORT of the State Geologist of N. J. for 1897. Trenton, 1898, 8vo., xl+368 pp. (Postage, 6 cents.)
ANNUAL REPORT of the State Geologist for 1898. Trenton, 1899, 8vo., xxxii+244 pp., with Appendix, 102 pp. (Postage, 6 cents.)
ANNUAL REPORT of the State Geologist for 1899 and REPORT ON FORESTS. Trenton, 1900, 2 vols., 8vo., Annual Report, xliii+192 pp. FORESTS, xvi+327 pp., with seven maps in a roll. (Postage, 5 and 7 cents.)
ANNUAL REPORT of the State Geologist for 1900. Trenton, 1901, 8vo., xl+231 pp. (Postage, 6 cents.)
ANNUAL REPORT of the State Geologist for 1901. Trenton, 1902, 8vo., xxviii+178 pp., with one map in pocket. (Postage, 6 cents.)
ANNUAL REPORT of the State Geologist for 1902. Trenton, 1903, 8vo., viii+155 pp. (Postage, 5 cents.)
ANNUAL REPORT of the State Geologist for 1903. Trenton, 1904, 8vo., xxxvi+132 pp., with two maps in pocket. (Price, 40 cents.)
ANNUAL REPORT of the State Geologist for 1904. Trenton, 1905, 8vo., x+317 pp. (Postage, 6 cents.)
ANNUAL REPORT of the State Geologist for 1905. Trenton, 1906, 8vo., x+338 pp., with three maps in a pocket. (Price, 55 cents.)
ANNUAL REPORT of the State Geologist for 1906. Trenton, 1907, 8vo., vii+192 pp. (Postage, 6 cents.)
ANNUAL REPORT of the State Geologist for 1907. Trenton, 1908, 8vo., ix+192 pp. (Postage, 6 cents.)
ANNUAL REPORT of the State Geologist for 1908. Trenton, 1909, 8vo., xi+159 pp. (Postage, 5 cents.)
ANNUAL REPORT of the State Geologist for 1909. Trenton, 1910, 8vo., vii+123 pp. (Postage, 5 cents.)

BULLETINS.

In 1910 the series of Annual Reports was replaced by a series of Bulletins, each being a separate report upon some subject. Up to date fifteen Bulletins have been issued.
BULLETIN 1.—Administrative Report of the State Geologist of New Jersey for 1910. Trenton, 1911, 43 pp. (Out of print.)
BULLETIN 2.—A report on the Approximate Cost of a Canal between Bay Head and the Shrewsbury River, by H. B. Kümmel. Trenton, 1911, 20 pp., 1 map. (Out of print.)
BULLETIN 3.—The Flora of the Raritan Formation, by Edward W. Berry. Trenton, 1911, v+233 pp. and xxix plates.
BULLETIN 4.—A Description of Fossil Fish Remains of the Cretaceous, Eocene and Miocene Formations of New Jersey, by Henry W. Fowler. Trenton, 1911, 192 pp.
BULLETIN 5.—The Mineral Industry of New Jersey for 1910, by H. B. Kümmel and S. Percy Jones. Trenton, 1911, 24 pp. (Out of print.)
BULLETIN 6.—Administrative Report of the State Geologist for 1911, including a report on Shark River Inlet by C. C. Vermeule. Trenton, 1912, 82 pp. and iv plates.
BULLETIN 7.—The Mineral Industry of New Jersey for 1911, by Henry B. Kümmel. Trenton, 1912, 37 pp.
BULLETIN 8.—Administrative Report of the State Geologist for 1912, including a second report on Shark River Inlet by C. C. Vermeule, Consulting Engineer, and a List of New Bench Marks. Trenton, 1913, 8vo., 102 pp.
BULLETIN 9.—A Preliminary Report of the Archæological Survey of the State of New Jersey, made by the Department of Anthropology in the American Museum of Natural History, Clark Wissler, Ph.D., Curator, under the direction of the State Geological Survey. Compiled by Alanson Skinner and Max Schrabisch. Trenton, 1913, 8vo., 94 pp. one map.
BULLETIN 10.—(In co-operation with the New Jersey State Agricultural Experiment Station). The Mechanical and Chemical Composition of the Soils of the Sussex Area, New Jersey, by A. W. Blair and Henry Jennings. The Analysis of Soils—Methods Used, by R. B. Gage. Trenton, 1913, 8vo., 110 pp., two plates.
BULLETIN 11.—The Mineral Industry of New Jersey for 1912, by M. W. Twitchell. Trenton, 1913, 8vo., 43 pp., one map.
BULLETIN 12.—Administrative Report of the State Geologist for 1913. Including a report on Recent Storm Effects on the Northern New Jersey Shoreline and their Supposed Relation to Coastal Subsidence, by Douglas W. Johnson and Warren S. Smith. Union Hill, 1914, 8vo., 51 pp.
BULLETIN 13.—Indian Habitations in Sussex County, New Jersey, by Max Schrabisch. Indian Remains near Plainfield, Union County, and along the Lower Delaware Valley, by Leslie Spier. Union Hill, 1915, 8vo., 99 p.

BULLETIN 14.—The Geology of New Jersey. A summary to accompany the Geological Map (1910–1912) on the scale of 1: 250,000, or approximately 4 miles to 1 inch. By J. Volney Lewis and Henry B. Kümmel. Union Hill, 1915, 8vo., 146 pp. two plates.

BULLETIN 15.—The Mineral Industry of New Jersey for 1913, by M. W. Twitchell. Union Hill, 1915, 8vo., 46 pp.

TOPOGRAPHIC MAPS.

ATLAS OF NEW JERSEY. The complete work is made up of seventeen sheets, each about 27 by 37 inches, including margin, on a scale of one inch per mile. They are numbered from 21 to 37, and have been extensively revised before publication. These sheets each cover the same territory as eight of the large maps, on a scale of 2,000 feet per inch, described under "Topographic Maps, New Series".

No. 21. Kittatinny Valley and Mountain, from Delaware Water Gap to Culver's Lake.
No. 22. Eastern Sussex and Western Passaic counties.
No. 23. Northern Bergen and Eastern Passaic counties. To West Point, New York.
No. 24. Southern Warren, Northern Hunterdon and Western Morris counties.
No. 25. Morris and Somerset counties, from Lake Hopatcong to Somerville and New Brunswick.
No. 26. Vicinity of Newark and Jersey City. Paterson to Perth Amboy.
No. 27. Vicinity of Trenton. Raven Rock to Palmyra, with inset Trenton to Princeton.
No. 28. Trenton and Eastward. Trenton to Sayreville and New Egypt.
No. 29. Monmouth Shore, with interior from Matawan to Lakehurst.
No. 30. Parts of Gloucester and Salem counties from Paulsboro on the north, to Quinton and Deerfield on the south, with adjacent portions of Pennsylvania and Delaware.
No. 31. Vicinity of Camden to Mount Holly, Hammonton and Elmer.
No. 32. Part of Burlington and Ocean counties, from Pemberton and Whitings to Egg Harbor City and Tuckerton.
No. 33. Vicinity of Barnegat Bay, eastern part of Ocean county.
No. 34. Western Cumberland county, including Bridgeton, with Delaware Bay and adjacent portion of Delaware.
No. 35. Vicinity of Millville, from Newfield to Port Norris and Cape May Court House.
No. 36. Parts of Atlantic and Cape May counties, Egg Harbor City to Townsend's Inlet, with inset of New Inlet and Great Bay.
No. 37. Cape May. Cape May City to Ocean City and Mauricetown.

All these maps are sold at the uniform price of 25 cents per sheet. In lots of 50 or more a wholesale price of 18 cents is made. Since the Survey cannot open small accounts, and the charge is merely nominal, remittance should be made with the order. Order by *number* of the State Geologist, Trenton, N. J. A key map showing distribution of these sheets will be sent upon request.

TOPOGRAPHIC MAPS, NEW SERIES.

These maps are the result of revision of the earlier surveys, and contain practically all of the features of the one-inch per mile maps, with much new material. They are published on a scale of 2,000 feet to an inch, and the sheets measure 26 by 34 inches. The Hackensack, Paterson, Boonton, Dover, Jersey City, Newark, Morristown, Chester, New York Bay, Elizabeth, Plainfield, Pluckemin, Amboy, New Brunswick, Somerville, Navesink, Long Branch, Shark River, Trenton, Camden, Mount Holly, Woodbury, Taunton and Atlantic City sheets have been published and are now on sale. The price is 25 cents per sheet, *payable in advance.* In lots of 50 or more, a wholesale price of 18 cents is made. Order by *name* any of the sheets above indicated as ready, of the State Geologist, Trenton, New Jersey. A key map showing distribution of these sheets will be sent upon request.

NEW STATE GEOLOGIC MAP.

This map shows in colors the location of the different varieties of rock, clay, sand, etc., within the State and the various periods of geologic history to which they belong. By means of eighteen colors and various patterns of dots and lines, fifty-seven different rock formations are distinctly represented and their location shown. The scale (about 4 miles to an inch) is sufficiently large to permit considerable detail, while the size of the map (2 feet by 4 feet) is not so large as to be unwieldy. The compilation was by Prof. J. Volney Lewis, of Rutgers College, and Dr. H. B. Kümmel, State Geologist, from published folios and manuscript data in the possession of the Survey.

Bulletin 14 gives a summary description of the geology of New Jersey as shown on this map. Copies of the map can be obtained of the State Geologist, Trenton, N. J., on payment of 50 cents, *remittance to accompany order.*

GEOLOGIC ATLAS OF NEW JERSEY.

The State Geological Survey, in co-operation with the U. S. Geological Survey, is engaged in the publication of a Geologic Atlas of New Jersey. It will be issued in several parts, each part containing a complete discussion of the geography and geology for the region covered. Each volume will comprise (1) pages of descriptive text, (2) a topographic map, (3) geologic maps showing the distribution and structure of the various rock formations, the occurrence of all mineral deposits of economic importance, and (4) in some cases pages of half-tone illustrations. The following folios are now ready:

THE PASSAIC FOLIO, which covers the region from Morristown to Jersey City, and from Perth Amboy and New Brunswick to Pompton and Westwood, comprising 945 square miles; scale, 2 miles to an inch. It includes 27 pages of text, a topographic map, 3 geologic maps and a page of illustrations. Price, 25 cents; postage, 6 cents; if sent by express, charges collect.

THE FRANKLIN FOLIO covers the territory from Branchville and Newton, on the west, to Stockholm on the east, and from Andover and Petersburg, on the south, to Libertyville on the north, or 235 square miles; scale, 1 inch to a mile. In addition to the regular text and maps it includes a special study and description of the famous zinc deposits at Franklin Furnace, and of the white crystalline limestones. Price, 25 cents; postage, 6 cents extra; if sent by express, charges collect.

THE PHILADELPHIA FOLIO covers parts of New Jersey and Pennsylvania adjacent to Philadelphia. It is a double folio (scale, 1 inch per mile), having four topographic maps, four geologic maps, two maps showing, by means of cross sections, the geological structure and the relation of the various rock formations to each other below the surface, a page of illustrations and twenty-four pages of descriptive text. Price, 50 cents; postage, 6 cents extra; if sent by express, charges collect.

THE TRENTON FOLIO describes the region around Trenton as far as Stockton, Millstone, Hightstown, New Egypt, Mount Holly, Delanco and Newtown, Pa., an area of 911 square miles. It contains descriptive text and three maps (scale, 2 miles per inch). It is published in two forms, the folio size (21¾ by 18½ inches) and a pocket or octavo size (9¼ by 6 inches). In the latter the maps are on thin paper, are folded and in a pocket. This size is more convenient for field use than the folio size. Price, folio edition, 25 cents, postage, 6 cents extra; pocket edition, with same maps and text, 50 cents, postage, 10 cents extra. If sent by express, charges collect.

THE RARITAN FOLIO is descriptive of the section extending from Blairstown and Andover on the north to Flemington and Millstone on the south, and from Bound Brook on the east to Washington on the west, an area of 905 square miles. In addition to numerous text illustrations, it contains one topographic and four geologic maps (scale, 2 miles per inch). It is published in both folio and octavo size. Price: Folio edition, 25 cents, postage, 6 cents extra; pocket edition, 50 cents, postage, 6 cents extra; if sent by express, charges collect.

Origin of the Secondary Minerals of the Triassic Trap Rocks

BY J. VOLNEY LEWIS.

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INTRODUCTION.

The beautifully crystalline minerals that occur so abundantly in many of the trap quarries of the State and in some of the railroad cuts and tunnels that penetrate Bergen Hill and the Palisades have long been known to mineralogists and collectors, both in this country and in Europe. It has been commonly assumed that these minerals were formed by the action of ground water upon the inclosing trap rocks through the solution of some of the constituent minerals, particularly the feldspars, and their recrystallization in combination with water in the wonderful series of the zeolites. The investigation of this question of origin that has been made for the Geological Survey, however, has led to different conclusions, the more important of which are summarized here, pending the completion of the report for separate publication.

THE PRIMARY MINERALS.

The Triassic, or Newark, trap rocks of New Jersey, both the intrusive variety (diabase) and the extrusive lava flows (basalt), consist chiefly of an intimate mixture of the minerals pyroxene and plagioclase feldspar. The pyroxene is near diopside in composition, and the feldspar is chiefly an andesine-labradorite near ab_1an_1 in composition. In addition to these principal constituents, the more basic facies of the rocks everywhere contain olivine and biotite, while the acidic portions have quartz and orthoclase, chiefly in pegmatitic intergrowth. Grains of magnetite and pyrite and minute crystals of apatite are scattered throughout the rocks, chalcopyrite has been often observed, and rutile has been found near contacts and inclusions of sedimentary rocks.

THE SECONDARY MINERALS.

Kinds.—The secondary minerals that occur in the fissures and other openings of the trap rocks, omitting products of weathering and metamorphism, are arranged in the following list in the approximate order of frequency; that is, the minerals that are most widely distributed, though not necessarily the most abundant, are named first, while those toward the end of the list have been found at but few localities. Some of these, however, are found in greater abundance than others that are named before them. The list includes 60 minerals, not counting varieties:[1] Calcite (including manganocalcite), quartz (including agate, amethyst, jasper, and chalcedony), chlorite, prehnite, chalcopyrite, pyrite, natrolite, stilbite, datolite pectolite (including manganpectolite), heulandite, apophyllite, analcite, epidote, chrysocolla, galena, laumontite, albite, hematite (specular), opal (including hyalite), orthoclase, chalcocite, copper, cuprite, sphalerite, dolomite, scolecite, tourmaline, actinolite, asbestos (including mountain cork), barite, silver, gmelinite, chabazite, ilmenite, mesolite, aragonite, biotite, serpentine (including chrysotile), hornblende, thomsonite, apatite, fluorite, talc, gypsum, rhodochrosite, bitumen, pyrrhotite, titanite, garnet, siderite, thaumasite, anhydrite, babingtonite, brookite, magnetite, hayesine, marcasite, pyrolusite, psilomelane.

Occurrence and distribution.—Not all of these minerals are found at any single locality, but most of them occur together at many places in both the diabase and the basalt. There is also great variation in the relative abundance of the minerals at different places, but there is generally little variation in their associations and habits. This is true whether the specimens are taken from the basalt (lava flows) or the diabase (intrusive), and is entirely in keeping with the close similarity of these rocks in mineral and chemical composition. Hence, it is altogether probable that the processes that produced the minerals have been the same in both cases. The copper minerals—chalcocite, cuprite, chrysocolla, and native copper—some of which are concentrated into beds of ore in the adjacent sediments at several localities, besides smaller amounts of galena, blende (sphalerite), and pyrite, occur intimately associated with the zeolites and other secondary minerals, and any adequate theory of origin must also take them into account, as well as the boron- and fluorine-bearing minerals, tourmaline, datolite, apophyllite, and fluorite.

In the basalts these minerals occur most extensively in the cellular and scoriaceous parts of the flows and in the cavernous interstitial spaces of the pillow structure. The latter has been notably developed in portions of the First and Second Mountain basalts, and is extensively exposed in the quarries of West Paterson and Great Notch. Fissures and joint cracks in both types of the trap rock also contain these minerals at many localities, and some of the most remarkable occurrences of crystals are found in fault breccias. Similar associations of minerals constitute veins in the adjacent sedimentaries at Byram, and also, at a greater distance (perhaps 1,000 feet) from the contact, at Princeton.

[1] The list has been compiled from various sources, but most of the minerals have been collected from the trap excavations during the progress of this investigation. A few of the less common zeolites doubtless need verification, and available specimens will be examined during the completion of the report on this work.

The very unequal distribution of the secondary minerals, as now known, may be accounted for in part by the unequal development of quarries and other excavations that furnish the chief means of observation and, in some localities, by the lack of frequent and careful search by mineralogists; but these are not the only, or even the chief, factors, for many quarries are as large and penetrate the basalt as deeply as those of West Paterson, Great Notch, and Upper Montclair, for example, but few of them approach these localities in the wonderful variety and abundance of their minerals. Similarly, Bergen Hill, Hopewell, and Moore far surpass all other localities in the diabase, although many excavations are as large and some even larger. Great contrasts are found between localities only a short distance apart. Thus some of the railroad cuts and tunnels that penetrate Bergen Hill at Jersey City and Weehawken have yielded magnificent crystals in great variety and abundance, while others very near by have scarcely produced a single specimen of interest. The old Erie tunnel and the new Erie cut are thus contrasted with the Pennsylvania tunnels. Two quarries only one-fourth of a mile apart at West Paterson are similarly contrasted, as well as others one-half a mile apart at Great Notch. Many large quarries that were formerly worked along the Palisades above Jersey City and many still in active operation along the Watchung Mountain ridges have encountered practically no secondary minerals, except the small veins of calcite and chlorite that are almost universal.

A careful study of the known distribution of these minerals brings out clearly two general conditions: (1) they are much more evenly distributed in the intrusive trap (diabase) than in the extrusives (basalt); (2) in the basalts the minerals are far more abundant in the First Mountain (lowest) sheet than in either of the others. This localization of the secondary minerals, like a similar condition in many ore deposits, is believed to be significant of important conditions that were concerned in their production.

THEORIES OF ORIGIN.

Percolating ground water.—The forces of weathering are now dissolving and removing calcite, oxidizing chlorite and other ferrous minerals, and decomposing the zeolites themselves, along with the inclosing rocks. Hence it is difficult to imagine the production of these minerals under conditions even remotely approaching those of weathering. In the deeper belt of cementation, however, the products of solution and decomposition might well recombine in the form of zeolites, and where these minerals occur alone and without great localization such a hypothesis may prove sufficient. The native metals (copper and silver) and the associated metallic sulphides (pyrite, pyrrhotite, chalcopyrite, chalcocite, galena, and sphalerite) might be accounted for in this manner also, for copper is a normal, though minute, constituent of the trap rocks themselves, and so doubtless are the other constituents of these minerals. A minute quantity of fluorine is found in the basalt glass (tachylite) of the pillow lavas, and microscopic crystals of apatite, which may be fluorine-bearing, are disseminated through the diabase. Hence it might be possible to ascribe the origin of apophyllite to similar processes of percolating ground water.

The abundant boron-bearing datolite, however, and the characteristic pneumatolytic minerals (specular hematite, fluorite, titanite, ilmenite, and brookite) seem to present an insuperable obstacle to this hypothesis. Wherry has examined specimens of the diabase in its extension across the Delaware into Pennsylvania and the most delicate tests failed to reveal the presence of boron. If produced by ground waters the zeolites and associated minerals ought to be found generally in the trap rocks wherever fissures and other openings occur favorable to the penetration of these universal solutions. That this is decidedly not the case in New Jersey has been pointed out in a preceding paragraph. Furthermore, the entire absence of zeolites, so far as now known, from vast areas of lava apparently well suited to their formation, as, for example, those of Hawaii, the Columbia River, the Crystal Falls and other iron-ore districts of the Lake Superior country, is also inconsistent with this hypothesis.

A hypothesis of magmatic origin.—It now seems possible to overcome the difficulties referred to above by ascribing the origin of the zeolites and their associates to the activity of magmatic emanations, which furnished the requisite additions of water and carbon dioxide as well as the small amounts of fluorine, boron, and the constituents of specular hematite, brookite, and titanite.

Fluorine, carbon, and sulphur, together with hydrochloric, sulphuric, boric, and carbonic acids, are among the common emanations of volcanoes and fumaroles and are carried in solution in the waters of geysers and hot springs in volcanic regions. The chemical activity of such solutions on solidified igneous rocks is shown by the extensive decomposition which they have produced in the rhyolites of Yellowstone National Park, where the process is still in operation. That fluorine, chlorine, and boron emanated from the magma of the New Jersey diabase is shown by the presence of tourmaline, scapolite, vesuvianite, and fluorite, in the zone of contact metamorphism. Hence this source furnishes the most natural explanation of the presence of these elements among the secondary minerals that accompany the zeolites, as well as the presence of the pneumatolytic minerals, specular hematite, rutile, brookite, ilmenite, and fluorite, both with the zeolites and in the zone of contact metamorphism.

The abundance of water in igneous magmas is evident in volcanic eruptions, but an intrusive mass, sealed within impervious rocks and under great pressure, retains its water and other volatile constituents in the fluid magma. The continuous crystallization of anhydrous minerals, however, as the rock solidifies, leaves a residual magma that becomes successively more and more hydrous until finally it consists chiefly of the volatile substances and such other mineral matter as (*a*) is present in very small amount and hence has not yet reached the point of saturation and crystallization, or (*b*) still remains highly soluble in spite of the falling temperature and perhaps because of the increasing content of water and other volatile constituents.

This fluid occupies such fissures, joints, and other spaces as may exist in and about the newly consolidated rock. Where fissures permit the escape of the liquid there will be a continuous flow through the intrusive and, following, perhaps, the feeding dikes, to and through the overlying lava sheets, as long as successively deeper portions of the magma continue to crystallize and keep up the supply. A certain amount of leakage will also take place into the joints and fissures of the country rock and the waters will escape at the surface as highly mineralized springs—in many cases hot springs. In addition to the silicates already carried in solution the liquid may dissolve portions of the fissure walls of the solid igneous rock through which it passes, and the crystallization of these substances in other fissures, gas cavities, and the interstices of pillow lava will produce the zeolites and their associated minerals.

In the great Palisade-Sourland Mountain sill a coarse-grained feldspathic facies of diabase with much micropegmatite was encountered in the upper portions of the sheet by the Pennsylvania railroad tunnels. A similar rock is conspicuously developed at Brookville, on the Delaware, where it includes the nephelite syenite and other syenitic facies described by Ransome. This is probably the last anhydrous product of the magma. In some places it is not sharply differentiated from the coarse-grained granophyric facies of the main sill. It is much coarser in texture, however, and consists chiefly of feldspars with one or more of the ferromagnesian minerals, augite, hornblende, and biotite.

These pegmatitic and syenitic facies of the diabase were doubtless formed while the main mass of the sill was still highly heated, though solid. Numerous fault fissures permitted the escape of the residual solution through the overlying strata and into the basalt sheets, portions of which may have gone into solution, particularly the glassy crusts and interstitial breccia of the pillow lavas. Through loss of heat from contact with cold rocks this solution now produced the hydrous zeolites and their associates during successive stages of cooling and crystallization. At a later time, when the diabase itself had cooled, water that still continued to rise from the deeper portions of the magma as they crystallized invaded the fissures and joints of the Palisade sill and formed zeolites there also.

With the addition of water and carbon dioxide the feldspathic constituents of these solutions, in part persisting from the parent magma, in part, perhaps, obtained from the trap rock through which the waters moved, produced the zeolites, prehnite, albite, orthoclase, quartz, and possibly a little calcite; but from chemical considerations it would appear that most of the transformations from plagioclase to the calcic zeolites would leave little or no calcium for the production of calcite. In combination with water, carbon dioxide, sulphur, boron, and fluorine, the pyroxenic constituents furnished the copper minerals, various metallic sulphides, chlorite, datolite, epidote, apophyllite, rhodochrosite, and most of the abundant and ever-present calcite. At some of the old mine workings and quarries along the Watchung Mountains the calcite soon blackens on exposure to the weather from the formation of manganese dioxide, although the color of the fresh mineral gives no hint of the presence of manganese. Some of the calcite is also magnesian and in places dolomite is found. The carbonates of calcium, magnesium, and manganese were doubtless all formed at the same time, or during the same stage of the process, from the pyroxenic constituents of the solutions. All of them crystallized in close association with one another at some localities and to a considerable extent in isomorphic combinations.

The Pillow Lavas of the Watchung Mountains

BY J. VOLNEY LEWIS.

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General character.—The structure called pillow lava has been variously described as cushion-like, sack-like, globular, spheroidal, ovoid, egg-shaped, ellipsoidal, lenticular, and concretionary. Once regarded as rare and peculiar but now widely known in the basalts and allied basic rocks of many countries, and of all ages from Archean to the present, it has given rise to a great diversity of opinion among geologists as to its real nature, and heuce an equal diversity of hypotheses as to its mode of formation. Among the numerous causes to which it has been attributed are spheroidal weathering, spheroidal jointing, brecciation in situ, columnar jointing with subsequent movement of the columns upon each other, concretionary action, explosive eruption (volcanic bombs in agglomerate), normal flow of lava on land, viscous flow and fracturing of stiff lava, lava flow under water, intrusion into unconsolidated sediments, fracturing and partial remelting of lava crusts, and rapid cooling and parting into separate masses by the action of steam.

Pillow lava consists of separate or nearly separate masses of consolidated lava, from a few inches to 6 or 8 feet in diameter, and with rounded or oval cross sections in all directions. In many localities they are molded in varying degree upon one another or even flattened out like cushions or half-filled sacks, and in the latter case they nearly or quite fill the space, without open interstices. These forms are to be clearly differentiated from the spheroidal jointing or exfoliation due to weathering. Where spaces exist between the masses they tend toward a rude tetrahedral form with concave sides, and hence are roughly triangular in cross section. These spaces are generally filled in part with flakes and angular fragments of glass of the same character as the curved surfaces of the bounding spheroids. Filling the remaining spaces in many localities and cementing the fragments into a breccia are a great variety of secondary minerals. Prominent among these are calcite, quartz, epidote, the remarkable series of zeolites, and many allied species.

Some degree of elongation is a very common, though by no means universal, characteristic of the "pillows." Where it exists there is commonly a pronounced parallelism of the long axes of the masses. Gradations into more irregular twisted and ropy lavas have also been observed, with half-formed pillows attached to each other and to the solid massive lava of the flow by necks or along the sides.

The individual masses are very commonly sheathed in a film of glass ranging in thickness from 2 or 3 millimeters to 25 or more millimeters, and the microscope shows that this passes gradually into the crystalline lava of the interior. In many cases the lava is massive or only slightly vesicular, although some very light and spongy lavas are also known in this form. A vesicular or variolitic zone, or both, very commonly lies just within the glassy crust, and in some localities a flow structure is developed parallel to the outer surface of each mass. Two or more concentric layers of alternating vesicular and solid lava are sometimes found, and the central portions of some pillows are extremely porous or even cavernous, the weathering out of such spongy interiors leaving only hollow shells. In the massive pillow lavas many of the individuals have a central or subcentral axial hollow resembling the pipe in a steel ingot.

A pronounced radial jointing is very commonly developed in the pillows, and when these are broken down by the mechanical processes of weathering or the action of waves and streams they fall into tapering, pointed, or wedge-shaped fragments. A concentric jointing or lamellar structure, so characteristic of spheroidal weathering, has been observed far less commonly.

Pillow Lavas in New Jersey.

Distribution.—This structure has been found typically developed in parts of both First and Second Watchung Mountain basalts. In First Mountain the structure has been traced from a point one-half mile northwest of Passaic Falls, Paterson, in a direction about S. 25° W., to the trap quarry near the railroad station at Great Notch, a distance of 4 miles. The exposures of pillow lava along this course vary in width from about 100 feet to more than 1,000 feet. On account of an almost continuous covering of glacial drift in both directions beyond the extremities of this line it has not been possible to trace the structure further. This belt lies almost exactly in the middle of the basalt outcrop, and therefore about the middle of its thickness, throughout the course.

Description.—Fine examples of the structure have been exposed in street grading along McBride Avenue from Rockland Street to Howard Street, Paterson, showing nearly circular cross sections in places, but also some ellipsoidal and long-drawn-out bolster-like masses. The common interstitial tachylite breccia, with calcite, quartz, zeolites, etc., has been weathered out and the spheroidal, bowlder-like appearance of the pillows is clearly shown.

Some of the masses are joined together by short necks. In the trap quarries just above the West Paterson station pillow structure has been exposed to depths of 50 to 75 feet in great perfection. This is one of the most noted localities for zeolites and associated minerals, which have been developed in great variety and beauty in the interspheroidal cavities of the pillow lava.

Most of the pillows are circular or elliptical in cross section and range from 1 to 2 feet in diameter, although both smaller and larger sizes occur. Although varying in shape from spheroidal to elongated forms, the prevailing structure is ellipsoidal and remarkably regular. Each mass is covered with basic glass (tachylite), ranging from a thin film to more than an inch in thickness, and thin sections show that this passes gradually into the completely crystalline mass of the interior. The glass is very brittle, has a pitch-like to waxy luster, and has a tendency to split off parallel to the surface in weathering or when struck with a hammer. Hence it is difficult to collect specimens of the crystalline rock with the glass attached to it.

The pillows consist of massive lava, with few amygdules, and these are small and distributed chiefly in the outer parts, near the surface coating of glass. Many of the masses, on the other hand, have a central or subcentral "pipe" or cavity from 1 to 6 or 8 inches in diameter, which are either rounded or more or less flattened in cross section. Radial columnar jointing is a common characteristic and is well shown in the weathered rock of the upper parts of the quarry walls. The spaces between the masses are either partly or wholly filled with flakes and angular fragments of glass like that which coats the individual pillows. This is generally cemented into a breccia by the deposition of quartz, calcite, many species of zeolites, and other less common minerals.

At the Great Notch quarry a section of exactly similar material has been exposed to a depth of 40 or 50 feet. Fifteen miles further southwest the same structure has been found along a small ravine and in the old prospecting pits locally known as the "copper mine" near Glenside Park (formerly Feltville), 2 miles northeast of Scotch Plains. This exposure is but a few feet deep and lies at the immediate upper surface of the First Mountain basalt, instead of near the middle. The interstitial material is a mixture of angular fragments of glass with red shale of exactly the same character as that which overlies the trap at this locality. The lava is somewhat vesicular, many of the masses having elongated tubular vesicles, 3 or 4 inches long and one-fourth of an inch or less in diameter, set at right angles to their outer surfaces. Most of these tubes are filled with chlorite, calcite, quartz, and zeolites.

In contrast with the preceding, the pillow lava of Second Mountain occurs at the bottom of the sheet of basalt and is markedly vesicular. At Little Falls it is exposed at the northeast corner of the concrete reservoir of the East Jersey Water Company and at short intervals along the eastern border of the trap northward for more than half a mile. The pillows attain maximum diameters of 2 or 3 feet, are coated with the characteristic glassy crust, and form accumulations 10 to 20 feet thick along the old quarry walls and in the cliffs. In places they form the bottom of the sheet and elsewhere they rise 10 feet or more above the base, the latter consisting in such places of normal basalt jointed into wedgy and splintery columns.

ORIGIN OF PILLOW LAVAS.

In connection with the study of this structure in the trap rocks of New Jersey the available literature of pillow lavas in all countries has been carefully compiled and compared and also that of the modern pahoehoe and aa lavas, with both of which the pillow structure has been compared by various geologists. An account of this investigation, together with a critical discussion of the numerous conflicting hypotheses of origin that have been advanced, has been published in the Bulletin of the Geological Society of America, volume 25. "A theory of bulbous budding," may be summarized from this publication as follows:

1. Highly liquid lava.—The structure occurs only in basalts and closely related free-flowing basic lavas, and it is evident that any high degree of viscosity must serve effectually to prevent its formation. The lava must retain a high degree of liquidity through a relatively long period of cooling and notable viscosity must appear only within a limited range of temperature as it approaches rigidity.

2. Small continuous supply.—In a lava flow that has become nearly motionless the formation of cracks and orifices in the crusts permits the escape of liquid lava along the front and lateral margins of the flow or, in some cases, even upon its upper surface. Thus a multitude of small flows may take the place of the great flow that has become retarded or stopped in its course. In the case of slow gentle extravasation of lava from the beginning of the eruption the multiple-flow process may come into play at once.

3. Bulbous budding.—With suitable temperature the numerous small flows will form bulbous or elongated masses, because of the tough membrane that quickly forms on the surface of each little outburst on exposure to the air. The pressure of lava within expands each bulb until the stretching of its skin is stopped by increasing rigidity. This stretching may induce in the thickening and stiffening crust a pseudo-flow structure parallel to the outer surface by the flattening of vesicles and the tangential arrangement of microlites. The crust finally stiffens, cracks again, and the process is repeated indefinitely as long as a supply of lava continues in suitable amount and at favorable temperatures, the liquid flowing through a succession of pillows connected by short necks or necks of no appreciable length at all. Layers of pillows of succeeding generations form upon the first, each layer protecting the pillows beneath from rapid cooling and thus prolonging the period during which lava may continue to pass through them and increase the extent of the flow. With varying conditions all degrees of transition would occur between typical pillow lava and pahoehoe, either passing into the other or alternating with it, according to circumstances of temperature and volume of the flow.

4. Semi-molded immobile forms.—As the pillowy masses are formed, first on the ground or the floor of a lake or sea and then in more or less rapidly succeeding generations one upon another, they tend to assume rounded or domed upper surfaces and molded bases. Hence the pillows at the bottom of a flow are apt to be flat beneath, while those higher in the bed tend to fit more or less perfectly upon the underlying ones, with varying degrees of adaptation. The longest axis marks the direction of flow and the shortest the vertical at the time of their formation.

5. Separation of individual pillows—At the time of their development these diminutive lava flows are connected together in an irregular budding series, somewhat after the manner of some bulbous varieties of cactus. The connections are points of weakness, however, that may readily be severed by contraction while cooling or by slight subsequent warping or other movement, leaving the individuals wholly isolated.

6. Interspheroidal cavities and breccia.—The spalling off of glass fragments from the outer crusts partially fills the interspheroidal spaces with breccia, where such openings exist owing to the failure of the pillows to fit perfectly together. These spaces may also contain fine sediment where the lava has flowed into soft mud or ooze under water, or sediment of any kind may subsequently be washed into the interstices from above, whether the flow is subaqueous or subaerial. Occasionally a growing pillow may crack in such a manner as to spill a portion of its liquid contents into the spaces between underlying or adjacent pillows. Where other suitable conditions exist these spaces afford favorable places for the wonderful variety of beautifully crystallized minerals for which some of these localities are famous. These include quartz, calcite, the zeolites, datolite, prehnite, pectolite, epidote, and many other less abundant species.

7. Radial columnar jointing.—Columnar jointing naturally forms at right angles to the cooling surfaces in pillow lavas as in others, and this produces the radial structure so commonly seen in these masses. A shell-like concentric parting is found in some pillow lavas with a strongly developed zonal structure, and it is characteristic of the tachylitic crusts generally to scale off easily and break into fragments.

8. Degree of vesicularity.—The masses become more or less vesicular according as much or little gas is retained in solution by the liquid lava. The outer crust may be entirely free from vesicles, while concentric lines or scattering cavities or amygdules appear only in the crystalline mass within, the central part being the most scoriaceous of all. This would be the normal result where the liquid remains in equilibrium, holding its volatile constituents until they are released by the process of crystallization. Glass, being a supercooled liquid that has become rigid without crystallization, often retains its volatile matter in solution and in such case does not become notably vesicular. Supersaturation and rapid escape of volatile materials make the whole mass spongy, and their continued separation from the liquid interior in advance of crystallization causes the accumulation of vesicles near the upper surfaces of the pillows.

9. Hollow pillows.—Where the flow of the interior liquid fails from any cause, such as the freezing of the intervening passage or the opening of freer channels in another direction, the growing pillow may be drained upon cracking and thus become wholly or partially hollow. Most hollow pillows, however, seem to owe their cavernous condition to either an excessive amount of contained gases, giving rise to a central steam cavity of large size, or to the breaking down of a spongy core by weathering, a process that may precede the breaking away of the outer shell.

10. Extent of flow.—Repeated budding may lead eventually to the covering of a considerable area, the extent finally attained depending chiefly upon the length of time during which a moderate supply of suitable lava continues. Even on flats and gentle slopes, the long-continued supply of lava and the formation of successive layers of pillows, one upon another, will gradually build up a slope like an aggrading river, and with increasing gradient the range of flow will be increased. Thus both the depth and the lateral extent are contingent upon the length of time during which a suitable supply is maintained.

11. Contact with water.—Possibly there are characteristic differences between subaqueous and subaerial flows of lava, but at present they are scarcely distinguishable with any degree of certainty. Presumably the rate of cooling is accelerated somewhat by immediate contact with water, at least in certain stages of the process, as at the initial protrusion of each new bud or pillow, and this probably has a modifying influence upon its size, shape, and other characters; but to a great extent these must depend upon the initial temperature of the lava of each diminutive outbreak, the pressure under which it flows, its chemical constitution, and other indeterminate factors. It is conceivable that contact with water may either hinder or promote the formation of pillow structure. Conditions of temperature and flow that are favorable to the production of extensive pillow lava on land might be so modified by water as to restrict the extent of the structure. On the other hand, a flow of such volume and fluidity as would spread rapidly on land, forming a continuous sheet, might be checked and largely transformed into pillow lava under water. Hence it is probable that neither the presence nor the absence of water, *per se*, is particularly favorable to the structure.

12. Intrusive pillow lava.—Direct intrusion of lava into soft oozes or loose sediments upon the sea bottom would differ in general from subaqueous eruption only in the slight resistance to flow offered by the sediments and perhaps also in less rapid cooling owing to the absence of convection currents. A subaqueous eruption upon such a bottom would of necessity penetrate the underlying sediments in part, and the same would be true of a lava stream from the land upon entering a body of water where such conditions prevail. In both cases the penetration or intrusion is due to the incompetence of the strata to sustain the weight of a flow.

Johnson-Lavis has shown that a dense viscous liquid on being injected into another assumes spheroidal forms with slight necks connecting them, some of which were severed, leaving the globes detached. Whether this would happen to a lava would depend largely, perhaps, upon relative density. A light and insubstantial ooze would probably offer too little resistance to cause the separation of a lava that had not already begun the budding process. On the other hand it would not interfere with the development and extension of the process through its mass, and this would give rise to pillow structure in every respect like that which forms upon the land or the firm sea bed, except perhaps in the absence of flat-bottomed pillows at the base of the flow.

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