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GEOLOGICAL SURVEY

No. 12

A CRYSTALLOGRAPHIC STUDY OF THE THINOLITE OF
LAKE LAHONTAN.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1884

ADVERTISEMENT.

(Bulletin No. 12.)

The publications of the United States Geological Survey are issued in accordance with the statute approved March 3, 1879, which declares that—

“The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classifications of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization. And the money resulting from the sale of such publications shall be covered into the Treasury of the United States.”

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

“That whenever any document or report shall be ordered printed by Congress, there shall be printed, in addition to the number in each case stated; the “usual number” (1,900) of copies for binding and distribution among those entitled to receive them.”

Under these general laws it will be seen that none of the Survey publications are furnished to it for gratuitous distribution. The 3,000 copies of the Annual Report are distributed through the document-rooms of Congress. The 1,900 copies of each of the publications are distributed to the officers of the legislative and executive departments, and to stated depositories throughout the United States.

Except, therefore, in those cases where an extra number of any publication is supplied to this office by special resolution of Congress, as has been done in the case of the second, third, fourth and fifth Annual Reports, or where a number has been ordered for its use by the Secretary of the Interior, as in the case of Williams's Mineral Resources, the Survey has no copies of any of its publications for gratuitous distribution.

ANNUAL REPORTS.

Of the Annual Reports there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880-'81, by J. W. Powell. 1882. 8°. lv, 568 pp. 61 pl., 1 map.

III. Third Annual Report of the United States Geological Survey, 1881-'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882-'83, by J. W. Powell. 1884. 8°. xii, 473 pp. 85 pl. and maps.

The Fifth Annual Report is in press.

MONOGRAPHS.

So far as already determined upon, the list of the Monographs is as follows:

I. The Precious Metals, by Clarence King. In preparation.

II. Tertiary History of the Grand Cañon District, with atlas, by Capt. C. E. Dutton. Published.

III. Geology of the Comstock Lode and Washoe District, with atlas, by George F. Becker. Published.

IV. Comstock Mining and Miners, by Eliot Lord. Published.

V. Copper-bearing Rocks of Lake Superior, by Prof. R. D. Irving. Published.

VI. Older Mesozoic Flora of Virginia, by Prof. William M. Fontaine. Published.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. Published.

VIII. Paleontology of the Eureka District, Nevada, by Charles D. Walcott. In press.

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by R. P. Whitfield. In press.

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Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons. In preparation.

Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague. In preparation.

Lake Bonneville, by G. K. Gilbert. In preparation.

Dinocerata: A Monograph on an Extinct Order of Ungulates, by Prof. O. C. Marsh. In preparation.

Sauropoda, by Prof. O. C. Marsh. In preparation.

Stegosauria, by Prof. O. C. Marsh. In preparation.

Of these Monographs, Nos. II, III, IV, V, VI, and VII are now published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by C. E. Dutton, Capt. U. S. A. 1882.

4°. 264 pp. 42 pl. and atlas of 26 double sheets folio. Price, \$10.12.

III. Geology of the Comstock Lode and Washoe District, with atlas, by G. F. Becker. 1882. 4°.

xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price, \$11.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price, \$1.50.

V. Copper-bearing Rocks of Lake Superior, by Prof. R. D. Irving. 1883. 4°. xvi, 464 pp. 29 pl. Price, \$1.85.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by William M. Fontaine. 1883. 4°. xix, 128 pp. 54 ll., 54 pl. Price, \$1.05.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xii, 200 pp. 15 pl. Price, \$1.20.

Nos. VIII and IX are in press and will soon appear. The others, to which numbers are not assigned, are in preparation.

BULLETINS.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not properly come under the heads of ANNUAL REPORTS or MONOGRAPHS.

Each of these Bulletins will contain but one paper, and be complete in itself. They will, however, be numbered in a continuous series, and will in time be united into volumes of convenient size. To facilitate this each Bulletin will have two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins Nos. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price, 10 cents.

2. Gold and Silver Conversion Tables, giving the Coining Value of Troy Ounces of Fine Metal, &c., by Albert Williams, jr. 1883. 8°. ii, 8 pp. Price, 5 cents.

3. On the Fossil Faunas of the Upper Devonian along the Meridian of 76° 30', from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8°. 36 pp. Price, 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price, 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price, 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price, 5 cents.

7. *Mapoteca Geologica Americana*. A Catalogue of Geological Maps of America (North and South), 1752-1881, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price, 10 cents.

8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Vanhise. 1884. 8°. 56 pp. Price 10 cents.

9. A Report of the Work done in the Washington Laboratory during the fiscal year 1883-'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price 5 cents.

10. On the Cambrian Faunas of North America. Preliminary studies by Charles Doolittle Walcott. 1884. 8° 74 pp. Price 5 cents.

11. On the Quaternary and Recent Mollusca of the Great Basin; with Descriptions of New Forms, by R. Ellsworth Call; introduced by a sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp. Price, 5 cents.

12. A Crystallographic Study of the Thinolite of Lake Lahontan, by Edward S. Dana. 1884. 8°. 34 pp. Price, 5 cents.

STATISTICAL PAPERS.

A fourth series of publications, having special reference to the mineral resources of the United States, is contemplated. Of that series the first has been published, viz: Mineral Resources of the United States, by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price, 50 cents.

Correspondence relating to the publications of the Survey, and all remittances, which must be by postal note or money-order, should be addressed to the

DIRECTOR OF THE UNITED STATES GEOLOGICAL SURVEY,

Washington, D. C.

WASHINGTON, D. C., September 30, 1884.

DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

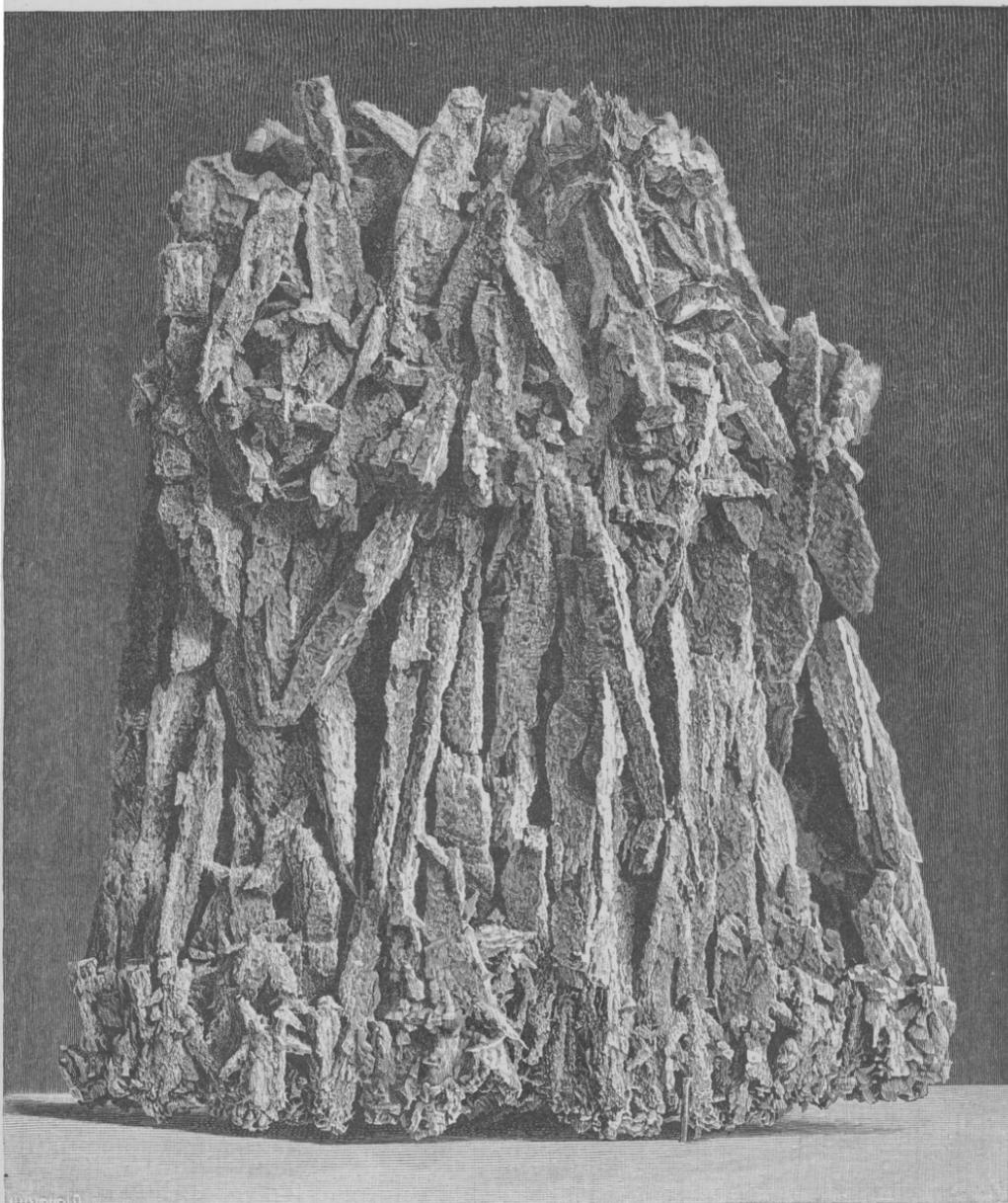
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THINOLITE.

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL DIRECTOR

A

CRYSTALLOGRAPHIC STUDY

OF THE

THINOLITE OF LAKE LAHONTAN

BY

EDWARD S. DANA



WASHINGTON
GOVERNMENT PRINTING OFFICE
1884

LETTER OF TRANSMITTAL.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF THE GREAT BASIN,
Washington, D. C., September 16, 1884.

SIR: I have the honor to transmit herewith, for publication, a paper on Thinolite, by Prof. Edward S. Dana, of New Haven.

The calcareous pseudomorph to which Mr. Clarence King gave the name "thinolite" has been referred by him and others to the mineral gaylussite, and the history of its conversion to calcite was believed to afford the key to the history of the oscillations of Lake Lahontan. Mr. Russell's later and fuller investigations demonstrated the physical impossibility of the lake-history deduced by King, and the question of the origin of the thinolite was thus reopened. Mr. Russell determined its distribution and geologic relations in a thorough and satisfactory manner, but his acquaintance with mineralogy did not permit him to undertake the necessary crystallographic study with confidence.

Application was accordingly made to Profs. George J. Brush and E. S. Dana, and the study of the mineral was finally undertaken by the latter gentleman. His report, which is eminently judicial and conservative, does not contain a complete solution of the problem; but it clears the ground by dissipating all earlier hypotheses, and indicates the line of future investigation. It renders to the geologic study the important service of freeing it from the embarrassment occasioned by the gaylussite hypothesis.

I remain, with great respect, your obedient servant,

G. K. GILBERT,
Geologist in Charge.

Hon. J. W. POWELL,
Director United States Geological Survey.

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A CRYSTALLOGRAPHIC STUDY OF THE THINOLITE OF LAKE LAHONTAN.

BY EDWARD S. DANA.

INTRODUCTORY STATEMENT.

Origin of the name Thinolite.—The name Lake Lahontan was given by Mr. Clarence King to the great Quaternary lake of northwestern Nevada, of which the present Walker, Carson, Humboldt, Winnemucca, Pyramid and Honey lakes are the relics. The extent of Lake Lahontan was first mapped out by Mr. King, and a description of it and of its history is given in his report.¹ As shown by him, the characteristic feature of the Lahontan Basin is the great abundance in it of deposits of calcareous tufa. Of this he says:²

“As compared with Lake Bonneville, the chief characteristic difference in the phenomena of terraces and shore lines is the great abundance in the Lahontan Basin of calcareous tufas. Modern subaerial gravels have been in great measure washed down over the calcareous matter, but it frequently exists even in the broad bottom of the lake in thick accumulations—covering areas of several miles with a tufaceous deposit from 20 to 60 feet thick. As will be seen later, this tufa is of very great chemical interest, and its mineralogical nature affords a clew to the history of the lake. From its very great importance and its peculiar origin, I have taken the liberty of giving it a lithological name. Since it formed on the shores of the lake, I have called it, from the Greek *Θῆς* (shore), Thinolite.”

The occurrence and characters of this tufa are described in considerable detail by Mr. King, and its general appearance is well shown in several plates in his report. Mr. King also discusses the condition of the formation of the calcareous tufa, and offers an explanation of its origin, to which reference will be made later.

¹Clarence King: Report of the Geological Exploration of the Fortieth Parallel, Vol. I, p. 488, *et seq.*, 1878.

²*Loc. cit.*, p. 508.

VARIETIES OF TUFA.

The Lahontan Basin has recently been studied by Mr. I. C. Russell, and a preliminary sketch of its geological history was published in 1883, embodying the results of a reconnaissance in the season of 1881.³ A complete report, embracing the results of later observations, is now in preparation.

Mr. Russell has mapped with great completeness the geographic extent of Lake Lahontan, and has traced out the topography of its shores at the different stages in its history. With respect to the calcareous deposits, he has been led to discriminate between three distinct varieties, superimposed upon each other, to which he gives the names *lithoid*, *thinolitic*, and *dendritic*. The following points with regard to them are taken nearly *verbatim* from his report.

The *lithoid tufa* was the first formed tufa deposit; it is found on the slopes of the basin from the level of the lithoid terrace, which is 30 feet below the highest water line of Lake Lahontan, downward as far as any sections are now exposed. This variety of tufa is usually gray in color and compact in structure; it occasionally shows concentric bands and open spaces, but is much more dense and stone-like than the varieties deposited later.

The *thinolitic tufa* forms the second layer, and was deposited at a lower stage of the water. Its upper limit on the sides of the basin is the thinolite terrace, which is 400 feet lower than the lithoid terrace just alluded to, and 100 feet above the present level (1881) of Pyramid Lake. A minor deposit probably also occurred (as noted in a subsequent paragraph) after the formation of the dendritic tufa. This second variety of tufa, to which the name *thinolite* is now restricted, is characterized by the fact that it consists of groups of distinct prismatic or pyramidal crystals, as will be described later. In the Lahontan Basin the thinolite is best developed about the base of the Marble Buttes, at the south end of Pyramid Lake; at the Needles, at the northern end; and at the Domes, and around the lower portions of Anaho and Pyramid islands, in the same lake. It occurs all along the borders of Winnemucca Lake, and less abundantly on Smoke Creek and Black Rock deserts. These deserts form a single basin, separated from the valley of Pyramid Lake by a low divide. It is found also along the borders of Carson Desert, and at a single locality in Walker Lake Valley. Outside of the Lahontan Basin it occurs in the basin of Mono Lake, in California. The deposits of thinolite are of very considerable magnitude; where best exposed the layer of interlaced crystals has a thickness of from 6 to 8 feet, and exhibits concentric zones of larger and smaller crystals.

³I. C. Russell: Sketch of the Geological History of Lake Lahontan, a Quaternary lake of northwestern Nevada. Washington, 1883. (Department of the Interior, U. S. Geological Survey, J. W. Powell Director.)

The *dendritic tufa* is the third variety of calcareous deposit in the Lahontan Basin. Its upper limit is about 200 feet below the highest water line, and from this level it coats the sides of the basin wherever the conditions were favorable. It is by far the most abundant of the three kinds of tufa, and in places attains a great thickness. Its greatest depth is not less than 20 feet, and may be as much as 50 feet. This kind of tufa is characterized by its distinct dendritic structure. It occurs over large portions of the bottom of the old lake, forming mushroom-shaped masses of all sizes up to 5 or 6 feet in diameter; in some places they make a pavement of blocks 2 feet in diameter, resting on the lake beds.

SUCCESSION OF TUFA DEPOSITS.

As has already been intimated, Mr. Russell has found that the three varieties of tufa succeeded each other in the order named above. Later observations have shown, as he has informed the writer, the probable existence of a second deposit of thinolite crystals, not exceeding 4 or 5 inches in thickness, which followed the precipitation of the dendritic tufa. The succession of the three prominent deposits of tufa in their relation to each other and the sides of the basin is illustrated by Mr. Russell by the accompanying figure. With his permission I insert this figure, and also quote two or three pages from his preliminary report descriptive of the succession of tufa deposits, their chemical composition, and general method of occurrence (pp. 215 to 218):

"The accompanying diagram, Fig. 48 [Fig. 1 of this publication], gives a generalized expression of the relation of the three successive

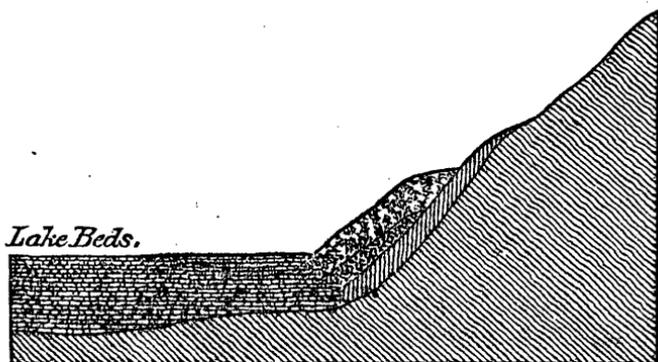


FIG. 1.—Diagrammatic section illustrating the relations of the tufas.

tufas to each other and to the sides of the basin. The first formed deposit, the lithoid tufa, represented in the notation of the diagram by vertical lines, extends upward about 500 feet above the horizontal lake beds occupying the bottom of the basin. The second deposit, the thinolitic tufa, finds its upper limit 100 feet above the present level of Pyramid Lake. The third and last, the dendritic tufa, which is far

more abundant than either of the others, extends upward to within about 200 feet of the highest shore line. The lower limits of these deposits cannot be determined with certainty, as they are concealed by lake beds.

"Chemical analyses were made by Prof. O. D. Allen of samples of each of these varieties of tufa, and the results, given below, show that their constituents are practically identical. The insoluble residue exhibited in each case may be due in part to foreign matter imprisoned in the tufa at the time of its formation, and is certainly due in a measure to foreign matter carried by atmospheric agencies into open cavities of the rock after the desiccation of the lake.

Constituents.	Lithoid tufa.	Thinolitic tufa.	Dendritic tufa.
Insoluble residue.....	1.70	3.88	5.06
Lime (CaO).....	50.48	50.45	49.14
Magnesia (MgO).....	2.88	1.87	1.99
Oxides of iron and alumina.....	.25	.71	1.29
Carbonic acid (CO ₂).....	41.85	40.90	40.31
Water (H ₂ O).....	2.07	1.50	2.01
Phosphoric acid (P ₂ O ₅).....	.30	Trace.	Trace.
Chlorine and sulphuric acid.....	Trace.	Trace.	Trace.
	99.53	98.81	99.80

"Not only do these tufa deposits still sheathe the slopes of the Lahontan Basin, but they appear also in isolated, castellated masses and rugged crags about the shores of Pyramid and Winnemucca Lakes and on the borders of the Carson Desert. These outstanding masses occur characteristically as upright cylinders, or groups of cylinders, with rounded, dome-shaped tops, and are of all sizes, from a few inches up to a hundred feet or more in height. The larger masses are composed of groups of many tower-like, cylindrical bodies of unequal height, and bear a striking resemblance to rugged mediæval castles with rounded towers and castellated battlements. A fine example of such a water-built castle stands about the middle of the western shore of Pyramid Lake, and rises 100 feet above the waves that wash its base. The domes between the eastern shore of the lake and Pyramid Island are the tops of similar towers, the foundations of which are deeply submerged. Other masses of the same nature, but smaller in size and usually broken and weathered, occur in abundance. Frequently these outstanding cylinders and castles of tufa are broken across, or split from base to summit, so as to reveal every desired section of their interiors. An examination of a large number of these dissected masses brought to light the interesting fact that all the tufa crags below the broad terrace 100 feet above Pyramid Lake—the thinolite terrace—have a tripartite structure, and all above that horizon have a bipartite structure.

"Each of the tufa towers below the thinolite terrace has a core of compact gray tufa in all respects identical with the first-formed sheath of tufa on the rocky sides of the basin. This core of lithoid tufa is com-

monly from 2 to 6 feet in diameter, and sometimes shows a tubular structure. When the base is exposed it is occasionally seen to spring from a small nucleus of rock.

“Outside the core of gray tufa is a coating of thinolite crystals, from 2 to 6 or 8 feet thick, that completely envelops its sides and top. These crystals are interlaced in every direction, but show a radial grouping, and also a concentric banded structure—zones of elongated prisms alternating with narrow bands of smaller crystals. The largest crystals are from 6 to 10 inches in length and an inch or more in diameter. This layer of thinolite is best displayed in the masses of tufa that occur low down near the surface of Pyramid Lake. The deposit is there thickest and the crystals are largest.

“About the layer of thinolite, and in turn completely covering it, is a third tufa deposit, equal to or even exceeding in thickness either of the previous layers. It usually arches over the top of the column in a low dome. This third layer is of dendritic tufa, and always shows the characteristic branching structure, resembling a group of cedar boughs changed to stone.

“Frequently the dome-shaped summits of these tufa towers are weathered into holes, and sometimes the entire top is dissolved away down to the layer of thinolite crystals, or even deeper. In the hollows thus formed, which are frequently 10 or 12 feet in diameter, a person can stand as on the top of a wide tower, with a parapet of dendritic tufa 3 or 4 feet high all about him. On the west side of Winnemucca Lake, near the southern end, there stands a tufa tower, fully 40 feet high, that has been split from base to summit into three sections, the open fractures being wide enough for a person to pass through. In remembrance of Heidelberg, I have called this the ‘Rent Tower.’ The whole of this tower is composed of tufa, the nucleus from which it started being some distance below the surface of the surrounding lake beds and gravels. It stands just above the level of the thinolite terrace, and is composed entirely of lithoid and dendritic tufa, the middle or thinolitic member being wanting. Near at hand, and a few feet below the horizon of the thinolite terrace, are other dome-shaped masses, showing the intermediate thinolite also.

“While the isolated tufa towers having thinolite as a middle member are confined to the shores of Pyramid and Winnemucca Lakes and to the borders of the Carson Desert, the similar masses in which the thinolite is wanting occur over a much wider area, especially along the borders of the Black Rock Desert. Examples may also be seen along the line of the Central Pacific Railroad southeast of Humboldt Lake.

“In some cases, where the lake beds and gravel have been washed away from the base of a tufa tower, we find the outer layer of dendritic tufa projecting as an irregular shoulder about the lower part of the column, thus showing how much of the column projected above the bottom of the lake at the time the dendritic layer was added. In one instance,

where the entire mass has been uprooted, the layer of thinolitic crystals extends about 2 feet lower down than the coating of dendritic tufa, and then terminates in the same abrupt manner. In this case the central core of lithoid tufa ends in a tapering, irregular base, the nucleus of which is a group of small pebbles.

“One of the physical conditions favorable, if not absolutely necessary, for the formation of tufa seems to be the presence of a solid nucleus about which the carbonate of lime can commence to crystallize. This nucleus may be a pebble resting at the bottom of the lake or it may be the solid cliff that forms the shore. It plays the same rôle here as it does in the crystallization of alum or rock candy in a laboratory experiment, or as may be seen in the structure of oolitic sand. The crystallization once started, the process was continued until hundreds and even thousands of tons had formed in a single isolated mass. Where the shores are too steep and solid for the ready formation of terraces and embankments of gravel, they favor the deposition of tufa. In such places the chemical deposit cannot be disturbed or carried away by the shore drift. The most favorable places of all for the accumulation of calcareous deposits are rocky islands. Tufa frequently cements the gravel and sand of which embankments are constructed, and sometimes forms a complete pavement on their surfaces. This happens when by a rise of the lake the surface of the embankment is so far submerged as to escape the action of the shore drift. Tufa has never been observed by the writer resting on beds of fine clay or silt unless there were pebbles for nuclei. In many instances every pebble on a surface of fine lake beds has its upper surface coated with tufa, or perhaps supports a mushroom-shaped growth some inches in height, while the surrounding plain of fine mud is entirely free from calcareous deposit.”

CRYSTALLOGRAPHIC STUDY.

The introductory statements which have been made will have served to give a sufficiently clear idea of the general relations of the calcareous tufas of the Lahontan basin, as established by the labors of Mr. Russell. The immediate object of the present writer is to state the results of a mineralogical study of the specimens of thinolite which have been placed in his hands, undertaken with the view to making out as fully as possible the crystalline form, so as to throw light upon the probable chemical nature of the original mineral, and thus further upon the history of the complex changes through which Lake Lahontan has passed.

In order to avoid all misapprehension, it may be repeated here that the word *thinolite* is employed in the restricted sense used by Mr. Russell, as designating that portion of the calcareous tufas which is distinctively crystalline, in distinction from the stony (lithoid) and

dendritic varieties. In a word, the thinolite is a crystalline deposit, now consisting chemically of almost pure calcium carbonate, but obviously pseudomorphous after some original mineral deposited on an immense scale during a certain period in the desiccation of Lake Lahontan.

GENERAL ASPECT OF THE THINOLITE.

In general it may be said that the thinolite collected from the different localities named, both in the basin of Lake Lahontan and of Mono Lake, while varying widely in external aspect, is yet remarkably uniform in all essential characters. It is thus established beyond question that the original mineral deposited was throughout the same, although, in consequence of the varied conditions to which it has been subjected, the forms resulting from its alteration are very diverse. Thus, in some specimens there is only a delicate skeleton remaining, the whole consisting of thin plates, held together in their parallel position by a slight central frame-work, while in others the whole is as firm and compact as a crystalline limestone, and between the two extremes many intermediate varieties occur. The most important condition upon which this difference depends is the varying extent to which a deposition of calcium carbonate has taken place subsequent to the first alteration of the original mineral. This will be more fully explained later.

THINOLITE FROM PYRAMID LAKE.

As has already been stated, the thinolite is most characteristically developed about Pyramid Lake. The writer has had in hand specimens from the Marble Buttes, from the Needles, from Anaho Island, and from the Domes, and, as they illustrate well the different varieties, it will be convenient to refer to them by localities, although no special significance is probably to be attached to the particular spot from which the individual specimens were collected.

The delicate, open, porous variety of thinolite is best shown in the specimens from the Marble Buttes, of which illustrations are given in Plate I (here inserted from Mr. Russell's report) and in Fig. 1 (reduced one-half) of Plate II. The external form of the crystals is roughly that of a rectangular prism, with projecting edges and generally tapering toward the extremities. The color is gray to brown. These crystals are commonly from a quarter of an inch to an inch in diameter and up to 8 or 10 inches or more in length. They are generally grouped in a more or less closely parallel position, often compactly, with only very little interlacing. In other cases, especially when the forms are smaller, they have widely divergent positions, interpenetrating each other, and giving a large mass an open, reticulated appearance. In addition to the elongated crystals, numerous smaller ones, half an inch or an inch

in length, make up parts of these masses, projecting from the sides of the larger crystals and forming divergent groups among themselves. The small crystals have generally the form of an acute pyramid, and are sometimes square in outline, sometimes rhombic; the sides are usually concave, and the edges project sharply. The exterior surface of the larger crystals is rough and open, often with a delicate mossy covering, and the whole crystal is porous throughout, as if eaten out so as to leave only a skeleton behind. Upon a superficial examination no regularity in the structure is evident, but on looking more closely it is seen that the apparently rough and irregular surface is made up of portions of thin plates, each set parallel to the sides of the crystal and uniformly converging in one direction. Thus when one of the groups of nearly parallel crystals is viewed end on, from one extremity or the other, it is seen that the edges of the plates, irregular as they are in outline, are all presented to view at once, as if each crystal, though prismatic in general outline, were made up of a series of acute skeleton pyramids, hopper-like in form, placed one within another. Still further, when the section produced by the cross-fracture of one of these elongated crystals is examined, there is seen, more or less distinctly, a series of apparently rectangular ribs forming concentric squares or rectangles, with diagonal ribs joining the opposite angles.

The specimens in hand from the Needles, Pyramid Lake, correspond closely with those which have been described, though hardly showing the structure so clearly. This is also true of some of those from Anaho Island. The majority from the latter locality, however, are much more firm and compact. Here, too, the crystals are usually elongated, and in a single specimen grouped in nearly parallel position. The edges of the plates are also commonly distinct on the sides, and show the same convergence toward one extremity. The masses, however, instead of being open and porous, and consequently light in the hand, are close, compact, and heavy. Instead of the delicate, open skeleton, with fretted surface, seen on the cross-fracture, the section is nearly solid, and sparkles with the reflection from the cleavage surfaces of the calcite grains. In other cases the outer surfaces are smooth and rounded, and the unaided eye sees little of the structure except on a cross-fracture; in these instances, as will be more fully explained immediately, a deposition of calcium carbonate has filled up the skeleton form and incrustated and smoothed over the surface.

The specimens from the Domes represent still another type of the thinolite. The crystals here have uniformly an acute pyramidal form, and are grouped in irregular, divergent positions. Their surfaces are brownish yellow in color and show little of the edges of the parallel plates conspicuous in the variety from the Marble Buttes. They are, on the contrary, nearly smooth, except when covered with warty excrescences, which in some cases are thickly clustered about the edges and extremities. One of these crystals (natural size) is shown in Fig. 11 of

Plate II. On the fracture this variety is found to be nearly as firm and compact as a fine-grained crystalline limestone; in fact, the unaided eye would regard the whole as crystalline throughout. The color on the fracture is slightly yellowish white.

EXAMINATION OF SECTIONS OF CRYSTALS.

In order to get at the true structure of the crystals which have been described it is necessary to resort to sections cut transversely and longitudinally; these reveal the form most clearly and satisfactorily. A cross-section of a crystal like those first described—the open porous variety from the Marble Buttes—is shown in Fig. 2 (natural size). As seen in the figure it is made up of lines in positions parallel to the sides of a square prism, and in addition there are two sets of distinct diagonal lines intersecting at right angles to each other; between these ribs are open spaces. A closer examination of the specimen represented in Fig. 2 shows that the material consists of rhombohedral calcium carbonate, or calcite, of a distinctly granular crystalline structure throughout. The whole presents an open tesellated appearance. The external form of the crystal which yielded Fig. 2 is shown, reduced one-half, in Fig. 6. The point at which it was divided is indicated by a black line. The form is roughly that of a square prism tapering slightly in both directions, but the external form does not conform, in this respect, to the internal structure except at the upper extremity. The irregular edges of the upwardly converging plates are clearly shown in this figure.

A longitudinal section of another crystal (one-half natural size) is shown in Fig. 5. It presents also an open skeleton appearance analogous to that of Fig. 2. As seen in the figure the plates converge upwards on either side of the longitudinal axis, meeting at an angle of approximately 35° . Like the previous case, it consists entirely of purely granular crystallized calcite with only a little mossy covering on the surfaces of the plates. It is to be noticed here that the plates all converge upwards from one extremity of the crystal to the other, and this, as will be remarked later, is almost universally true even in the case of crystals, the external form of which tapers off at both ends.

Another transverse section (natural size) is shown in Fig. 3. It is like Fig. 2 in most respects, except that the square is elongated in one direction and the diagonals meet in a central rib. Moreover, while the skeleton frame-work consists as before of crystallized calcite (left white in the drawing), the intermediate spaces are partially filled up with a secondary deposit of calcium carbonate which is apparently amorphous, and has been deposited in granular form and, too, in lines parallel to the crystalline plates. This subsequent deposition, however, has not gone far, and the general appearance is nearly as open as the one first described. The outline of the crystal which yielded this section is shown in Fig. 7 (reduced one-half). As seen here it tapers gradually

to the terminal edge, forming a sharp extremity. The external form approximates to the true crystalline form of the original crystal, but is somewhat more acute, as shown by the edges of the plates exposed on the surfaces and by the angle at which the plates within converge.

In Fig. 13 another section is given (natural size). This shows much the same tessellated appearance, the structure being essentially the same as in the others described, but the secondary deposition of amorphous calcium carbonate has gone still further, so that as a whole it is more compact. The skeleton ribs parallel to the sides and the diagonals are, however, still very distinct and entirely crystalline. The form of the crystal which gave this section is shown in Fig. 8 (one-half natural size). As seen here it is an acute square pyramid, approximately conforming in outward form to the internal structure. The surface is here no longer open and fretted, as in the others, but nearly smooth, except as it is covered with small wart-like prominences. The color is a dark brown. The line in which the section was cut is shown in the figure.

Still another section is shown in Fig. 14 (natural size), and one which marks a further degree of deposition of secondary calcium carbonate. The crystal from which it was taken had a square form tapering slowly upward, and the surface was covered with small mammillary prominences. The skeleton of crystalline calcium carbonate is here nearly concealed by the added amorphous material, and the outer portion consists of concentric layers of the same substance.

The exterior appearance of another crystal is shown in Fig. 4 (one-half of natural size). As seen, it tapers slightly toward both extremities, and it was cut longitudinally, in the idea that it might be a doubly terminated crystal, but the structure lines all converged toward one end, showing that, like most of the others, the growth was only in one direction. As the surface indicates, the crystalline skeleton has been nearly filled up with amorphous calcium carbonate.

In addition to the sections given and others like them of large crystals, numerous thin sections were also cut transverse and longitudinal to smaller crystals. They revealed under the microscope the same points which the microscopic examination of the larger sections showed—that is, the presence of the same skeleton of crystallized calcium carbonate with the concretionary depositions added to it. The calcite grains are large, each one having a distinct rounded or elliptical outline, and they are packed closely together, with a little brownish amorphous matter between them. Many of them show the rhombohedral cleavage; others show a crystalline nucleus which has apparently grown by the addition of further crystalline matter. The secondary calcium carbonate has generally a concentric or banded structure resembling some kinds of opal.

These sections also show another point of interest, namely, the presence of groups of acicular crystals in parallel position filling more or

less completely the cavities in the skeleton structure, and sometimes projecting into the cavities. These are seen in many cases, and are the general rule, though sometimes absent; they are indicated magnified eight times in Fig. 15. These acicular crystals show uniformly extinction parallel to their prismatic direction, and hence it seems clear that they must belong to an orthometric system. It seems probable that they are aragonite. A chemical examination of an uncovered slide gave results in accordance with this suggestion.

A section of one of the crystals from the Domes is shown in Fig. 12 magnified eight times. To the eye the broken crystal appeared to be crystalline throughout; in the section, however, as examined under the microscope there is seen to be a crystalline frame-work made up of calcite grains, filled in with amorphous matter, and in addition outer layers of banded opal-like carbonate, so that it conforms in general to cases like those before represented. The diagonal lines are here clearly developed, and there are also rectangular lines more or less distinctly indicated. These are illustrated somewhat obscurely in the figures. Other sections illustrated essentially the same relations.

Structure in dissected crystals.—As has been stated, the external form of the thinolite crystals seldom gives the true crystalline form. The process of dissection, however, which has laid bare the skeleton-like ribs which have been described, sometimes results in showing the true pyramidal form of the original mineral. In such cases we may have a series of skeleton crystals, each a hollow pyramid as a cap to the one preceding. This is shown in Fig. 9, which will explain itself, and again in Fig. 10 (both natural size). In another case a mass of the calcareous tufa, showing little structure, has its surface partially covered with pyramidal crystals an inch in length. Each one was a skeleton crystal inclosing a pyramidal crystal, and sometimes several crystals, after the fashion of a nest of pill-boxes. The outer surface of the crystals was incrustated with a moss-like covering, often entirely hiding the form. Two of these are represented in Figs. 16 and 17 (natural size), and another in Fig. 29, Plate III.

THINOLITE FROM MONO LAKE.

The thinolite from the shores of Mono Lake conforms in all essential respects to that which has been described from Pyramid Lake, although on a superficial examination it presents a somewhat different aspect. It belongs in general to the more compact variety, although the same skeleton character appears on the cross fracture, and occasional specimens are nearly as open and porous as those from the Marble Buttes. The common color is light gray to nearly white. Many of the specimens consist of groups of elongated crystals, in which each crystal is built up of an indefinite number of sub-individuals bundled together in parallel position, each of these having an acute pyramidal form more or less dis-

tinct. This is shown in Figs. 19 and 20, Plate III, and even more clearly in Fig. 21; Fig. 24 also shows something of it (all natural size). Groups of sharp, almost acicular crystals in widely divergent positions are also common, and their surfaces are generally studded with rounded warty elevations of subsequently deposited calcium carbonate (see Figs. 23 and 24). The substance of these crystals is frequently perfectly firm and compact, as much so as a very fine-grained white marble, and no evidence of the characteristic structure is seen until a cross-section is cut and polished. In other cases the groups of crystals are so thickly coated with the subsequent deposit that they appear like a mass of stalactites rather than crystalline forms. On the other hand, a cross-section of a composite group of minute parallel crystals, like that in Fig. 21, shows the same open system of rectangular and diagonal ribs represented in Plate II. Fig. 22 represents a section from the extremity of the specimen shown in Fig. 21, both ends of which were sawn across transversely.

THINOLITE FROM WALKER LAKE, AND FROM BLACK ROCK AND SMOKE CREEK DESERTS.

As has already been stated, Mr. Russell has found evidence of a second deposit of thinolite in the Lahontan basin subsequent to the formation of the dendritic tufa. This deposit was apparently only of limited extent. The localities noted are on the shores of Walker Lake and in the Black Rock and Smoke Creek deserts. A few specimens have been placed in the hands of the writer. The specimen from Walker Lake is a little obscure and exhibits the characteristic forms with much less distinctness than the specimens from Pyramid Lake. Many of the crystals have lost their original shape entirely, and others are only faintly suggestive of the square pyramidal form. There are enough, however, which do show this to remove all doubt as to the correctness of identification.

The specimens from the Black Rock Desert are peculiar, in that the nucleus of thinolite crystals passes into a dense stony tufa, which forms a cluster of rosettes about it somewhat like a head of cauliflower. This is shown in Fig. 18 (reduced one-half). The crystals offer no points of special interest, but exhibit the characteristic form distinctly enough.

ORIGINAL CRYSTALLINE FORM OF THE THINOLITE.

The description of the specimens of thinolite given has revealed clearly the crystalline form of the original mineral. Distinct crystals, showing the external form sharply, are, to be sure, rare, but there are many which suggest this form. What is wanting in them, however, is made good by the wonderful process of dissection which has gone on, revealing, as perfectly as could be desired, the true crystalline structure of the original mineral.

All of the forms observed conform to an acute tetragonal pyramid. The section in Fig. 2, showing the system of parallel plates at right angles to each other, is alone evidence that the original crystals belonged to an orthometric system; and further, the diagonal lines, also crossing each other at right angles, fix this system as the tetragonal. The external form, wherever distinct, agrees with this (see Fig. 7; also Figs. 9, 10, 16, 17, 29); so that the question may be considered as definitely settled beyond all reasonable doubt. A form approximating closely to the tetragonal, but belonging to a system of lower symmetry, would also answer the conditions; but everything seems to point to the fact that both the sets of diagonal ribs shown in the figures are similar crystallographic lines, and that the same is true of both sets of rectangular ribs, which can be the case only in the tetragonal system. The measurement of angles leads to the same conclusion, but only an approximate degree of accuracy is attainable. If attention were directed alone to the external pyramidal form, many exceptions seemingly at variance with the tetragonal system might be observed. Many of the pyramidal forms are flattened in the direction of one of the diagonals. This is true both of the skeleton forms and of those which have been rounded out by subsequent deposition. In the former case the explanation is simply that in the direction of one of the diagonals more of the crystal has been dissolved away than in the other, and when this has first happened, and then calcium carbonate has been deposited upon the skeleton, the result has been to produce a form looking like an orthorhombic or monoclinic pyramid, with a wide difference in the pyramidal angle.

The terminal angle of the ideal square pyramid, to which the thinolite is to be referred, can be measured only approximately. The measurement of the external forms of the crystals is extremely uncertain, because the alteration which has taken place, as noted above, has naturally had the result of changing the dimensions of the original form widely. The measurement of the angle given by the structure lines, as shown in Fig. 5, is more reliable, but is also uncertain because of their want of sharpness, and because of the doubt as to whether the longitudinal section has been cut exactly parallel to the vertical axis or somewhat inclined to it. The results given by such forms as those in Figs. 9 and 10 seem a little more trustworthy, but those, too, do not admit of exact measurement. The angle obtained in a number of cases from such dissected crystals, measured over the summit, varied from 26° to 36° , and some forms were even more acute. The most probable result, perhaps, is 35° which, as nearly as can be measured, is the angle of the structure plates, as shown in Fig. 5. In any case the result can be considered as but a mere approximation.

The ideal form, then, may be accepted as that of a tetragonal pyramid or octahedron, measuring over the summit 35° , and consequently having a terminal pyramidal angle of $95\frac{1}{2}^{\circ}$ and a basal angle of 145° .

The corresponding length of the vertical axis is $c=2.24$. It is very probable that two or more acute pyramids, all referable to the same fundamental form, were present in the original crystals; the measurements seem to point to this, and the analogous pseudomorphs after phosgenite, mentioned later, certainly show this variation.

It has already been stated that in all the larger elongated crystals the pyramidal structure is developed in one direction only, this being true even in cases like that of Fig. 4, where the external form would suggest that the crystal had a double termination. The small crystals, however, which have grown more freely, many of them attached in the middle, seem to be complete at both extremities, although the evidence gained of this is not absolutely conclusive.

CHEMICAL NATURE OF THE ORIGINAL MINERAL.

The description of the original crystalline form of the thinolite, so far as it can be made out, is sufficiently complete to give an emphatic negative answer to the question as to the nature of the original mineral. It was *not* gaylussite, nor gypsum, nor anhydrite, nor celestite, nor glauberite, nor, in fact, any one of the minerals which might suggest itself as a solution of the problem. The crystalline form is totally irreconcilable with any one of these. This is so clear, from what has gone before, that the question admits of no argument at all. But more can be said: the original mineral was one which does not appear thus far to have been observed in its natural condition, although, as will be shown later, it probably has occurred abundantly at numerous other localities. Furthermore, a review of all the artificial salts of calcium, sodium, and magnesium has failed to bring to light any one which would satisfy the conditions required.

It seems, therefore, that any explanation of the original condition of the thinolite beds of Lake Lahontan must, at present, rest on hypothetical grounds, and much as a definite solution of the problem is to be desired, it is not now attainable. A few suggestions may not be out of place here, although the full discussion of the subject belongs rather to the geologist who has the whole subject in charge. The open skeleton forms, consisting now of crystallized calcium carbonate, make it seem very probable that the original mineral was a double salt, and that a salt containing calcium carbonate as one of its members. Only on such a supposition is it easy to understand the removal of so large a part of the original material and the leaving behind of these plates of calcium carbonate, marking the original crystalline structure. Whether the original crystals were or were not solid throughout, at the time of their formation, it is not possible to say now with certainty; very probably they varied much at different points in this respect. From the analogy of soluble

salts deposited rapidly from aqueous solutions, it seems likely that open, cavernous forms were common, perhaps the rule. But even supposing this to be true, no one can inspect such groups of skeleton crystals as those from the Marble Buttes without seeing that what now remains is only a part of what originally crystallized out of the saline waters of Lake Lahontan. This fact, coupled with the other just mentioned, that the remaining skeleton consists of crystallized calcite in granular form, gives a very important hint as to the changes which these crystalline beds have undergone. The successive steps may have been as follows: (1) The deposition of crystals as the lake waters evaporated; (2) a change of conditions, *e. g.*, an addition of fresh water to the lake (as supposed by King), leading to the solution of a part of the substance of the crystals and the simultaneous recrystallization of the remaining calcium carbonate; (3) the subsequent and independent deposition of the carbonate, solidifying and coating over the skeleton forms. The conclusion reached by Mr. King⁴ that the original mineral was gaylussite satisfies the requirements tolerably well, for it is then necessary only to explain the removal of the sodium carbonate, and the calcium carbonate remains behind. Unfortunately for this hypothesis, it is impossible to reconcile the forms which now remain, showing how the original mineral crystallized, with the monoclinic form of gaylussite.⁵ Furthermore, Mr. Russell finds other grounds, independent of this crystallographic proof, for the belief that the supposed enormous deposit of gaylussite could not have taken place. But if not gaylussite, what was the original mineral?

It is hardly profitable to go beyond the above suggestion, that it may have been a double salt, containing CaCO_3 , unless the hypothesis can be based upon some observed facts; but fortunately some facts can be pointed to which lead to a possible explanation of the enigma, and which are in any case very suggestive.

The only crystalline forms bearing any close resemblance to the acute tetragonal pyramids of the thinolite, of which the writer has any knowledge, are those of the *pseudomorphs of lead carbonate after phosgenite*,

⁴ Geological Exploration of the Fortieth Parallel, Vol. I, p. 517.

⁵ At the time when Mr. King had this subject under investigation he submitted several specimens to the writer for inspection, and he then gave a qualified assent to the conclusion Mr. King had reached in regard to them. One of these specimens, as Mr. King had noted, showed some crystals which bore a remarkably close resemblance to the well known Sangerhausen pseudomorphs, then generally referred to gaylussite. This similarity suggested identity of origin—a conclusion which (after a further study of the same specimen) the present investigation has confirmed, as noted below—and thus gave apparent support to the gaylussite hypothesis. The other specimens then in hand were somewhat like Fig. 1, on Plate II, and upon the inspection given them—no opportunity was had for careful study—they gave negative results; a certain outward similarity to the elongated crystals of gaylussite from South America (called *clavos*, nails) was noted, but nothing more definite.

first described by Krug von Nidda,⁶ from the zinc mines in Upper Silesia. This similarity in habit and angle is the more striking, as the thinolite form is an unusual one. A number of these pseudomorphs are in the Blum collection, which became the property of the Yale Mineralogical Museum in 1872. They correspond to the description given by Krug von Nidda. They have the form of a square prism, sometimes terminated by a pyramid having an angle over the extremity of about 36° , and occasionally show traces of an octagonal pyramid; other forms show only a very acute square octahedron, with a summit angle of about 13° in one case and 26° in another. One specimen shows these forms imbedded in a white clay. They are now completely altered to compact, fine-granular lead carbonate, except for the presence of an occasional minute nucleus of the original mineral.

The hypothesis to which this resemblance leads is this: that *the original mineral may have been a chloro-carbonate of calcium isomorphous with phosgenite*; that is, a mineral having the composition $\text{CaCO}_3 + \text{CaCl}_2$ isomorphous with $\text{PbCO}_3 + \text{PbCl}_2$, and now altered to CaCO_3 as is the phosgenite to PbCO_3 . The hypothesis, as far as the crystallographic relations are concerned, is a most natural one. The difficulty arises when we consider the peculiar nature of calcium chloride, and hence question whether an anhydrous molecular compound of calcium carbonate and calcium chloride could have been deposited from the waters of Lake Lahontan. Obviously this is a subject for synthetic experiment, and whatever the nature of the original mineral, it ought to be possible to approximate to the conditions under which it was made and so to reproduce it. It is to be hoped that the work now being carried forward by the chemists of the Geological Survey may lead to some decisive results in this direction.

In the mean time it is interesting to note the only case in which, so far as the writer can ascertain, a chloro-carbonate of calcium has been formed. The experiments are described by Fritzsche in the Bulletin of the St. Petersburg Academy, iii, 235, Nov. 30, 1860, and reprinted in the Journal für praktische Chemie.⁷ He states that on evaporating the solution of crystallized calcium chloride, prepared in large quantities for technical purposes, there remained a small amount of a sandy powder, which kept a yellowish aspect so long as the calcium chloride solution was concentrated, but in a dilute solution became finally white. When some of the crystals were placed on a glass slide under the microscope, and then water poured upon them, it was observed that they for a moment were completely transparent and underwent no change; soon, however, the surface became clouded, and then a granular separation took place gradually. As the CaCl_2 was dissolved they entirely lost their

⁶ Krug von Nidda: Ueber das Vorkommen des Hornbleierztes und des Weissbleierztes in den Krystallformen des ersteren in Oberschlesien, Zeitsch. geol. Gesellsch. ii, 126, 1850. See also Blum, Pseudomorphosen, Zweiter Nachtrag, 68.

⁷ J. Fritzsche: Ueber ein Doppelsalz aus kohlen-saurem Kalk und chlorcalcium, Journ. prakt. Chem., lxxxiii, 213, 1861.

transparency, and finally there remained *only a skeleton of calcium carbonate corresponding in form and size to the original crystal*. These fell to pieces when touched, and there resulted minute spherical masses of probably amorphous carbonate. This salt was found to have the composition $2\text{CaCO}_3 + \text{CaCl}_2 + 6\text{H}_2\text{O}$. The crystals were shown by v. Kokscharof to belong either to the orthorhombic or monoclinic system. It is not to be supposed that this salt of Fritzsche is in any way an explanation of the thinolite enigma, and yet his observations are of great interest in this connection. In order to complete the subject the fact may be noted that Berthier⁸ speaks of forming a compound of calcium carbonate and chloride by fusion.

Another hypothesis may be offered as to the composition of the original mineral, viz, that it was a double salt of calcium and sodium, perhaps conforming to the formula $\text{CaCO}_3 + \text{NaCl}$, or better $\text{CaCO}_3 + 2\text{NaCl}$, which, it is possible, might also be isomorphous with phosgenite. This is so purely hypothetical that very little weight can be given to it; still it may not be entirely useless to throw out the suggestion, although various serious objections at once come up to mind. In any case it must be borne in mind that carbonates and chlorides were the salts most likely to be precipitated from the lake water, and calcium and sodium were the prominent basic elements at hand.

RELATION OF THE THINOLITE TO THE SO-CALLED GAYLUSSITE PSEUDOMORPHS OF SANGERHAUSEN AND OTHER LOCALITIES.

The interest connected with the thinolite is much increased by the fact of its relation to the well-known "barleycorn" pseudomorphs from Obersdorf, near Sangerhausen, in Thuringia, one of the most remarkable and enigmatical cases of pseudomorphs ever recorded. These crystals were first described by Freiesleben⁹ in 1827, and at that time referred by Breithaupt¹⁰ to gaylussite. They were early called "natrocalcite" on the mistaken idea that they contained soda. This conclusion has been accepted by most authors since that time, although Des Cloizeaux,¹¹ in 1843, referred them to the variety of celestite called by Haiüy *apotome*, and Kenngott,¹² in 1870, suggested that gypsum might be the original mineral, and Groth,¹³ in 1878, suggested anhydrite. The Sangerhausen

⁸Berthier: Ann. Chim. Phys., II, xxxviii, 253, 1828.

⁹Freiesleben: Isis, xx, 335 *et seq.*, 1827. Mag. Orykt. Sachsen, No. 7, 118 *et seq.*, 1836 (quoted by Blum).

¹⁰Breithaupt: Mag. Orykt. Sachsen, No. 7, 237, 1836 (quoted by Blum).

¹¹Des Cloizeaux: Déterminations des formes primitives et secondaires de la Gaylussite. Ann. Chim. Phys., III, vii, 489, 1843. Observations sur la calcite, *ib.*, p. 494. See also Minéralogie, ii, 119, 1874.

¹²Kenngott: Quoted by vom Rath, Poggendorff's Annalen, Erg.-Bd., v, 442, 1870.

¹³Groth: Min. Samml. Strassburg, p. 142, 1878.

pseudomorphs are described in detail in Blum's work on Pseudomorphs.¹⁴ They occur imbedded in clay as complete crystals, either single or in complex groups formed by two or more crystals, interpenetrating each other; sometimes as many as twenty are united to form a star-shaped group. They average half an inch in length, but occasionally are 1, 2, or even 2½ inches long. The color is generally a pale yellow. They consist of a hard shell, with polished surface, smooth, except for a system of fine markings, and within contain a confused mass of loosely cohering calcite grains. They are represented in Figs. 26, 31, and 32. Dr. E. Geinitz,¹⁵ who has made a special study of them, has observed within a series of zones of harder material parallel to the sides, rib-like, between which the loose calcite grains are inclosed. Similar pseudomorphs have been observed at a number of other localities. Haidinger¹⁶ has described them as occurring in lake deposits in a limestone cave in the Tufna at Hermanecz, near Neusohl, Hungary. This cave contained large quantities of bone remains, especially those of cave bears, and the crystals themselves came from the skull of an *Ursus spelæus*.

G. Rose¹⁷ announced the occurrence of similar pseudomorphous crystals at the village Kating, in the neighborhood of Tönningen, in Silesia. They were found here in marl, 6 or 7 feet under the soil, and resembled those from Sangerhausen closely, except that they did not have the smooth, hard shell; one of these is represented in Fig. 38. Still other localities are the east coast of Australia, mentioned by Volger¹⁸ and Blum;¹⁹ in the clay at the Krummer Horn, on the Dollart, in North Friesland, as mentioned by Vom Rath;²⁰ and from the Zechstein, between Amt-Gehren and Königsee, at the base of the Thuringian forest, as noted by E. E. Schmid.²¹ To the above should probably be added Glendon, in New South Wales, and Astoria, Oregon, mentioned by J. D. Dana.²² The first of these last-mentioned localities afforded in clay pseudomorphous crystals of granular crystallized calcite, dark in color, and having a rough surface, and up to 20 inches in length, but usually 3 or 4 inches; often in star-shaped groups of two, four, or more crystals. At the second were obtained crystalline forms, also of compact granular calcite, and of an irregular quadratic or rhombic form, sometimes much

¹⁴ Blum: Pseudomorphosen, p. 18, 1843.

¹⁵ E. Geinitz: Studien über Mineral-Pseudomorphosen. Inaug. Diss. Stuttgart, 1876, p. 35.

¹⁶ Haidinger: Ueber eine neue Localität von Gay-Lussit-Pseudomorphosen. Poggendorff's Annalen, liii, 142, 1841.

¹⁷ G. Rose: Poggendorff's Annalen, liii, 144, 1841.

¹⁸ Volger: Erde und Ewigkeit, die natürliche Geschichte der Erde, etc., p. 497, 1857, Jahrb. Min., 1864, 339.

¹⁹ Blum: Pseudomorphosen; dritter Nachtrag, p. 13, 1863; vierter Nachtrag, p. 8, 1879.

²⁰ G. vom Rath: Calcitkrystalle (Froiesleben) am Dollart in Ostfriesland, Poggendorff's Annalen, cxxxv, 588, 1868.

²¹ E. E. Schmid: Sitz. med.-nat. Ges. Jena, July 9, 1880.

²² J. D. Dana: Geology, U. S. Exploring Expedition, 1849, p. 481 and p. 656.

flattened. Figs. 34, 35 (Oregon), and 36, 37 (New South Wales) are copied (reduced one-half) from those given in the report mentioned. Thin sections of both occurrences showed only a compact granular structure, nothing resembling Fig. 2 or 3. P. W. Jereméjew²³ speaks of aragonite pseudomorphs (after celestite) from the sea bottom near Archangelsk, Russia, which resemble the Sangerhausen crystals; they are brought up by the fishermen, and believed to have a remarkable healing power.

The suggestion of the probable identity of the Sangerhausen crystals with the Lake Lahontan thinolite may at first thought seem worthy of little attention. It is certainly true that the two occurrences are most diverse in many of their forms. And yet, on the other hand, it is easy to find crystals of thinolite which bear a marvelously close resemblance to the Sangerhausen pseudomorphs. In the confused mass of small interpenetrating crystals, which have been described as coming from the Marble Buttes, Pyramid Lake, many of the individuals have the same quadratic or rhombic section, the same curved and tapering form, and the same method of grouping. Among the crystals from Mono Lake, too, are many which have a like resemblance. One specimen in particular, collected by Mr. King from Pyramid Lake, exhibits the similarity most strikingly; it was this specimen which, as already mentioned, had most weight in leading Mr. King to his conclusion (*l. c.*, p. 518) that "the entire thinolite formation, with all its enormous development, its extent of hundreds of miles, its thickness of 20 to 150 feet, was nothing less than a gigantic deposit of gaylussite crystals." This specimen shows a number of acute tapering pyramidal crystals closely resembling the Sangerhausen crystals. Two of these, which project into a little cavity, are represented in Figs. 27 and 28. The larger of these is nearly square in section, and the other is distinctly rhombic; both of them show on their surface markings similar to those which characterize the Thuringian pseudomorphs, as shown in Figs. 32 and 33. It should be added, too, that in the groups of crystals from Mono Lake are to be found some which have a hard, shell-like exterior, and which bear similar markings. These are, in the opinion of the writer, not striations characteristic of the original mineral (as suggested by Des Cloizeaux), but structure forms of the pseudomorphous calcite, analogous to the vicinal prominences of scalenohedral or rhombohedral form, which calcite crystals often show. Compare the figures given by Scharff²⁴ in his memoir on calcite; compare also Figs. 25 and 33 with 26; also 27, 28, and 30 with 31 and 32.

Were a comparison, then, to be made only between these pseudomorphs and certain selected crystals of thinolite, exceptional in their perfection

²³ P. W. Jereméjew: *Zeitsch. Kryst.*, vii, 204 (Verhandl. Russ. Min. Ges. St. Pet., II, xvii, 319, 1882).

²⁴ Scharff: Ueber den inneren Zusammenhang der verschiedenen Krystallgestalten des Kalkspaths. *Abhandl. Senck. nat. Ges.* x, 1876.

of form, no one could hesitate to decide that there was every probability of their having had the same origin, especially when it is remembered that chemically they are identical. This conclusion is not invalidated by the fact that the thinolite crystals are developed in other forms in which this resemblance is not observable. It may be objected that it is difficult to believe that the original mineral, in the case of the Sangerhausen pseudomorphs, for example, belonged to the tetragonal system. It is true that many of these crystals are most decidedly rhombic in appearance. One in the writer's hands, for example, afforded approximate terminal pyramidal angles of 85° and 127° ; but, on the other hand, of the crystals which the writer has had an opportunity to examine—upwards of fifty in number—three-fourths vary but little from the tetragonal type. Of course no trustworthy measurements are possible, because of the tapering, rounded form. The differences observed, then, are believed to be due to the pseudomorphous process through which they have passed, involving the solution and removal of part of the original substance and the deposition of more or less calcium carbonate subsequently. The variation from the tetragonal type in the acute pyramidal forms of the thinolite is as great as in the foreign crystals which they so closely resemble, and the true form of the former would be doubtful were it not for the dissected crystals in which the tetragonal structure is so clearly shown. Note here the observations of Dr. E. Geinitz on Sangerhausen crystals (p. 26) showing the presence of ribs within parallel to the sides; these appear to be analogous to the ribs as shown in Figs. 2 and 3, etc.

The writer is of the opinion, then, that the original mineral, deposited on an enormous scale in the Lahontan Basin, was, in all probability, the same as that which formed the isolated crystals in the Sangerhausen clay, in the marl at Kating, and in the skull of the cave bear at Hermanecz; and if this is the case, then whatever hypothetical conclusion is reached in regard to the origin of the thinolite must apply also to the other cases. It is on this account that, in view of the importance of the subject under discussion, it has seemed worth while to consider these foreign pseudomorphs at such length. Unfortunately this most interesting problem can be considered as only half solved.

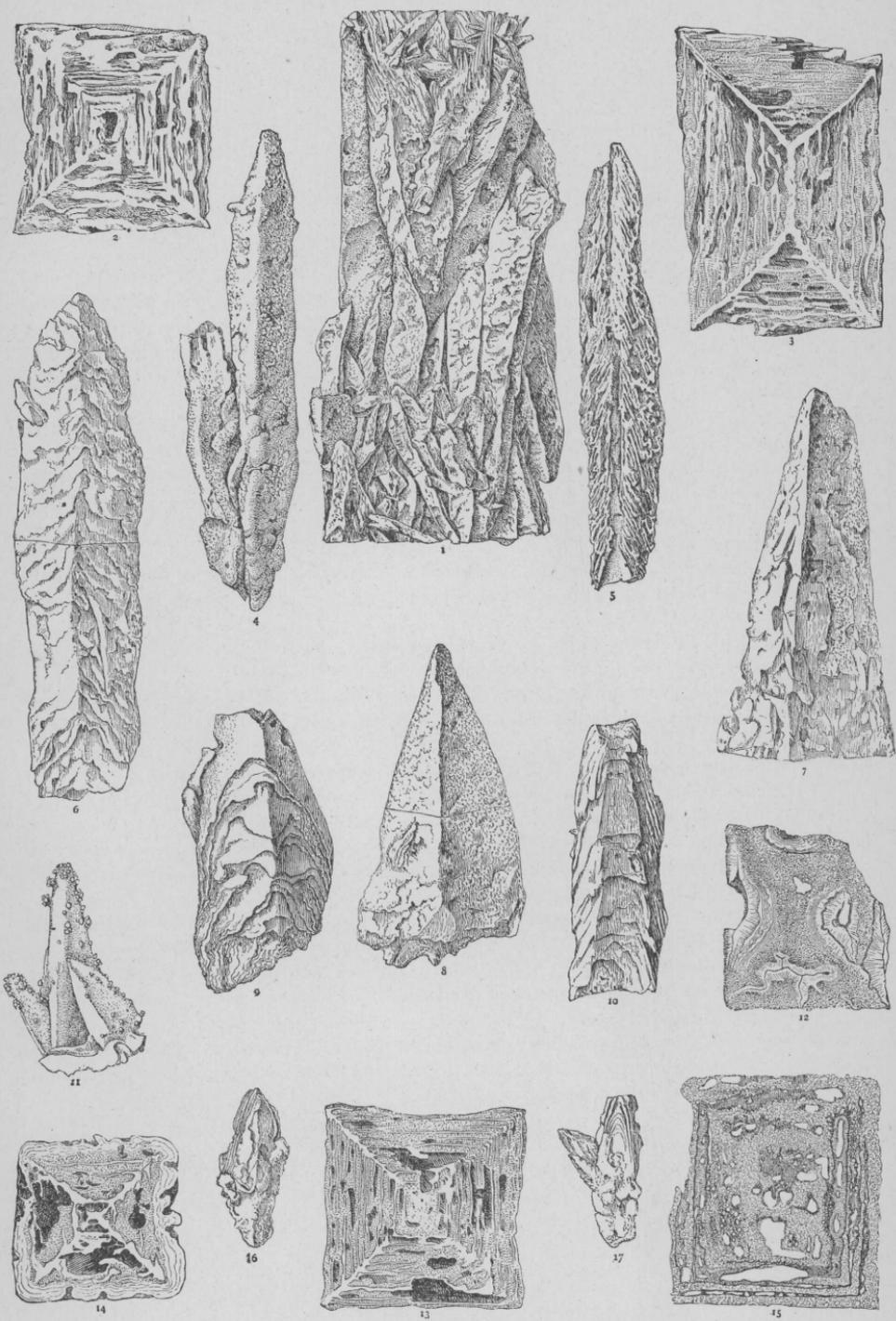
In concluding this paper the writer would express his appreciation of the kindness with which Mr. Russell has assisted him at every point in his investigations:

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PLATE II.

- FIG. 1. Group of thynolite crystals from Marble Buttes, Pyramid Lake (reduced one-half); open porous variety.
- FIGS. 2 and 3. Transverse sections, natural size; Fig. 2, open skeleton form; Fig. 3, partially filled up with amorphous CaCO_3 . These sections show the system of rectangular (square) and diagonal ribs, which consist of granular crystalline CaCO_3 .
- FIG. 4. External appearance (reduced one-half) of a single crystal, with part of a second, the internal structure of which shows that it has but a single termination; the comparatively smooth surface is due to the secondary deposition of CaCO_3 .
- FIG. 5. Longitudinal section of open variety (reduced one-half), showing the two systems of plates converging upward at an angle of about 35° .
- FIG. 6. Complete crystal (reduced one-half) which yielded the section in Fig. 2; the line in which the section was made is indicated.
- FIG. 7. Acute pyramidal crystal (reduced one-half) which yielded at its base the section given in Figure 3.
- FIG. 8. Square pyramidal crystal (reduced one-half) which gave, at the point indicated, the section in Figure 13; the surface has been made smooth by subsequent deposition of CaCO_3 .
- FIGS. 9 and 10. Skeleton crystals (natural size) showing cap-in-cap structure, and thus revealing the true square pyramidal form of the original mineral.
- FIG. 11. Crystals (natural size) from the Domes, Pyramid Lake; the surface smoothed over by subsequent depositions of CaCO_3 , with sproutings from the edges and extremities.
- FIG. 12. Section (magnified 8 times) of a crystal from the Domes, like that in Figure 11, showing a diagonal and rectangular frame-work, partly crystalline, granular, partly amorphous, with layers of secondary carbonate opal-like in structure.
- FIG. 13. Section (natural size) of the crystal shown in figure 8, cut transversely at point indicated; it shows the same frame-work of granular crystalline carbonate, partially filled in with secondary CaCO_3 .
- FIG. 14. Section (natural size) showing the usual frame-work, partially filled in with secondary CaCO_3 , and with successive layers also around the outside.
- FIG. 15. Section of a crystal from the Marble Buttes, magnified 8 times, and showing the structure lines of crystallized carbonate, and also in the cavities the acicular crystals of aragonite. (?)
- FIGS. 16 and 17. Small pyramidal crystals (natural size), showing by dissection the cap-in-cap structure, and thus, like Figs. 9 and 10, revealing the true pyramidal form of the original mineral.



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PLATE III.

- FIG. 18. Thinolite from Black Rock Desert (reduced one-half), the individual crystals running off into a compact stony tufa, so that the mass from above has a cauliflower-like form.
- FIGS. 19 and 20. Thinolite from Mono Lake, California (natural size), showing the grouping of the composite crystals.
- FIG. 21. Thinolite from Mono Lake (natural size), fragment of a large composite crystal, made up of small acicular crystals in parallel position.
- FIG. 22. Transverse section of the crystal represented in fig. 21, showing the same skeleton structure distinct in crystals from Pyramid Lake (Figs. 2, 3, etc.).
- FIGS. 23 and 24. Group of thinolite crystals from Mono Lake (natural size), showing the acicular form, and also the way in which the crystals are coated over with secondary carbonate.
- FIG. 25. Group of small crystals (magnified 4 times) from Mono Lake, showing the same method of grouping common in the Sangerhausen pseudomorphs, as shown in Fig. 26.
- FIG. 26. Group of Sangerhausen pseudomorphs (natural size); compare Fig. 25.
- FIGS. 27 and 28. Isolated thinolite crystals (magnified twice), showing resemblance in form and surface marking to Sangerhausen crystals; compare Figs. 31 and 32.
- FIG. 29. Thinolite crystal (natural size), showing cap-in-cap pyramidal structure, similar to Figs. 16 and 17, Plate II.
- FIG. 30. Thinolite crystal (magnified 4 times), showing resemblance in form to the Sangerhausen pseudomorphs; compare with Figs. 31, 32, and 38.
- FIGS. 31 and 32. Single Sangerhausen crystals, showing form and external markings; fig. 31, natural size; Fig. 32, magnified twice.
- FIG. 33. Group of small thinolite crystals (magnified 4 times); compare with Fig. 26
- FIGS. 34 and 35. Pseudomorphous crystals, consisting of granular calcite from Astoria, Oregon, copied (reduced one-half) from figures by J. D. Dana in the Geology of U. S. Exploring Expedition, p. 656.
- FIGS. 36 and 37. Pseudomorphous crystals, consisting of granular calcite, from New South Wales; copied (reduced one-half) from figures by J. D. Dana in the Geology of the U. S. Exploring Expedition, p. 481.
- FIG. 38. Pseudomorphous crystal from Kating, Silesia (natural size).



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