ZEOLITES FROM RITTER HOT SPRING, GRANT COUNTY, OREGON

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INTRODUCTION

The minerals described in this paper were collected in June, 1915, by D. F. Hewett while engaged in making a geological reconnaissance of a region lying west of the Blue Mountains in Oregon for the United States Geological Survey. Recently a study of the minerals was undertaken by E. V. Shannon, of the United States National Museum, who has done the crystallographic and microscopic work and part of the analyses. The remainder of the analyses were made by Forest A. Gonyer. Even though some of the minerals found are uncommon in the United States and are well developed in this area, the study was first undertaken to throw light on the paragenesis of the zeolites, rather than to investigate the characters of the minerals themselves. The lapse of time between the field study and laboratory investigation leaves some doubt that highly satisfactory conclusions regarding the paragenesis have been reached, though the results seem worthy of presentation.

OCCURRENCE OF THE ZEOLITES

By D. F. Hewett

Surface features.—Ritter Hot Spring lies in sec. 6, T. 8 S., R. 30 E., Willamette meridian, Grant County, on the north side of the Middle Fork of John Day River, and about 45 miles north of John Day on the road from that town to Ukiah, Umatilla County. In this region the three main forks of John Day River flow generally

northwest in narrow valleys that lie from 1,000 to 1,500 feet below the adjacent rolling uplands. Locally the main roads follow the river valleys, but travel northward is difficult. If the spring were more accessible, it could form the basis of a popular resort.

Pre-Tertiary rocks.—The stratified rocks exposed at the surface in the region are Carboniferous and Triassic and include limestones, argillites, and quartzites. These are intruded successively by gabbro, peridotite (now largely altered to serpentine), and several varieties of granite, all of the pre-Cretaceous age.[1] During late Mesozoic time these rocks were extensively eroded, so that the region west of Blue Mountains was reduced to low relief. Doubtless some of these rocks underlie the area near Ritter Hot Spring at no more than 1,000 feet below the surface.

Tertiary rocks.—The rocks of Tertiary age in the region include a wide range of volcanic tuffs and flows separable on lithologic and structural bases into five formations (ascending order): Clarno and John Day formations, Columbia River basalt, and Mascall and Rattlesnake formations.[2] Ten miles east of Ritter the Columbia River basalt rests on pre-Cretaceous altered gabbro, but 30 miles west the other Tertiary beds attain a maximum thickness of 5,000 feet. Only the Columbia River basalt flows and associated scoria outcrop near Ritter, and probably none of the earlier Tertiary rocks separate the basalt from the underlying pre-Cretaceous rocks.

The Columbia River basalt is well exposed on the walls of the Canyon of the Middle Fork of John Day River, which is 1,300 feet deep at Ritter. This thickness is made up of many flows, each of which displays a dense columnar phase overlain by vesicular phase and more or less scoria. The columnar phase is dark greenish black, but the vesicular phase and scoria are mingled dark green and brick red. Most of the flows range from 50 to 125 feet in thickness. In the small area shown in Figure 1 only three flows are exposed, a partial section of which is given below:

Section of Columbia River basalt at Ritter Hot Spring, Oreg.

	Thickness
Upper flow, vesicular and scoria phases.	
Upper flow, columnar phase_____feet__ 15–20	
Middle flow, vesicular phase_____do____ 30–40	
Middle flow, columnar phase_____do____ 15–25	
Lower flow, vesicular and scoria phases_____do____ 50	
Lower flow, columnar phase.	

[1] Lindgren, W., The Gold Belt of the Blue Mountains of Oregon: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 561–776, 1901.
  Pardee, J. T., and Hewett, D. F., Geology and mineral resources of the Sumpter quadrangle: Oregon Bur. of Mines and Geology, vol. 1, No. 6, pp. 7–128, 1914.
[2] Merriam, J. C., A contribution to the geology of the John Day Basin: Univ. of California, Dept. of Geol., Bull., vol. 2, pp. 269–314, 1901.
  Collier, A. J., Geology and mineral resources of the John Day Basin: Oregon Bur. of Mines and Geology, vol. 1, No. 3, pp. 1–47, 1914.

The basalt has not been studied microscopically, but doubtless its mineral make-up is that generally characteristic of the rock in northern Oregon.

Although the basalt flows appear to be nearly horizontal over a large area, observations made during this investigation indicate that
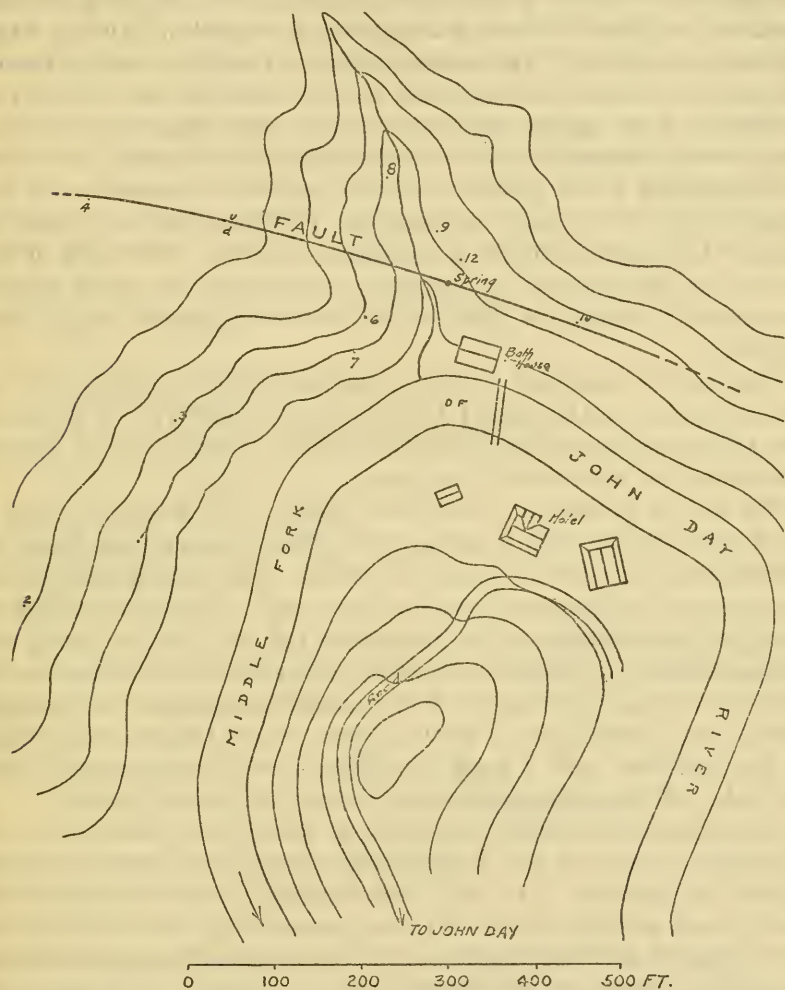

FIG. 1.—SKETCH MAP OF RITTER HOT SPRING AREA, GRANT COUNTY, OREG.   CONTOUR INTERVAL APPROXIMATING 20 FEET

there are a number of gentle anticlines which trend northwest, and a few faults of small displacement roughly parallel to the anticlines. Ritter lies near the crest of a gentle anticline that plunges northwest, and the spring issues from a fault that trends north of west, along which the flows on the south side have dropped about 20 feet.

No intrusive rocks younger than the Columbia River basalt were noted in the region. In the Blue Mountains the only late Tertiary intrusive rocks noted [3] were dikes of olivine basalt.

Hot springs.—So far as the writer could learn in the region, the only hot springs known on the upper parts of the John Day River are at Ritter and that which lies in sec. 15, T. 13 S., R. 30 E., 3 miles northeast of Mount Vernon and 32 miles due south of Ritter. Only the first was visited. The present outlet of the Ritter spring lies on the fault referred to, 32 feet above the river and 100 feet north of it. Doubtless in an earlier period the outlet was higher but has been progressively lowered as the river has carved its channel. The flow was estimated at 35 gallons a minute and the temperature at the outlet is 110° F. A few bubbles of gas rise from the outlet and the odor of hydrogen sulphide is noticeable near by. The taste of the water is mildly alkaline. No analysis is available but where it flows over rocks it deposits a thin film of calcium carbonate and a little sulphur.

The zeolites described in the second part of this paper occur in two ways, (1) on the line of fault referred to and (2) in the vesicular and scoriaceous phase of the lower flow. Only traces of zeolites were noted in the two overlying flows.

The fissure is separable into three parts. The southwest part is filled with stilbite, 4 to 6 inches wide, which is separated from the central part by 7 feet of unaltered basalt. The central part shows, in succession beginning at the southwest wall, a layer of stilbite as much as three-fourths of an inch thick (pl. 2b), which locally envelops angular fragments of calcite; a layer of scalenohedrons of clear pale yellow calcite, 4 to 6 inches thick; a layer of arborescent calcite 1 to 3 feet thick; a layer of clear yellow calcite, and, finally, on the northeast wall a layer of stilbite, 2 to 6 inches thick. Here the order of deposition appears to be calcite, stilbite, calcite.

In the scoria over the lowest flow, at locality 12, analcite is most abundant in area 10 feet in diameter. Here good crystals rest on a layer of mesolite. (Pl. 2a.) At locality 9 some vesicles in the scoria show scalenohedrons of calcite overlain by rhombs of chabazite, which in turn are overlain by fibers of mesolite, and others are completely filled with fibrous mesolite. At locality 8 fragments of scoria are covered with a layer of thomsonite one-fourth inch thick. (Pl. 1c.) This mineral is abundant here but was not noted elsewhere. Near by, veinlets in the flow show (1) a layer of mesolite, (2) rhombs of calcite, (3) milky opal which fills the remaining voids. Opal was not observed elsewhere. South of the fissure, at locality 6, in the upper part of the vesicular zone of the lowest flow,

there are separate vesicles filled with calcite, with chabazite, and with mesolite. Others show analcite on chabazite, and still others, stilbite on chabazite. Near by, at locality 7, there are vesicles filled respectively with calcite and chabazite as well as others showing the following succession: Calcite, chabazite, pseudomesolite, and stilbite. At locality 1 some of the vesicles near the top of the lowest flow are filled with calcite, others with chabazite, and still others with mesolite. At locality 2 some of the vesicles at the top of the middle flow are filled with chabazite; others show crusts of mesolite on calcite.

Paragenesis—In many places near the spring, as noted above, certain zeolites occur in abundance but not associated with other zeolites. There are summarized below the order of deposition of the zeolites and other minerals where two or more are associated and their relations are clear, the numbers indicating the localities shown on the map.

1. Chabazite, mesolite (or pseudomesolite).
2. Calcite, mesolite.
6a. Chabazite, analcite.
6b. Chabazite, stilbite.
7. Calcite, chabazite, pseudomesolite, stilbite.
8. Mesolite, calcite, opal.
9a. Calcite, chabazite, pseudomesolite.
9b. Mesolite, pseudomesolite.
10 (fissure). Calcite, stilbite, calcite.
12. Mesolite, analcite.

From this summary it is clear that there is not a simple order of deposition for the entire area in which each mineral appears but once. On the other hand, if the minerals of the fissure be ignored the simplest succession indicated is as follows:

1. Calcite ($CaCO_3$).
2. Chabazite ($CaO.Al_2O_3.4\,SiO_2.6H_2O$).
3. Mesolite ($[CaO, Na_2O].Al_2O_3.3\,SiO_2.3H_2O$).
4. Pseudomesolite ($[CaO, Na_2O].Al_2O_3.3\,SiO_2.3\,H_2O$).
5. Analcite ($Na_2O.Al_2O_3.4\,SiO_2.2\,H_2O$).
6. Stilbite ($CaO.Al_2O_3.6\,SiO_2.6\,H_2O$).
7. Opal (SiO_2+H_2O).

This sequence does not take into account thomsonite which, though abundant in one locality, is not associated with another zeolite. It would seem that in the area outside of the fissure there was a tendency for the least siliceous minerals to be deposited first and the most siliceous last. Unfortunately, the fissure contains but two minerals, one of which, calcite, is repeated, and the sequence does not confirm the conclusion stated above.

Genesis.—The association of the zeolite-bearing areas, the fault fissure and the active hot spring indicate a genetic relation between them. The age of the fault is obscure, but it was probably formed

in late Pliocene or early Pleistocene time. No intrusive rocks of assured late Pliocene or Pleistocene age are known in the region, so that no close connection between the hot spring and intrusive rocks can be shown. Doubtless the hot spring once reached the surface several hundred feet or even more above its present outlet and the zeolites were deposited by it. An attractive hypothesis assumes that the minerals with increasing silica content were deposited during a period of rising temperature of the waters and that the final calcite in the fissure represents the latest mineral of the cooling stage.

DESCRIPTION OF THE MINERALS

By EARL V. SHANNON and FOREST A. GONYER

DIABANTITE

In many of the specimens the first lining of the amygdaloidal cavities consists of a very thin layer of deep olive green to greenish-black material, of waxy appearance and dull luster, which resembles a clay mineral. This dark mineral preceded the zeolites in all cases where it occurs and lines some vesicles which contain no other mineral. The layer is seldom more than a fraction of a millimeter in thickness, and the material is not present in amount sufficient for analysis. The thickest crust of it observed lined the small cavity containing the zeolite described as levynite. Under the microscope the dark mineral shows a micaceous, aggregated structure and consists of small plates either interwoven or arranged in fan-shaped groups and spherulites. It has fairly high birefringence and greenish-yellow color. Plates on edge show parallel extinction with faint plechroism in greenish brown parallel to the fibers and brownish green across the plates. The elongation is positive. No interference figure could be obtained, but since plates lying on the base are dark in all positions between crossed nicols it is believed that the axial angle is near zero and the mineral optically negative. The refractive index is variable, but the mean index of most of the grains is between 1.590 and 1.600.

Though this mineral resembles some of the high-iron varieties of the clay mineral beidellite, the optical properties are somewhat nearer the chlorites diabantite and delessite, which are commonly formed in amygdaloidal cavities of basic igneous rocks in association with zeolites.

LEVYNITE ?

A single small specimen of a white glassy zeolite not in amount sufficient for analysis could not be satisfactorily identified, although it may, wholly or in part, consist of levynite. The properties obtained for this mineral are somewhat contradictory and its positive identification must await the finding of additional material.

The specimen is contained in a piece of greenish, rather coarsely crystalline basalt which appears fresh and unaltered, and contains a few sparsely scattered vesicles of nearly spherical form. The smaller of these are empty except the thin lining referred to diabantite. The largest cavity, however, nearly 2 centimeters across, contains a thicker layer of diabantite, and a filling of tabular crystals of the white zeolite. The crystals are transparent, colorless, and are as much as 1 millimeter thick by 8 millimeters broad. Though the centers are glassy and transparent there is a narrow border, visible where the crystals are broken, [across] which parallels the basal faces and is whiter, less transparent and has a cross-fibrous silky appearance.

When the crystals are crushed and examined in powder under the microscope, grains broken across the plates show the border to have a cross-striated appearance and higher birefringence than the cores, although the border is continuous with the central part and uniform with it in extinction. Many grains show basal cleavage and a striped appearance suggesting the polysynthetic twinning in a plagioclase. Although the optical properties are variable and confusing, a majority of the grains seem to be optically positive ($+$) with 2V small, marked dispersion r<v, and the indices of refraction $\alpha=1.489$, $\beta=1.491$, $\gamma=1.494$, all ±0.002.

A tabular crystal selected from the specimen and embedded in an oil of index 1.490 appeared homogeneous and dark between crossed nicols. It was uniaxial and negative with the optic axis perpendicular to the basal face. The index $\varpi=1.493\pm0.002$. These features agree with the optical properties of levynite.

Although the uniaxial character, if coinciding with the external form would indicate a hexagonal or tetragonal mineral—and the specimen looks like the tabular forms of the minerals of the chabazite group—this symmetry could not be confirmed. The crystals are not suited for crystallographic study. A single very unsatisfactory crystal which gave a few approximate measurements on the goniometer had faces of what appeared to be two pyramids with rho (ρ) angles of 45° and 58° approximately and with phi (ϕ) angles 45° apart. These appeared hemimorphic and twinned on the basal plane. Edingtonite is the only zeolite belonging to such a symmetry class and the mineral is certainly not edingtonite.

If collectors visit the locality and make extensive collections, sufficient material of this character will probably be found to permit a complete investigation. Until then its identity must remain in doubt.

CALCITE

Calcite is widespread but is neither abundant nor of unusual character or quality in the Oregon collection. It occurs as rhom-

bohedral crystals of poor luster and imperfect form as the first deposit in cavities containing later mesolite, pseudomesolite and stilbite. In other very similar specimens the calcite has steep scalenohedral form. The dense fibrous mesolite crust closely coats the calcite and, when broken away preserves perfect molds of the calcite crystals. Some of these molds are 4 or 5 centimeters on an edge. The calcite is colorless to pale brownish and when broken shows brilliant cleavage surfaces. In a lot of specimens which contain broad crusts of stilbite such rhombohedral crystals of calcite occur both under and above the stilbite crust in such manner as to indicate that the calcite is of two generations.

Another small lot of calcite specimens consists of arborescent masses of very small, steep rhombohedra aggregated in parallel position. The calcite is white except where stained by soil or algae. The only associated mineral is pseudomesolite in scattered cottony tufts resting upon and evidently later than the calcite.

HEULANDITE

In the specimens in which thomsonite occurs as crusts lining large open spaces in a slaggy, often highly vesicular and altered basalt, the smaller cavities, up to 5 millimeters across, are lined with a crust about 0.5 millimeter thick of opaque-looking white crystals of another mineral. Most of the smaller cavities have open centers but a few of them have a solid central filling of bladed thomsonite. The symmetry of the white crystals could not be made out. Some of them look like chabazite twins, others look like small trapezohedra of analcite, and still others suggest portions of complex phillipsite-like twins. Although lustrous without, these crystals are porous within and somewhat skeletal as though partly dissolved out. Frequently the crust rests on a thin layer of waxy greenish clay. When the white crystals are crushed and examined under the microscope the grains lie on a perfect cleavage face which is perpendicular to the acute bisectrix. The mineral is biaxial and positive, with 2V small to medium. An occasional grain shows a dividing line on either side of which the mineral differs in extinction showing that the crystals are more or less sectored. The index of refraction, β, is 1.500.

These optical properties are in close agreement with heulandite although the mineral looks unlike heulandite in the specimen. The material is granular and finely aggregated making optical measurements difficult. It seems probable that this is heulandite which is secondary and pseudomorphous after some other zeolite, possibly harmotome or phillipsite. Careful qualitative tests gave negative results for potassium and barium. In age relations this pseudomorphous heulandite is known to be younger than the greenish clay mineral and older than the thomsonite.

Normal heulandite occurs in the collection under discussion but rarely and as very thin crusts or druses lining amygdules. This heulandite was seen to be overlain by stilbite and chabazite in different specimens. Since the mineral preceded chabazite it was deposited very early in the series and is probably the oldest of the zeolites now found in the specimens. The little crystals have the usual form and are colorless and glassy with pearly luster on the (010) face.

MESOLITE

Two minerals which are conspicuous in a considerable number of the specimens of the Ritter Hot Springs collection occur in intimate relation to each other; are very similar in their fibrous structure and appearance; and, as shown by analysis of carefully selected and optically proven samples, are practically identical in composition. Nevertheless these two minerals are sharply distinguished from each other optically and it has been necessary to consider them as two distinct minerals. One seems quite certainly to be mesolite of normal character. The other is described below as pseudomesolite, although it presents some small differences from the material described by Winchell under that name.

The analyzed sample of mesolite is the cast of the interior of a cavity about 5 centimeters across and similar in character to the specimen illustrated. (Pl. 1b.) The first deposit in this cavity was calcite in crude, nearly colorless rhombohedra up to 2 centimeters across. Upon the calcite crystals lies a layer of compact fibrous zeolite which for the first 3 to 5 millimeters has a silky luster and dense texture. Beyond this zone the fibers diverge, are free, and are stained brownish. Entangled in the free fibers and penetrated by them are rude crystals of stilbite averaging 3 by 5 millimeters in size. None of the minerals completely lined the cavity and in different parts of the specimen either calcite, the fibrous material, or stilbite may rest against the wall.

Optical study proves that there are two distinct minerals included in the fibrous material. The densest compact-fibrous material shows a moderately low birefringence and finely fibrous, nearly parallel structure, and though there is a suggestion of slightly inclined extinction, it could not be proven owing to the small inclination and the low birefringence. The elongation of the fibers is Y and their apparent elongation therefore changes from positive to negative alternately as they are rolled between crossed nicols under the gypsum plate. The mean of refraction index, β, is about 1.517 ± 0.002 (variable). Aggregates of fibers give, when in a position to show maximum birefringence, a confused figure probably of the obtuse bisectrix with negative elongation, whereas those in position to give lowest birefringence have positive elongation. These

features would seem to indicate a biaxial positive mineral with 2V small and, assuming the direction of elongation to be parallel to the c axis, $c = Y$. Except in that the index of refraction is approximately 0.01 higher, the optical properties of the mineral agree with those given for mesolite in Larsen's tables.[4]

At a sharp line about 3 millimeters from the base of the zeolite layer it becomes more glassy, coarser, and quickly diverges into free fibers. Under the microscope these fibers differ from the more compact material in having lower birefringence and slightly lower index of refraction, β being about 1.512 ± 0.002, with the birefringence approaching $0°$. The elongation of these free fibers is Z, and they are positive in all positions—an easy method of distinguishing them from mesolite. The optical properties of the mineral agree with those of okenite but, as shown by analysis of a sample from another specimen having identical optical properties, the composition is identical with that of mesolite. This mineral is described below as pseudomesolite. Each of the free needles of this specimen has a narrow border of a distinct, undetermined mineral of high birefringence, higher indices of refraction, and positive elongation.

The calcite breaks cleanly away from the other minerals, leaving rhombic molds in the mesolite crust. As it was impossible to separate the two fibrous zeolites by hand picking, they were crushed together, screened between 40 and 100 mesh sieves, and run several times through bromoform-methylene iodide heavy solution. The sample thus prepared consisted almost entirely of the pure material of Y elongation, here called mesolite, with only a very little of the material of Z elongation, here referred to as pseudomesolite. This sample was analyzed with the following results:

Analysis and ratios of fibrous mesolite

Constituent:	Per cent			Ratios
SiO_2	42. 02	0. 697	0. 697	0. 92×3
Al_2O_3	28. 94	. 283	. 283	1. 12×1
CaO	10. 46	. 187		
MgO	. 06	. 001	. 270	1. 07×1
Na_2O	3. 24	. 052		
K_2O	1. 92	. 020		
H_2O above 125° C	13. 20	. 732	. 768	1. 02×3
H_2O below 125° C	. 64	. 036		
	100. 48			

These results give the mesolite formula commonly adopted with

$$(Ca,Na_2)O.Al_2O_3.3SiO_2.3H_2O.$$

The ratio between Ca and Na_2 is nearly 2:1, so that the formula may be expanded to

$$2CaO.Na_2O.3Al_2O_3.9SiO_2.9H_2O.$$

[4] Esper S. Larsen. Optical determination of the nonopaque minersls : U. S. Geol. Survey Bull. 679, p. 208, 1921.

In the specimens at hand the mesolite is confined to one lot and is neither so abundant nor so varied in habit and associations as pseudomesolite. The specimen illustrated in Plate 1 is very similar to the one from which material for analysis was taken. In the illustrated specimen the broad crude crystals of calcite are coated with a compact layer of the white mesolite about 2 millimeters thick, consisting mainly of fibers with elongation Y and an index of refraction of about 1.520. Mixed with this is more or less material with the optical properties of the pseudomesolite. The central part of the specimen is a cavity loosely filled with free fibers of pseudomesolite with almost zero birefringence, positive elongation, and an index of 1.510. These fibers also have a narrow border of some mineral of high birefringence and higher refractive indices. Much of the mesolite appears to be in polysynthetic twins.

Other specimens show mesolite in fibrous masses, the fibers up to 1 centimeter long, radiating from sharp scalenohedral crystals of calcite, and terminating in free fibrous crystals in the cavities. The fibrous crystals are truncated by a bright basal plane, but it was found impossible to obtain any signals from them on the goniometer. One specimen shows considerable amounts of chabazite, in colorless masses with only a suggestion of crystal form, which is believed to have been deposited later than the mesolite. Adjacent small amygdules are filled with granular chabazite and contain none of the fibrous zeolites. Another specimen has the two fibrous zeolites overlain by a considerable amount of stilbite. In this specimen the zeolites preserve molds of rhombohedral calcite crystals 5 centimeters on an edge.

The mesolite is soluble in 1:1 hydrochloric acid and gelatinizes.

PSEUDOMESOLITE

As stated above under the description of mesolite there occurs intimately intergrown with that mineral in some specimens a second fibrous zeolite distinguished by distinctly lower birefringence, slightly lower index of refraction, and positive elongation, for which the name pseudomesolite is here used. The two minerals may be readily identified by the difference in index of refraction when immersed in an oil of index 1.515. The difference in specific gravity of the two minerals is sufficient to permit satisfactory separation with heavy solutions, the mesolite being the heavier, owing perhaps to its denser and more compact texture. The birefringence of pseudomesolite is extremely low and the thinner fibers are almost invisible between crossed nicols. The free fibers loosely occupy cavities in the mesolite specimens, as shown in the specimen illustrated in Plate 1. The pseudomesolite occurs in parallel position as a continuation of

the mesolite fibers and is older than the stilbite of the same specimens. It was found impossible to obtain pseudomesolite from the specimens of mesolite in pure enough form for analysis.

A second group of specimens of pseudomesolite consists of somewhat slaggy basalt coated with broad crusts of loose-textured fibrous white material a centimeter or more thick, and containing in this loose-textured fibrous material numerous more or less perfect trapezohedral crystals of analcite a centimeter or so in diameter. Optical examination showed the fibrous zeolite to be identical with the pseudomesolite associated with mesolite, but entirely free from mesolite. By avoiding the analcite and by scraping the best material from the specimens, a sample pure enough for analysis was secured. Under the microscope it had almost zero birefringence, positive elongation, an extinction not measurable owing to extremely low birefringence, and mean index of refraction 1.510 ± 0.002. The material is easily soluble in hot 1:1 hydrochloric acid and gelatinizes. The analysis gave the following results:

Analysis and ratios of pseudomesolite

Constituent:	Per cent		Ratios	
SiO_2	43. 80		0. 726	0. 242×3
Al_2O_3	28. 20		. 276	. 276×1
CaO	10. 48	. 187 ⎫		
MgO	. 04	. 001 ⎪		
K_2O	1. 46	. 016 ⎬ . 256		. 256×1
Na_2O	3. 22	. 052 ⎭		
H_2O above 120° C	13. 24	. 735 ⎫ . 737		. 246×3
H_2O below 120° C	. 32	. 002 ⎭		
	100. 76			

The analysis shows the material to be identical in composition with mesolite, the only difference being in the optical properties. For this reason it is designated pseudomesolite; a name was applied by A. N. Winchell [5] to a zeolite of similar composition found in the anorthosite of Carlton Peak, Minn. Pseudomesolite of Winchell differs from normal mesolite in optical properties, being positive in elongation, with an index of 1.5 and birefringence of 0.002. It has inclined extinction up to 20°. Owing to the thinness of the fibers here described and their very low birefringence no inclination of extinction could be detected.

A third mode of occurrence is in the form of tufts on thomsonite or, in one case, calcite.

By its position in several different types of association the pseudomesolite is shown to be older than analcite and younger than thomsonite, mesolite, and calcite. It is more abundant and more widely distributed than mesolite in the specimens from Ritter Hot Spring.

[5] Amer. Geologist, vol. 26, p. 275, 1910.

THOMSONITE

The most abundant and, in some respects the most attractive mineral from the locality is thomsonite. This zeolite, comparatively uncommon elsewhere in the United States, makes up the larger part of the specimens collected, and in form and appearance is somewhat unlike the thomsonite from any other American locality. Its characteristic mode of occurrence here is as the lining of amygdaloid cavities, often several inches across, as shown in Plate 1*c*. The lining itself is seldom more than 4 millimeters thick and consists of radiating blades of snowy color and pearly luster, which terminate in the surface of the crust as chisel-shaped groups of dull, lusterless knife edges, without definite crystal form and often soiled and dirty.

The thomsonite is usually a more or less solitary mineral. It rests upon a very thin skin of a whitish zeolite described under heulandite. Very rarely there rest upon the thomsonite fine cottony tufts of fibers of pseudomesolite. In one set of specimens the thomsonite layer rests on a thin layer of chabazite and is overlain by crystals of stilbite.

The matrix of the thomsonite specimens is a slaggy basaltic lava which, as already stated, is highly porous and vesicular. The smaller vesicles are lined only with a thin skin of supposed heulandite although an occasional one is filled solidly with thomsonite blades. Much of the matrix basalt is altered to greenish clayey material which is quite soft when moist.

The specimen which was analyzed was purified as far as possible by cracking up and hand picking the pearly fragments of the crust. The fragments were then crushed and screened between 60 and 100 mesh sieves, and run several times through a bromoform-carbon tetrachloride heavy solution. The resultant sample was apparently pure and all of the same specific gravity. The analysis gave the following results:

Analysis of thomsonite

Constituent:	Per cent			Ratios		
SiO_2	37. 84	0. 630	0. 630	0. 630	0. 315×2	1. 01×2
Al_2O_3	31. 72	. 311	. 311	. 311	. 311×1	1. 00×1
CaO	12. 20	. 218 ⎫	. 239 ⎫			
MgO	. 84	. 021 ⎬	⎬ . 316	. 316×1	1. 00×1	
Na_2O	4. 08	. 066 ⎫	. 077 ⎭			
K_2O	. 96	. 011 ⎭				
H_2O above 110° C.	12. 56 ⎫	. 726	. 726	. 726	⎰. 290×⅚	. 93×⅚
H_2O below 110° C.	. 52 ⎭				⎱. 363×2	1. 17×2

100. 72

The results agree very well with the formula for thomsonite given by Dana, which is $(Na_2,Ca)O.Al_2O_3.2SiO_2.2\frac{1}{2}H_2O$, the ratio $Ca:Na_2$ being 3:1. The composition calculated from this formula is: SiO_2, 37.0; Al_2O_3, 31.4; CaO, 12.9; Na_2O, 4.8; H_2O, 13.9 = 100.0.

There has been considerable discussion for some time regarding the composition of thomsonite.[6] It was hoped that the present material might throw some new light upon this problem, but optical examination proved the sample analyzed to have little value for this purpose.

Under the microscope the grains of the sample all lie on a perfect cleavage plane and show two other cleavages at right angles to this and to each other. Dana makes the perfect cleavage of thomsonite $b(010)$ with $a(100)$ less perfect and $c(001)$ in traces. The elongation is parallel to the c axis. All of the grains lying on the perfect (010) cleavage show an excellent biaxial positive interference figure, with the axial plane across the laths or parallel to the plane $c(001)$, and the acute bisectrix Z perpendicular to (010). In an oil of index 1.525, however, the sample is found to be slightly inhomogeneous in index. A part of the grains lying on (010) cleavage have a small axial angle and strong dispersion r<v with the refractive indices: $a=1.522$, $\beta=1.524$. Another part of the grains has a little higher birefringence when lying on this plane, slightly larger axial angle, and the indices: $a=1.526$, $\beta=1.529$, $\gamma=1.533$. The dispersion and optical orientation are the same in both and it is evident that the sample consists of two varieties of thomsonite differing slightly in composition. There seems, however, to be no graduation in indices between these two and they are so similar in specific gravity that repeated attempts to separate them by the use of heavy solutions were unsuccessful. Most of the free grains were composed of a single one of the varieties but a coarser sample which was examined showed an occasional core of the variety of lowest indices bordered by later growths of the material of higher indices.

Aggregates of plates occasionally lie on the less perfect $a(100)$ cleavage. These are groups of slightly divergent individuals grown together approximately parallel to (010). They show brilliant interference colors and essentially parallel extinction. Such groups give the gamma (γ) index across the length and show the emergence of the obtuse bisectrix. They also show negative elongation, whereas the elongation of blades lying on (010) is positive. The laths may be rolled between crossed nicols and the change of elongation observed with the gypsum plate.

The collection contains one thomsonite specimen of somewhat different type. This is an irregular mass which represents a completely

[6] S. G. Gordon. Calciothomsonite from Franklin, N. J. Proc. Acad. Nat. Sci. Phila., vol. 75, pp. 273–274, 1923.

E. T. Wherry. Note on the composition of thomsonite. Amer. Min., vol. 8, p. 121, 1923.

S. G. Gordon. The composition of thomsonite. Proc. Acad. Nat. Sci. Phila., vol. 76, pp. 103–107, 1924.

A. N. Winchell. The composition of thomsonite. Amer. Mineralogist, vol. 10, pp. 90–97, 1925.

filled cavity about 4 centimeters across. The material is white and pearly in luster, with a fine, confused, platy-massive structure. Embedded in the massive material, especially near or attached to the wall, are rosettes 6 to 8 millimeters across composed of radiating blades. The rosettes when crushed give laths lying on a perfect cleavage with two other cleavages bounding the grains. These have elongation Y with the acute bisectrix normal to the perfect cleavage; are optically positive $(+)$ with 2V medium, dispersion $r < v$ strong; indices $\alpha = 1.525$, $\beta = 1.527$, $\gamma = 1.530$. This is unquestionably thomsonite like the higher index material of the analyzed sample. The fine, platy-massive material which makes up the solid filling of the cavity shows the same optical characters: Elongation Y, Biaxial positive $(+)$, 2V medium, $\alpha = 1.522$, $\beta = 1.525$, $\gamma = 1.529$. This mineral is also thomsonite.
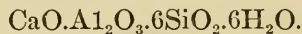
STILBITE

Stilbite is rather common and forms attractive specimens, some of considerable size, as that illustrated in the lower photograph of Plate 2. In the specimens of this group the only associated mineral is calcite in large, dirty-white cleavage fragments and rhombohedral crystals. These are found both above and below the stilbite crust, indicating two generations of this mineral. The stilbite forms crusts averaging nearly 10 millimeters thick, made up of divergent blades of pearly to silky luster and of white color where unstained. The surfaces of the crusts have vitreous luster and are made up of large numbers of minute crystal terminations, averaging 0.5 millimeter in size, aggregated in nearly parallel position in rounded groups 5 or 6 millimeters across. The principal crystal face is the pinacoid $c(001)$ of the position of Goldschmidt, modified by sharp and lustrous pyramid faces. The stilbite crusts are more or less stained by iron or soil. The sample for analysis was carefully selected from the cleanest fragments of such a crust. When ground and screened between 80 and 200 mesh sieves and examined under the microscope, it was found to be ideally pure. It was composed of elongate laths lying on the most perfect cleavage and bounded on the sides by a less perfect cleavage. The grains lying on the best cleavage give an interference figure indicating the emergence of the obtuse bisectrix perpendicular to this plane, with negative elongation, and with the optic axial plane parallel with the length. If, as usually considered, the best cleavage is parallel to $b(010)$ and the elongation of the crystals is vertical, the orientation is $X = c$, $Y = a$, and $Z = b$. In stilbite Y is usually b, and it therefore seems probable that in the present specimens the orientation is normal crystallographically and optically, but the a cleavage is unusually well developed. All grains show sensibly parallel extinction. The indices of refraction are

$\alpha=1.488$, $\beta=1.498$, $\gamma=1.500$; birefringence$=0.012$. The analysis gave the following results:

Analysis and ratios of stilbite

Constituent:	Per cent		Ratios	
SiO_2	56. 24	0. 933	0. 933	0. 155×6
Al_2O_3	17. 16		. 168	. 168×1
CaO	8. 56	. 153 }		
MgO	. 40	. 010 }	. 166	. 166×1
K_2O	. 32	. 003 }		
Na_2O	Trace.	----- }		
$H_2O+120q$ C	16. 80	. 933 }	. 986	. 164×6
$H_2O-120°$ C	. 96	. 053 }		

100. 44

The composition is that of an ordinary stilbite represented by the formula:

$$CaO.Al_2O_3.6SiO_2.6H_2O.$$

Another group of stilbite-bearing specimens is that containing mesolite. The stilbite occurs as white crystals up to 1 by 3 by 5 millimeters, entangled in the loose fibers of the pseudomesolite or as loose aggregates occupying the center of the cavity. The stilbite is the youngest mineral in these specimens. The crystals have the usual form—tabular parallel to b (010), with pearly luster on the broad pinacoid, and terminated by a rude pyramid. They are aggregates, tending toward a sheaf form, of small individuals not quite in parallel position. Some small specimens show these irregular crystal aggregates, or sheaf-like crystals, alone filling narrow seams up to 1 centimeter wide. Another specimen shows them resting upon a thin crust of white rhombohedral crystals of chabazite and in another they rest upon a thin druse of tiny heulandites.

One lot of thomsonite specimens, containing cavities of considerable size and irregular form, contains small stilbite crystals. The inner crust forming the lining of the cavity is made up of a thin layer of minute rhombs of chabazite averaging 0.25 millimeter in size. Upon this rest hemispherical masses of radiating blades of thomsonite 2 millimeters thick. The surface of the thomsonite is covered with small variously oriented, stilbite crystals of the usual form and about 1 millimeter long. These are perfect and show the pyramidal termination with no basal plane. In places, especially in the smaller cavities of the specimens, the thomsonite is lacking and the stilbite rests directly on the chabazite layer. Under the microscope these crystals of stilbite lie on the flat side, which is perpendicular to the optic normal or Y. They are very beautiful objects and show brilliant interference colors. At the position of maximum extinction, especially in convergent light, they show strikingly the complex hour-glass structure illustrated in Figure 4, under stilbite, in Dana's mineralogy.

Analcite forms normal trapezohedral crystals up to 1 centimeter in diameter in a number of specimens, invariably in association with pseudomesolite. The two minerals seem to have grown almost simultaneously, although the analcite is slightly later in age. One of the best specimens is shown in natural size in the upper illustration of Plate 2. In this specimen the mode of occurrence in an irregular cavity in highly vesicular lava can be seen to advantage. The associated acicular crystals and fibrous material are pseudomesolite, Sometimes these two minerals rest upon the basalt itself but in most cases they are preceded by a thin skin of chabazite. In the hand specimen the analcite crystals range from grayish and translucent to white and opaque, the difference depending on the quantity of included pseudomesolite.

The sample for analysis was prepared by cracking up selected large crystals, of which the cleanest and most glassy-translucent fragments were picked out, ground, screened between 80 and 200 mesh sieves, and purified as far as possible with heavy solutions.

Under the microscope the analyzed sample was composed of clear grains which showed no cleavage, were uniformly birefringent in low-order gray with grating structure, and give a biaxial negative $(-)$ figure with 2V small and dispersion weak, r<v. The mean index of refraction is 1.488. All of the grains show a few penetrating fibers of pseudomesolite but the amount of this is not sufficient to affect the analytical results seriously. Upon analysis this sample gave the following results and ratios:

Analysis and ratios of analcite

Constituent:	Per cent		Ratios	
SiO_2	53. 92	0. 893	0. 893	0. 223×4
Al_2O_3	24. 69	. 243	. 243	. 243×1
CaO	. 96	. 017		
MgO	. 04	. 001	. 204	. 204×1
K_2O	2. 24	. 024		
Na_2O	10. 04	. 162		
$H_2O+110°$ C	8. 62	. 479	. 479	. 239×2
$H_2O-110°$ C	None.			
	100. 51			

These results approximate as closely as usual the formula

$$Na_2O.Al_2O_3.4SiO_2.2H_2O$$
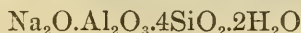
which is the formula given by Dana. The material is thus normal analcite and presents no unusual features.

Chabazite appears in numerous specimens, but in very few is it conspicuous. Its most common mode of occurrence is as tiny white

rhombohedral crystals lining cavities beneath crusts of other zeolites. The larger rhombohedra reach extreme dimensions of 1.5 centimeters. A typical specimen is illustrated in Plate 1a. The faces of the larger crystals are usually ribbed or striated parallel to the rhombohedral edges, the striae meeting in a line which is the shorter diagonal of the face. The chabazite in some specimens rests against the rock of the cavity wall, but more often it has a thin layer of diabantite between it and the wall, and in one specimen a layer of small heulandite crystals lies beneath the chabazite.

The analyzed sample was prepared from the largest crystal of the lot, which was about 1.5 centimeters on an edge. This was broken up and the best pieces were selected, ground, and sized between 80 and 200 mesh sieves. Under the microscope it was found to be ideally pure, consisting of irregular transparent fragments of very low birefringence, with index of refraction of 1.488 ± 0.002. It was biaxial positive with 2V about 30°. The analysis gave the following results:

Analysis and ratios of chabazite

Constituent:	Per cent	Ratios		
SiO_2	47. 56	0. 789	0. 789	0. 197×4
Al_2O^3	20. 40	. 200	. 200	. 200×1
CaO	10. 52	. 188 ⎤		
MgO	. 20	. 005 ⎥		
K_2O	. 92	. 010 ⎬ . 208		. 208×1
Na_2O	. 32	. 005 ⎦		
$H_2O + 120°$ C	16. 28	. 903 ⎤ 1. 094		. 182×6
$H_2O - 120°$ C	3. 44	. 191 ⎦		

99. 64

The results agree fairly well with the general formula given by Dana, $CaO.Al_2O_3.4SiO_2 6H_2O$. The alkalies are rather low, but the mineral is apparently normal chabazite presenting no unusual features.
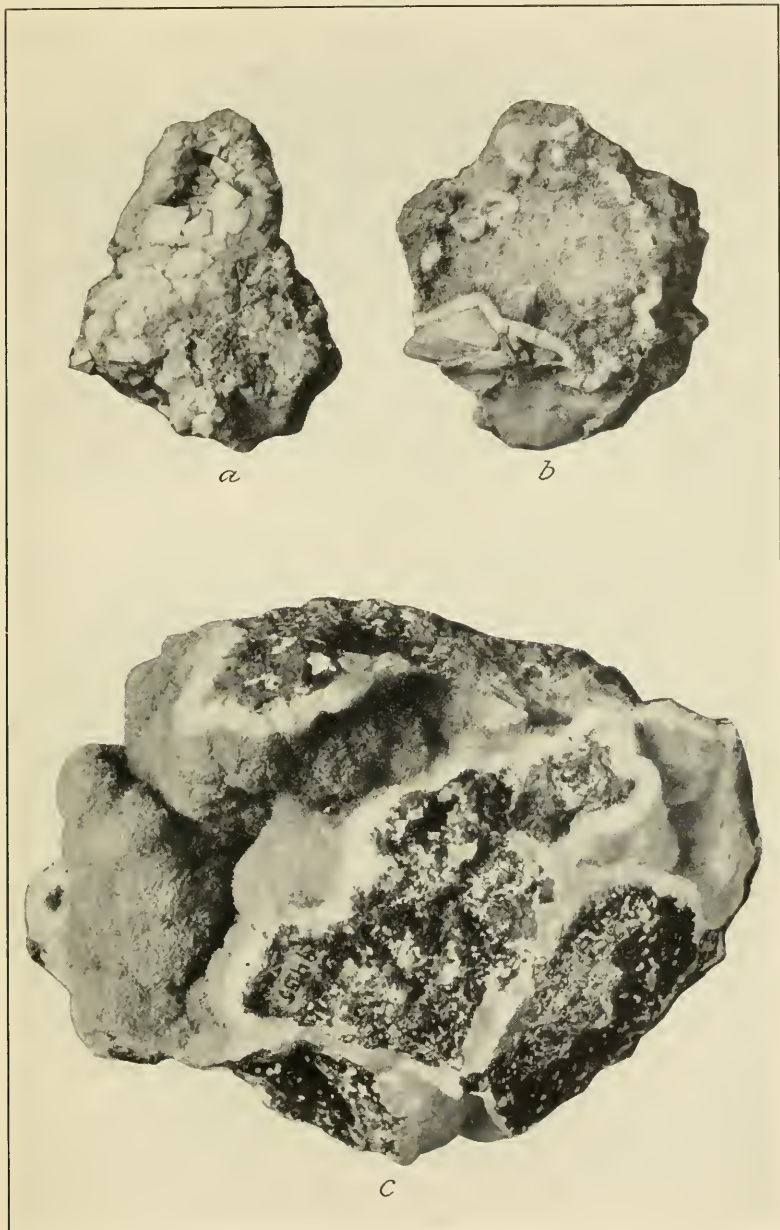
EXPLANATION OF PLATES

PLATE 1

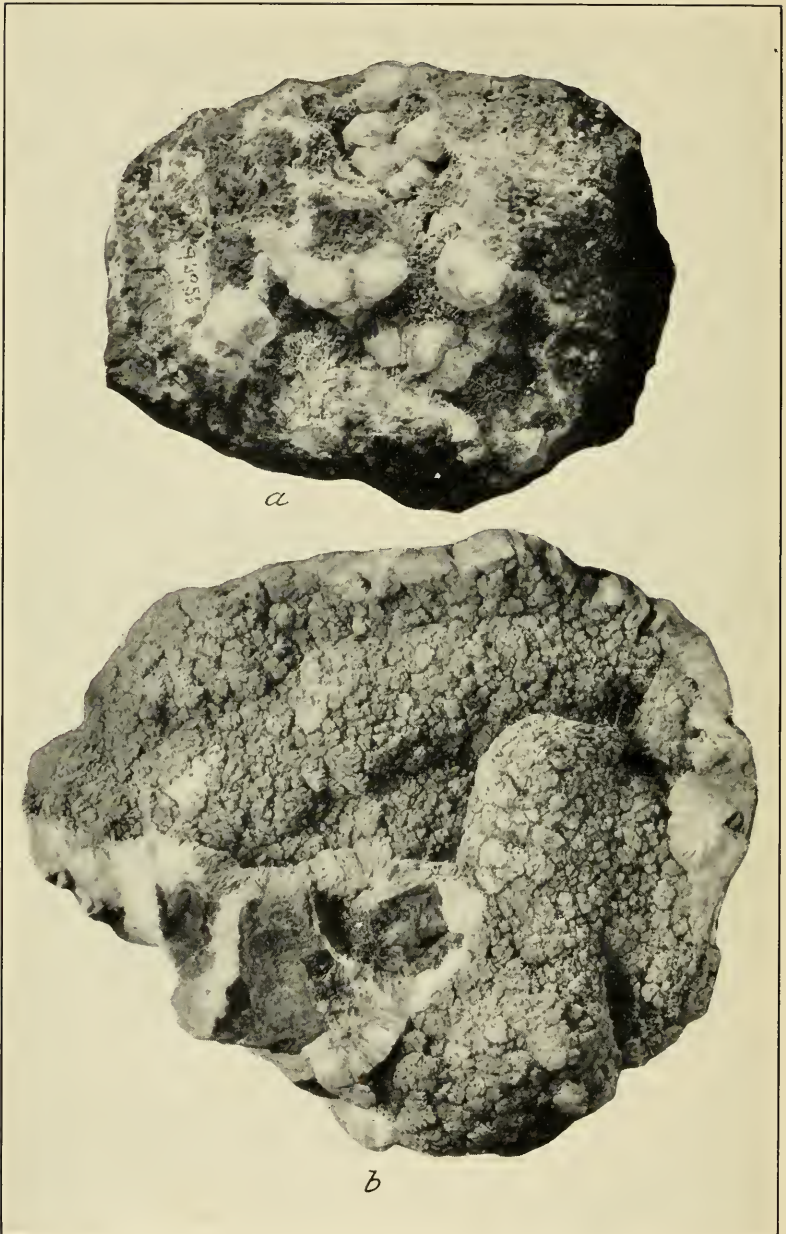*a*, Chabazite; *b*, mesolite and pseudomesolite; and *c*, thomsonite

PLATE 2

a, Pseudomesolite and analcite, and *b*, stilbite

○

a, CHABAZITE, *b,* MESOLITE AND PSEUDOMESOLITE, AND *c,* THOMSONITE

a, PSEUDOMESOLITE AND ANALCITE, AND *b*, STILBITE