

MORDENITE AND ASSOCIATED MINERALS FROM NEAR CHALLIS, CUSTER COUNTY, IDAHO.

By CLARENCE S. ROSS,

Geologist, United States Geological Survey,

AND

EARL V. SHANNON,

Assistant Curator of Geology, United States National Museum.

INTRODUCTION.

In 1917 Mr. Milton A. Brown, of Challis, Idaho, sent a specimen of a very fine cottony mineral of snow white color to the United States National Museum for identification. This mineral, which was thought to be asbestos, was said to be available in considerable quantity. Upon examination in the Museum laboratory this was found to be a fibrous zeolite, and optical examinations by Wherry and Larsen showed it to have properties similar to those of the rare mineral ptilolite. Chemical examination by Koch supported this conclusion, although the mineral was so mixed with small grains of quartz that it was not suitable for analysis. A short note on the occurrence was published by Koch.¹

In 1921 a box of some 50 pounds of specimens of the zeolite and associated minerals from this locality was received at the Museum. This material has been subjected to a detailed examination, the results of which are here presented.

NOMENCLATURE.

Dr. Waldemar T. Schaller has recently critically reviewed the group of zeolites which includes mordenite, ptilolite, and flokite. In addition to the existing literature, which includes recent work by Walker and Boggild, Schaller has considered new analyses made by himself and the analytical data presented below together with numerous new optical determinations. One of the results of this admirable work was to show that the Idaho mineral here considered is not ptilolite, as at first supposed, but is, in reality, mordenite.²

¹ Louis A. Koch. A new occurrence of ptilolite. *American Mineralogist*, vol. 2, p. 143, 1917.

² Waldemar T. Schaller. Unpublished paper presented before the first meeting of the Mineralogical Society of Washington, February, 1923. See abstract in *Amer. Mineralogist*, vol. 8, p. 93, 1923.

LOCALITY.

The specimens were received from Dr. Charles L. Kirtley, a physician of Challis, who is the original discoverer of the occurrence. Some years ago Mr. Brown had found, in the low hills south of Challis, some pebbles of colored corundum of such a quality as to indicate the possible occurrence of gem material. While searching for the corundum locality, which has not been rediscovered, Doctor Kirtley found the mordenite. The writers wish to gratefully acknowledge their indebtedness to Doctor Kirtley for his generosity in supplying these interesting materials together with notes on their place and mode of occurrence.

Challis is an interior community in Salmon River Valley 58 miles by stage northwest of Mackay, the nearest railroad point and the terminus of the Lost River branch of the Oregon Short Line Railroad. The zeolites and other minerals are from a small area of amygdaloidal rock in the low hills south of Challis in the wedge formed by Salmon River and Antelope Valley and a short distance west of the Challis-Mackay road.

GEOLOGY.

As described by Doctor Kirtley, the zeolite bearing formation occupies an area 3 acres in extent, surrounded by low hills of yellowish clay underlain by soft shale, the stratification being inclined about 20°. In this area the large masses of mordenite may be seen at many places, although the specimens collected all came from a single shallow cut. The shale hills are strewn with small pebble-like masses of translucent quartz and chalcedony. A map accompanying a reconnaissance report by Umpleby³ shows this area is occupied by lacustrine sediments with included tuffs and flows of andesite and basalt of probable Miocene age. The following description is quoted from this report.

Lacustrine deposits occur in the northeastern and eastern portions of the area studied. The northern area comprises an irregular belt about 10 miles across with tongues reaching up the several valleys tributary to the basin in which Challis is situated. To the south, west, and north the lake beds give way to lava flows, but to the south they connect across a low divide at the head of Antelope Valley with similar deposits in the valley of Big Lost River. The area east of Bay Horse is of peculiar shape but seems to have an outward continuation south of Antelope Ridge.

Perhaps the best exposures of these beds are along the east bank of Salmon River below Challis. Here the bluffs are about 200 feet high and, as seen from across the river, are made up of light gray sandstones, probably tuffaceous, and dove-colored shales. Conglomeratic members are sparsely and irregularly distributed through the section. The beds vary in thickness from less than an inch to several feet. In bluffs north of Challis, tuffaceous material, generally

³ Joseph B. Umpleby. Some ore deposits in northwestern Custer County, Idaho. U. S. Geol. Survey Bull. 539, p. 27, 1913.

very fine grained and of green, gray, or white color, predominate. It is nicely bedded, in places thinly laminated.

The hurried observations afforded little idea of the thickness of the deposits, although it must unquestionably be hundreds of feet.

Fossils were not found in this area, but the topographic relations of these beds are similar to those at Salmon, which were assigned to the Miocene on floral evidence.

Julien⁴ has published petrographic descriptions of several volcanic tuffs from Challis.

It seems most probable that the bed containing the mordenite and other minerals here described is an exceedingly vesicular andesite flow interbedded with the Miocene lake sediments. The larger geodal masses of the zeolites have some inclosing rock attached, but this is friable and sandy textured and falls to pieces except where it has been silicified by processes attending the deposition of the minerals in the cavities. One specimen which was labeled "country rock" consists of very numerous small pebblelike amygdules filled with mordenite, heulandite, and diabantite or a related chlorite, in a friable greenish matrix. A thin section of this rock, which below is frequently referred to as "the amygdaloid," shows the matrix to consist of phenocrysts of augite in a glass base. Fully half of the volume of the rock is occupied by the filled vesicles, as shown in the two middle illustrations of plate 2. The forms of these small amygdules vary from spherical to irregular, but show them unquestionably to be gas cavities rather than replacement nodules in a tuffaceous rock.

MORDENITE.

Mordenite was originally described from Nova Scotia, where it has been found at several localities, but only in relatively small amount at each, as compact masses with confused fibrous structure filling small cavities in lavas. No finely fibrous or cottony material is known from Nova Scotia, although, as shown by Schaller in the paper previously cited, the flokite from Iceland, which has such structure, is identical with mordenite. The mineral seems to be present as finer specimens and in greater abundance at the Idaho locality than at any other known occurrence. In the Idaho specimens examined the mordenite occurs in a variety of forms ranging from fine cottony felted aggregates through radial-fibrous masses to dense compact porcellaneous materials. Most abundant and conspicuous are the large geodal masses of fine cottony material which reach a diameter of a foot or more. These vary from round to irregular in cross section and consist usually of a thin shell of chalcedonic material filled with the light tufted fibers of the mordenite. Although this cottony material appears entirely homogeneous to the unaided eye, it all contains gritty particles which can be felt when it is crushed, and upon

⁴ Alexis A. Julien. Volcanic tuffs from Challis, Idaho. Trans. N. Y. Acad. Sci., vol. 1, pp. 49-53, 1882.

microscopic examination these are found to be minute spherulitic or spindle-shaped grains of quartz with radial structure. Koch selected what he thought was a very pure material for analysis and estimated, after the analysis had shown an abnormal amount of silica, that the analyzed material had contained about 33 per cent of quartz. Schaller's recalculation shows that about 40 per cent would be nearer the truth. The small quartz spherulites are pinned through by the mordenite fibers and have clearly developed subsequent to the mordenite. None of the fine cottony material was found to be free from quartz, although the compact varieties are frequently free from any impurity. Practically all of the geodes of the cottony type have a very thin outer shell of heulandite which forms the first lining in the cavity. Within this there is usually a thin layer of chalcedony upon which the mordenite was deposited, filling the interior of the cavity with loosely aggregated fibers. A typical specimen of this sort, although one of the smallest received, is that shown in plate 1, upper left. Many of the cavities have a thicker crust which is found upon microscopic examination to consist of chalcedony including mordenite fibers which have the same attitude as those which occur free in the middle portion of the cavity. This chalcedony appears to be later than the mordenite and to have formed a crust by saturating the pore space of the loose-textured mordenite. In some geodes of moderate size only a small area remains in the center where the mordenite is not saturated with silica, the specimen shown in plate 2, lower, being an example, while in extreme cases, noted only in the smaller masses, the entire content of the cavity has been saturated with chalcedony, or, more rarely, granular quartz. One striking specimen illustrated in plate 3, lower, has silky bundles of short fibers of mordenite attached to masses of small quartz spherulites which project from platy (argentine) calcite. Analc occurs as flattened crystals between the calcite plates. Both this spherulitic quartz and the calcite are probably younger than the mordenite and the calcite has apparently, in part, been dissolved away. The microscope shows the mordenite fibers of this specimen to be individually coated with a thin film of calcite. In other specimens the fibers were similarly incrustated with quartz. A part of the light cottony variety contained many of the small radial grains of quartz but was free from the incrustations. This was separated from its included quartz grains by alternate rubbing between hardwood boards and screening, the quartz grains when freed from the fiber, passing through the meshes of the sieve while the tufts of mordenite remained behind. This process was continued until no more gritty particles could be felt in the sample when it was examined optically and found to be pure and free from quartz. Upon analysis this sample gave the following results and ratios.

Analysis (1) and ratios of cottony mordenite.

Constituent.	Per cent.	Ratios.		
SiO ₂ -----	64.84	1.075	0.119 x 9	1.00 x 9
Al ₂ O ₃ -----	12.07	.118	.118 x 1	.99 x 1
CaO-----	3.08	.055		
MgO-----	.26	.006		
Na ₂ O-----	3.80	.061	.126 x 1	1.06 x 1
K ₂ O-----	.38	.004		
H ₂ O+110° C-----	10.42			
H ₂ O-110° C-----	4.37	.822	.137 x 6	1.15 x 6
Total-----	99.22			

The material of this analyzed sample was biaxial and negative with the orientation $X\Delta c=3^{\circ}40'$, $Y=a$, $Z=b$, the indices of refraction being $\alpha=1.470$, $\beta=1.475$, $\gamma=1.475$, $\gamma-\alpha=0.005$.

The second sample analyzed came from a pure nodule about 8 centimeters in maximum diameter which has evidently been weathered upon the surface for some time, as it is weather stained; the original shell is bleached, and the mordenite is in places stained green by algae. The nodule is red on its original surface from a thin coating of heulandite, succeeded inward by a thin shell of chalcedony, inside which the mass consists of pure mordenite in fibers extending from all sides toward the center. The fibers are straight and close packed and reach a maximum length of 2 centimeters. The color is creamy white and the luster, on fresh fracture, is faintly silky. The analysis gave the following results:

Analysis (2) of weathered fibrous mordenite nodule.

Constituent.	Per cent.	Ratios.		
SiO ₂ -----	65.88	1.093	0.121 x 9	1.00 x 9
Al ₂ O ₃ -----	12.40	.121	.121 x 1	1.00 x 1
CaO-----	3.52	.063		
MgO-----	.48	.012		
Na ₂ O-----	3.52	.057	.138 x 1	1.13 x 1
K ₂ O-----	.56	.006		
H ₂ O+110°C-----	9.08	.504		
H ₂ O-110°C-----	4.32	.240	.124 x 6	1.02 x 6
Total-----	99.76			

The refractive indices of this sample, measured on the analyzed material are: $\alpha=1.472$, $\beta=1.475$, $\gamma=1.476$, $\gamma-\alpha=0.004$. All of the fibers which are thick enough to have appreciable birefringence were found to have a small inclined extinction.

Many of the specimens received are amygdules free from matrix which apparently were gathered, like so many pebbles, from the

surface. These vary in size and are very irregular in form but apparently they represent casts of the interiors of very irregular bubble cavities probably formed by the sudden expansion of steam in viscous lava. They all preserve the original outside crust of red color which resembles a stain of iron oxide, but which, upon more minute examination, is found to be the thin skin of heulandite which formed the first lining of the cavity. All of these heulandite coated masses are hard and compact, but they vary somewhat in internal structure and composition. Some of them are entirely filled with bluish chalcedony and quartz, others are mixtures of mordenite and chalcedony or of mordenite and quartz, while a majority contain only pure mordenite. The mordenite of the latter varies from distinctly radial fibrous to very compact in structure. The third analysis was made upon such a nodule which was exceedingly tough and difficult to break. Under a lens this shows a confused and interwoven fibrous structure and when examined under the microscope its structure is finely felted fibrous. The mean index of refraction, the only one determinable, is 1.473. This description applies equally well to a type specimen of How's original mordenite from Nova Scotia in the Roebing collection which has a mean index of refraction of 1.473 and a birefringence of about 0.005. The material from this nodule which was analyzed was shown to be pure and free from extraneous substances by optical examination. The analysis gave the following results:

Analysis (5) and ratios of compact nodule of mordenite.

Constituent.	Per cent.	Ratios.		
SiO ₂	67.24	1.115	0.124 x 9	1.00 x 9
Al ₂ O ₃	12.94	.127	.127 x 1	1.02 x 1
CaO.....	2.72	.049		
MgO.....	.28	.007	.126 x 1	1.01 x 1
Na ₂ O.....	4.08	.066		
K ₂ O.....	.36	.004		
H ₂ O+110° C.....	8.44	.746	.124 x 6	1.00 x 6
H ₂ O-110° C.....	5.00			
Total.....	101.06			

The fourth and last analysis of the Idaho mordenite was made upon several of the small masses from the peculiar amygdaloid rock mentioned on page 3. This rock consists of granular lava having half the volume occupied by gas cavities filled with pebblelike masses a few millimeters in diameter which differ strikingly in color. Mordenite occurs alone in this rock as snow-white masses of very compact texture, also as larger and looser textured flesh-pink masses, the color being due to a very thin outer coating of heulandite, and as

rare thin fibers attached to heulandite crystals lining hollow flesh-red masses of heulandite. The snow-white masses show on fracture the texture of porcelain and are lusterless and exceedingly tough. These, when ground for analysis were found to be pure with a very finely felted fibrous structure. The mean index of refraction of the analyzed material was 1.473. The analysis gave the following results and ratios:

Analysis (4) of small pebblelike masses of mordenite.

Constituent.	Per cent.	Ratios.		
SiO ₂ -----	66.25	1.099	0.122 x 9	1.00 x 9
Al ₂ O ₃ -----	11.88	.116	.116 x 1	.95 x 1
CaO-----	2.75	.049		
MgO-----	.44	.011	.133 x 1	1.09 x 1
K ₂ O-----	.69	.007		
Na ₂ O-----	4.05	.066		
H ₂ O+110° C-----	8.80	.488	.128 x 6	1.05 x 6
H ₂ O-110° C-----	5.05	.280		
Total-----	99.91			

The four analyses of the Idaho material agree in giving the silica ratio as 9 instead of 10 molecules and the water as 6. For convenience in comparing the silica content, the several analyses are brought together and their average compared with the values calculated to suit the two formulas (Na₂,Ca)O.Al₂O₃.9SiO₂.6H₂O. and (Na₂,Ca)O.Al₂O₃.10SiO₂.6H₂O in the following table, a 1 : 1 ratio between CaO and Na₂O being assumed in calculating the theoretical compositions:

Comparison of mordenite analyses with formula percentage values.

	1	2	3	4	Average.	9SiO ₂	10SiO ₂
SiO ₂ -----	64.84	65.88	67.24	66.25	66.06	66.81	69.12
Al ₂ O ₃ -----	12.07	12.40	12.94	11.88	12.32	12.59	11.72
CaO-----	3.08	3.52	2.72	2.75	3.02	3.45	3.21
MgO-----	.26	.48	.28	.44	.36		
Na ₂ O-----	3.80	3.52	4.08	4.05	3.86	3.83	3.56
K ₂ O-----	.38	.56	.36	.69	.50		
H ₂ O-----	14.79	13.40	13.44	13.85	13.87	13.32	12.39
	99.22	99.76	101.06	99.91	99.99	100.00	100.00

This comparison indicates quite conclusively that the correct formula for all of the several physical modifications of the Idaho mordenite is (Ca,N_a)O.Al₂O₃.9SiO₂.6H₂O which is identical with the formula assigned to flokite and contains 1 molecule less of silica and 1 molecule less of water than the accepted formula for

the Colorado ptilolite $(Ca, K_2, Na_2)O \cdot Al_2O_3 \cdot 10SiO_2 \cdot 7H_2O$, and 1 molecule of silica and $\frac{2}{3}$ molecule of water less than the formula commonly given for mordenite, based upon Pirsson's Wyoming material $(Ca, K_2, Na_2)O \cdot Al_2O_3 \cdot 10SiO_2 \cdot 6\frac{2}{3}H_2O$. Boggild⁵ has recently concluded that flokrite is identical with ptilolite, while Walker⁶ suggests that ptilolite and mordenite are probably identical. Schaller, in the paper above referred to, however, has shown that mordenite and flokrite are identical, but that mordenite, which is monoclinic, is distinct, chemically as well as crystallographically, from ptilolite which is orthorhombic. The material from Wyoming described as mordenite by Pirsson, which is distinct from either mordenite or ptilolite (clinoptilolite, Schaller), was instrumental in confusing the species mordenite. The best available data on the refractive indices of these minerals is assembled below:

Refractive indices of mordenite and related minerals.

Mineral.	Locality.	Authority.	Refractive indices.			Extinction.
Mordenite---	Idaho-----	Koch-----	1.475	1.477	1.478	Undetermined.
Do-----	Idaho (1)---	Ross-----	1.470	1.475	1.475	Inclined.
Do-----	Idaho (2)---	do-----	1.472	1.475	1.476	Do.
Do-----	Idaho (3)---	do-----	-----	1.473	-----	Not determin- able.
Do-----	do (4)-----	do-----	-----	1.473	-----	Do.
Ptilolite-----	Colorado---	Larsen---	1.476	1.480	1.480	Parallel.
Mordenite---	N o v a Scotia.	do ¹ ---	-----	1.473	-----	Not determin- able.
Do-----	do-----	Ross ² ---	1.471	-----	1.475	Do.
Flokite-----	Iceland---	Callisen--	1.472	-----	1.474	Inclined.

¹ Specimen of How's original material from Morden, Nova Scotia, owned by Col. W. A. Roebling. The value given originally (1.465) in Larsen's tables (Bull. U. S. Geol. Surv. No. 679, p. 113, 1921) has been found to be an error.

² Specimen of recent collection by Walker and Parsons from Hall's Harbor, Kings County, Nova Scotia (Cat. U. S. N. M. 94, 552). Data determined by Ross and not previously published.

Two fibrous minerals, one orthorhombic with parallel extinction, and the other monoclinic, with inclined extinction, are represented by ptilolite and mordenite which differ one molecule in silica and one molecule in water. These minerals are very similar, however, both in composition and properties, and very careful work is necessary to distinguish between them. It may be mentioned, in passing, that erionite has the same formula type, the same habit, and similar optical properties, although the refractive indices are much lower. This mineral has the formula $(Ca, K_2, Na_2)O \cdot Al_2O_3 \cdot 6SiO_2 \cdot 6H_2O$. Miss Callisen made flokrite monoclinic on the basis of a constant extinction inclination of 5° on (010) combined with twinning on (100). These observations Boggild set aside as probably due to inexact ob-

⁵ O. B. Boggild. Dansk. Videnskab. Selskab. Mathemat.-Phys., vol. 4, No. 8, p. 19, 1922.

⁶ Thos. L. Walker. Contributions to Canadian Mineralogy, 1922. Univ. Toronto Geol. Series, No. 14, p. 59, 1922.

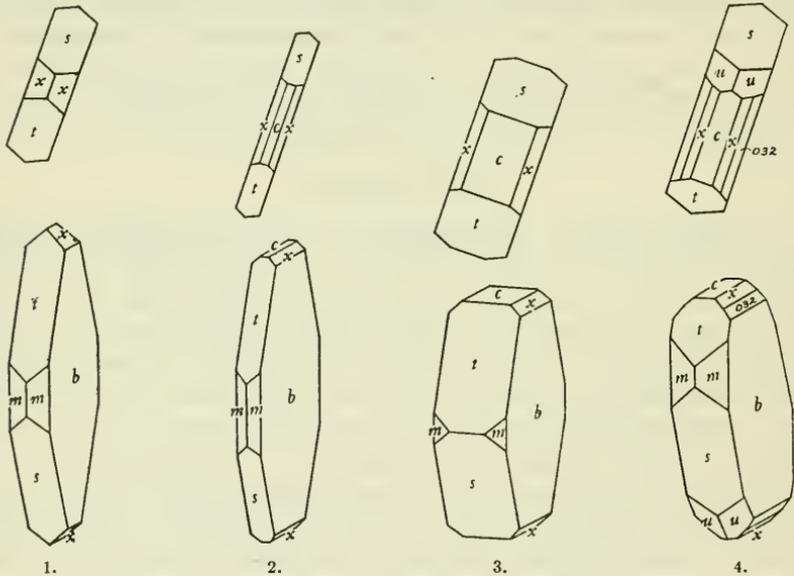
servation despite the fact that Thugutt had described a "ptilolite" from Seiser Alp which showed inclined extinction. With this in mind the Idaho material was very carefully examined, its composition and refractive indices being identical with those given for flokite. Since the fibers are very thin and the birefringence is very low an extinction obliquity of several degrees might readily evade observation. Such a small angle might also be attributed to lack of adjustment between the cross hairs and nicols of the microscope. After specially adjusting the microscope the Idaho material was found to give, as the mean of about 20 good measurements, an extinction inclination of $3\frac{1}{2}^{\circ}$, measured from the elongation of the fibers. Instead of containing errors of observation, Miss Callisen's work on flokite appears to be a very commendable and highly exact research which has furnished the key for the interpretation of the group.

The Idaho mordenites are interesting especially as furnishing a complete gradation between the physically very dissimilar compact mordenite from Nova Scotia and the cottony fibrous "flokite" from Iceland.

HEULANDITE.

Heulandite occurs in the specimens as a complete filling of small vesicles in the rock, as drusy linings of cavities, and as thin crusts forming the first lining of cavities later filled with mordenite, chalcedony, or quartz. The characteristic flesh-red masses in the amygdaloid consist of fine transparent heulandite, and many of these small masses are hollow and present fine terminations of acute wedge-shaped crystals, the habit being as shown in figures 1 and 2. These show very well developed cleavage parallel to the pinacoid $b(010)$ as well as some other less perfect cleavages at right angles to this plane. Usually two or several crystals are grown together in more or less parallel position, but the tendency to parallel growth is not so conspicuous as usual in the heulandite of this type. A majority of these pebbles are not hollow, but are solid masses of the heulandite. Those which do show open centers often have a few fine fibers of mordenite extending across the central cavity. Other heulandite-lined vesicles in the same rock are completely filled with closely packed cottony mordenite and the faintly pink to salmon colored masses which fill many of the larger bubble cavities are compact mordenite with a thin outer skin of heulandite. The numerous irregular masses which have weathered free from the inclosing rock, and which consist of compact mordenite, of mordenite saturated with quartz or with chalcedony, or of quartz or chalcedony alone, all have a brick-red outer coating which resembles a stain of ferric oxide, but which, when examined with a lens, is found to consist of a thin outer crust of crystalline heulandite. All of the larger geodal masses of mordenite, of whatever type, have a thin deposit of heulandite next the

inclosing rock. Optical examination of the clear crystals from hollow heulandite amygdules showed them to be transparent and colorless and devoid of any visible pigmenting material to which the red color might be attributed. Optically the crystals lining the small cavities or making up the flesh-red amygdules of the amygdaloid rock are biaxial positive (+) with $2V=52^\circ$. The indices of refraction are $\alpha=1.482$, $\beta=1.485$, $\gamma=1.489$, $\gamma-\alpha=0.007$. The acute bisectrix (Z) is perpendicular to the $b(010)$ face, while the extinction, measured from the c crystallographic axis averages 35° , the optic plane being nearly parallel (measured 5° to 8°) to the trace of one of the terminal clinodomes, either $t(101)$ or $s(\bar{1}01)$. The crystals as seen between crossed nicols are frequently not entirely simple, being



FIGS. 1 TO 4.—HEULANDITE CRYSTALS FROM CHALLIS, IDAHO.

divided by sutures into areas which differ slightly in extinction angle. Thus the crystal measured and illustrated by the drawing (fig. 2), was found to be divided vertically by a straight line, on one side of which the extinction, measured from the vertical cleavage lines, gave $38\frac{1}{2}^\circ$ while on the other side it was $44\frac{1}{2}^\circ$ and a wedge entered at the termination of the crystal in which the extinction was 33° , the latter being about the normal extinction angle of homogeneous crystals. In addition to this peculiarity the crystals frequently show a very narrow outer border of a material of decidedly higher index of refraction.

The crystals of this heulandite which were measured did not give overly satisfactory angles, mainly because of the poor development,

bulging, or parallel growth in the vertical zone rendering accurate orientation on the goniometer very difficult. The average degree of agreement may be shown by giving, in detail, the measurements obtained upon two crystals, shown in figures 1 and 2, which were as follows:

Measurements obtained on heulandite (fig. 1).

Letter.	Miller.	Quality.	Measured.		Calculated.	
			ϕ	ρ	ϕ	ρ
			° /	° /	° /	° /
b	010	{ Poor, multiple-----	0 00	90 00	0 00	90 00
		{ do-----	0 25	90 00	— —	— —
m	110	{ Fair but faint-----	66 07	90 00	68 02	— —
		{ Good-----	68 15	90 00	68 02	— —
		{ Poor, faint-----	67 38	90 00	68 02	— —
t	101	{ Poor, very faint-----	67 05	90 00	68 02	— —
		{ Good-----	89 52	65 36	90 00	65 05
s	$\bar{1}01$	{ do-----	91 46	65 42	90 00	65 05
		{ do-----	89 22	64 14	90 00	64 34
x	011	{ do-----	1 05	43 20	1 39	40 39
		{ do-----	2 32	44 46	1 39	40 39

Measurements on heulandite crystal (fig. 2).

Letter.	Miller.	Quality.	Measured.		Calculated.	
			ϕ	ρ	ϕ	ρ
			° /	° /	° /	° /
b	010	{ Very good-----	0 00	90 00	0 00	90 00
		{ Excellent-----	0 00	90 00	— —	— —
m	110	{ Good-----	67 38	90 00	68 02	90 00
		{ do-----	67 41	90 00	— —	— —
c	001	{ do-----	91 30	1 06	90 00	1 25
t	101	{ Excellent-----	90 00	65 23	90 00	65 05
s	$\bar{1}01$	{ Good-----	90 00	64 44	90 00	64 34

The agreement, while not satisfactory, is sufficiently close to show the essential crystallographic identity of the mineral with heulandite. The abrupt displacement of certain forms so that they give angles a degree or more off is no doubt connected either with compound character or with the heterogeneous internal structure as seen in polarized light.

This material was analyzed, the material for analysis being selected small red nodules and the analyzed powder was shown to be

essentially pure and homogeneous by optical study. The percentages and ratios obtained are as follows:

Analysis and ratios of heulandite.

Constituent.	Per cent.	Ratios.		
SiO ₂ -----	61.14	1.014	0.145 x 7	1.00 x 7
Al ₂ O ₃ -----	14.52	.142	.142 x 1	.98 x 1
CaO-----	3.60	.064		
MgO-----	.28	.007		
K ₂ O-----	.94	.010	.153 x 1	1.05 x 1
Na ₂ O-----	4.48	.072		
H ₂ O-----	14.16	.787	.157 x 5	1.09 x 5
Total-----	99.12			

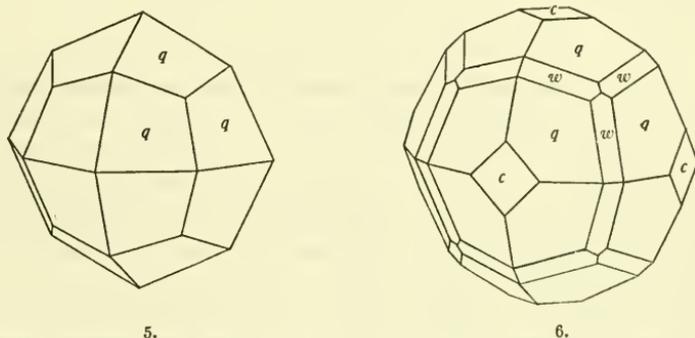
This analysis gives the formula $(Ca,K_2,Na_2)O.Al_2O_3.7SiO_2.5H_2O$. This differs from the formula for heulandite given by Dana in containing one more molecule of silica. The replacement of lime by alkalies has, furthermore, progressed to the point where the combined soda and potash are in excess, both molecularly and by weight, of the lime.

A form of heulandite of somewhat different properties occurs rarely in the amygdaloid rock as small solid pebblelike bodies coated on the outside by deep green chlorite and, where fractured, showing coarse granular structure, well defined cleavage, pearly luster, and a faintly pink color. A similar material occurs as drusy crusts of brilliant crystals of faintly pink color lining small flat open cavities in the rock adjacent to the large masses of mordenite. These crystals when examined optically are seen, like the preceding, to be made up of sectors not identical in extinction angle, the angle between adjacent sectors varying 10° or more. Moreover, they are strongly zoned, the outer zone having the following optical properties: Biaxial, positive (+), $2V=68^\circ$, $\alpha=1.494$, $\beta=1.496$, $\gamma=1.501$, $\gamma-\alpha=0.006$, while the properties of the cores are: Biaxial positive (+), $2V=90^\circ$, $\alpha=1.483$, $\beta=1.487$, $\gamma=1.490$, $\gamma-\alpha=0.007$. Crystallographically these are, like the others, in fair agreement with the heulandite angles, the forms identified being $b(010)$, $m(110)$, $c(001)$, $t(101)$, $s(\bar{1}01)$, $x(011)$, and $w(032)$. The latter is a rare form previously noted only on heulandite from Scotland. In habit these pale crystals are much stouter than the others, as shown in figures 3 and 4, and they are grown together in parallel groups over considerable areas, the plane of contact being $b(010)$.

ANALCITE.

Analcite occurs as single crystals and groups of aggregated crystals embedded near the centers of the larger masses of cottony mordenite and as crusts and druses of crystals lining cracks in the adjacent

rock or filling gashes in the mordenite which probably result from the solution of plates of calcite as shown in plate 1, upper right. Individual crystals of the analcite reach an extreme diameter of 14 millimeters. Where free from inclusions the analcite is clear and colorless, but the crystals commonly inclose fibers of mordenite and spherulites of quartz, giving them a milky appearance. They are for the most part simple trapezohedrons of the form $q(112)$, which is a common form for analcite as shown in figure 5. Occasionally however, one shows faces of the cube $a(100)$ and of the trigonal trisoctahedron $w(233)$ which, though previously known, are rare forms on analcite. A modified crystal is shown in figure 6. Certain very interesting crystals occur in the platy argentine calcite. These are attached to the calcite plates by the equatorial plane and, where space was available, the top halves have developed completely. Where the space between the calcite plates was thin the analcites



FIGS. 5 AND 6.—ANALCITE CRYSTALS FROM MORDENITE MASS, CHALLIS, IDAHO.

are very much flattened and are bounded only on their edges by narrow crystal planes. Both undeformed and greatly flattened crystals are shown attached to calcite in plate 3, right. The disk-like crystals may reach 1 centimeter in diameter with a thickness of only 0.2 millimeter, although most of them are thicker than this, with a smaller diameter. Selected ones of these are ideal thin sections, and show admirably the birefringence and division into sectors. Such a crystal photographed in polarized light between crossed nicols is shown in plate 3, upper. The flattened analcites adhere to the quartz films which coat the platy calcite and usually show very numerous quartz spicules attached to their surface. This quartz was ground off of the crystal shown in the photograph. Optically the analcite is biaxial and negative with large axial angle and a mean index of refraction of 1.486. The biaxial interference figure is extremely sharp and definite and this, together with the geometrical perfection of the division into sectors and the sharpness of the

lamellæ, makes it hard to accept the idea that the mineral owes its nonisotropic character to anomalies explained by internal strain.

A sample for analysis was selected carefully and its homogeneous character and purity were established microscopically. The analysis gave the following composition and ratios:

Analysis and ratios of analcite.

Constituent.	Per cent.	Ratios.		
SiO ₂	57.47	0.953	0.238 x 4	1.19 x 4
Al ₂ O ₃	20.85	.204	.204 x 1	1.03 x 1
CaO.....	.52	.009		
MgO.....	.21	.005		
K ₂ O.....	.64	.007	.199 x 1	.98 x 1
Na ₂ O.....	10.94	.177		
H ₂ O+110° C.....	8.43	.468	.234 x 2	1.17 x 2
H ₂ O-110° C.....	None.			
Total.....	99.06			

The above ratios are not satisfactorily close to whole numbers to conform to the analcite formula given by Dana, both water and silica being high. Parsons⁷ recently, in discussing the composition of analcite from Nova Scotia, has shown that all of the analyses of analcite given by Dana can be satisfactorily interpreted by the assumption that the mineral is composed of an isomorphous mixture of two compounds of the composition (A) Na₂O.Al₂O₃.6SiO₂.3H₂O and (B) Na₂O.Al₂O₃.2SiO₂.H₂O. Considered from this standpoint the Idaho material may be regarded as made up of almost exactly two parts of (A) and one of (B) molecularly, as shown by the following table in which the condensed figures of the analysis are given in column 1 compared with the percentages calculated for a mixture of the 2 : 1 composition in column 2.

	1	2
	Found.	Calculated.
SiO ₂	57.47	57.71
Al ₂ O ₃	20.85	20.96
Na ₂ O (+CaO+MgO+K ₂ O).....	12.31	12.71
H ₂ O.....	8.43	8.62
Total.....	99.06	100.00

The paragenetic position of the analcite is late, as it grew between the laminae of calcite or occupied cavities left by removal of calcite

⁷ Arthur L. Parsons. Univ. of Toronto Geol. Series No. 14. Contributions to Canadian Mineralogy, 1922, pp. 34-38, 1922.

and incloses mordenite and spherulitic quartz. No other mineral is deposited on the analcite, and it is probably the youngest of the minerals represented in the Challis specimens.

CHLORITE.

About one-fourth of the total number of small pebblelike fillings in the amygdaloid rock consist of a soft, foliated, brownish-green chlorite. These chlorite fillings, which reach an extreme diameter of 7 millimeters, are easily freed from the surrounding matrix and when crushed yield a homogeneous sample for analysis. This chlorite does not occur in the same vesicles with any of the zeolitic minerals, but it is sparingly distributed in the silicified portions of the inclosing rock near the large zeolite-filled cavities. Under the microscope the chlorite is seen to consist of yellow-green irregular folia. These are biaxial and optically negative (-) with 2V near 15°. The indices of refraction, which are high for a chlorite are, $\alpha=1.615$, $\beta=1.637$, $\gamma=1.638$, $\gamma-\alpha=0.023$. The mineral is strongly pleochroic with X and Y olive-green and Z brownish-yellow. This material was analyzed yielding the following results and ratios:

Analyses and ratios of brownish-green chlorite.

Constituent.	Per cent.	Ratios.		
SiO ₂ -----	30.76	0.510	0.170 x 3	1.00 x 3
Al ₂ O ₃ -----	12.12	.119}	.176 x 1	1.03 x 1
Fe ₂ O ₃ -----	9.12	.057}		
FeO-----	22.76	.317}	.160 x 4	.94 x 4
MnO-----	1.24	.018}		
CaO-----	Trace.	---		
MgO-----	12.36	.307}	.160 x 4	.94 x 4
H ₂ O+110° C-----	9.76	.542}		
H ₂ O-110° C-----	1.80	.100}		
Total-----	99.92			

This analysis yields as the formula, $4RO.R_2O_3.3SiO_2.4H_2O$, with $RO=MgO : FeO=1 : 1$ and $R_2O_3=Fe_2O_3 : Al_2O_3=1 : 2$. This can not be definitely assigned to any member of the chlorite group but is most closely related to diabantite and delessite, chlorites occurring characteristically as amygdule fillings in basic igneous rocks. The content of ferric iron is noteworthy, and this doubtless explains the relatively high index of refraction and birefringence of the mineral. In a recent description of diabantite from Nova Scotia, Walker⁸ obtained from an analysis a formula slightly different from that of

⁸ Thomas L. Walker. Univ. Toronto Geol. Series No. 14, p. 47, 1922.

Hawes, and points out that both his and Hawes's minerals can be interpreted as isomorphous mixtures of two compounds, namely (a) $RO.R_2O_3.2SiO_2.2H_2O$, and (b) $2RO.SiO_2.H_2O$. This is distinctly not true of the present analysis in its present form. However, if the ferric iron be calculated back to ferrous iron and the water below 110° be excluded, the formula obtained is $4FeO.3MgO.Al_2O_3.5SiO_2.5H_2O$, which may be regarded as composed of Walker's (a) x 1 with $RO=MgO$ plus (b) x 1 with $RO=MgO$ plus (b) x 2 with $RO=FeO$. The analysis, recalculated on this basis, is given in column 1 below, while in column 2 is given the calculated composition of a mixture of the above formula:

	1	2
SiO ₂ -----	31.64	33.30
Al ₂ O ₃ -----	12.47	11.33
FeO-----	31.86	31.74
MnO-----	1.28	-----
MgO-----	12.71	13.63
H ₂ O-----	10.04	10.00
Total-----	100.00	100.00

Heated before the blowpipe in the forceps this chlorite exfoliates somewhat, becomes magnetic, and finally fuses with some difficulty to a black magnetic slag. In the closed tube it yields abundant water having an acid reaction, indicating a small fluorine content. It is quickly and completely soluble in hot 1 : 1 hydrochloric acid.

In the same specimens there occurs a second chlorite which never completely fills the cavities but merely forms a thin lining 0.5 millimeter or less in thickness in cavities containing fillings of mordenite and serves as coloring matter in the surrounding andesite. It is impossible to obtain enough of this material in pure form for analysis. It is deep blue green in the specimen and under the microscope is seen to consist of finely felted shreds and scales of a deep blue-green color which, in the aggregate, do not show any noticeable pleochroism. The indices of refraction are, $\alpha=1.606$, $\gamma=1.608$, $\gamma-\alpha=0.002$. Aside from the difference in color, these chlorites differ sharply in birefringence.

In the following table the optical properties of these two chlorites are repeated in comparison with those of several other occurrences of similar chlorites.

	1	2	3	4	5	6
α -----	1.615	1.606	1.555	-----	1.540	1.605
β -----	1.637	-----	1.595	1.605	1.590	1.619
γ -----	1.638	1.608	1.595	-----	1.605	1.619
Sign-----	(-)	-----	(-)	(-)	(-)	(-)
2V-----	15°	Small.	0°	Small.	Large.	0°
X-----	Olive-green.	Blue-green.	Pale yellow.	Olive-buff.	Gray-green.	Various.
Y-----	Brown-yellow.	Blue-green.	Olive-green.	Olive-buff.	Gray-green.	Various.
Z-----	Brown-yellow.	Blue-green.	Olive-green.	Olive-buff.	Gray-green.	Various.
Biref-----	0.023	0.002	0.040	-----	0.065	0.014

(1) Challis analyzed chlorite (Ross).

(2) Challis blue-green chlorite (Ross).

(3) Nova Scotia, analyzed chlorite of Walker (Larsen).

(4) Bergen Hill, New Jersey, diabantite (Larsen, Bull. 679, U. S. G. S., p. 67).

(5) Plainfield, New Jersey, diabantite (Larsen, Bull. 679, p. 67).

(6) Delesite (Larsen, Bull. 679, p. 255).

The results show the marked variability in optical properties as well as in composition of the materials which have been referred to diabantite and delesite. Examinations of new occurrences of these minerals can scarce do more at present than to add accurate data to the literature that it may in the future be available for use in the interpretation of the groups as a whole.

CALCITE (ARGENTINE).

Several specimens of calcite are included in the Challis material with the statement that they come from the centers of the larger mordenite geodes. These are all of the unusual variety of calcite which shows lamellar or platy structure and parting parallel to the basal pinacoid (0001), and which is commonly given the varietal name "argentine." The largest specimen of this argentine received has plates 16 centimeters in diameter and while containing quartz and analcite shows no mordenite. Another large specimen, shown in plate 3, lower, is evidently a solution remnant and includes analcite, quartz, and mordenite. A third specimen, in which the platy character is not so evident, is a rounded cast of the central portion of a geodal cavity and is coated on the outside with fibrous mordenite. When clean cleavages from the interior of this mass are dissolved in acid, long silky needles or mordenite remain behind. The broadly platy specimens are snow-white in color. The characteristic pearly luster on the basal pinacoid, usually shown by argentine, is lacking, doubtless because the plates have a uniform thin coating of peculiarly reticulated quartz. A specimen in the United States National Museum from Republic mining district, Washington, is identical

with the Challis argentine in appearance and like it has the calcite plates coated with thin reticulate layers of quartz. The Washington argentine is associated with laumontite.

The large argentine masses clearly are later, in age, than both the mordenite and the spherulitic quartz and the calcite is older than the reticulated quartz and the analcite, which occurs as flattened crystals between the calcite plates. In the specimen shown in plate 1, lower, however, the calcite plates are embedded in the mordenite and thin sections show that the calcite plates of this specimen not only certainly are earlier than the mordenite, but that they are older than the early heulandite deposit which lines the cavity and coats the free plates of calcite on both sides. Elsewhere in the large mordenite specimens there are flat gashes, now lined with analcite, which are apparently casts left by the removal by solution of early calcite plates. There are obviously two generations of the calcite in the specimens, both of which have the unusual argentine habit. The habit of the calcite may be due to the fact that the solutions from which it crystallized were highly saturated with silica and the calcite plates and their surfacing films of quartz are more or less contemporaneous, the silica presumably having deposited in colloidal form.

CONCLUSION.

The assemblage of minerals here described occurs as fillings of cavities, often of very irregular form and large size, in what is probably a flow of rather glassy andesite with a porphyritic development of augite, poured out in a Miocene lake basin. The cavities with their fillings may be so closely spaced as to make up a large proportion of the bulk of the rock. In general, the augite phenocrysts of the andesite are quite unaltered and there is no evidence of extensive alteration of the groundmass, so that it is evident that the minerals of the cavities were not derived by the breaking down of any of the constituents of the immediately adjacent rock. So far as can be determined from a study of the specimens available the order of deposition has been as follows, beginning with the earliest mineral deposited: Chlorites (diabantite, etc.), chalcedony, calcite (argentine), heulandite, mordenite, quartz (spherulitic), calcite (argentine), quartz (films), analcite.

The deposition of both quartz and chalcedony was apparently repeated or was continuous over a considerable period. Of the minerals, mordenite, a comparatively rare zeolite, is by far the most abundant. The area deserves further study and may be expected to produce other minerals of interest if carefully explored.

EXPLANATION OF PLATES.

PLATE 1.

Upper left. Geodal mass of cottony type of mordenite with chalcedonic shell.

Upper right. Analcite crystals in cottony mordenite.

Lower. Argentine calcite inclosed in compact fibrous mordenite. Note thin shell of heulandite which lines the cavity. The small black specks on or near the calcite plates are small dendrites of manganese oxide. All natural size.

PLATE 2.

Upper. Small pure mass of compact, felted-fibrous mordenite filling gas cavity in andesite.

Center. Two specimens of amygdaloidal andesite containing amygdules of mordenite, heulandite, and chlorite.

Lower. Mordenite-filled cavity, all except the central part of the loose-textured mordenite being saturated with granular quartz. All natural size.

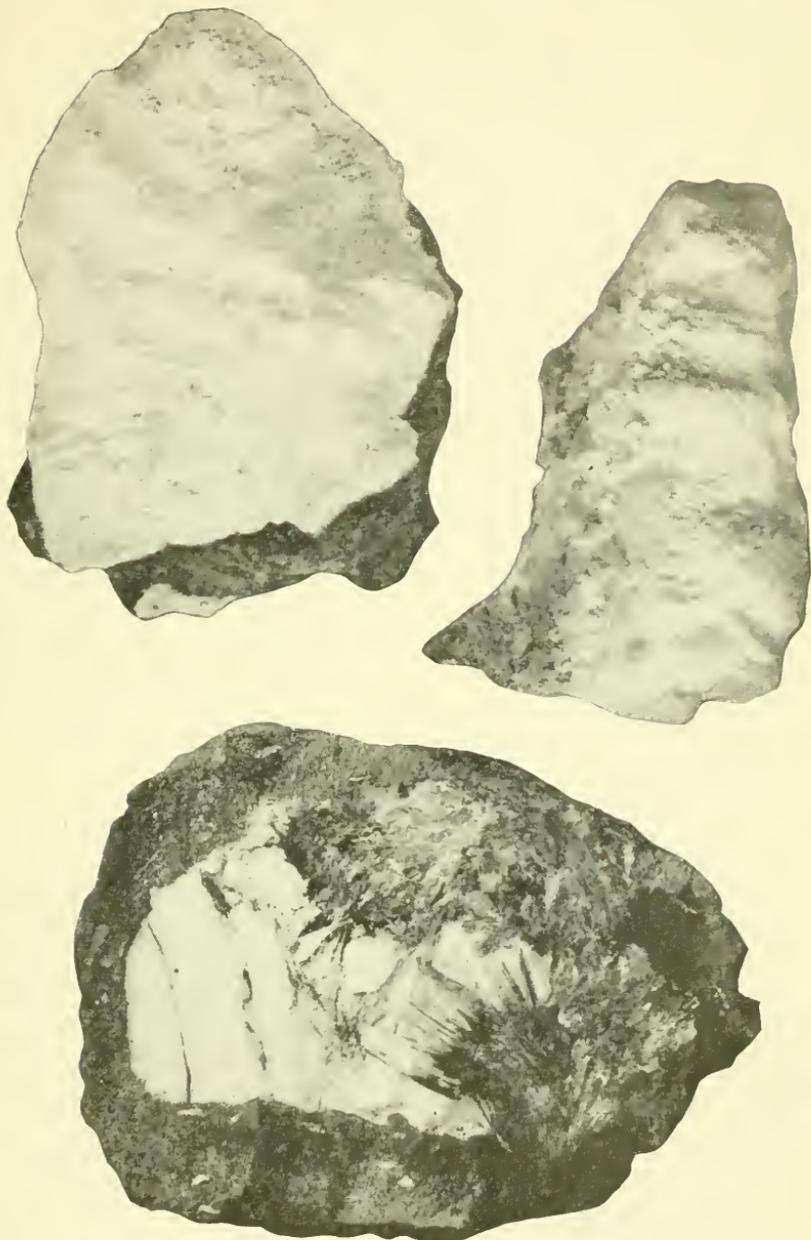
PLATE 3.

Upper. Natural thin flattened analcite crystals from between plates of argentine calcite. Photographed between crossed nicols to show anomalous birefringence and division into sectors. $\times 20$.

Right. Argentine (calcite) coated with quartz spicules and bearing small flattened analcites. Natural size.

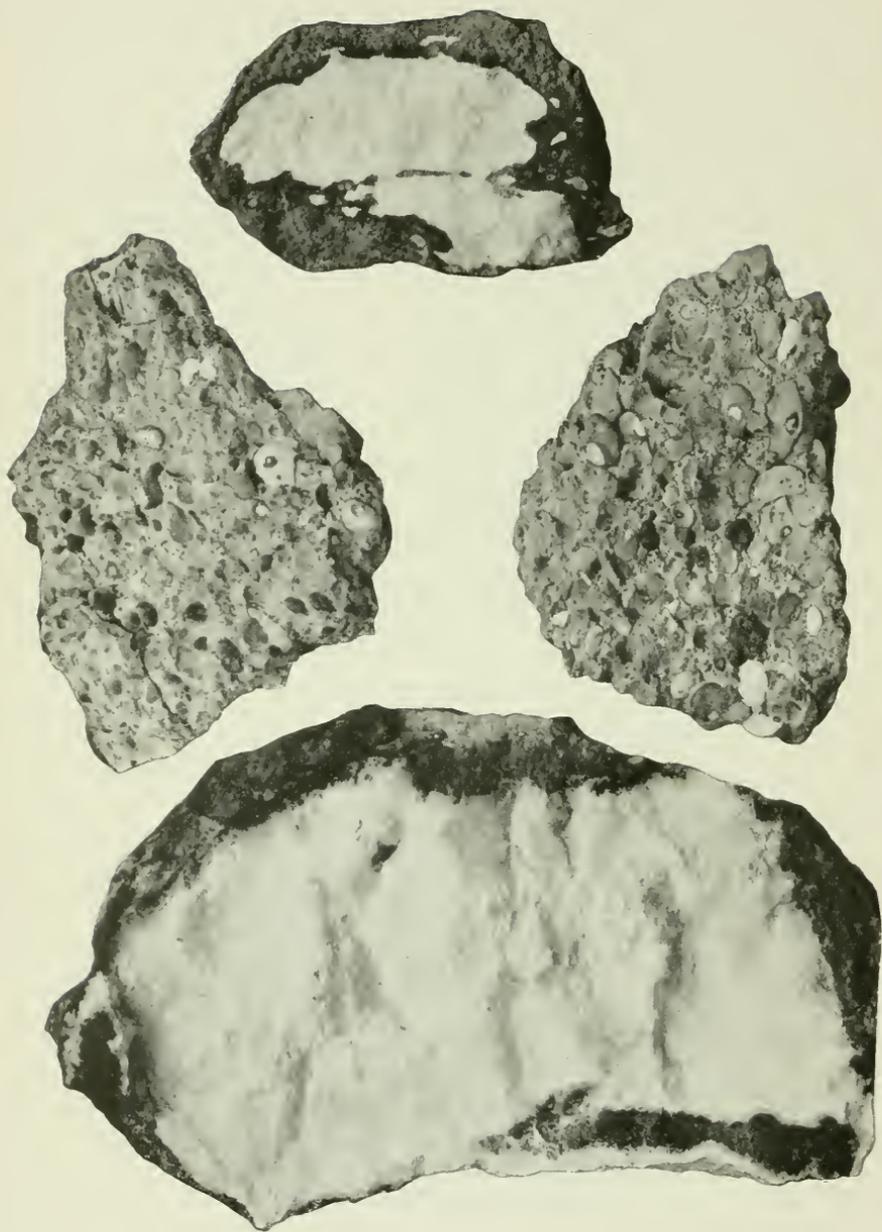
Lower. Tufts of mordenite fibers attached to groups of quartz spicules projecting from platy argentine calcite. Natural size.





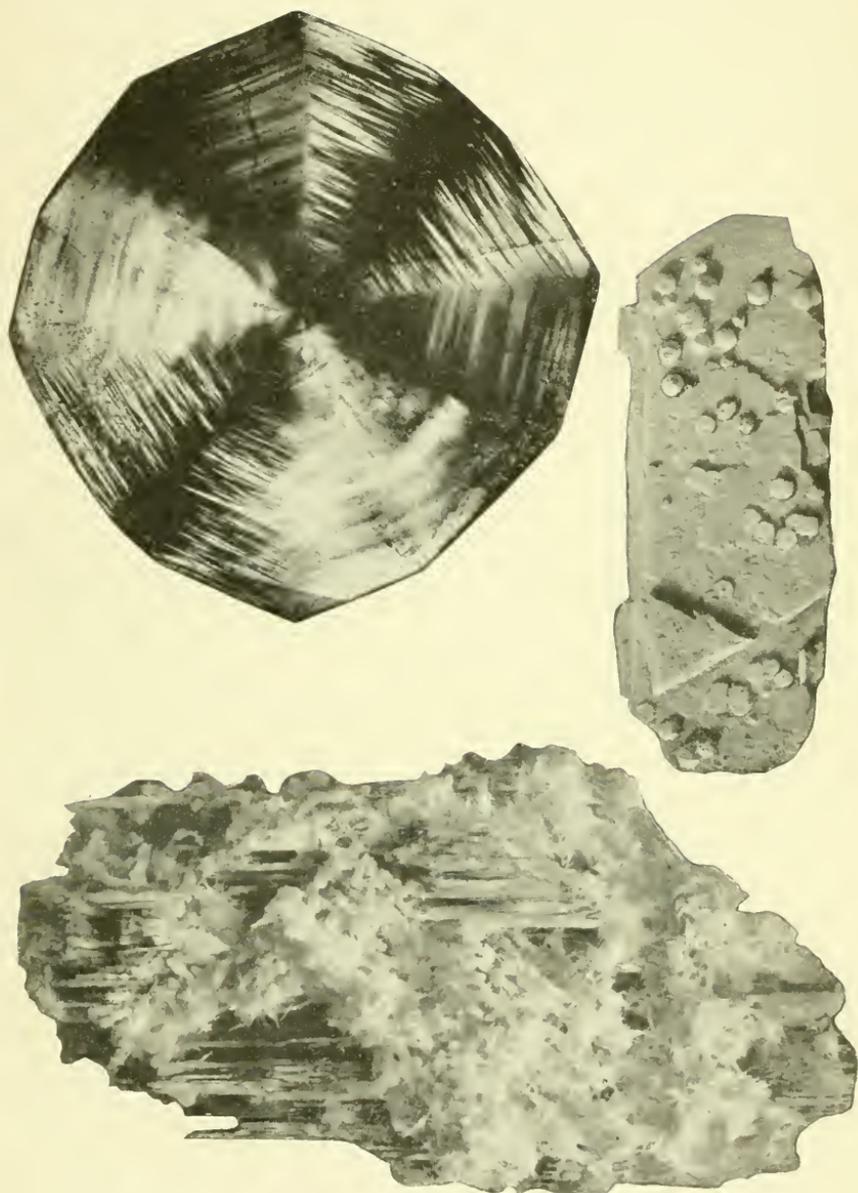
MORDENITE, ANALCITE, AND ARGENTINE.

FOR EXPLANATION OF PLATE SEE PAGE 19.



MORDENITE MASSES AND AMYGDALOIDAL ROCK, CHALLIS, IDAHO.

FOR EXPLANATION OF PLATE SEE PAGE 19.



ANALCITE, ARGENTINE CALCITE, MORDENITE, AND QUARTZ.

FOR EXPLANATION OF PLATE SEE PAGE 19.

