

# MINERALOGY AND PETROGRAPHY OF TRIASSIC LIMESTONE CONGLOMERATE METAMORPHOSED BY INTRUSIVE DIABASE AT LEESBURG, VIRGINIA

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## INTRODUCTION

The present article is intended to follow a preceding much lengthier paper on Triassic diabase at Goose Creek, Virginia.<sup>1</sup> In that paper the diabase, which forms an intrusive sill-like mass several hundred meters in thickness, is described in detail, and it was concluded that certain secondary minerals, among them datolite, prehnite, apophyllite, and certain zeolites, were deposited by magmatic waters expelled by the diabase magma at the end of its consolidation. Various hydrothermal effects of the magmatic solutions upon the consolidated diabase were also considered. The following description considers the case where these magmatic solutions, emanating from the crystallizing diabase, ascended along fissures in the overlying limestone and the alteration of the limestone and the secondary minerals deposited, both as fillings of open cavities and by metasomatic replacement of the limestone itself, are described in detail.

The quarry was visited at various times with several other mineralogists, namely, Frank L. Hess, Esper S. Larsen, Clarence S. Ross, Waldemar T. Schaller, and Ralph W. G. Wyckoff, to all of whom I am deeply indebted for valuable assistance and advice.<sup>2</sup> I would especially express my thanks to Doctor Ross for help and

<sup>1</sup> Earl V. Shannon. Mineralogy and Petrography of intrusive Triassic diabase at Goose Creek, Loudoun County, Virginia. Proc. U. S. National Museum, vol. 66, pp. 1-86, 1924.

<sup>2</sup> Since this paper was written and following the December, 1923, meeting of the Geological Society of America and the Mineralogical Society of America in Washington, a field trip was held to this locality under direction of the writer, which was attended by numerous other scientists of national and international repute.

opinions throughout the preparation of the paper and to Dr. Edgar T. Wherry for kindly reviewing the manuscript and offering numerous helpful criticisms.

#### LOCALITY

The locality described is a quarry at the north side of the Washington & Old Dominion Electric Railway a short distance east of Leesburg station. The main pit now being worked is about 80 meters long by 30 meters wide and about 30 meters deep. The rock is the limestone conglomerate, known as Potomac marble, which frequently occurs at the western border of the Triassic area, and consists of limestone fragments in a calcareous matrix, the product being used as lime, mainly for agricultural purposes. The location is about three miles northwest of the previously described Goose Creek diabase quarry and is immediately above the roof of the same intrusive diabase sill.

#### GENERAL RELATIONS

The bottom of the quarry is believed to be, at most, only a few meters from the roof of the large sill, the contact of which is reported to have been encountered in an adjoining quarry which is now filled with water. Near the bottom of the east wall of the pit two dikes of basalt are exposed, which are doubtless apophyses of the main igneous mass. The exact relations of the dikes are not clear mainly because of a fault which is exposed here and which has greatly fractured the limestone, locally largely replaced by diopside, but they seem to dip at a low angle to the east toward the sill, the roof of which apparently dips west. The rock quarried from the eastern side of the quarry is much harder than the rest, owing to being higher in silica, and is used mainly for road "metal." The exact attitude of the faulting likewise could not be made out but both the basalt and the silicated limestone have been involved in crushing movements. The large amount of diopsidation of the limestone adjacent to the dikes is probably not due to the fact that the dikes are intruded here but rather to the fact that the fissures along which the dikes were intruded have been reopened giving a channel which carried the heated solutions emanating from the sill. Although the attitudes of the large masses of diopside and diopside garnet rock are not clear, the manner of their formation is indicated by certain smaller altered zones along smaller fractures where the replacement of the limestone can be studied in detail. Some of these are well exposed in the north wall of the quarry, and a typical cross section of one of them, illustrated in plate 1, shows the principal features of the replacement. These are re-

garded as having originated by the hydrothermal replacement of the limestone and some of them are persistent to a considerable distance from the diabase mass. The minerals thus developed in the limestone are those typical of what are commonly called contact metamorphic deposits in limestone. Inasmuch as the replacement is clearly a result of the action of heated solutions, or possibly aqueous vapors, on the walls of the fissure, the conception of contact metamorphism is not greatly emphasized here, the minerals being described instead as high temperature hydrothermal replacements. The minerals occurring in this manner include diopside, garnet, magnetite, serpentine, wollastonite, xonotlite, and probably thaumasite. The other class of secondary minerals, regarded as probably having originated at a somewhat later period marked by a considerably lower temperature, occurs as crystals and fillings of cracks and open spaces along slight fissures in limestone. The limestone of the walls of these fissures is not greatly altered. Deposits of this class include datolite, calcite, diopside, apophyllite, and barite; probably anhydrite was also among these.

#### THE LIMESTONE CONGLOMERATE

Little that is original can be added regarding the limestone which is quarried. It is Triassic limestone conglomerate which is commonly known as "Potomac marble" and is made up of fragments of limestone of various sizes and colors in a matrix of calcareous sand, the average tone of the rock as a whole being light gray to almost white. Considering its heterogeneous origin the conglomerate is unusually low in quartz and other impurities. Keith<sup>3</sup> gives the following description of the formation:

The limestone conglomerate is made up of worn pebbles of limestone of various colors, usually blue, interbedded in a reddish calcareous matrix. Rarely pebbles of slate and gray sandstone also occur with those of limestone. The pebbles were deposited in their matrix in a very irregular manner and in sharply limited areas. The areas of conglomerate point off into the sandstone like wedges, their form being due either to thinning out away from shore or to subsequent cutting off by faults. From these masses of limestone pebbles it is inferred that a large body of limestone was exposed to erosion and that from its fragments were produced the worn pebbles. The conglomerate being coarse, it was probably laid down by strong currents or waves along a shore, and is therefore apparently a beach deposit.

Doctor Merrill gives the following account of the formation:<sup>4</sup>

The only true conglomerate or breccia marble that has ever been utilized to any extent in the United States is found near Point of Rocks, Frederick County,

<sup>3</sup> Arthur Keith. Geol. Atlas U. S., U. S. Geol. Survey, Harpers Ferry Folio. Folio 10, p. 3, 1894.

<sup>4</sup> George P. Merrill. Stones for Building and Decoration. New York, 1891, pp. 92-93.

in this State (Maryland). The rock, which belongs geologically to the Triassic formations, is composed of rounded and angular fragments of all sizes, up to several inches in diameter, of quartz and magnesian limestone imbedded in a fine gray calcareous groundmass. This composition renders the proper dressing of the stone a matter of some difficulty, since the hard quartz pebbles break away from the softer parts in which they lie, leaving numerous cavities to be filled with colored wax or shellac. It should therefore never be worked with hammer and chisel, but only with saw and grinding material, and no attempt made at other than plain surfaces. The stone was used for the pillars of the old Hall of Representatives in the Capitol at Washington, and a polished slab 34 inches long by 20 inches wide may be seen in the National Museum at Washington. The pebbles forming the stone are of so varied shades that to state its exact color is a matter of difficulty. Red, white, and slate-gray are perhaps the prevailing tints. On account of its locality the stone has been popularly called "Potomac" marble, or sometimes calico marble, in reference to its structure and spotted appearance. The formation from whence it is derived is said to commence near the mouth of the Monocacy River, and to extend along the Potomac to Point of Rocks and along the valley on the eastern side of the Catoctin Mountain to within 2 miles of Frederick. The writer is informed, moreover, that the same formation occurs in Virginia, near Leesburg, and that here the quartzose pebbles are almost entirely lacking, thereby rendering the stone less difficult to work.

At the Leesburg quarry the rock consists of pebbles of white, slaty blue or buff fine to coarse-grained marble in a light colored calcareous matrix, so that the general tone of the rock is light colored with no red tints. No quartzose or siliceous pebbles are to be seen and, where the silica content increases it is apparently due to secondary introduction of diopside and other silicates.

#### THE BASALT

The basalt is exposed on the east side near the bottom of the quarry where it occurs apparently as two flat easterly dipping dikes about a meter in thickness, separated by several meters of diopside rock. The dike rock apparently has been shattered in part by later faulting which took place at various times and some of the basalt was probably broken up and dragged as fragments into the sheared material, subsequent to its consolidation yet previous to the alteration of the limestone to diopside rock.

In the hand specimen the rock is medium dark purplish gray in color and dense in structure, no individual minerals being distinguishable under a lens. It is practically lusterless in the crystalline portion but varies to waxy-lustered in the glassy chilled border phases. The dikes are so jointed that it is difficult to secure a piece large enough to trim into a hand specimen.

Under the microscope the average rock from the dikes is a very fine grained holocrystalline aggregate of feldspar and pyroxene, both of which tend to assume euhedral form, the pyroxene in short

prisms and the feldspar in elongated laths. The rock is all more or less affected by alteration and the feldspars are so sericitized that their determination is impossible. The lath-like habit of the feldspars gives the rock an ophitic appearance but the crystallization of the pyroxene and feldspar was apparently nearly simultaneous. Irregular or rounded rather large dark spots in the section are apparently aggregates of very minute grains of magnetite, dense in the center and thinning toward the borders of the spot. Where small un-sericitized remnants of the feldspar remain they have a refractive index distinctly above that of Canada balsam showing that they have not been albitized. In addition to the fine crystalline fabric which forms the body of the rock, there are visible in thin sections certain scattered areas, much larger than the average grain of the rock, which are now green serpentine clearly secondary after original olivine. Occasionally they inclose a core of unaltered olivine. These olivine pseudomorphs seldom show complete crystal outline but have the appearance of fragments of broken up larger crystals. Colorless and fresh pyroxene also occurs rarely like the olivine as larger isolated crystals or groups of several crystals. The freshest rock is cut by very thin cracks filled with fibrous, colorless serpentine.

At the borders of the dikes there are chilled glassy phases which have the same purplish color as the body of the rock except where hydrothermally altered to a dull green. The glassy material has a waxy luster and faintly conchoidal fracture. It is clear isotropic glass of dark brown color in thin section and, like the crystalline rock, contains scattered talc and serpentine pseudomorphs after olivine and a few pyroxenes. The isotropic glass grades into birefracting material and at a distance of 16 millimeters from the contact in one specimen, had graded into wholly birefracting very fine grained material having a fibrous structure suggesting the structure of the crystallized basalt.

#### HYDROTHERMAL ALTERATION OF THE BASALT

The alteration of the limestone, which, in the vicinity of the basalt dikes is largely converted to lime-silicate rock, by the action of thermal solutions is believed in great part to be subsequent to the intrusion of the basalt. The solutions might naturally be expected to exert some profound influence on the shattered basalt while producing such drastic changes in the limestone but such is not the case. All of the feldspar of the basalt is sericitized, and, as has been mentioned, it is extensively traversed by narrow seams of serpentine. Moreover, there occur, here and there, scattered in the diopsidized limestone, small masses and fragments of more or less glassy basalt from the dikes. These have lost their original purple color and are

now dull olive green. The glassy basalt at the contact with the diopside rock is changed to this green color for a distance of about 5 millimeters. Under the microscope this green glassy basalt has precisely the same appearance as the normal purplish glass and the line of contact between the two can not be distinguished in the thin section, although the glass is banded in more and less transparent bands parallel to the contact. It may be recalled from the description of hydrothermal alteration of the diabase of Goose Creek that the principal effect of the solutions was removal of some of the iron of the original augite and the changing of this high iron pyroxene to pale green or colorless diopside. The effect here on the basaltic glass has probably been a similar substitution of bases although it is not susceptible of proof by microscopic examination.

Many specimens of the crystalline basalt of the dikes show narrow seams and veinlets cutting the normal rock. These have a central white seam averaging  $\frac{1}{2}$  mm. in width bordered on either side by a dense olive green layer about 1 mm. wide beyond which is a bleached greenish band from 1 to 2 mm. wide which shades into the normal rock. Under the microscope these bands are not so conspicuous. The central filling is composed of granular datolite. The dense greenish band is largely pyroxene, apparently an enrichment by enlarging the original grains of the rock. The outer bleached streak presents no conspicuous difference from the adjacent normal basalt under the microscope except that the pyroxene looks clearer and less colored while by comparison that of the adjacent unaltered basalt appears brownish. It seems most probable that this alteration is, like that observed in the Goose Creek diabase, diopsidization of the augite. The outer band contains scattered grains of pyrite.

#### HYDROTHERMAL MINERALS REPLACING THE LIMESTONE

As has been previously pointed out, large amounts of diopside and diopside-garnet rock are developed adjacent to the basalt dikes or, probably better, in and adjacent to the shear zone which is associated with the dikes where they are exposed on the east side of the quarry. These lime silicate rocks are fine grained and lusterless, with dull green to brownish green and brownish gray colors. Their relations are not clear, and perhaps the best method of describing them is to describe the several specimens collected as typical of the several variations.

The writer's No. "Lb-3" in the hand specimen is a sugary granular dull green rock showing no minerals clearly identifiable with the unaided eye, except a little coarse calcite. It shows ghost outlines

of the original conglomeratic structure, remnants of the original pebbles showing either as deeper green or browner green masses or as incompletely replaced granular areas richer in calcite than the matrix. Under the microscope this is seen to consist predominantly of diopside, with less calcite, garnet, and serpentine. The diopside is fine granular, colorless, and of normal optical properties, and is anhedral except where it projects into calcite or serpentine there forming short, stout prisms. The garnets are hexagonal in outline and are anomalously birefracting, some with division into sectors. The centers of some are isotropic, the outer border having a relatively high birefringence, while others show a uniform low order blue interference color. Occasionally they have yellow-brown cores. The serpentine forms fine flaky colorless interstitial areas or fills cracks in the diopside, and is probably the latest mineral in the section.

“Lb-4” is a massive granular lusterless rock like the last but of a more yellowish green tone. Pebbles of the original structure are shown by masses of more yellowish color dotted with dark specks. This contains much less visible calcite than “Lb-3.” Under the microscope this rock is also found to consist principally of granular diopside, with large poikilitic crystals of a uniaxial positive mineral of low birefringence and high refractive index which is probably vesuvianite. Groups of small colorless isotropic garnets and a little flaky interstitial serpentine occur.

“Lb-5” is a dense fine-grained rock having a greenish-gray to lilac-gray color dotted with dark spots only about 0.2 mm. in size, which give the rock a speckled “pepper-and-salt” appearance. Under a lens these dark spots, which look like minute manganese oxide stains, are seen to be resinous and lustrous. They are small patches of garnet. Under the microscope this rock is found to be composed of calcite, diopside, and garnet in roughly equal amounts. The calcite, which is a fabric of coarse interlocking grains, forms a matrix in which the other minerals have developed, probably by replacement. The diopside is colorless and of normal optical properties. It occurs as large ragged and irregular crystals inclosing much calcite and also as radial aggregates of slender prisms. The garnet forms granular areas, ragged in outline and including much diopside. It is completely isotropic, and varies from colorless to resinous brown.

One section was cut showing the actual contact between glassy chilled basalt and the lime-silicate rock. The latter is made up of coarse and fine granular diopside, sharply euhedral garnets, scattered large vesuvianite grains and interstitial patches of serpentine and calcite. The body of the rock and the earliest mineral now shown

by the section is diopside, which includes the later large ragged and poikilitic vesuvianites. The garnets have sharp outlines where they abut against calcite or serpentine and are isotropic except at the borders, where they have a narrow double refracting outer layer. They are grouped in a manner indicating that they probably developed lining minute cavities which were later filled with serpentine now largely replaced or saturated with still later calcite.

The replacement of the limestone by the high temperature solutions moving along fissures is well shown by the specimen illustrated in plate 1. The solutions were controlled by narrow fractures, seldom of any significant size. Along some of these there is some crushing and slickensiding indicating some movement, but in others they are simply weak cracks which have not been accompanied by any displacement at all. They vary somewhat in attitude and dip, ranging from some  $60^\circ$  to vertical, and in general have a north-south strike. Adjacent to this crack the limestone has been replaced by lime silicates, principally diopside with less garnet and serpentine, and some vesuvianite. This replacement extends to variable distances from the fissure. In the illustrated specimen the width of the central filled crack averages only about 2 millimeters, yet the replacement with development of abundant diopside reaches a distance of 10 centimeters from the crack and abundant magnetite has developed up to 4 centimeters away. The specimen is composed predominantly of two kinds of limestones in the usual sandy cement. The matrix of the pebbles has been preferentially replaced by the lime silicates while at the same distance from the fracture the coarse-grained gray-and-white mottled marble has not been attacked at all while a finer granular buff-white marble has been slightly replaced in porous streaks and along rifts. The controlling factor in the replacement has apparently been permeability. Near the fissure many of the fragments of limestone which did not yield to the alteration to lime silicates have been impregnated with fine scales of serpentine in concentric layers parallel to their outer surface. The magnetite has not replaced the lime silicates to any great extent but has developed principally by replacement of these serpentized limestone masses, the structure of the replaced marble being retained in the structure of the magnetite.

The lime silicate rock is not so well individualized in these small replacements as in the large diopside rock masses previously described, the garnet being in the form of irregular and indistinct patches.

The central crack is lined with a layer of about 1 millimeter of diopside, overlain by a layer of minute magnetite grains following which the remaining open space was filled with coarse white calcite.



Thin sections from a second similar vein show the same relations. The central crack is filled with granular calcite containing disseminated magnetite grains and bordered by several alternate layers of diopside and magnetite. There are also layers of another bladed fibrous mineral of low birefringence, with an index of refraction of about 1.56. This mineral is optically positive and probably uniaxial. In optical properties it agrees with brucite or colerainite. It is probably a white chlorite allied to colerainite. Small cavities in the rock adjacent to the crack are lined with a botryoidal brown layer and filled centrally with pale yellow to colorless material which is isotropic at the borders to feebly birefringent with a fine confused fibrous structure at the center. These have the appearance of opal and chalcedony.

Another specimen shows abundant magnetite associated with the colorless chloritic material, and large anhedral areas of garnet which is colorless and isotropic and grades into a thick layer of garnet coating a slickenside along the parent crack. This garnet is largely replaced by a golden brown isotropic material of high refractive index which tends, in places, to form spherical globules each of which has a minute nucleus which appears to be a colorless octahedral crystal.

The minerals which occur as constituents of what are here called high temperature hydrothermal replacements may now be enumerated, with descriptions.

#### DIOPSIDE

Diopside is the most abundant of the minerals replacing limestone and makes up large masses of secondary lime-silicate rock as described above. It is always microscopic granular and never recognizable with the unaided eye. In thin section it is colorless with normal optical properties. Some of the masses of rock consisting predominantly of diopside are a meter or two in diameter.

#### VESUVIANITE

Vesuvianite occurs only as scattered microscopic grains, conspicuous in thin section but invisible to the unaided eye. It is a minor constituent of the lime-silicate rocks.

#### MAGNETITE

Magnetite occurs as fine granular masses adjacent to fissures in the limestone where it accompanies the various secondary silicates. It has chiefly formed by replacement of limestone masses adjacent to the fractures and is younger in age than the lime silicates and serpentine.

## COLERAINITE

A mineral having the optical properties of colerainite was seen in a few thin sections as a microscopic mineral associated with magnetite along fractures.

## GARNET

Garnet is an easily recognized microscopic constituent of the lime silicate rocks where it forms minute sharply bounded euhedral crystals. These vary from completely isotropic to rather notably doubly refracting, with division into sectors. Some crystals have an isotropic core with a birefracting border. The mineral also forms irregular poikilitic areas in diopside rock which appear to the unaided eye as black specks giving a "pepper and salt" appearance in the hand specimen.

Garnet forms large and somewhat irregular areas associated with magnetite along fissures. This garnet is nearly colorless, isotropic, and devoid of crystal outlines. With it is associated another isotropic substance of unknown character which has a golden brown color and index of refraction below that of the garnet but still very high. This brown mineral seems to replace the garnet and in places tends to form globular masses, each of which contains what appears to be a minute colorless octahedron having the index of the garnet.

The most unusual garnet found in the quarries is obtained as a coating on slickensides. Many of the small fissures along which high temperature replacement of the limestone with diopside, magnetite, etc., has taken place are not healed but have been kept open by slight movements which have produced slickensides. These slickensides are coated, to an average depth of several millimeters, with a green material which has all the appearance of serpentine, which might be expected to occur in such manner. These were thought to be serpentine in the field but the specimens of them collected were found to be garnet when further examined. This garnet is so unusual in appearance and occurrence as to warrant a detailed description.

The coatings are associated with magnetite, diopside, etc., which have developed in the adjacent rock and are usually well polished by slickensiding. They have a pale serpentine green color, and are dense with an opaline texture and waxy luster and subconchoidal fracture. Like some amorphous minerals they tend to contract with the formation of cracks which disintegrate them somewhat. The material was found upon microscopic examination to be isotropic with a refractive index above 1.82, the highest oil at hand. A pure piece of the mineral was selected for analysis, ground and treated

with dilute acid to remove a little calcite present as impurity. The resulting material was homogeneous garnet but varied in color under the microscope from transparent colorless to brown, the brownest material being faintly anisotropic but grading into the isotropic material with lessening of the color. The analysis gave the following results:

*Analysis of slickensided garnet coating*

SiO <sub>2</sub> -----	33.23
Al <sub>2</sub> O <sub>3</sub> -----	4.65
Fe <sub>2</sub> O <sub>3</sub> -----	26.37
FeO-----	.04
CaO-----	34.18
MgO-----	Trace
H <sub>2</sub> O-----	1.79
Total-----	100.26

The analysis shows the material to be garnet, principally of the lime-iron molecule andradite with a little of the lime-alumina molecule, grossularite.

SERPENTINE

Serpentine is common though not abundant in the lime silicate rocks as fine scaly interstitial material. It frequently replaces limestone pebbles to a slight extent as disseminated grains scattered throughout the pebble. Sometimes small flat thin fragments of limestone in the breccia are completely replaced by oil green translucent serpentine when it becomes conspicuous to the naked eye. In other cases a layer of pale yellow green waxy serpentine from a millimeter to a centimeter thick surrounds a rounded pebble of dense white marble as a continuous envelope, and penetrates it along cracks. In thin section this serpentine is clearly seen to be a replacement of the calcite of the marble and to vary from isotropic through fine scaly material of low birefringence to coarser flakes of high birefringence.

XONOTLITE

The calcium silicate described as a new mineral from California<sup>5</sup> and later shown to be identical with xonotlite<sup>6</sup> was identified in a single specimen found loose on the floor of the Leesburg quarry by Doctor Schaller. The xonotlite forms rounded patches up to 5 or 6 centimeters in diameter, surrounded by rims from 1 to 4 millimeters wide of cross fibered pale bluish green material which is largely

<sup>5</sup> Esper S. Larsen. Eakleite, a new mineral from California. Amer. Journ. Sci., vol. 43, pp. 464-465, 1917.

<sup>6</sup> Esper S. Larsen. The identity of eakleite and xonotlite. Amer. Mineralogist, vol. 8, pp. 181-182, 1923.

calcite mixed with some fibrous silicate. After treatment with cold dilute acid there remains a residue of fibrous material of very low birefringence with a refractive index below 1.50. This may be silica from the decomposition of thin wollastonite fibers. The interstices between the xonotlite areas are filled with pearly granular wollastonite.

This xonotlite, like those previously described from other localities, is densely fibrous and very tough. When freshly broken the mineral is distinctly pink in color and somewhat translucent but upon exposure to air the pink color gradually fades and the mineral becomes more opaque at the surface with a chalky appearance. A selected fragment from the center of one of the purer masses was analyzed yielding the results given in the following table. The sample was not of very pure material as it was shown by microscopic examination to contain two minerals as impurity, amounting to several per cent. The most abundant of these was apparently diopside, the second probably thaumasite.

*Analysis and ratios of compact xonotlite from Leesburg*

Constituent	Per cent	Ratios	Constituent	Per cent	Ratios
SiO <sub>2</sub> .....	45.62	0.757	H <sub>2</sub> O+110° C.....	6.00	0.333 0.111×3
(Al, Fe) <sub>2</sub> O <sub>3</sub> .....	2.05	.016	H <sub>2</sub> O-110° C.....	1.00	.....
CaO.....	41.28	.736	Total.....	98.21	.....
MgO.....	2.26	.056			
		0.110×7			
		.113×7			

The ratios give the formula 7CaSiO<sub>3</sub>·3H<sub>2</sub>O as compared with the 4CaSiO<sub>3</sub>·H<sub>2</sub>O or 5CaSiO<sub>3</sub>·H<sub>2</sub>O of previous analyses. This may be due to water absorbed in the fine fibrous mass. The material used for analysis was too impure to do more than establish the identity of the species.

Under the microscope the mineral is finely fibrous with parallel extinction and positive elongation. The refractive indices are somewhat variable, the average being,  $\alpha=1.580$   $\gamma=1.592$ .

The xonotlite-bearing mass found loose and its original position in the quarry is not known. It was near the eastern wall and may have come from the vicinity of the basaltic dikes. Although specially sought, none of the mineral could be found on several subsequent visits.

When the field trip party of the Mineralogical Society of America visited this locality following the Christmas, 1923, meeting, a very different type of xonotlite was found, in thin seams in relatively unaltered limestone in the north end of the quarry. This formed veinlets up to 5 mm. wide filled with flaky fibrous xonotlite with pearly luster and pale pinkish color which greatly resembles the

coarser varieties of pectolite. The feel is harsh and needles break off and enter the fingers as splinters like pectolite. The xonotlite is mixed with calcite and some of the fissures have an earlier layer of datolite next the wall. The needles form radiating bundles and rosettes on the crack-surfaces, sometimes 3 cm. across. Under the microscope these lie on a perfect cleavage which is probably perpendicular to the obtuse bisectrix. If this be taken as  $b(010)$  the optical orientation is  $X=b$ ,  $Y=a$ ,  $Z=c$ . The elongation of the needles is positive and they give parallel extinction. The mineral is biaxial positive with  $2V$  probably small. The refractive indices are  $\alpha=1.583$ ,  $\beta=1.583$ ,  $\gamma=1.595$ . The material gave the following composition upon analysis:

*Analysis of coarse xonotlite*

SiO <sub>2</sub> -----	49.60
Al <sub>2</sub> O <sub>3</sub> -----	1.00
CaO -----	46.32
H <sub>2</sub> O+110°C -----	2.80
H <sub>2</sub> O-110°C -----	None.
	<hr/>
Total-----	99.72

THAUMASITE

Certain glassy transparent grains making up about 1 per cent of the first analyzed sample of xonotlite were not fibrous, had a fairly high birefringence and were uniaxial negative with  $\omega=1.505$  and  $\epsilon$  decidedly lower. These, to judge from their optical properties, were probably thaumasite. The analyzed sample gave faint qualitative reactions for carbonic and sulphuric acids.

WOLLASTONITE

Small interstitial areas between the masses of xonotlite are filled with a glistening material of fine bladed structure varying in color from pearly white to pale greenish. This material, when powdered and examined under the microscope, yields laths with parallel extinction, biaxial negative,  $2V$  small,  $r < v$  weak,  $Y$ =elongation,  $\beta$  above 1.62. This is doubtless wollastonite. It is difficultly distinguishable, with the naked eye, from the crystalline calcite of the marbles and, although none was found on a later visit to the quarry, the mineral may not be uncommon.

DISCUSSION

The foregoing descriptions may now be summarized. Magmatic solutions, emanating from diabase, have traversed fissures penetrating overlying limestone and have largely replaced the rock adjacent

to the fissures with secondary silicates. These are principally diopside and andradite garnet, with less vesuvianite and serpentine, and a little wollastonite, xonotlite, and thaumasite. Magnetite was later introduced in considerable quantity. The order of formation of the most important minerals was diopside, vesuvianite, garnet, serpentine, and magnetite.

This assemblage of secondary silicates is entirely like that found in so-called lime-silicate contact zones and, because of such lime-silicate zones frequently being associated with workable deposits of copper or iron ore, they have been carefully studied by a number of able geologists, and the literature relating to them is rather voluminous. A majority of the authorities who have done detailed work on deposits of this type agree in assigning the source of most of the material of the so-called "garnet-zones" to emanations from the cooling magma and consider that there has been a large addition of material, notably silica and iron, from the igneous rock. There is an alternate opinion supported by some, however, which holds that there has been relatively little material added from the magma and that the lime silicates have formed by simple combination of the lime of the limestone with the impurities already present to form the silicates, under the influence of the heat of the intrusive, the excess of calcium carbonate having been removed from the vicinity. It is not desired to enter here into an exhaustive review or discussion of the two theories nor of the various phenomena which characterize lime-silicate zones in general. The literature of the subject has been reviewed in detail in a paper by Uglow<sup>7</sup> who favored the idea that the recrystallization of the materials of the limestone was the process of fundamental importance in the production of the lime-silicate zones. The discussion provoked by this opposition to the favored view was entered into by a large proportion of the leading American authorities on the subject.<sup>8</sup> The consensus of opinion is that both processes are operative, but the majority favor the conclusion that the addition of material from the magma has greatly overshadowed the mere concentration of impurities by reduction in volume in most of the known cases.

While the term "contact zones" is generally used for these lime-silicate masses, they are characterized, usually, by marked irregularity of distribution, even about a single intrusive mass. In some places great quantities of the silicates are developed at one point

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<sup>7</sup> W. L. Uglow. Review of the existing hypotheses on the origin of the secondary silicate zones at contacts of intrusives with limestones. *Econ. Geology*, vol. 8, pp. 19-30 and 215-234, 1913.

<sup>8</sup> *Econ. Geol.*, vol. 8, 1913, pp. 501-507 (C. A. Stewart), and pp. 597-610 (J. F. Kemp); vol. 9, 1914, pp. 73-77 (D. F. Higgins); pp. 175-183 (W. L. Uglow); pp. 278-281 (C. A. Stewart); p. 282 (J. F. Kemp); 283-292 (W. Lindgren); 292-299 (C. K. Leith); 593-594 (J. B. Umpieby).

in the contact while at other places, where the same igneous rock is in contact with identical limestone, no appreciable effect can be found. Sometimes secondary minerals form at a considerable distance from the intrusive as tabular bodies along fissures or as pipes and in many places the garnetization follows single beds for a long distance from the contact while the other beds of the series are completely unaltered. The latter phenomena have been explained by the proponents of the residual crystallization theory as being due to impurities, capable of forming secondary silicates, in the replaced beds while the unreplaced beds were devoid of the constituents, notably silica, alumina, iron, etc., necessary to form the garnet and other silicate minerals; but several authors have shown that this does not hold true for in many cases it is the purer beds which have been converted to silicates.

The formation of these lime-silicate zones in limestone is in almost all cases at the contacts of acid rocks, basic rocks very seldom giving rise to such deposits. In the case of the Leesburg quarry, however, the lime silicates are formed adjacent to a diabasic intrusion. Referring again to the preceding Goose Creek paper, it may be recalled that it was there concluded that the heated magmatic solutions were released only after they had concentrated in residual areas in the magma and had induced differentiation in these areas so that the last rock to crystallize, preceding the release of the solutions, was a quartz albite rock. The solutions, as such, were thus in fact emanations from very acid rocks, despite the small amount of the acid rocks and their derivation from a great body of basaltic magma. These solutions were not stable in contact with the already solidified basalt but reacted with it adjacent to the fissures which formed channels for their escape, metasomatically replacing augite by diopside, plagioclase by albite and sericite, and magnetite by titanite. It is these solutions which, escaping along fissures in the limestone, accomplished the mineralization described in the present paper. This small-scale process of elimination of concentrated solutions at the final consolidation of acid end products of differentiation is, if we may credit modern petrologic theory, precisely what has happened in the larger batholithic masses of relatively acid rocks.

Emanations, by which is here meant principally water solutions, may be given off in the earlier stages following the intrusion of a batholith into its chamber, particularly if it be saturated with volatile materials, but it seems improbable that a high degree of saturation often obtains. The water enters the magma chamber in solution in the magma. There must be some essential difference in the behavior of water in abyssal chambers crystallizing to give a plutonic rock of granitoid texture and in a stock crystallizing at moderate depth.

In the former case it may be presumed that there was no means of escape for the contained water and it was retained until final consolidation, the expulsion of the water being the result of crystallization. In the case of hypabyssal intrusions, forced into magma chambers at moderate depth, on the other hand it may be conceived that the surrounding rock was to some extent permeable, permitting the escape of some of the vapors and corresponding reduction of the vapor pressure of the magma. Such action might be expected to give general contact action by the magma on its walls proportional to the porosity or permeability of the confining rock at any given point. If this rock were limestone the extent to which it was affected would be dependent on its permeability, a property not directly connected with its chemical or mineralogical composition.

Such loss of volatile constituents of the igneous mass, by permeation of the enclosing walls, results in a decreased vapor pressure in the mass of fused material and a lessening of the content of dissolved gases. It would thus act to constantly raise the point of consolidation of the magma and, taking place concurrently with loss of heat by diffusion into the surrounding rocks, would inevitably hasten the final consolidation. Since the presence of phenocrysts, carried already crystallized in the magmas filling many such bodies, precludes the idea that they were greatly superheated when intruded, the combined influences would tend to crystallize them rather quickly with little opportunity for further differentiation. At the crystallization of the mass as a whole, however, the remaining volatile constituents, including the remainder of the water must be expelled, either through the consolidated rock as a mass or through fissures which might be developed from the act of crystallization or by some outside agency. If the final elimination of water took place uniformly without fissures it might be expected to continue to move as the earlier emanations had moved, controlled by the permeability of the surrounding rocks. In most cases, however, fractures seem to have developed at the critical moment, giving localized channels for the escape of the materials. These late emanations doubtless were laden with materials in solution and were capable, in their earlier and hotter stages, of producing lime-silicate masses like those resulting from the earlier emanations. Whether the materials carried in solution at a given place outside the magma were the original constituents of the solutions at the moment of crystallization or whether they are the result of reactions and substitution in the traversed rock, where they have produced alterations so generally as to be difficultly demonstrable, can not in all cases be determined. Sericitization of the feldspar seems a common effect of such late solutions and this can be detected, but minor substitutions might take



place extensively without obvious effect. In the examples which, because of their economic importance have received much careful study the solutions have produced, in their early stages, when enclosed in limestone, garnet zones, while at greater distance or in different surroundings and under other conditions they gave rise to metalliferous veins. There is no real difference between metalliferous veins, such as are widely known, on the one hand and the less conspicuous zeolite-bearing veins arising from basaltic rocks on the other hand, and ore minerals are frequently noted in association with the zeolites while zeolites are not infrequent in association with valuable ores.

At Leesburg the solutions emanating from the crystallizing diabase have penetrated the limestone, after some reaction with the traversed igneous rock, and have followed fissures replacing the limestone adjacent to these fissures by lime-silicates. The most abundant mineral is diopside, followed by garnet and vesuvianite and later serpentine, followed by magnetite. The diopside replaced, first, the porous material of the calcareous sand groundmass and, later, the more porous of two kinds of marble making up the pebbles of the conglomerate, leaving even small pebbles of the other less porous marble isolated in a diopside groundmass. The serpentine-forming solutions coming later penetrated these residual pebbles of limestone, coloring them with disseminated flakes of serpentine and surrounding them with a serpentine crust. The magnetite moreover replaced these serpentized pebbles of limestone in preference to the previously formed diopside and garnet of the matrix. Advocates of the origin of lime-silicate zones by decrease in volume and recrystallization might maintain that the presence of clay and sand as impurities in the groundmass was the controlling factor in this localization. The attitude of the silicates along a fissure in unaltered rock shows, however, that whatever agency created them traveled along, and confined itself to the immediate vicinity of, the fissure. Moreover, the structure of the conglomerate is retained, showing that there has been no considerable decrease in volume or concentration of impurities. The process has apparently been entirely metasomatic and volume for volume without any alteration or loss of structure. It is conceivable from a study of the specimen illustrated in plate 1 that, assuming the limestones to have been a bedded series instead of the conglomerate, the buff marble might have been completely converted to silicate rock while the gray and white marble remained unchanged or was replaced by magnetite, it being assumed, of course, that the supply of replacing solutions was adequate and not limited as in the illustrated specimen. On the eastern side

of the quarry, where the action was more intense, all parts of the limestone have finally succumbed to the replacement.

It seems probable that the extent of the metamorphic replacement of the limestone at Leesburg is more or less coincident with and dependent upon the abundance of water in the underlying sill and upon the formation of pegmatites and acid differentiates in the sill. This mass thus behaved more or less as an abyssal chamber, retaining its volatile emanations and concentrating them in differentiates.

Characteristic of a somewhat later phase of the activity of the solutions are the low temperature veins, corresponding to the zeolite veins at Goose Creek, which are described below as containing datolite and calcite with less apophyllite, diopside, and barite.

#### LOW-TEMPERATURE VEINS

Under this heading are considered narrow fractures in the limestone containing fillings of calcite or, more frequently, datolite, and having numerous open spaces lined with datolite, calcite, and less of a peculiar form of diopside, apophyllite, and barite. These veins average only about 2 centimeters in width, although they widen out in places to 8 or more cm. with open centers. The veins fill open cracks which are apparently feeble breaks of practically no displacement. The open space which they have filled may in part be due to solution of the limestone along the break. The adjacent limestone is not conspicuously altered. These veins are considered to represent the material deposited from solution by emanations from the underlying diabase in the same manner that datolite with zeolites and prehnite were deposited in the veins in the diabase. The source for these vein minerals is thus the same as that of the materials added to the limestone to form the replacements composed of lime-silicate minerals and magnetite. The datolite-calcite bearing veins are considered to represent a slightly later phase of deposition, marked by lower temperature and perhaps pressure, indicated by the fact that they cut the lime silicate rock but have produced no notable alteration where they have intersected the original limestone. The parent cracks which controlled the lime-silicate deposition described above are filled with calcite and datolite occurring in the cracks along which the basalt has been hydrothermally altered. In general the deposition of the later veins followed new fractures, but the veins are linked to the high temperature replacements by a number of features in common. Calcite veins cut the lime silicate body on the east side of the quarry and one of these had a central filling of chalcedony like that observed in thin section in lime silicate rock. Moreover, diopside, the most abundant product of the lime silicate replacement, occurs as a true vein mineral intimately associated with the datolite.

It is not believed that there can be any separation into two distinct phases of alteration and deposition of secondary minerals and there is probably every gradation from the so-called high-temperature replacements to the presumable low-temperature veins. The fact that the low-temperature veins are later in the observed cases than the lime-silicates merely indicates that they were formed by superposition at a period when the environment had become cooler, either by the dying stage of the same current of material or by a new pulse of solutions ascending along new fractures, from a deeper part of the sill. In the earlier stage, the zone characterized by deposition of datolite was well beyond that where the diopside and associated minerals were formed.

The minerals occurring in the veins are separately described below.

#### DIOPSIDE

Some of the specimens of crystallized datolite show minute translucent white blades which are aggregated into masses, sometimes filling a small cavity, and resembling frost crystals. In most cases the mineral rests upon the bare portions of the limestone base of the specimens where they are not coated by datolite. Sometimes a completely bounded datolite crystal is impaled upon one of the minute blades. In a few cases they seem to rest definitely on the crusts of datolite crystals as though younger.

The amount of the mineral is so small that it was with difficulty that 4 milligrams of pure material was obtained for qualitative testing. It is infusible before the blowpipe, insoluble in acids, and suffers no loss on ignition. Its constituents are silica, lime, and magnesia in approximately equal amounts. Optically the laths are biaxial positive with  $2V$  medium, dispersion pronounced  $r < v$ . In some positions the extinction is parallel with positive elongation, in others the extinction is inclined with  $Z \wedge c = 44^\circ$ . The refractive indices are  $\alpha = 1.670$ ,  $\beta = 1.680$ ,  $\gamma = 1.690$ ,  $\gamma - \alpha = .020$ . All of these properties unite to identify the mineral as diopside, although it looks more like a zeolite and its occurrence and appearance are so unlike those of a pyroxene that the identification was reluctantly accepted.

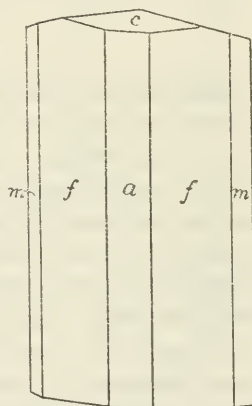
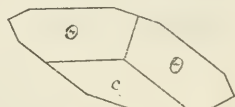


FIG. 1.—DIOPSIDE. HABIT OF MINUTE COLORLESS CRYSTALS OCCURRING IN VEINS WITH DATOLITE

One of the best of the minute crystals yielded approximate measurements sufficient to identify the forms, after the other properties had served to identify the mineral. The angles are given in the following table. The flat lath-like form is due to the predominance of the prism  $f(310)$ . The habit of the measured crystal is shown in figure 1.

*Measurements of vein diopside, Figure 1*

Form		Symbol		Quality; description	Measured		Calculated	
No.	Letter	Gdt.	Miller		$\phi$	$\rho$	$\phi$	$\rho$
					$\phi$	$\rho$	$\phi$	$\rho$
1	<i>c</i>	0	001	V. p. minute.....	90 00	14 06	90 00	15 51
2	<i>a</i>	$\infty 0$	100	V. p. minute.....	93 00	88 00	90 00	90 00
3	<i>m</i>	$\infty$	110	V. p. minute.....	43 30	90 00	43 38	90 00
4	<i>f</i>	300	310	V. p. minute.....	72 00	90 00	70 41	90 00
5	$\Theta$	$-1\frac{1}{2}$	313	V. p. minute.....	55 42	20 17	54 36	18 44

#### ANHYDRITE? MOLDS

Many of the specimens of datolite from Leesburg contain tabular hollow cavities, now empty or partially filled with a late deposit of calcite, which evidently owe their form to crystals of some mineral which has now been completely removed. Many of these cavities are mere gashes showing the mineral to have been very thin tabular and they have often formed parallel aggregates or slightly divergent sheaves of plates and in a few cases rosettes of thin tables radiating from a center. In size the gashes range from exceedingly thin ones with a length of 1 or 2 millimeters to an extreme size, in those examined, of about 3 by 20 millimeters in cross section. The cavities are rectangular in cross section and no impressions of terminations could be made out (See pl. 3).

These are entirely similar to the tabular empty cavities so common in zeolite specimens from the New Jersey localities and to similar impressions or molds which have also been noted at Westfield and elsewhere in Massachusetts and at Meriden, Connecticut. At some of these places they are associated with anhydrite which partly fills them, and it seems altogether probable that in all of the localities, including that at Leesburg, the cavities are the impressions of anhydrite crystals.

\* The minerals which preserve the cavities are datolite and calcite of the generation which formed immediately after the datolite but the anhydrite was removed earlier than the deposition of the later globular calcite which occurs in the crystal molds. The main generation of the datolite is later than the anhydrite but the cavities

do not penetrate quite to the base of the datolite layer so that they are probably approximately contemporaneous.

## DATOLITE

Datolite is the most abundant mineral of the low temperature filled veins. The veins are narrow, averaging about 2 to 3 cm. in width, and are, throughout most of their length, filled with granular massive datolite of a translucent pale yellowish-green color. They open out into vuggy open spaces lined with crusts of crystals of datolite (pl. 2). Sometimes a vein so splits as to include flat pieces of limestone which are coated on both sides with datolite crystals. The datolite rests upon the brecciated limestone conglomerate which, adjacent to the veins, is comparatively unaltered. The crystals of datolite vary from pale transparent yellow green in the larger to opaque and white in the smaller. They reach a maximum diameter of about 7 millimeters.

The crystal habit of most of this datolite is rather unlike that of any American datolite heretofore described. The crystals are thick tabular parallel to the front pinacoid  $a$  (100) and most of them, as shown in figure 2, are orthorhombic in habit. Quite contrary to the usual development of this mineral the positive and negative clinopyramids in a majority of the crystals are simultaneously developed. Most of the faces are not

plane enough to afford good signals on the goniometer, and the crystals would be considered orthorhombic on the basis of these measurements, the deviation of datolite from orthorhombic symmetry being within their limit of error. Owing to the habit of the crystals it was found most advantageous to measure some of them in the Goldschmidt position; that is, with the  $a$  axis (Dana) vertical. The angle tables given below are in part made in this orientation and in part in the Dana orientation. The figures are all drawn in the Dana orientation and the indices given are the Dana indices. A small crystal of the habit shown in figure 2 gave the following measurements:

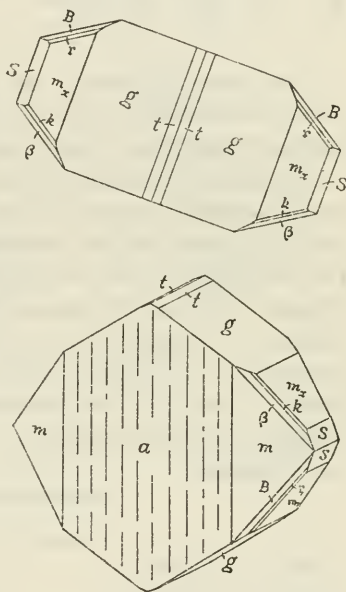


FIG. 2.—DATOLITE. SMALL CRYSTAL SHOWING COMMON HABIT WITH APPARENTLY ORTHORHOMBIC SYMMETRY

## Measurements of datolite, Figure 2

Form		Symbol		Quality description	Measured		Calculated	
No.	Letter	Gdt.	Miller		$\phi$	$\rho$	$\phi$	$\rho$
					$^{\circ}$ /	$^{\circ}$ /	$^{\circ}$ /	$^{\circ}$ /
1	<i>a</i>	$\infty 0$	100	P. bunch.....	90 00	0 00	90 00	0 09
2	<i>S</i>	02	021	Medium.....	21 56	90 00	21 33	90 00
3	<i>m<sub>x</sub></i>	01	011	Excellent.....	38 25	90 00	38 18	90 00
4	<i>g</i>	$0\frac{1}{2}$	012	Medium.....	57 44	90 00	57 40	90 00
5	<i>t</i>	$0\frac{1}{2}$	013	V. p.....	68 41	90 00	67 07	90 00
6	<i>c</i>	0	001	V. p.....	91 12	90 00	90 00	90 00
7	<i>m</i>	$\infty$	110	Excellent.....	00	32 28	14	32 24
8	$\beta$	-12	121	Medium.....	21 33	53 57	21 39	53 47
9	<i>B</i>	-12	121	Fair.....	21 58	53 30	21 27	53 44
10	<i>n</i>	$+\frac{1}{2}$	132	Medium.....	27 26	65 00	N. e.	N. e.
11	<i>r</i>	$-\frac{1}{2}$	132	Dull.....	N. s.	N. s.	27 50	65 05

The letters, symbols, and indices of the above table are for the Dana orientation, while the calculated angles are for the equivalent indices taken from Goldschmidt's Winkeltabellen.

The larger and more highly modified crystals usually have some small negative pyramid faces developed without the corresponding positive forms or the opposite and, where the forms are the same, the faces of one end are slightly larger than at the other end of the crystal. Where the larger faces are of forms occurring more frequently as negative forms they are made negative although the orientation is wholly arbitrary. One such crystal is shown in figure 3 and the measurements are given in the following table. This crystal was measured in the Dana orientation and the angles are so given.

## Measurements of datolite, Figure 3

Form		Symbol		Quality description	Measured		Calculated	
No.	Letter	Gdt.	Miller		$\phi$	$\rho$	$\phi$	$\rho$
					$^{\circ}$ /	$^{\circ}$ /	$^{\circ}$ /	$^{\circ}$ /
1	<i>c</i>	0	001	Poor.....	90 00	0 00	90 00	0 03
2	<i>a</i>	$\infty 0$	100	Excellent.....	90 00	90 00	90 00	90 00
3	$\Delta$	$2\infty$	210	V. g.....	71 45	90 00	72 24	90 00
4	<i>m</i>	$\infty$	110	V. g.....	57 42	90 00	57 37	90 00
5	<i>o</i>	$\infty 2$	120	V. g.....	38 03	90 00	38 14	90 00
6	<i>g</i>	$0\frac{1}{2}$	012	Good.....	0 38	32 39	0 14	32 19
7	<i>m<sub>x</sub></i>	01	011	Ex.....	0 12	52 18	0 07	51 41
8	<i>S</i>	02	021	Good.....	0 12	68 00	0 04	68 27
9	<i>n</i>	+1	111	V. p.....	57 47	67 30	57 38	67 04
10	$\beta$	+12	121	Ex.....	37 35	72 48	38 15	72 14
11	$\pi$	-23	231	Good.....	46 10	79 40	46 24	79 24
12	<i>B</i>	-12	121	Good.....	38 06	72 55	38 12	72 46
13	$\epsilon_1$	$-\frac{1}{2}$	112	V. g.....	49 48	75 31	49 45	75 41
14	<i>t</i>	$-\frac{1}{2}$	212	Good.....	72 50	64 37	72 23	64 26
15	$\epsilon$	$-\frac{1}{2}$	112	V. p. dull.....	N. m.	N. m.	57 33	49 42

Another habit occurring as a variant among crystals of the preceding kinds is shown in figure 4. The same choice exists as in

the preceding as to whether the modifying pyramids and dome be made positive or negative. The five forms, however, are fairly common on datolite as positive forms and are much rarer as negative forms, hence the orientation adopted was as drawn. The crystal is unique, however, since in datolite negative hemipyramids are usually developed much more frequently and in greater number than are positive hemipyramids. The crystal shown in figure 4 gave the angles of the following table. As in the first table above it was found best to measure this with the *a* axis vertical and the table is composite, the indices, etc., being those for the Dana orientation, while the angles are for the corresponding forms taken from the Winkeltabellen.

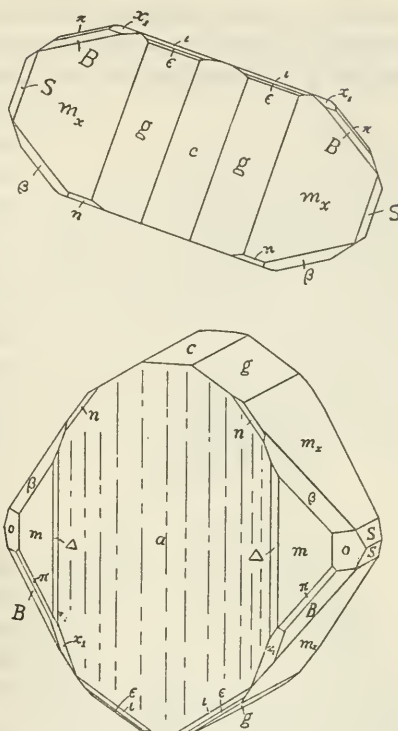


FIG. 3.—DATOLITE. SIMILAR TO FIGURE 2 BUT HAVING SOME NEGATIVE PYRAMIDS NOT REPRESENTED BY CORRESPONDING POSITIVE FORMS

Measurements of datolite, Figure 4

No.	Form		Symbol		Quality description	Measured		Calculated	
	Letter	Gdt.	Miller	$\phi$		$\rho$	$\phi$	$\rho$	
1	<i>a</i>	$\infty 0$	100	P. multiple	90 00	0 26	90 00	0 09	
2	$\Delta$	2 $\infty$	210	Poor	30	18 31	23	17 26	
3	<i>m</i>	$\infty$	110	Good	30	33 06	14	32 24	
4	<i>o</i>	$\infty 2$	120	V. p.	30	52 26	07	51 45	
5	<i>g</i>	0 $\frac{1}{2}$	012	Good	57 57	90 00	57.40	90 00	
6	<i>m<sub>x</sub></i>	01	011	Med	37 37	90 00	38 18	90 00	
7	<i>S</i>	02	021	Good	22 00	90 00	21 33	90 00	
8	<i>u</i>	+ $\frac{1}{4}0$	104	Med	90 00	63 56	90 00	63 31	
9	<i>q</i>	+ $\frac{3}{2}\frac{1}{2}$	312	V. g.	58 00	21 47	57 52	21 41	
10	<i>Q</i>	+ $\frac{1}{2}1$	122	Poor	39 27	57 42	38 33	58 17	
11	$\beta$	+12	121	Excellent	20 00	54 05	21 39	53 47	

In the several variations of the crystals above described the front pinacoid  $a$  (100) is marked by vertical striations, which make this form easy of identification and facilitate orientation of the crystals.

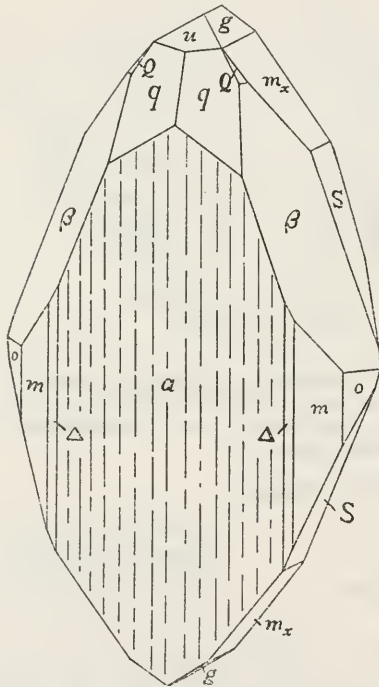
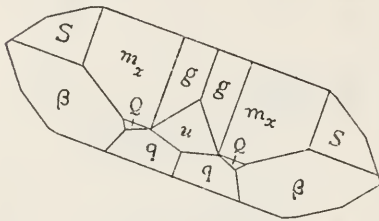


FIG. 4.—DATOLITE. SIMILAR HABIT TO FIGURE 3 BUT SHOWING ONLY POSITIVE HEMIPYRAMIDS

The only other noteworthy feature is the presence of  $\Delta$  (210), ordinarily a rare form on datolite, which is present as narrow but distinct faces on nearly every one of the larger crystals. The negative pyramid  $\alpha_1$  ( $\bar{3}42$ ) reported as a new form on datolite from Westfield, Massachusetts, is present as a small face on one of the measured crystals from Leesburg.

Although all of the datolite crystals of a large number of specimens from several veins had the general habit above described, one specimen, found loose on the east side of the quarry, contained crystals of distinctly different type. This specimen consists of brecciated limestone cemented by massive datolite containing vugs lined with colorless transparent crystals up to 6 millimeters in diameter, all of which have the development shown in figure 5. These are, in general aspect, like some crystals found in veins in diabase at Goose Creek quarry. They exhibit several forms which, while not new, have not been encountered on any datolite crystals which I have heretofore examined. The crystals are very thick tabular parallel to  $\alpha$  (102), while the base  $c$  (001) is

prominent, and the front pinacoid  $a$  (100) is a small and inconspicuous face. The one of these which was measured gave the forms and angles of the following table, oriented, as drawn, in the Dana position.



## Measurements of datolite crystal, Figure 5

Form		Symbol		Quality description	Measured		Calculated	
No.	Letter	Gdt.	Miller		$\phi$	$\rho$	$\phi$	$\rho$
1	<i>c</i>	0	001	Ex. 2 signals	89 37	0 00	90 00	0 00
2	<i>a</i>	$\infty 0$	100	Good	90 00	90 00	90 00	90 00
3	<i>m</i>	$\infty$	110	V. g.	57 54	90 00	57 37	90 00
4	<i>o</i>	$\infty 2$	120	V. g.	38 50	90 00	38 14	90 00
5	<i>m<sub>x</sub></i>	01	011	Uniformly dull	N. s.	N. s.	0 07	51 41
6	<i>g</i>	$0\frac{1}{2}0$	012	Excellent	0 30	32 31	0 14	32 19
7	<i>x</i>	$+\frac{1}{2}0$	102	Deeply corroded	N. s.	N. s.	90 00	45 00
8	<i>p</i>	$+\frac{1}{6}0$	106	Rounded, fair	90 00	18 32	90 00	18 31
9	<i>Z</i>	$+\frac{1}{6}$	116	V. g.	56 25	21 23	57 48	21 36
10	<i>Q</i>	$+\frac{1}{2}1$	122	Dull, etched	38 12	57 52	38 19	58 12
11	<i>\gamma</i>	$+\frac{1}{2}$	124	V. p. dull	38 14	39 34	38 23	38 55
12	<i>\epsilon</i>	$+\frac{1}{4}1$	144	Excellent	21 12	53 54	21 36	53 43
13	New	$+\frac{1}{2}$	2. 3. 10	Medium	47 37	28 57	46 26	28 51
14	<i>\epsilon</i>	$-\frac{1}{2}$	112	Med., wavy	57 02	49 41	57 33	49 42
15	<i>Y</i>	$-\frac{1}{2}$	324	Excellent	67 20	58 23	67 03	57 49
16	<i>\nu</i>	-1	111	Etched dull	57 02	64 01	57 34	67 03
17	<i>u</i>	-21	211	Fair	72 44	78 34	72 25	76 34

The faces of *m<sub>x</sub>* (011), *Q* (122)  $\gamma$  (124), and *u* ( $\bar{1}\bar{1}\bar{1}$ ) are etched uniformly dull while *x* (102) is not merely dull but is deeply pitted and corroded.  $\epsilon$  ( $\bar{1}12$ ) and *Y* ( $\bar{3}34$ ) are ribbed and striated parallel to their mutual intersection, a peculiarity since such striations on  $\epsilon$  ( $\bar{1}12$ ), almost invariably present on the crystals of this mineral from other localities, are usually parallel to its intersection with *m* (110).

A small face, not shown on the drawing, which occurs between *Z* (116) and  $\gamma$  (124) gives angles indicating a new form with the indices (2.3.10). The negative pyramid *u* ( $\bar{2}\bar{1}\bar{1}$ ), recorded as a new form on datolite from Westfield, Mass., is here confirmed.

There is an alternate position possible for these crystals whereby the broad face indicated as *c* (001) in the drawing becomes *a* (100) and the small triangular face, above made *a* (100) becomes *c* (001),

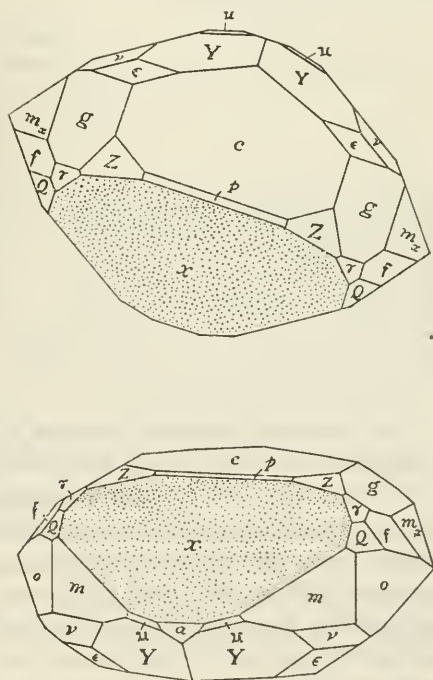


FIG. 5.—DATOLITE. CRYSTAL FROM A SPECIMEN ON WHICH ALL THE CRYSTALS, LIKE THE ONE FIGURED, ARE DIFFERENT FROM THE PREVAILING HABIT AT THE LOCALITY. SHOWS SEVERAL UNUSUAL FORMS

$x$  (102) remaining the same. The latter orientation makes  $a$  (100) prominent as in the previously described crystals, while the striations on  $\epsilon$  ( $\bar{1}12$ ) become normal in direction and  $Y$  (324) becomes  $\lambda$  ( $\bar{1}13$ ). The assumption that the latter is the correct orientation would make it evident that the crystals were measured in the Goldschmidt, rather than the Dana, orientation. The angles measured may therefore be compared with those in the Winkeltabellen and the forms thus identified may be transposed to those for the Dana position. The angles are below compared with those for the Goldschmidt position and the equivalent indices for the Dana orientation are given in the last column.

*Comparison of angles measured on datolite crystal, Figure 5, with angles for Goldschmidt position and equivalent indices for the two positions*

Form		Gold- schmidt indices	Measured		Calculated		Dana indices
No.	Letter		$\phi$	$\rho$	$\phi$	$\rho$	
			° /	° /	° /	° /	
1	$a$	001	89 37	0 00	90 00	0 09	100
2	$c$	100	90 00	90 00	90 06	90 00	001
3	$g$	110	57 54	90 00	57 40	90 00	012
4	$m_x$	120	38 50	90 00	38 18	90 00	011
5	$o$	021	N. s.	N. s.	07	51 45	120
6	$M$	011	0 30	32 31	14	32 24	110
7	$x$	101	N. s.	N. s.	90 00	45 09	102
8	$s$	103	90 00	18 32	90 00	18 36	302
9	$q$	113	56 25	21 23	57 52	21 41	312
10	$Q$	121	38 12	57 52	38 23	58 17	122
11	$n$	122	38 14	39 34	38 27	39 01	111
12	$B$	142	21 12	53 54	21 39	53 47	121
13	$x$	235	47 37	28 57	46 40	29 01	534
14	$\epsilon$	111	57 02	49 41	57 36	49 49	112
15	$L$	322	67 20	58 23	67 05	58 28	113
16	New.	553	57 02	64 01	N. c.	N. c.	3. 5. 10
17	New.	952	72 44	78 34	N. c.	N. c.	2. 5. 18

The above table shows that the alternate position gives no closer agreement in angles and, although the face which is a new form (2.3.10) in the first orientation becomes (534) an established form, two others which in the first orientation are  $v$  ( $\bar{1}11$ ) and  $\epsilon$  ( $\bar{2}11$ ) established forms with simple indices, become new forms with the more complex indices ( $\bar{5}53$ ) and ( $\bar{9}52$ ) respectively. For these reasons the orientation as drawn is believed to be correct. The cause for the abrupt departure of the crystals of this specimen from the habit characteristic for the locality is not apparent.

#### APOPHYLLITE

Apophyllite is rare at Leesburg, occurring as scattered minute colorless transparent crystals, seldom 1 mm. long, resting upon crusts of datolite crystals. On other specimens the apophyllite is largely altered and is opaque white, and friable, many of the crystals being mere skeletons or shells.

Under the microscope the transparent unaltered crystals are uniaxial and positive with  $\epsilon = 1.535$ ,  $\omega = 1.532$ . They are for the most part poised upon needles of diopside and include the colorless vein diopside as numerous fibers.

The crystals, as shown in figure 6, are dominated by the unit pyramid  $p$  (111) with a short prism zone composed of small faces of  $m$  (110) rounded into faces giving angles approximating the form (780). The measurements follow.

Measurements of apophyllite, Figure 6

Form		Symbol		Quality description	Measured		Calculated	
No.	Letter	Gdt.	Miller		$\phi$	$\rho$	$\phi$	$\rho$
1	$m$	$\infty$	110		P. minute.....	45 00	90 00	45 00
2	New?	$\infty^5/7$	780	P. minute.....	41 04	90 00	41 11	90 00
3	$p$	+1	111	Medium.....	45 00	60 41	45 00	60 32

The apophyllite is definitely later than datolite and diopside and is probably earlier than all of the calcite.

#### BARITE

Barite was found in a number of specimens, all apparently from a single narrow but persistent vein. It rests upon crystallized datolite and is doubtless later than the datolite but its age relation to diopside, apophyllite and calcite could not be made out. The barite forms flat tables which reach a diameter of 3 centimeters, some of them being very thin. Many of the plates are curved and they tend to aggregate in sheaves (pl. 3). The surfaces of the plates are etched with a silky sheen but inside they are transparent and colorless with good cleavage. Small free plates are square tables with round corners and show no bounding faces.

The forms assumed by the barite are precisely those shown by the empty cavities assumed to have originally held anhydrite. The barite is, however, a rather insoluble mineral. There is no indication that it is removed in solution and its age relation to the datolite is different.

#### CALCITE

Calcite is an abundant mineral in the veins, probably as abundant as datolite, which is not surprising as the limestone of the walls is capable of furnishing any amount of calcium carbonate to be recrystallized in the open spaces. Some of the small filled veins contain only calcite. One flat seam in diopside rock above the uppermost of the two basalt dikes on the east side of the quarry averaged

2 to 3 cm. wide and was traceable for 2 meters. This was first filled with opaque white calcite crystals of the form  $\varphi$  ( $\overline{22}41$ ), 2 mm. in average diameter, to a thickness of 5 millimeters and was later reopened along one wall and a later filling 15 millimeters wide of

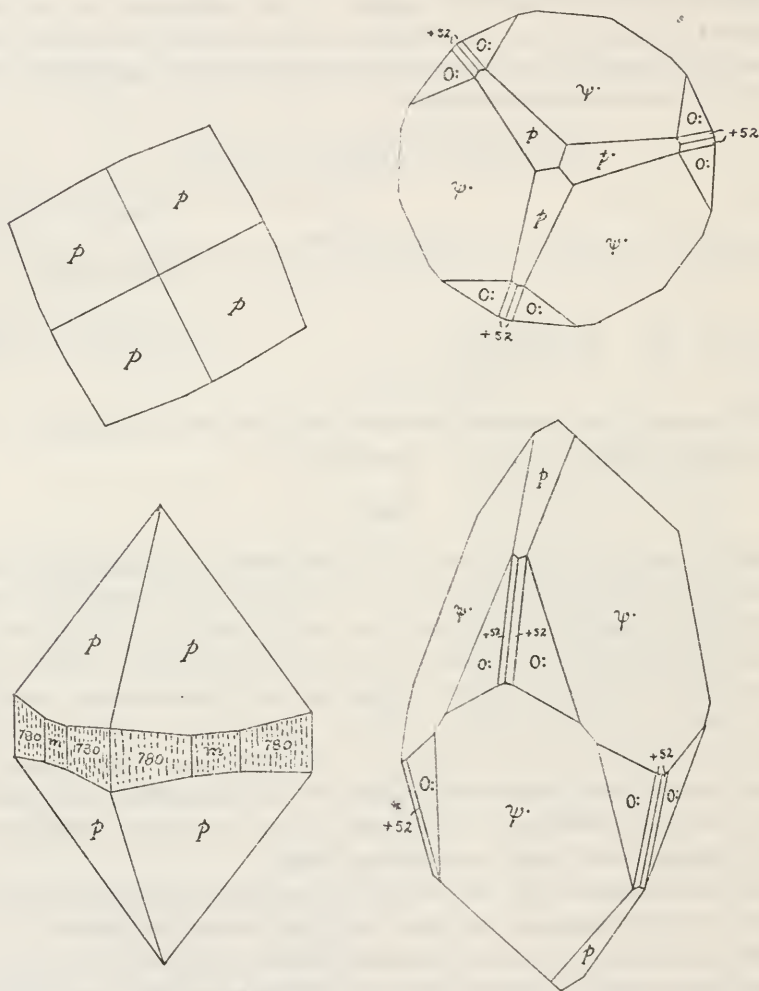


FIG. 6.—APOPHYLLITE. HABIT OF MINUTE CRYSTALS WHICH REST ON DATOLITE

FIG. 7.—CALCITE. HABIT OF SMALL YELLOWISH TO AMBER CRYSTALS

yellowish transparent crystals of the form ( $\overline{33}61$ ) was then introduced, these averaging 5 millimeters in length. One small vug in this seam was filled with chalcedony.

Some specimens show datolite resting on coarse granular bluish calcite which is apparently older than the datolite. Most of the calcite crystals are, however, distinctly younger and rest upon the

datolite. The first and simplest type of these forms transparent pale amber "dog-tooth" crystals resting thickly upon free surfaces of small white datolite crystals. These average 4 mm. in length and have the habit shown in figure 7. Those which were measured gave the following forms and angles:

*Measurements of calcite from Leesburg, Figure 7*

Form		Symbol		Quality description	Measured		Calculated	
No.	Letter	Gdt.	Miller		$\phi$	$\rho$	$\phi$	$\rho$
					$^{\circ}$	$'$	$^{\circ}$	$'$
1		+1	1121	V. g.-----	30 00	44 31	30 00	44 36
2	$\frac{1}{2}$	$-\frac{1}{2}$	5.5.10.2	P. dull-----	30 00	66 20	30 00	67 55
3	$\psi$	+52	5271	Med.-----	15 32	75 35	16 06	74 18
4	0	+61	6171	Med.-----	7 45	76 26	7 35	75 00

Another habit of calcite occurs as clear colorless and transparent to translucent crystals up to 2 centimeters in length resting on the larger datolite crystals. These calcites, which are associated with barite plates, have in general the habit shown in figure 8. The averages of the angles measured on several of these are given in the following table:

*Angles of Calcite crystals of the habit of Figure 8*

Form		Symbol		Quality description	Measured		Calculated	
No.	Letter	Gdt.	Miller		$\phi$	$\rho$	$\phi$	$\rho$
					$^{\circ}$	$'$	$^{\circ}$	$'$
1	$\phi$	-2	2241	Ex.-----	30 03	63 03	30 00	63 07
2	$m$	+4	4481	P. dull-----	30 00	75 33	30 00	75 47
3	$\Theta$	-4	4481	Med.-----	29 51	76 30	30 00	75 47
4		-6	6.6.12.1	P. dull-----	29 51	80 52	30 00	80 24
5		$-\frac{1}{2}$	3362	P. blurred-----	30 03	56 16	30 00	55 57
6	$p$	+1	1121	Med.-----	30 03	44 32	30 00	44 36
7	$\infty$	40	4041	P. etched-----	00	66 10	00	66 18
8		$-\frac{2}{2}$	4372	P.-----	25 20	60 10	N. c.	N. c.
9	$\mathcal{D}$	$-2\frac{1}{2}$	20.8.28.7	P. blurred-----	16 11	63 37	16 06	63 48
10	$n$	+5	5.5.10.1	Medium-----	30 17	78 21	30 00	78 32
11	$\chi$	$-\frac{1}{4}$	9.9.18.4	V. p.-----	30 03	66 06	30 00	65 45
12	$f$	$+\frac{1}{2}$	1122	Medium-----	29 56	26 22	30 00	26 15
13	$K$	41	4151	Good.-----	10 16	71 48	10 53	69 02

A later deposit of calcite occurs as a minutely drusy botryoidal crust. This varies from a continuous crust which may envelope large crystals of the last described form, to minute spherical globules, and ranges in color from white through yellowish to smoky gray. The surface of this crust is made up of minute curved flat rhombohedral crystals. This deposit of calcite was formed after the removal of the anhydrite and occurs in places in the anhydrite cavities.

Chalcedony was found in megascopic masses only once as a purplish-gray filling of a cavity lined with calcite crystals. Its micro-

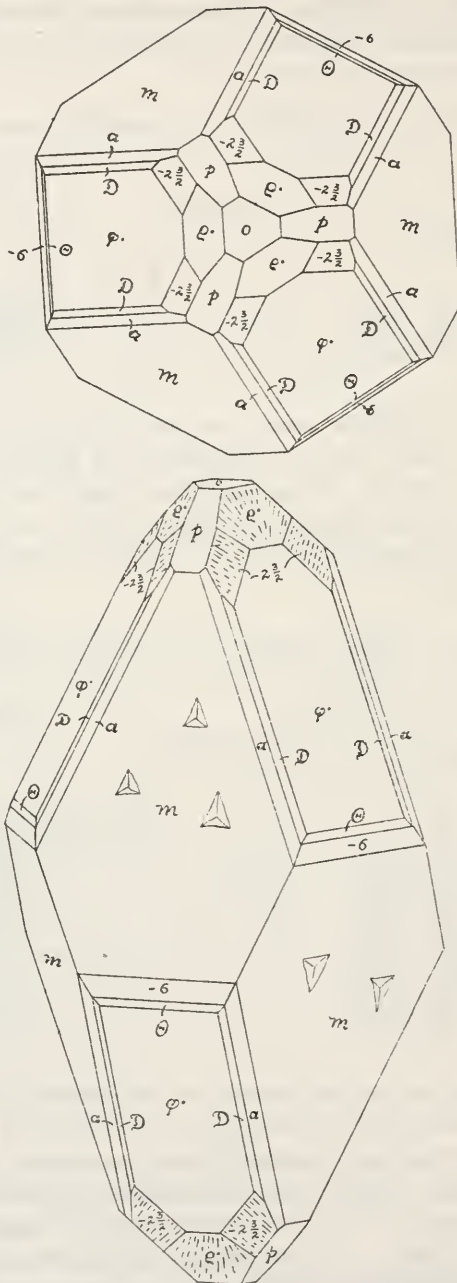


FIG. 8.—CALCITE. HABIT OF LARGER COLORLESS CRYSTALS

scopic occurrence in lime-silicate rock has been noted above. The chalcedony is in the white earliest calcite in the calcite veinlet above

the basalt dikes as described above. It forms an irregular mass 15 millimeters in maximum diameter, varying from chalky white at the borders to translucent purplish gray in the center. It has the usual lusterless surface and flinty fracture.

#### EXPLANATIONS OF PLATES

##### PLATE 1

Replacement of limestone conglomerate along a narrow fissure. Shows the replacement of the calcareous sand forming the matrix of the pebbles by a mixture of diopside vesuvianite and garnet and, nearer the fissure, later replacement by magnetite. Two-thirds natural size.

##### PLATE 2

Crust of datolite crystals encrusting the walls of a narrow open fissure in limestone. Natural size.

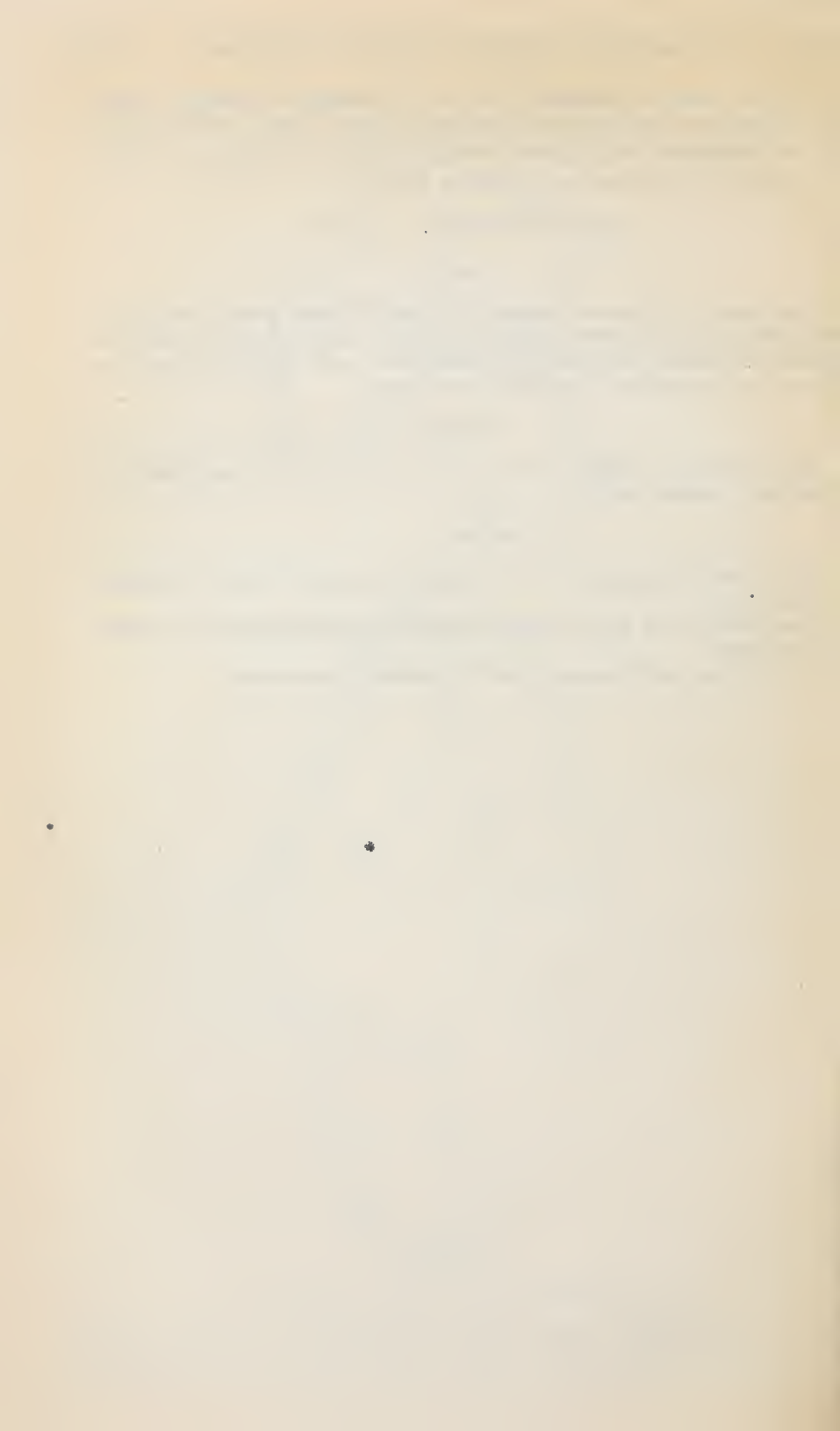
##### PLATE 3

Upper left: Rectangular mold of anhydrite crystal preserved in datolite. Natural size.

Upper right: Thin platy molds of anhydrite crystals preserved in calcite. Natural size.

Lower: Platy barite resting on datolite crystals. Natural size.



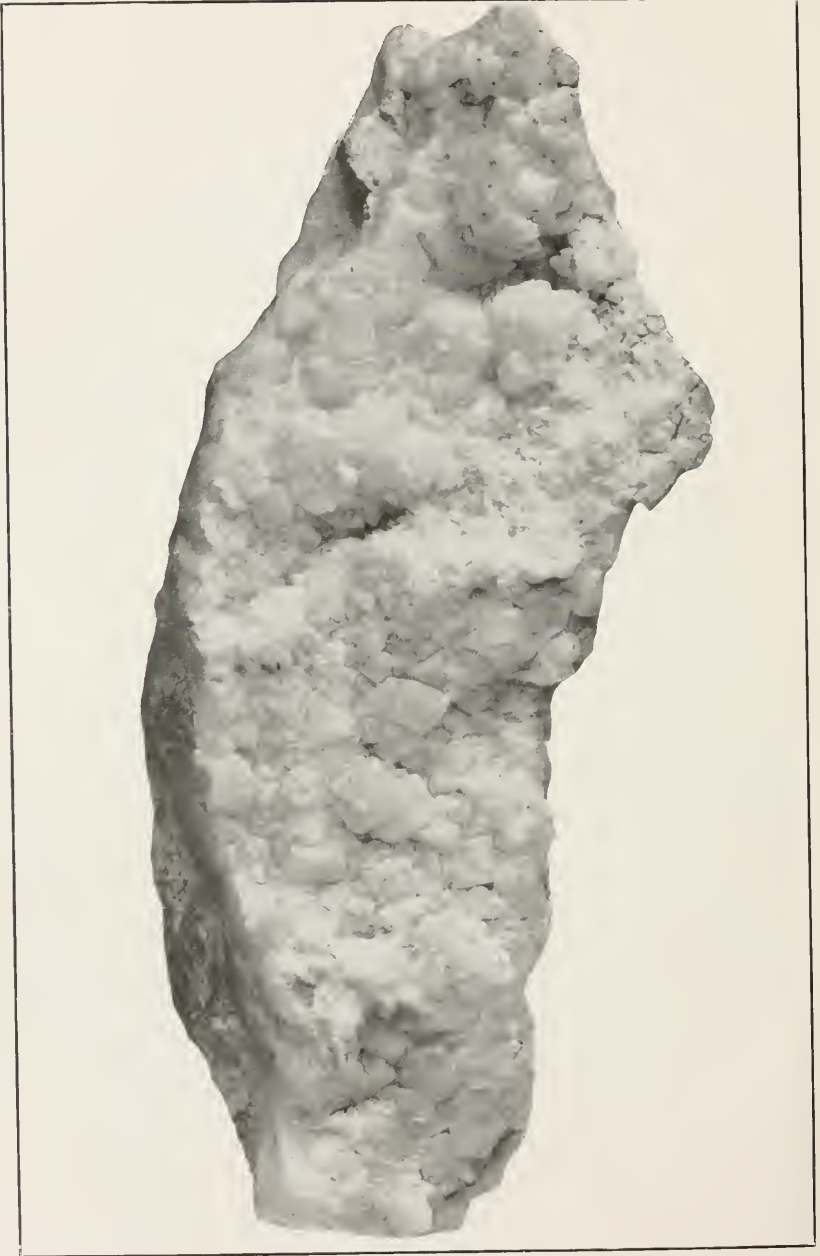






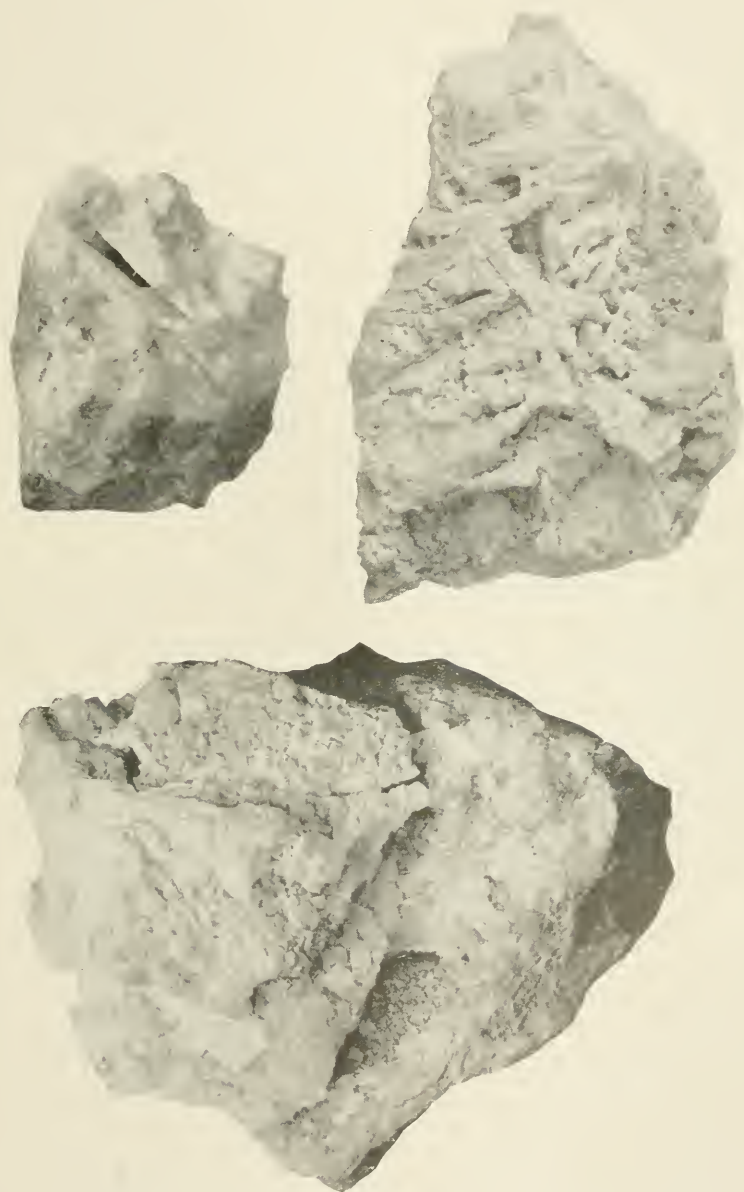
REPLACEMENT OF LIMESTONE CONGLOMERATE ALONG FISSURE

FOR EXPLANATION OF PLATE SEE PAGE 31



CRUST OF DATOLITE CRYSTALS

FOR EXPLANATION OF PLATE SEE PAGE 31



ANHYDRITE MOLDS, CALCITE, DATOLITE, AND BARITE

FOR EXPLANATION OF PLATE SEE PAGE 31