SILICA-FLUORITE PSEUDOMORPHS

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ABSTRACT

An occurrence of silica-fluorite pseudomorphs, closely related to intrusions of basalt, has been observed in Los Angeles County, California. The prevalent form is a simple cube, with an occasional modifying tetrahexahedron (210). A rather odd form of built-up or "platy" cubes, was observed at one locality.

The material of the pseudomorphs is in great part finely fibrous silica, either "feathery," or intricately interlocking aggregates of fibrous grains. In part the silica is in the form of normal quartz grains, which may be more or less replaced by later fibers. A distinct zonal arrangement is not uncommon. Optical and *x*-ray evidence leads to the conclusion that the apparently different fibrous forms of silica are due to variant orientations of microcrystalline quartz.

Formation of the pseudomorphs is due to replacement from the outside, the exact character of the resultant silica depending on the precise conditions of temperature and concentration at the time of deposition. Warmer solutions are supposed to be responsible for the formation of quartz grains rather than of chalcedony, and continued deposition of silica, with falling temperatures, has allowed replacement of earlier formed quartz grains by chalcedony.

INTRODUCTION

Recently the writer has had the privilege of investigating an occurrence of pseudomorphs of quartz and chalcedony after fluorite. These have not been hitherto reported from California, and the occurrence presents some interesting and unusual features.

A search through geologic literature brings to light a moderate number of examples of the pseudomorphic replacement of fluorite by quartz or chalcedony. Some seventeen localities for this combination have been noted, a few of which, however, are described as incrustations, and which perhaps should not properly be classified as pseudomorphs.[1]

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[1] Haidinger W., Der rothe "Glaskopf," eine Pseudomorphose nach braunen, nebst bemerkungen über das Vorkommen der wichstigsten Eisenhaltigen Mineral-Spezies in der Natur: Abstr. in *Neues Jahrb. Min.*, **1847**, p. 66 [Johann-Georgenstadt, Saxony].

Sillem A., Ueber Pseudomorphosen: *Neues Jahrb. Min.*, **1851**, p. 385 [Zinnwald, Bohemia].

Sillem A., Bericht über eine Sammlung von Peudomorphosen: *Neues Jahrb. Min.*, **1852**, p. 513. [Brioude, Haute Loire; Cornwall; Tresztya, Transylvania; Schneeberg, Saxony; Schwartzenberg, Thuringia].

La Croix A., *Mineraux de France et ses colonies*, vol. **II**, p, 779, p. 783. [Arouze and la Tourette, Haute Loire; Arne, Normandy; Morhiban, Brittany; various points in Loire Inferieure, Nièvre, and Saône et Loire].

Miers H. A., Some British Pseudomorphs: Abstr. in *Zeit. Krist.*, vol. **31**, 1899, p. 192 [Cornwall].

Miers H. A., and Bowman H. L., *Mineralogy*, New York, **1929**, p. 433 [Tresztya]:

Credner, Pseudomorphosen von Quarz nach Flussspat, von Bischofsrode, bei Schleusingen: *Neues Jahrb. Min.*, **1859**, p. 799.

GENERAL GEOLOGY

The principal occurrence of the pseudomorphs is near the town of Encino, on the north slope of the Santa Monica Mountains, in Los Angeles County, California. A second locality is about four miles to the eastward, near the head of Higgins Canyon, and likewise on the northern margin of the mountains. The geology of the region in general has been mapped by Hoots,[2] who has shown this to be an area of Miocene sedimentary rocks, dipping to the north, and intruded by basalt. Detailed mapping shows that locally there has been developed a secondary dome-like structure on this northward-dipping series. The sediments are mainly thick-bedded, coarse arkosic sandstone, with a little intercalated shale, and occasional lenses of limestone carrying *Pecten peckhami.* This fossil, and the general correlation with surrounding territory, indicates a general Middle Miocene age (Topanga or Modelo).

Intruded into the sandstone, and probably causing its doming, is a thick, laccolithic mass of basalt, which has a surface outcrop about one hundred by four hundred yards. A thin-section of the fresh rock shows that it is largely made up of minute laths of twinned feldspar (probably andesine), with a few irregular grains of olivine and a very subordinate amount of glassy groundmass. A sub-parallel arrangement of the larger feldspars indicates flowage of the magma after partial solidification. The basalt shows no evidence of primary quartz, though quartz-bearing basalts are known in the Santa Monica Mountains.

The basalt was very thoroughly shattered, perhaps during the cooling process, though no regular joint systems are observable, and in some places it is so weathered along the joints as to resemble a volcanic breccia. It has baked and reddened the sandstone, particularly along the upper (southern) edge, for a distance of at least twenty feet from the contact. This intrusion, and its associated fractures apparently ended vigorous diastrophism at this locality, for veins, filling the fractures, are not broken or disturbed by later movement. These veins, from their field relations, are clearly connected in origin with the basalt. In addition to the larger mass, there are several other sill-like intrusive bodies, some with diabasic texture. These are mostly badly weathered, and likewise show no indication of original quartz.

Jumbo K., Some Korean and Sakhalin Minerals: Abstr. *Neues Jahrb. Min.*, **1908,** II, p. 334 [Sakhalin].

Redlich K. A., Mineralogische Mittheilungen: *Neues Jahrb. Min.*, **1899,** II, p. 218. [Cinque Valle, South Tyrol].

Laubmann H., Ueber Pseudomorphosen von Quarz nach Kalkspat aus den Flusspatgangen am Wolsenberg in der Oberpfalz: *Centralbl. Min.*, **1913,** p. 355.

[2] Hoots H. W., Geology of the Eastern part of the Santa Monica Mountains, Los Angeles County, California: *U. S. Geol. Surv., Prof. Paper* **165-C.**

Occurrence and Types of Pseudomorphs

In the sandstone there are, as noted, numerous irregular fractures, most of which are now filled, or partially filled, with chalcedony or crystalline quartz, the latter forming drusy surfaces in the open spaces. It is in these veins that the pseudomorphs occur, usually at scattered points close to the contact of the intrusive, but in one important locality at a considerable distance from the nearest outcrop of the main body of the basalt, though close to the termination of one of the small diabase sills. At the Higgins Canyon locality there is no indication of igneous rock for at least one fifth of a mile from the point of discovery.

Locality "B"

At this place a rather pronounced zone of jointing cuts at a high angle across the bedding of the sandstone, which here dips some 10° to 15° to the north. The veins are developed in this fracture zone, and form a close network, or stockwork, of chalcedony and quartz, some of which is pseudomorphous after fluorite. A diligent search in this area and at all other occurrences has failed to reveal the least trace of the original fluorite, which has evidently been completely removed.

Where the pseudomorphs occur, they are relatively abundant in the fissures where filling has not been complete, and there has been space for the free development of crystal faces. Even where the fissures have been completely filled, the outlines or "ghosts" of crystals may often be observed in the solid chalcedony, and it is not improbable that the fluorite was really much more widespread than at first appears, and has been covered by the later chalcedony. These buried pseudomorphs may also be observed in some of the thin-sections (Fig. 3). The megascopic character of the replacement and the consequent degree of perfection of the resulting forms, has been quite variable. The variations occurring at Locality "B" may be grouped into the following types:

(*a*) Perfect crystal forms, frequently translucent, with shiny faces and sharp edges and corners (Fig. 1).

(*b*) Crystals with sharp edges and corners, but with dull, though smooth, faces.

(*c*) Similar to *b*, but with occasional rectangular or square, clear shiny areas, or small inset cubes of clear material. (Not a common type.)

(*d*) Crystals with slightly rounded edges, and very dull, or even white, enamel-like surfaces (Fig. 4).

(*e*) A series of forms with increasingly rounded edges, becoming more and more botryoidal, till the edges and corners are bounded by a series of part-globular surfaces, resembling a string of mutually interfering beads. The faces of such specimens are of course finely botryoidal also.

(*f*) Similar to type *e*, but coated over with a crust of minute quartz crystals. One specimen showed a single individual pseudomorph partly "sugared" with quartz and partly plain botryoidal (Figs. 2 and 3).

(*g*) The extreme type of modification, the forms showing more and more rounded edges, until by degrees the original forms are merely suggested on the surface, and finally are completely obliterated.

(*h*) Aggregates of type *a* or *b* crystals, built up into towerlike or rounded protuberances on a crystal covered surface. In these aggregates, there is no particular orientation of the individuals, which project out in all directions from the core of the group.

Any of these different types of pseudomorphs may occur as a drusy coating over the entire surface, or as more or less widely separated individuals. The type and mode of occurrence may vary, even within the limits of a single hand specimen, from closely packed to widely spaced crystals, or from clean-cut to botryoidal forms. Almost invariably the crystals are perched on a series of thin layers of chalcedony which coats the fissure walls, and in some instances are apparently embedded in this material. Several specimens show minute cubical cavities, iron-stained, or even filled with limonite, probably pseudomorphous after pyrite.

The largest crystals at this locality do not exceed one quarter inch on edge, and most of them are considerably smaller. They are usually simple cubes, with occasional interpenetration twins parallel to the octahedron, but a few individuals show a modifying tetrahexahedron (210). No other forms were observed, but these characteristics render reasonably certain the identification of the original material as fluorite. Some of the quartz crystals from adjacent cavities show a strongly rhombohedral habit, and since the rhombohedron is cuboid (the interfacial angle is 85°46′) these may be mistaken on casual inspection for pseudomorphs. The difference in form, shown by closer examination, and the true vitreous luster of these crystals, serves to distinguish them from the less brilliant pseudomorphs.

Thin-sections of the pseudomorphs from Locality "B" show in general, normal microscopic structures, well illustrated by the photomicrographs (Figs. 3, 4, 5). Zoning is pronounced in some specimens, and nearly absent in others. The constituent grains vary in size from 1 mm. to .005 mm. across, and betray their uniformly fibrous character by their ragged extinction under crossed nicols. Only two of the specimens from this locality showed any indication of originally larger grains replaced by aggregates. As will be seen, this is in marked contrast to structures from Locality "A." All specimens from Locality "B" if cut normal to the crust, show underlying layers of chalcedony with colloform texture, upon which the pseudomorphs themselves are seen to rest. The exterior coatings of chalcedony are definitely later than the chalcedony of the pseudomorphs themselves, and show the physical characteristics of the ordinary mineral. This is in distinct contrast with the underlying layers, and the pseudomorphs.

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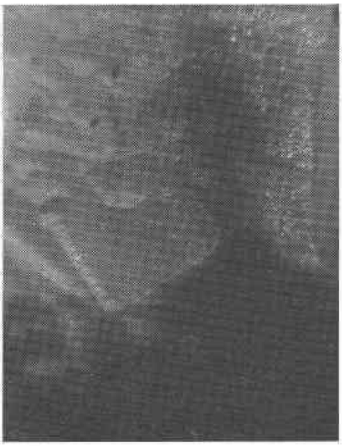

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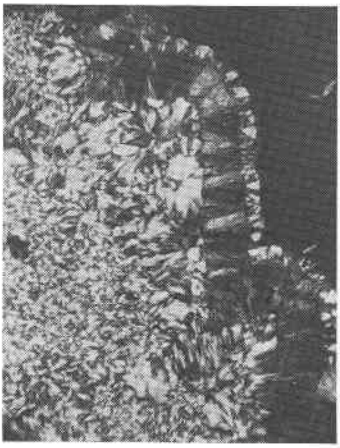

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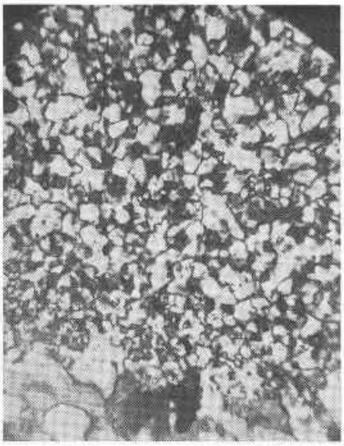
FIG. 1. "B"×18. Typical specimen of type *a* crystals, with simple cubes scattered over a botryoidal surface. Shows twinning on (111).

FIG. 2. "B"×10. Cube crusted with botryoidal chalcedony and partly "sugared" with quartz.

FIG. 3. "B"×34. Same specimen as Fig. 2, thin section with crossed nicols. "Sugared" cubes. The outline of the cubes themselves is clear-cut, while the crust has rounded and softened the external outline. Note the variable size of grains in the replacing chalcedony, with a zonal tendency. In the lower portion of the figure, the border grains tend to be roughly normal to the surface. The chalcedony of the crust is typical long-fibered material, in cone-like bundles, and is capped by a thin layer of quartz crystals, which show crystal faces on their outer ends.

FIG. 4. "B"×34. Crossed nicols. Section of type *b* crystals, showing a thin coating of very fine-grained material on the surface, then a layer of "feathery" chalcedony, with the fibers arranged roughly normal to the surface. The interior shows almost exclusively fine-grained jasperoid chalcedony.



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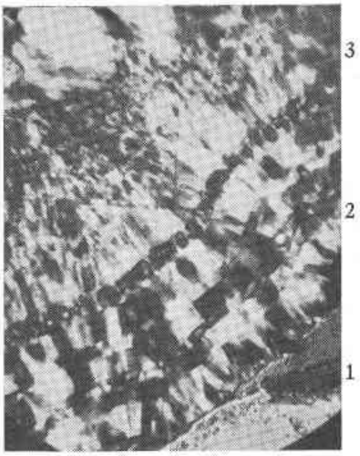

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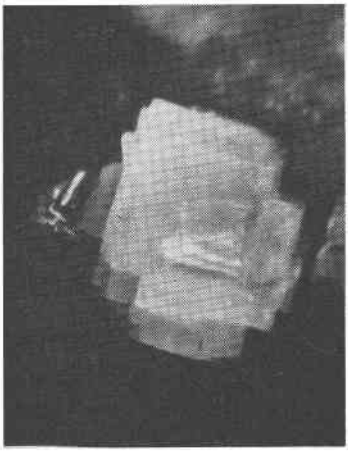

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Fig. 5. "B"×144. Same specimen as Fig. 4, crossed nicols. Shows in detail the texture of the jasperoid silica. As may be seen, the grains interlock with each other most intimately, and by racking the microscope tube up or down, the apparent contact between grains migrates one way or another, showing that this texture is distinctly three-dimensional. The extinction of these grains is wavelike, travelling with the rotation of the stage, indicating a fibrous structure.

Fig. 6. "B"×144. Crossed nicols. Vertical section through a crust of *a* type crystals, showing the sandstone foundation (1), overlain by a series of layers of chalcedony (2), which shows a sharp contact with (1), and a less distinct contact with the overlying crystals (3), which were originally fluorite but are now altered to "feathery" and jasperoid chalcedony.

Fig. 7. "A"×7. Typical mode of occurrence of "platy" cubes on a botryoidal crust. Sometimes the crystals are so closely spaced as to cover the surface completely.

Fig. 8. "A"×7. A single individual of the "platy" type. Note the building out of the cube faces, and the tilting inward of some of the slabs. Photograph taken parallel to a cube axis.

Locality "A"

Here the pseudomorphs occur in the reddened sandstone close to the basalt contact, and show several decided differences from those at the other localities. The crystals are not ordinarily simple, though some cubes, and some twinned forms, were noted. Instead, they are typically in a unique form, which is basically cubic, but built up along the cubic axes so that the form, in profile, frequently approaches the aspect of a Maltese cross (Fig. 8). Built-up crystals are of course rather common in fluorite, but are apt to produce either octahedral forms with cube faces, or quite irregular aggregates of parallel growths, in contrast to these cruciform or "dished" crystals.

The crystals in this locality are practically all translucent or quite transparent, often with a distinctly bluish cast, and as most of them rest on a more or less reddened surface, the color effect is frequently almost purple. Most of them are superimposed on a thin, botryoidal crust of chalcedony or of red iron oxide. Many crystals are so transparent that the underlying crust can be seen directly through them, affording positive proof that they were formed earlier than this crust.

A thin-section of some of the "platy" crystals from this point showed a most unexpected result. Instead of showing a fine-grained aggregate of chalcedony particles, they were seen to be made up of relatively large individuals of ordinary quartz (Fig. 9). One point in the section, in fact, seems to show that a single quartz grain has replaced parts of two adjacent fluorite grains. More commonly a single fluorite crystal has been replaced by several quartz grains. In other thin-sections, the original presence of larger quartz grains is usually quite evident, but they are seen to have been replaced wholly or in part by "feathery" chalcedony. This replacement has proceeded from the borders of grains (Fig. 10), or along crevices (Fig. 11), in some cases leaving residual cores, and in others only the outline of the original grain (Fig. 12). As at Locality "B," every section cut vertically through the crust of crystals, shows them to be emplaced on a layer, or series of layers, of finely botryoidal chalcedony which has been deposited directly on the crevice walls.

Several specimens here, also, show a coating of later botryoidal chalcedony, under which the crystals may be partly or completely buried. This chalcedony, as usual, is definitely later than the crystals, and is distinctly different in type from the earlier material. Many of the crystals here are larger than those at "B," some reaching a size of 5/16″, though others may be much smaller. They occur covering the whole surface, or scattered over it, as in the other localities. No opaque or milky white crystals were observed at this point. The smaller, simple cubes are in general much more transparent than any of the others.

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FIG. 9. "A" ×34. Crossed nicols. Section, nearly parallel to a cube face, through a crystal like that shown in Fig. 8. Shows complete replacement of fluorite by quartz grains of considerable size. In this and similar crystals in the section, there has been little or no secondary chalcedony developed in the outer part, but at their "roots" this replacement appears to have begun. The sections show that this secondary replacement is the general rule and that unaltered specimens are the exception.

Fig. 10. "A" ×144. Crossed nicols. Another point in the same section as Fig. 9, showing in detail the secondary replacement of quartz by chalcedony. Note the clear-cut boundary between the original quartz and the new material, though the fibers do not all seem to reach it. This is due to their variable orientation, as rotation of the stage shows that the fibrous material in all cases extends up to this boundary, and that the apparently ragged contact is not real, but due to the peculiar extinction of the fibers.

FIG. 11. "D" ×144. Crossed nicols. An illustration, from a different specimen, of the same process shown in Fig. 10, proceeding from a crack in the quartz, instead of from the periphery. Here also it can be seen that the true contact between old and new is a smooth surface. In addition this slide shows (lower right), "growth-lines" of the fluorite, retained in the quartz.

FIG. 12. "A" ×34. Crossed nicols. This section is from a specimen on which occur both simple and "platy" cubes, coated by or completely buried under ordinary chalcedony. The figure shows one of the simple cubes, and is introduced to show complete secondary replacement of originally large quartz grains by "feathery" chalcedony. The borders of these grains are in many cases quite evident, but there was probably also some fine-grained chalcedony present in the original replacement of fluorite.

Locality "D"

Only one specimen was collected at this point, showing crystals of type *a*, but with the apparent luster of true quartz on the fresh fracture. This is apparently unique, as none of the other pseudomorphs shows this luster, but a thin section shows their true character. They are very perfect pseudomorphs, made up of large quartz grains, which in a few places have been partially replaced by later chalcedony (Fig. 11). The distance of this specimen from the igneous rock contact is unknown, since the outcrop is small, and bedrock is covered largely by a mantle of weathered material.

Locality "E"

One other unimportant locality, between "A" and "B," shows a few small pseudomorphs of the "A" type, and the sandstone has the same appearance as at "A," although no igneous rock is visible nearer than a hundred yards. It is likely that the contact is close beneath the surface at this point.

Locality "F"

This occurrence, near the head of Higgins Canyon, about four miles east of the main locality, shows a number of differences from the latter. The pseudomorphs are in a limestone breccia (or occasionally in shale), and the crusts of crystals are frequently broken up, disturbed in position, and re-cemented by fine-grained calcite. As a rule the crystals are almost microscopic in size, requiring the use of a hand lens for their sure determination. A few specimens, however, show crystal faces a quarter inch across, comparable to those elsewhere. The specimens usually occur in a very thin, drusy crust, which in some cases shows a crude parallelism of the individuals. Most of the crystals here are not simple cubes, but are parallel aggregates, sometimes suggesting the "platy" crystals seen at Locality "A." The distinct botryoidal underlying crusts of the other localities are conspicuously absent, though poorly indicated at a few points.

Thin-sections cut normal to the crust show usually a surface of calcite crystal terminations coated over by fine-grained chalcedony (frequently interlocking), on which, with a fairly sharp contact lies a zone of coarser "feathery" chalcedony, showing a distinctly parallel arrangement of elongated grains, exactly like the shingles on a roof.

As indicated in the hand specimens, none of the characteristic underlying layers were observed, though the transition from fine-grained to coarser chalcedony is quite similar to that in the other localities. The outermost part of the crust is made up of ordinary granular quartz, showing on the surface the outline of the fluorite cubes. The specimens here show in general more preservation of fluorite "growth-lines," or crystal boundaries, than at "A," and one particularly good instance was noted of at least two fluorite individuals replaced by a single quartz grain. One section showed alternating layers of calcite and quartz beneath the pseudomorph crust.

In the case of the larger quartz grains, there is no good indication of replacement by a second generation of chalcedony, although in some of the grains are small inclusions of differently oriented quartz. These inclusions appear, with higher magnification, to be blebs or rodlike grains scattered haphazard through or between the larger quartz individuals. Some of these may be fibrous, though this is somewhat dubious.

Formation of the Pseudomorphs

The process of formation of the pseudomorphs may have taken place somewhat as follows: Enveloping any crystal in an essentially stagnant solution, is a zone in that liquid, more or less narrow, of a saturated solution of the crystal substance.[3] Unless the whole body of the solution is saturated, the concentration of this solution diminishes with increasing distance from the surface of the crystal. If now a new substance is brought near the crystal by diffusion (or other means), this saturated solution of the crystal may produce, close to its surface, a supersaturation of the new substance. If this happens, the new material, as it is brought in, will be precipitated practically on the surface of the old, which in turn will continue to be dissolved (perhaps at an increased rate, because of the presence of the new), removed by diffusion, and dissipated. The result will be, at first, the formation of an extremely thin layer of the new substance on the surface of the old, out through which the old may diffuse and in through which additional new material may work its way. Since this crust is newly deposited, it is probably relatively porous in texture, and hence readily pervious in this manner. Inside this crust, or shell, the solution will remain saturated for the old mineral, and hence able to cause precipitation of the new. Outside, however, since the crust was first deposited at the outer margin of the saturated zone, the solution will be more dilute, and unable to produce this result. Accordingly, new material will be added only on the inner surface of the crust. A continuation of this process under uniform conditions will result in the perfect preservation of the external form of the old crystal. The internal texture will depend on several factors, such as temperature, pressure, character of the solutions, state and concentration of the new substance, and rate of replacement. The varying modes

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[3] Noyes A. A., and Whitney W. R., Ueber die Auflösungsgeschwindigkeit von festen Stoffen in ihren eigenen Lösungen: *Zeit. physik. chem.*, vol. **22**, p. 689, 1897.

of aggregation of the silica in these pseudomorphs reflect changes, perhaps quite minor, in local conditions at and following the time of precipitation.

FORM OF THE SILICA

There is general agreement that silica is largely transported as a colloid,[4] and the suggestion has been made that it is deposited as a gel, and recrystallized, if at all, in successive stages, due to the rearrangement of constituent parts, and growth of larger grains at the expense of smaller.[5]

As may be seen from inspection of the photomicrographs, the silica of the pseudomorphs occurs in three physically distinct forms. These forms are: (1) ordinary quartz grains, of fair size, showing all the optical properties of the normal mineral (Fig. 9); (2) closely interlocking grains, very small, showing by their uneven extinction a fibrous structure. Occasionally a "eutectoid" texture is produced by a tendency towards parallel extinction of part of the grains over a limited area (Fig. 6); and (3) elongated fibers, or "feathery" silica, sometimes radiating or subparallel, or irregularly oriented (Fig. 12).

Optical observations on the interlocking material are unsatisfactory because of its almost sub-microscopic texture, but suggest characters similar to those of the "feathery" fibers. In the case of the latter, some of the properties were determined for the writer by Professor J. E. Wolff,* as follows:

> the length of the fiber is in the negative direction, and consequently represents the lower index of refraction; assuming this as the vertical axis, this is the extraordinary ray and across the fibers the ordinary ray, the opposite of quartz. Of course if the vertical axis lies across the fiber this would be the ordinary ray like quartz, but there is no way of telling. I find for the ray vibrating parallel to the fibers, in eight determinations on separate pieces for sodium light, values varying from 1.5360 to 1.5460, the average being 1.5399. Across the fibers the index is slightly higher than parallel, but it is impossible to get an accurate reading. In general with this material there has been great difficulty in getting reliable refractive indices, due to the minute size of the fibers, their curving and overlapping. This also was noticed: the fibers sometimes, while still negative, exhibit a small obliquity of extincion to the length (like lutecite), and also have a higher relief than an isotropic substance filling minute interspaces parallel to the length,

[This isotropic substance is quite probably opal.] These properties cor-

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[4] Boydell H. C., The Role of Colloids in Ore Deposition: *Trans. Inst. Min. and Met.*, vol. **34,** 1925, Part I, p. 145.

Lindgren W., in Bogue, *Theory and Application of Colloid Behavior:* vol. II, *New York,* **1924,** p. 454.

Moore E. S., and Maynard J. E.: Solution, Transportation and Precipitation of Iron and Silica: *Econ. Geol.*, vol. **24,** p. 390, 1929.

[5] Boydell H. C., *Op. Cit.*

* Private communication

respond in general to those of chalcedony, and since the interlocking grains appear similar, though with less distinguishable structure, it is likely that they also are chalcedony.

According to a number of authors,[6] there are three varieties of fine-grained silica, differing from quartz [chalcedony, quartzine and lutecite]. These authors are not in entire agreement about these, some considering them biaxial, and some uniaxial. Further, the indices of refraction, and specific gravities, as determined by Wetzel, are to be regarded with caution, in view of his recognition of the presence of opal admixed with the finely fibrous material. Others[7] suggest that the observed differences are probably due to different orientations of the fibers, and to mechanically admixed opal. The writer has confirmed the findings of White and of Kerr with respect to *x*-ray structures, and has determined, by *x*-ray powder photographs,[8] that the pattern is identical for quartz, ordinary chalcedony, and the "feathery" chalcedony of the pseudomorphs. Rogers,[9] in writing of the different forms of silica, does not mention quartzine or lutecite, evidently considering them identical with chalcedony. Accordingly, we may probably consider the fibrous varieties of silica in the pseudomorphs mere variants of ordinary quartz, in fibrous form, and call them all chalcedony.

Outside of the pseudomorphs there are also three modes of occurrence of silica, namely, the normal, long-fibered, botryoidal chalcedony coating the crystals, the ordinary quartz crystals, and the thin botryoidal crusts on which the crystals rest. The last of these seems to correspond

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[6] Miers, H. A., and Bowman H. L., *Mineralogy*, New York, **1929,** p. 433.

Lacroix A., Min. de la France et ses Col., vol **III,** pp. 120, 131.

Wetzel W., Untersuchungen über das Verhältnis von Chalcedon und Quarzin zur Quarz: *Centralbl. Min.*, p. 356, **1913.**

Balogh E., Die bituminosen Kalke und ihre Mineralien aus der Umgebung von Kolozvar, Kajanto und Torda: Abstr. in *Neues Jahrb. Min.*, II, p. 40, **1914.**

[7] Dana E. S., and Ford W. E., *Textbook of Mineralogy* 4th Ed. New York, **1932,** p. 472.

White W. P., Quartz Inversion in Chalcedony: Abstr. in *Bull. Geol. Soc. Am.*, vol. **35,** p. 122, 1924.

Palache Charles, Private Communication.

Peacock M. A., The Nature and Origin of the Amphibole Asbestos of South Africa: *Am. Mineral.*, vol. **13,** p. 241–286, 1928.

Kerr P. F., Determination of Ore Minerals by *X*-Ray Diffraction Patterns: *Econ. Geol.*, vol. **19,** p. 30, 1924.

[8] These *x*-ray pictures were kindly made for the writer by Professor O. L. Sponsler of the University of California at Los Angeles, to determine the atomic structure of the silica, since it had been suggested that possibly this silica might have occupied the lattice of the original fluorite. This was shown not to be the case, as the pseudomorph material gave identical patterns with ordinary quartz, and totally different from fluorite.

[9] Rogers A. F., Natural History of the Silica Minerals: *Am. Mineral.*, vol. **13,** p. 74, 1928.

closely to the "feathery" chalcedony in the pseudomorphs, but the first is physically quite different, though optically the same. In the underlying crusts the fibers frequently show patchy extinction, the shadow travelling along the length of the fiber with rotation of the microscope stage, indicating possibly a spiral or twisted structure. This curving, as noted above, was also observed in the "feathery" chalcedony of the pseudomorphs.

PARAGENESIS

Fluorite may occur under a wide range of conditions of temperature and pressure, even as the product of relatively cold waters in sedimentary rocks[10], but in the vast majority of cases is closely connected with igneous rocks. The usual association for fluorite is with acid magmas, but in this instance the connection with the basalt is very close, and apparently constitutes a good example of an uncommon type.

The temperature of formation of the original fluorite veins was probably not very high, not over 360°C., judging by its close association with the early chalcedony. Experiments in the synthesis of quartz and chalcedony[11] indicate a probable upper limit for the formation of chalcedony at about 360°C., which would then be a maximum for this deposit. The fluorite solutions must have been fairly well heated, due to the presence of the igneous intrusion, so that this maximum temperature is likely to have been near the minimum also.

Deposition of fluorite in small crystals apparently exhausted the supply of this mineral, and its place was taken by silica, which was not present, or at least not being deposited, during the fluorite period. This silica, in the cooling but presumably still warm solutions, replaced the fluorite and formed the pseudomorphs. In the areas nearest to the igneous rock, where the solutions were warmer, the silica was deposited largely as quartz, while in the cooler places replacement was in the form of jasperoid or "feathery" silica.

At Locality "A," after the formation of the pseudomorphs, there was apparently a change in conditions, allowing the replacement of originally deposited quartz by later chalcedony. The latter is identical in appearance with that deposited earlier both here and in the other localities. This new generation of silica is clearly shown in the partial or complete replacement of the original large quartz grains.

After a distinct time interval, and under clearly different conditions,

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[10] Mügge O., Sandstein mit Flusspatzement: *Centralbl. Min.*, p. 33, **1908.**

Fitzgerald P. E., and Thomas W. A., Occurrence of Fluorite in the Monroe Formation, Vernon Township Pool, Michigan. *Bull. Am. Assoc. Pet. Geol.*, vol. **16,** p. 91, 1932.

[11] Koenigsberger J., und Muller W. J. Versuche über die Bildung von Quarz und Silicaten: *Centralbl. Min.*, pp. 339, 353, **1906.**

the pseudomorphs were in many places coated over, or even completely buried by a crust of chalcedony, sometimes followed by later quartz. As noted above, this chalcedony is quite different in its microscopic appearance from the underlying crusts, and invariably rests on the pseudomorphs with a sharp contact, never blending even with the second generation chalcedony of the pseudomorphs.

While the crystals from some of the localities are normal cubes, or cube and tetrahexahedron, many, though not all, of those from "A" show the curious "platy" form already described. There is no microscopic evidence as to the original internal structure of these, so it is impossible to say, from what can now be seen, whether the original material was in simple individuals, or as crystal aggregates with an approximation to parallelism. This latter suggestion is possible, and might account for the odd forms here developed. No particular reason has occurred to the writer as to why such crystals or aggregates should have developed, except the presence of special conditions of material supply, or peculiar internal molecular stresses, or both. It is true that certain other specimens show a possible incipient development of this form, in the shape of jagged or "stepped" faces, notably at Locality "F," and in other cases there are knob-like aggregates of cubes (Locality "B"). These latter resemble the "platy" cubes only to a very limited extent, as the component crystals project in all directions from the clumps, without any semblance of orderly arrangement. Moreover, many of the "platy" cubes rest on a flat surface which can in some instances be actually seen through the crystals, and the knobs are usually built up from underlying knobs of chalcedony.

Summary

The general sequence of events at Localities "A" to "E" appears to have been as follows:

1. Intrusion of basalt, with doming and fracturing of the sandstone cover.
2. Deposition of thin layers of chalcedony from heated solutions whose source was presumably the basalt.
3. Deposition of fluorite crystals, apparently unaccompanied by silica. The solutions were still hot, but under 360°C.
4. Replacement of fluorite by quartz or "feathery" chalcedony.
5. Replacement of some of this quartz by later "feathery" chalcedony.
6. Deposition, perhaps from rather cool solutions, of the overlying chalcedony crusts.
7. Finally, in a few places, deposition of tiny quartz crystals on all earlier crusts.

At Locality "F" the sequence is somewhat different.

1. Deposition of alternate layers of calcite and silica (quartz or chalcedony), by solutions from an assumed underlying igneous source.
2. Deposition of fluorite.
3. Replacement of fluorite by quartz and "feathery" chalcedony.

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