EPIDOTE AS A PRIMARY COMPONENT OF ERUPTIVE ROCKS

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THE EPIDOTE-BEARING ROCKS.

Occurrence and eruptive Origin.—Very conclusive evidence has been found recently showing that certain granites of Maryland are eruptive in origin. The granitic masses occur in irregular bosses breaking through gneiss, gabbro and other crystalline rocks. In the central part of the state, at Dorseys Run station, Woodstock, Ilchester and Ellicott City, the acid eruptives are true granitites, granular aggregates, consisting essentially of quartz, feldspar and black mica, with considerable amounts of epidote and allanite as accessory constituents. These rocks vary considerably in color, from dark iron-gray to nearly white, according to the percentage of ferro-magnesian silicates they contain.

Microscopic Characteristics.—Under the microscope thin sections sometimes show that the incipient stages of dynamic metamorphism have set in. In other occurrences the granites show little or no signs of mechanical deformation. The occurrence of the two prominent accessory min-

erals in the Maryland acid rocks was first noted by Hobbs,* who had under consideration the porphyritic granites of the last two localities just mentioned. In the published notes particular attention is called to the isomorphous intergrowths of epidote and allanite. Since the appearance of the paper alluded to considerable additional material has been examined, both from the Ilchester and Ellicott City districts, besides three other places.

Comparison of Granites with Granitites.—In all their general characters the epidote-allanite bearing granites are essentially identical with the granitites of the region, except as a rule they are more basic and consequently much darker in color. The essential constituents show no noteworthy differences from the acid components of the typical granitites. In hand specimens a distinct greenish cast is often quite noticeable. Upon closer investigation the green specks are found to have frequently a reddish core. Microscopic examination in thin sections show that the two minerals are clear, usually idiomorphic or hypidiomorphic epidote, and reddish; intensely pleochroic allanite in parallel growths.

ALLANITE.

The mineralogic Associate of Epidote.—Before considering the epidote in detail a few words in regard to the allanite may not be out of place, as it is intimately associated and closely related chemically.

As a rock-forming Mineral reviewed.—As a rock-forming mineral, allanite has long been regarded as one of the rarer occurrences. Within the past few years, however, Iddings and Cross† have found this silicate of the rare earths widely distributed among acid eruptives, in some rocks forming an important accessory. Among the rocks in which the mineral under consideration was found may be mentioned gneiss, granite, quartz-porphry, rhyolite, diorite, porphyrite, andesite, dacite and others. The localities in this country where allanite has been found to form a rock constituent are numerous, and are even widely separated geographically.

In Europe the apparent rarity of rock-forming allanite has made the observed occurrences somewhat noteworthy. There is a further interest centering around this mineral which is of no little importance from a historical point of view also. It is the fact that the presence of allanite in granite formed one of the chief arguments against the theory of the igneous origin of granite in the long-continued controversy that took place during the second quarter of the present century. The inability of this mineral to withstand a temperature higher than a dull-red heat

* Johns Hopkins University Circulars, no. 85, 1888, p. 76.

† Am. Jour. Sci., 3d ser., vol. xxx, 1885, p. 108.

without changing its physical character was evidenced as a strong proof against the igneous origin of granite. This objection was met by Scheerer* as early as 1842, in a paper entitled "Erste Fortsetzung der Untersuchungen über Gadolinit, Allanit, und damit verwandte Mineralien," read at Stockholm before the Society of Scandinavian Naturalists. Some years later the same writer† discussed an aqua-igneous theory of the origin of granite, and suggested that owing to the presence of water the magma may cool down considerably below the temperature necessary for solidification under the conditions of ordinary dry fusion, and thus allow minerals which cannot endure great heat to crystallize out before other constituents more difficult to fuse by the simple dry method. Both Élie de Beaumont and Daubrée and later others have confirmed this theory experimentally.

Since Scheerer's time a number of writers have noted the occurrence of allanite in various igneous rocks. Chief among these allusions may be mentioned those of Blomstrand,‡ von Fritsch,§ Vom Rath,|| Liebis,¶ Törnebohm,** Iddings and Cross,†† Michel-Levy and Lacroix,‡‡ Hobbs,§§ and Lacroix.||||

In Maryland, Hobbs appears to have been the first to call attention to the presence of allanite in the rock of the state. The specimens especially studied were from certain granites and porphyritic granite from the immediate vicinity of Ilchester. Since the announcement of these occurrences similar allanites and allanite-epidote intergrowths have been found at other places—at Dorseys Run station, and in less abundance at Woodstock, and on the Gunpowder river, northeast of Baltimore. Since the appearance of the first note on the allanite-epidote intergrowths from the porphyritic granite of the Ilchester district some doubts have been raised as to whether the exterior clear portions of the grains are not in reality the same mineral as the interior dark parts, but differing slightly chemically. For this reason the author¶¶ just referred to reexamined some of his earlier preparations and after the complete isolation of the dark central allanite had a chemical analysis made of some of the

*Poggendorff's Annalen der Phy. u. Chemie, lvi Band., 1842, p. 479.

†Bul. Soc. géol. de France, 2d ser., tome iv, 1847, p. 468.

‡Oefvers. af akad. Förhandl., no. 9, 1854, p. 296.

§Zeitsch. d. d. geol. Ges., xii Band., 1860, p. 105.

||Zeitsch. d. d. geol. Ges., xvi Band., 1864, p. 255.

¶Zeitsch. d. d. geol. Ges., xxix Band., 1877, p. 725.

**Geol. Fören i Stockholm Förh., vi Band., 1882, p. 185; also, Vega Exped., vol. iv, Stockholm, 1884, p. 115.

††Am. Jour. Sci., 3d ser., vol. xxx, 1885, p. 108.

‡‡Bul. Soc. min. de France, tome xi, 1888, p. 65.

§§Johns Hopkins University Circulars, no. 65, 1888, p. 70; also, Am. Jour. Sci., 3d ser., vol. xxxviii, 1889, p. 223.

||Bul. Soc. min. de France, tome xii, 1889, p. 139.

¶¶Am. Jour. Sci., 3d ser., vol. xxxviii, 1889, pp. 223-228.

epidote fragments, which show a very close correspondence with epidote of other localities, particularly Ludwig's specimen from the Untersulzbach. The following are the results obtained from the Maryland specimens by Dr Hillebrand, of the United States Geological Survey, and from the Tyrolean locality by Ludwig. The TiO_2 is probably due to the presence of sphene, which was not separated from the powder completely :

	Maryland.*	Untersulzbach.
SiO_2	37.63	37.83
Al_2O_3	18.40	22.63
TiO_2	3.78	
Fe_2O_3	15.29	15.02
FeO		
MnO	0.31	0.93
CaO	22.93	23.27
MgO	0.31	
P_2O_5	0.44	
H_2O	2.23	2.05
	101.32	101.73

EPIDOTE. .

Its Abundance in Maryland Granite.—The epidote of the allanite-bearing granites of Maryland is frequently so abundant as to give a decided greenish cast to the color of the rock. Under a pocket lens the yellowish-green mineral is seen in small sharply bounded crystals or irregular grains, showing glistening surfaces of fracture and usually containing a central reddish interior, which already has been shown to be allanite.

Its microscopic Appearance.—Under the microscope the epidote usually appears in sharply defined crystals or grains enveloping reddish grains of allanites, with which they are strictly isomorphous. Twins have not been observed, though the included mineral is often twinned. The sections are transparent, colorless or slightly yellowish, with imperfect cleavage. The pleochroism is quite marked, *a* being colorless or very faint yellowish; *b* light yellow, often tinged with green; *c* greenish yellow. The absorption is $c > b > a$. Interference colors brilliant. The plane of the optic axes is perpendicular to the cleavage and direction of elongation. These characters, together with the chemical analysis given, correspond in all particulars with those of rock-making epidote.

Its Crystallography.—The simple crystals of epidote are usually quite small, and commonly have their crystallographic planes much better defined than in the other cases. The most frequently observed faces

* See also Bul. 64, U. S. Geol. Survey, p. 42.

are $OP \{001\}$, $\infty P \infty \{100\}$, $2P \infty \{20\bar{1}\}$, $\infty P \infty \{010\}$, and occasionally two small hemipyramids, probably $+P \{1\bar{1}1\}$ and $-P \{111\}$. The crystals, as well as many of the intergrowths with allanite, occur as a rule completely surrounded by biotite.

FIGURE 1.—Microscopic Crystal of Epidote in Ellicott City (Maryland) Granite.

FIGURE 2.—Epidote in Ellicott City Granite.

An interesting occurrence of epidote is as an inclusion in sphene, along with an apatite and a greenish mineral having all the optical and physical characters of pleonaste. In other masses the sharply bounded

FIGURE 3.—Epidote in Woodstock (Maryland) Granite.

FIGURE 4.—Epidote in Woodstock Granite.

epidote comes in contact with unaltered feldspar, quartz and biotite grains and gives outlines to them.

Its Origin.—The origin of the epidote in the granite rocks under consideration is of great interest. Rock-making epidote has been regarded

almost universally as never forming a primary constituent of eruptives, or Archean masses, while as a characteristic ingredient it is abundantly developed in metamorphic gneisses, schists and phyllites. It is also a common product of both acid and basic rocks containing feldspar. The occurrence of epidote in acid eruptives has occasioned considerable discussion. Among the earlier references may be mentioned certain papers of Becher* and Blomstrand,† while the principal allusions to the subject during the past decade have been made by Törnebohm,‡ Geikie.§ Rosenbusch,|| Hobbs,¶ and Adams.**

The general consensus of opinion as derived from the literature referred to has been against the idea that the epidote was original in any of the cases mentioned. Hobbs,†† who was the first to study the Ilchester (Maryland) granite, was inclined to believe that the epidote was of metamorphic origin. Very recently Adams‡‡ has investigated some epidote-bearing granites from Alaska, in which the mineral alluded to is thought to result from the recrystallization of certain of the rock's constituents after the original solidification of the mass. The epidote is regarded as "having grown into the surrounding minerals by first sending out little arm-like extensions from its substance which subsequently met one another, in this way including some of the foreign minerals, which may or may not finally disappear" (page 349). Parallel growths of allanite and epidote are explained by the former being regarded as "a primary mineral around which the epidote would naturally crystallize, if any were developed in the rock, the two minerals being isomorphous" (page 350).

In his "Contributions à l'étude des gneiss à pyroxène et des roches à wernerite" §§ Lacroix has figured and described some interesting occurrences of isomorphous growths of epidote and allanite in the amphibolitic gneiss of Geffren-en-Roscoff. They are considered analogous to Ilchester examples with which he has compared them. These growths are also reported from certain rocks of Finisterre, Norway, and Waldviertel, the epidote in all these instances being regarded as primary (page 353).

The association of certain of the allanites and epidotes in the granites of Maryland is so intimate that there can be but little doubt that both

* Ueber das Mineralworkomen in Granite von Striegan, u. z. w. (Boslau).

† Oefvers af. akad. Förhandl., no. 9, 1854, p. 296.

‡ Geol. För. i Stockholm Förhandl., vi, 1882, p. 245.

§ Quar. Jour. Geol. Soc. vol. xxxix, p. 314.

|| Mik. Phys., i Band, 1885, p. 498.

¶ Johns Hopkins University Circulars, no. 65, 1888, p. 70; also Am. Jour. Sci., vol. xxxviii, 1889, pp. 223-228.

** Canadian Record Science, 1891, pp. 344-358.

†† Loc. cit.

‡‡ Loc. cit.

§§ Bul. Soc. min. de France, tome xii, 1889, p. 139.

minerals were formed under the same physical conditions, so that any remarks upon the origin of the one would apply equally as well to the other. In attempting to determine whether or not these minerals are of primary or secondary origin in granitic rocks, the evidence must necessarily be based in great measure upon the observed association with the other minerals. Allanite, as has already been stated, is comparatively easily fusible, and on this account it long has been quoted as one of the proofs against the igneous origin of granite; but its occurrence in such rocks as unaltered porphyrite, quartz-porphry, dacite, andesite, and rhyolite masses whose eruptive nature, as shown by Iddings and Cross,* is not to be questioned, shows conclusively that this mineral actually does form in a molten magma.

Furthermore, the epidote occurs included in well-defined crystals of sphene whose primary character cannot be doubted; besides, it is not uncommon to find sharply defined crystals completely mantled by biotite, along with similar inclusions of zircon, apatite and magnetite. There is further evidence pointing toward the original character of the epidote in the occurrence of broken crystals of allanite-epidote intergrowths, into the open fractures of which biotite has formed. To all appearances these fractures are protoclastic in nature. Finally, crystals of epidote or isomorphous growths of epidote and allanite, with the crystallographic planes well defined, are found giving shape to the unaltered feldspars, quartz and mica.

SUMMARY.

In summing up the facts already presented it would appear that the evidence of the primary occurrence of epidote in the eruptive rocks is essentially the same as that for allanite. Attention has been called to the fact that allanite, though easily fusible, is now known to be widely distributed, and is often an abundant accessory in such rocks as dacite, porphyrite, diorite, quartz-porphry, rhyolite and others the igneous nature of which cannot be questioned. All physical obstacles as to its primary origin are manifestly removed. The evidence, therefore, in any particular case that this mineral is either primary or secondary must be derived largely from the study of its associations with other minerals.

Now the epidote of certain of the Maryland granites is found in isomorphous growths with allanite, as well as in separate well-defined crystals. Both occurrences are found in sharply bounded individuals, and the following remarks apply to the intergrowths and single crystals

* Am. Jour. Sci. 3d ser., vol. xxx, 1889, p. 109.

alike. That these must be original constituents, and not secondary products, is indicated by—

1. Its presence in perfectly fresh rocks or rock but slightly altered, by orographic movements.
2. Its inclusion in sphene, one of the earliest components to crystallize out from the molten magma.
3. Its occurrence with sharply defined crystallographic faces, completely mantled by clear, unaltered biotite or feldspar, and giving shape to some of the essential constituents of the granite.
4. Its presentation in long crystals, broken and bent, and the interstices and parted cracks filled with biotite, and often continuous with, and optically oriented the same as, the surrounding black-mica crystals, whose shape is partially given by the epidote. These fractures appear without doubt to be protoclastic in origin.