TWO NEW OCCURRENCES OF PIEDMONTITE IN CALIFORNIA[1]

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During the winter of 1929–'30, in the course of a petrographic study of some metamorphic rocks collected the previous summer in northeastern Madera County, California, it was discovered that the rare mineral piedmontite occurred in one of the specimens as a replacement of biotite. A year later, a fragment of piedmontite-sericite schist, from a locality only a few miles from that at which the former specimen had been obtained, was sent to the Geology Department, at Cornell University, for identification. Since all the previously-noted occurrences of this mineral in California seem to be in fragmental rocks, it was thought worth while to record these new localities, together with such data as could be obtained on the origin and nature of the material. A brief historical résumé is inserted, because very little information on this subject seems to be available in English.

Piedmontite, a manganese-bearing mineral of the epidote group, was first noted at Saint Marcel, in Piedmont, Italy.[2] The first investigator to write concerning this substance seems to have been Cronstedt, who, in 1758, named the mineral "röd Magnesia." It was analyzed in 1790 by the Chevalier Napione, who termed it "Manganèse rouge." Haüy, in 1801, on the basis of Napione's analysis, designated the substance as "Manganèse oxidé violet silicifère." In 1803, Cordier, on the basis of a new analysis[3] recognized the mineral as an "Épidote manganésifère," a name which was later adopted by Haüy.[4] It thus became known to English writers as "manganesian epidote," and to German ones as "Manganepidot." Werner, in 1817, chose for this mineral the name "Piemontischer Braunstein." The name piedmontite ("Piemontit"), proposed in 1853 by Kenngott, has largely taken the place of other designations for manganese-bearing epidote, although the term

[1] Published by permission of the California State Division of Mines.

[2] Hintze, Handbuch der Mineralogie, vol. **2,** pp. 254–255, 1897.

[3] Cordier, L., Analyse du Minéral connu sus le nom de Mine de Manganèse violet du Piémont, faite au Labratoire de l'Ecole de Mines: *Journ. de Min.*, vol. **13,** p. 135, 1803.

[4] Haüy, R. J., Traité de Mineralogie, vol. **2,** p. 575, 1822.

withamite*[5] may be used for the monoclinic mineral, of positive optical character, when it contains but a small amount of manganese;[6] and the somewhat analogous orthorhombic form is known as thulite. A very rare monoclinic form, with negative optical character, and containing as much as 4.52 per cent Mn_2O_3, is called mangan-epidote. It occurs in the manganese ore deposits of Jakobsberg, in Sweden.[7]

Piedmontite was for a time thought to be orthorhombic, like zoisite and thulite,[8] but it was shown to be monoclinic by Des Cloizeaux,[9] whose conclusions were verified by Bücking[10] and Laspeyres.[11] Besides the original locality at Saint Marcel, mentioned above, the mineral has been found at a number of widely distributed places in various parts of the world, some of which are listed at the end of this paper. A discussion of the Californian occurrences follows.

The Californian Occurrences

This is not the first notice of piedmontite from California, for it was found by Rogers in a thin section of quartz prophyry in a boulder from the Pliocene or Pleistocene gravels at Pacific Beach, in San Diego County. The piedmontite was "a secondary mineral, replacing some original ferromagnesian mineral, probably biotite."[12] It has also been reported by Reed and Bailey, as a detrital constituent in the "granitic" zones of lacustrine sediments in the Lazard area, west of Lost Hills, in the southern part of the San Joaquin Valley.[13] The material from the two new localities, which form the subject of this paper, will now be considered.

* The asterisk is employed to designate articles not seen by the writer.

[5] Brewster, D., *New Edinburgh Journ. Sci.*, vol. **2**, p. 218, 1825.

[6] Heddle, Minerals New to Britain: *Mineralog. Mag.*, vol. **5**, p. 15, 1884. Gives a chemical analysis of withamite.

[7] Flink, G., *Zeitschr. f. Kryst.*, vol. **15**, p. 88, 1889.

[8] Breithaupt, A., Mineralogische Studien, *Berg-und Huettenmaennische Zeitung*, vol. **24**, pp. 341–343, 1865.

[9] Des Cloizeaux, Manuel de Mineralogie, vol. **1**, p. 254, 1862.

[10] Bücking, H., Ueber Krystallformen des Epidot: *Zeitschr. f. Kryst.*, vol. **2**, pp. 384–385, 1878.

[11] Laspeyres, Die krystallographischen und optischen Eigenschaften des Manganepidot (Piemontit): *Zeitschr. f. Kryst.*, vol. **4**, p. 435, 1880.

[12] Rogers, A. F., Notes on Rare Minerals from California: *School of Mines Quarterly*, vol. **33**, p. 378, 1912.

[13] Reed, R. D., and Bailey, J. P., Subsurface Correlation by Means of Heavy Minerals: *Bull. Am. Assoc. Petrol. Geol.*, vol. **11**, pp. 359–368, 1927.

1. Occurrence in Piedmontite-Sericite Schist

The small specimen of pink, piedmontite-sericite schist was collected by Mr. W. E. Selbie, a prospector, who states that it occurs near Shadow Lake, in northeastern Madera County, as a "vein" perhaps fifty feet wide, and traceable for about a mile. This small fragment was found to contain better material for study than that in the specimen previously collected, hence it is discussed first.

Megascopic character. The rock is of pinkish-red color, with a silky luster due to abundant sericite. The specimen tends to split along two well-defined directions of schistosity, that make angles of about 25° or 155° with one another. Small knots in the sericitic matrix indicate the positions of minute grains of quartz, as may be seen on the rough surfaces which have broken normal to the schistosity and exposed the cores of the little knots. Minute, dull white specks mark the positions of feldspar grains.

Irregularly-shaped, black stains occur in the sericite along the surfaces of schistosity. Some of this black material, scraped off the specimen, yielded, with sodium carbonate, the familiar test for manganese. With the aid of a hand lens, minute, prismatic crystals of dark-red piedmontite can be seen, embedded in a matrix which apparently consists mainly of pale pink sericite.

Microscopic character. Two thin sections were prepared, one parallel to the more prominent rock cleavage, and one perpendicular to both cleavages. These sections are referred to as "A" and "B," respectively.

Section A reveals an extremely fine-grained mosaic, apparently of quartz and feldspar individuals with a diameter of about .01 mm., in which are embedded abundant wisps of sericite, "streams" of piedmontite needles, accompanied by minute (.05 mm.) crystals of apparently colorless garnet (Fig. 1A), and angular fragments of quartz, reaching 0.4 mm. in diameter. These quartz fragments occasionally show by their outlines the trace of one or more crystal faces. One shattered, but nearly complete, subhedral grain was seen near the edge of the section. A lens-shaped quartz grain, 3.5 mm. long, exhibits, between crossed nicols, the cataclastic texture. It seems as though quartz grains, or crystals, as large as this one were unable to resist deformation and granulation which the smaller ones escaped.

Occasional rectangular areas, probably marking the positions of former sanidine crystals, occur in the section. These palimpsests are about .5 to .7 mm. long and .3 to .4 mm. wide, and consist of a mosaic of recrystallized, untwinned feldspar material, with refractive indices less than canada balsam, together with flakes of sericite, and a pale brown mica having 2V = about 4° or 5°. Irregular bodies and dusty streaks of manganese oxide occur sparingly in the section. A few minute euhedra of zircon are present, and tiny, needle-like prisms of secondary apatite are fairly abundant, though scarcely noticeable.

Besides the mineral constituents noted above, a few irregular, apparently lithic, fragments, 1 or 2 mm. long, are to be seen. The mineral composition of these fragments is somewhat similar to that of the enclosing rock, except that the former are much poorer in sericite, and are highly charged with manganese oxide.

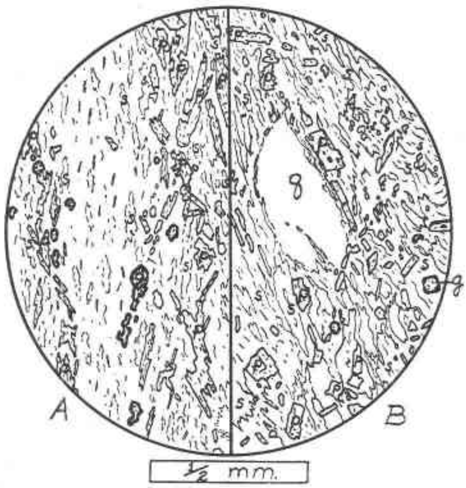

Fig. 1. Sections of piedmontite-sericite schist.
g = garnet; p = piedmontite; q = quartz; s = sericite.

In section B, which was cut at right angles to the schistosity, the two intersecting sets of rock cleavage can be seen. The piedmontite occurs mainly as tiny rectangles and rhombs, representing cross-sections of prisms like those in section A, although a few elongated grains were seen here also. These are unoriented with respect to the schistosity of the rock. These unoriented crystals, and especially the smaller ones, are more nearly euhedral than the oriented prisms of section A.

Character of the piedmontite. The elongated individuals of piedmontite measure from .2 to .3 mm. in length, and .02 to .05

mm. in thickness. Occasionally the crystals show faces belonging to the forms (100), (001), and (h0*l*), although most of the grains are without recognizable crystal forms. One individual, lying on the orthopinacoid, and so oriented that the *b*-axis is horizontal, is shown in Fig. 2. The axial colors, seen when the indicated directions are parallel to the direction of vibration of the lower nicol, are shown in the figure. A positive, acute bisectrix interference figure, with large axial angle, and axial plane perpendicular to the long dimension of the crystal, was obtained from the horizontal grain

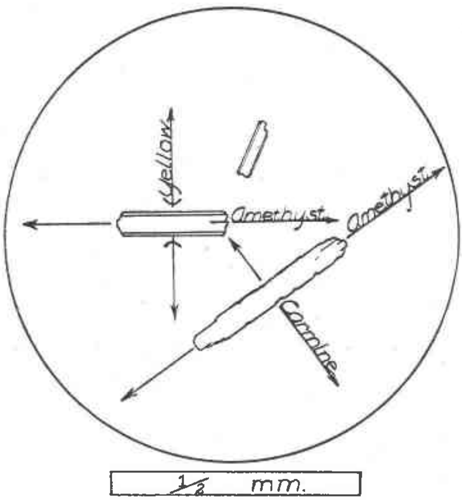

FIG. 2. Axial colors of crystals in piedmontite-sericite schist.

of Fig. 2. Crystals showing axial colors like those indicated on the lower grain, yield, in convergent polarized light, an apparently negative interference figure, with the trace of only one optic axis, visible at the extreme edge of the field. These tests, supported by a comparison with slides of the piedmontite from South Mountain, Pennsylvania, so ably described by George H. Williams,[14] indicate beyond doubt that the material from California has the usual pleochroism scheme: X=orange, to lemon-yellow; Y=amethyst, or amethystine red; Z=carmine. A study of the piedmontite occurring in spherulites in the rhyolite of South Mountain reveals no essential difference in the axial colors of the Pennsylvanian and Californian minerals.

[14] Williams, George H., Piedmontite and Scheelite from the Ancient Rhyolite of South Mountain, Pennsylvania: *Amer. Jour. Sci.* [3], vol. **46,** pp. 50–57, 1893.

The piedmontite in both sections occasionally contains minute inclusions. In some cases, these appear to be quartz, similar to that of the groundmass; in other cases there are lines of round, or oval-

FIG. 3. Showing a flake of altered biotite in the metamorphosed volcanic rock. e = epidote; f = feldspar; m = mica (secondary biotite); p = piedmontite; black is manganese oxide.

shaped bodies, arranged parallel to the *b*-axis of the host. From their shape and extreme negative relief, the latter inclusions are thought to be liquid-filled cavities.

HISTORY OF THE ROCK. Evidence as to the nature of the original rock is furnished by the remnants of quartz phenocrysts, or fragments of former quartz crystals, as seen in the sections. When such a crystal, or crystal fragment, is nearly complete, the shape is extremely suggestive of the phenocrysts of high-quartz (inverted to low-quartz), found in acid lavas.[15] The fact that so many of the quartz crystals are now represented by fragments only, suggests that the original deposit may have been fragmental, such as ash, or tuff, instead of lava, but it is thought that this fragmentation of earlier complete crystals may possibly have been due to later orogenic movements. Whether or not the original rock was a lava, it is evident that granulation, produced by directed pressures, resulted in recrystallization, which gave rise to the secondary quartz

[15] Rogers, A. F., Natural History of the Silica Minerals: *Am. Min.*, vol. **13,** p. 88, Fig. 1, 1928.

and feldspar of the groundmass. Apparently the pale brown mica, mentioned above, crystallized at this time, and was followed by garnet and piedmontite. Sericite replaces nearly every piedmontite grain to a slight extent, but is never enclosed by the latter; hence this mica would seem to be restricted to a narrow time interval, near the close of crystallization of the piedmontite, and perhaps for a time thereafter. It is probable that the pink color of the sericite is due to small amounts of manganese taken up by the mica as it partially replaced the manganesian epidote. The age relations of the apatite and manganese oxide with respect to the other secondary minerals remain uncertain, but the apatite is earlier than sericite.

2. Occurrence as a Replacement of Biotite in a Metamorphosed Volcanic Rock

The specimen in which this occurrence of the piedmontite appears, was collected at the summit of the eastern end of Volcanic Ridge, in northeastern Madera County. (See the Mt. Lydell topographic sheet, U. S. Geol. Survey.) It is light, bluish gray in color, with schistose structure. With the hand lens, abundant grayish-white feldspar crystals, colorless, glassy quartz grains, and flakes and pseudohexagonal tablets of dark brown biotite can readily be distinguished. These minerals are embedded in an aphanitic, gray matrix.

Microscopic character. In the thin section, large, fractured crystals of quartz, reaching 3 mm. in diameter, are the most conspicuous objects. The shapes of some of the crystals suggest that nearly all of the quartz individual is still present; missing parts, and isolated fragments may often be accounted for by fracturing due to movements along surfaces of schistosity. The traces of such surfaces are easily seen when the analyzer is thrown out of position. These traces pass directly through the quartz grains, the two halves of which may be slightly offset, or, quite commonly, one portion is represented only by a few small fragments strewn along the surface of schistosity. In spite of the amount of fracturing and breaking up, very little recrystallization of the quartz has taken place. The crystal fragments reveal, by their shapes, a former euhedrism, which has been considerably subdued, apparently by magmatic resorption. Embayments and enclosures of the groundmass in the quartz are common.

With crossed nicols, numerous crystals and crystal fragments of plagioclase, and occasionally of microcline (by inversion from sanidine under directed pressure?), seldom attaining a diameter as great as 1.5 mm., are plainly revealed. The plagioclase contains abundant minute grains of epidote, flakes of light, greenish-brown biotite (interference figure almost uniaxial), and granules of a black, opaque substance, which chemical tests indicate to be an oxide of manganese.

Around and between these larger crystals is a very fine-grained matrix, apparently of quartz and feldspar, in which are embedded flakes of the greenish-brown mica, irregular bodies of manganese oxide, fractured, euhedral crystals of apatite, grains of epidote, and altered remnants of what appears to have been biotite. These remnants are perhaps the most interesting feature of the rock.

THE ALTERED PRIMARY MICA. Flakes of this mineral averaged about .7 mm. in length, and .4 mm. in width. The mica-substance remaining is light greenish-brown, like that occurring as secondary inclusions in the plagioclase, and scattered through the groundmass. The cleavage traces of the mica are commonly marked by lines of manganese oxide; granules of epidote usually form a fringe around the mineral, and are occasionally developed along the cleavage traces. Most interesting of all are small, elongated, or spindle-shaped bodies of piedmontite, grown along the cleavage of the mica. A few epidote-fringed grains of piedmontite also occur in the groundmass of the rock. Both occurrences are illustrated in Fig. 3. In some cases the pleochroism is nearly as strong as that of the South Mountain, Pennsylvania, piedmontite, but in many of the grains the axial colors are quite faint, and are commonly more intense in the center of the grain, grading into the colors of common epidote on the edges.

The transmitted light which vibrates parallel to the long dimension of the piedmontite bodies, in nearly every case is orange yellow, and that vibrating perpendicular thereto is always some shade of rose or carmine. Rarely, the light vibrating parallel to the length of the grains is pale amethyst in color.

From this it would appear that the piedmontite crystals are tabular, due to their having grown along cleavage planes in the mica; that the shortest dimension of the tablets is always parallel to Z, or nearly so, and that the longer diameters are approximately parallel to X and Y, but that most of the individuals are so oriented as to appear elongated parallel to X.

Origin of the rock. The nature, relations, and shapes of the original constituents leave no doubt that the rock is of volcanic origin, but here again there is some doubt as to whether it was a lava or a tuff. The primary constituents were quartz, plagioclase (more basic than albite), a little potash feldspar (possibly sanidine) and biotite; hence the original rock is thought to have been a dacite, or a dacite tuff. In this rock the apatite is also a primary constituent; the greenish-brown biotite is secondary, and was followed by piedmontite, manganese oxide, and epidote. The dynamic conditions through which this rock has passed were much less severe than those which obtained during the metamorphism of the schist from Shadow Lake. Hydrothermal solutions were probably present at high temperatures only, since sericite is completely absent, even though the materials to form it were present.

Other Occurrences of Piedmontite

In searching the literature on the various occurrences of piedmontite, the information obtained from Hintze's Handbuch,[16] in the paper by Williams,[17] and in a paper recently published by Lausen,[18] was especially helpful. The localities mentioned below are presented in the order given by Williams in 1893, and the more recently-discovered occurrences are introduced in their proper places.

With manganese ore deposits, the mineral occurs at San Marcel, Italy, with braunite, quartz, tremolite, calcite, violan, greenovite manganese garnet, manganese-bearing mica, and tourmaline;[19] at Viù, Italy, as needle-like crystals in a quartz vein traversing mica schist; and at Mezzenile, Italy, with braunite.[20*]

At Jakobsberg, in Sweden, the optically negative mangan-epidote is found with light yellow titanite, barite, manganophyllite, calcite, and a light yellow pyroxene.[21] Associated with the manganese ore deposits of India, piedmontite occurs in the Nagpur district, in Jhabua State, and in Nárukot State, as nodules in crystalline limestone, on schistosity planes in sericitoid phyllites, as fine-

[16] Hintze, *loc. cit.*

[17] Williams, *loc. cit.*

[18] Lausen, Carl, Piedmontite from the Sulphur Spring Valley, Arizona: *Am. Mineral.*, vol. **12**, pp. 283–287, 1927.

[19] Hintze, *loc. cit.*

[20*] Jervis, quoted by Hintze.

[21] Hintze, *loc. cit.*

grained patches in epidote rock, with quartz as cavity linings in apatite-spessartite-piedmontite rock, and as rose-pink patches in granite which has absorbed portions of the manganiferous series (Jothvád, Nárukot State), etc.[22]

In spherulites, or as veins in eruptive rocks, the mineral occurs at Glencoe, Scotland (withamite)[23] and at South Mountain, Pennsylvania. (In spherulites, with quartz, and at times with scheelite.)[24]

As a secondary constituent of eruptive rocks, piedmontite has been noted in the "porfido rosso antico," at Djebel Dokhan, Egypt;[25] in the quartz porphyries near Annapolis, Missouri;[26] in the granulite of Haute Loire, France;[27] at South Mountain, Pennsylvania (microscopic constituent of the ancient lavas); at Pacific Beach, San Diego County, California (in a boulder);[28] in a basic andesite at Sulphur Spring Valley, Arizona;[29] and in Madera County, California.

As a constituent of crystalline schists, the mineral is found in chlorite-sericite gneiss and in glaucophane schists in Japan;[30] on the Island of Groix, France;[31] in gabbro-diorite, as an alteration product of hornblende, at Chichibu, Japan;[32*] and in piedmontite-sericite schist in Madera County, California.

[22] Fermor, L. L., The Manganese Deposits of India: *Mineralogy, Mem. Geol. Surv. of India*, vol. **37**, pp. 187–191, 1909.

[23] Brewster, D., *loc. cit.*

[24] Williams, *loc. cit.*

Bascom, Florence, The Ancient Volcanic Rocks of South Mountain, Pennsylvania: *U. S. Geol. Survey*, Bull. **136**, p. 41, 1896.

[25] Liebisch, Th., Mineralogisch-petrographische Mittheilungen aus dem Berliner mineralogischen Museum: *Zeitschr. d. Deutschen geol. Gesellschaft*, vol. **29**, pp. 710–734, 1877.

[26] Hawarth, E., A contribution to the Archean Geology of Missouri: *Am. Geol.*, vol. **1**, pp. 365–367, 1888.

[27] Lacroix, A., Mineralogie de la France, vol. **1**, p. 155, 1893.

[28] Rogers, A. F., *loc. cit.*

[29] Lausen, Carl, *loc. cit.*

[30] Koto, B., Some Occurrences of Piedmontite in Japan: *Jour. Col. Sci., Imp. Univ. Tokyo*, vol. **1**, pt. 3, pp. 303–312, 1887.

——— On some occurrences of Piedmontite-Schist in Japan: *Quart. Jour. Geol. Soc.*, vol. **43**, pp. 474–480, 1887.

[31] Lacroix, A., Épidote Manganésifère (piémontite) de L'île de Groix: *Bull. Soc. Fr. de Min.*, vol. **11**, p. 148, 1888.

[32*] Harada, T., Die Japanischen Inseln, Erste Lief., *Berlin*, **1890**, p. 75.

Finally, the mineral has been noted as a detrital constituent in sediments near Lost Hills, California.[33]

Besides the occurrences mentioned above, Williams, in his paper, previously referred to, mentions piedmontite in the porphyries and felsites of the Boston Basin, and from "the Archean area of Georgia near Tennessee." It is likely that many localities in which this mineral occurs in small amounts have not been reported, but from those on record, it can be seen that the piedmontite is a mineral of wide-spread occurrence, and that it develops in quite a number of geologic situations, usually in minor amounts, but occasionally in such abundance as to be an important rock constituent, as, for example, in some crystalline schists of Japan.

ACKNOWLEDGMENT

The writer wishes to express his thanks to Professors A. C. Gill and H. Ries, for helpful suggestions concerning the preparation of the manuscript.

[33] Reed, R. D., and Bailey, J. P., *loc. cit.*

NOTES AND NEWS

AN OCCURRENCE OF NATIVE SULPHUR IN CENTRE CO., PA.

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Of considerable scientific interest, but of no economic importance, is the occurrence of a small deposit of native sulphur in Centre County, Pennsylvania. Native sulphur has previously been reported from but three counties of this state.[1] The deposit was noted while the writer was examining an abandoned quarry located four miles northwest of State College.

The quarry is located in limestones of middle Chazy age, the beds of which show an almost vertical dip as they lie on the northwest limb of the Nittany anticline. Fractures developed at the time of folding have been filled with calcite which, at this locality, frequently carries native sulphur. Good crystals of the sulphur are not found, the material being massive, of high purity, and intimately associated with the calcite. Bands of sulphur, ranging from two to four millimeters in width and up to twenty centimeters in length, are seen. In all cases calcite separates these bands from the containing rock which is a pronounced stinkstone.

The sulphur is looked upon as resulting from the incomplete oxidation of hydrogen sulphide carried by ground waters and derived from organic matter in the impure containing rock. No associated gypsum has been found.

[1] S. G. Gordon, The Mineralogy of Pennsylvania: *Special Publication of Acad. Nat. Sci. of Phila.*, No. **1**, 1922.

A Correction

In the article "An Arizona Gold Nugget of Unusual Size" written by Robt. E. S. Heinemann and published in the *American Mineralogist* for June 1931, a cor-