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THE SOURCE OF HYDROTHERMAL SOLUTIONS AT PUERTO MAUNABO AND ITS BEARING ON THE BASE-METAL–POTASSIUM FELDSPAR ASSOCIATION IN PUERTO RICO

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Abstract.—A quartz oligoclase porphyry exposed near Puerto Maunabo may provide evidence to further our understanding of the base-metal–potassium feldspar association known to occur in many of the porphyry-type copper deposits of Puerto Rico. The porphyry appears to be a magmatic differentiate on the border of the San Lorenzo batholith that may represent a source of mineralizing hydrothermal solutions. The porphyry intrudes an albitized quartz diorite border phase of the batholith that contains large roof pendants of metavolcanic rock. These roof pendants are mostly metamorphosed to greenschist metamorphic facies, but in the vicinity of Puerto Maunabo south of the porphyry, they reach amphibolite metamorphic facies; north of the porphyry, similar xenolithic lenses of metavolcanic rock appear to have been converted entirely to an oligoclase quartz felsite. The layered albitized quartz felsite has the same composition and texture as irregular veinlets in the albitized quartz diorite and as the groundmass in the porphyry. The K^{+} ions and basic ions of Fe^{+2}, Cu^{+2}, Mg^{+2} apparently were mobilized during final magmatic crystallization and then escaped as hydrothermal solutions that followed open conduits within a zone of structural weakness which also permitted the emplacement of the porphyry. The volcanic rock of Cerro Piedra Hueca, in contact with the albitized quartz diorite, and generally along strike west of the porphyry, has been altered to a quartz sericite rock entirely devoid of mafic silicates. This is the southeasternmost exposure of hydrothermally altered volcanic rock in the regional zone of northwest-trending faults that contains the principal porphyry-type copper deposits of Puerto Rico. The texture, mineralogy, and geologic environment of the porphyry at Puerto Maunabo are similar to those of the ore-bearing porphyries but differ in one important aspect. Most ore-bearing porphyries contain hydrothermal potassium feldspar and reddish-brown biotite intimately associated with the base-metal sulfides. In the porphyry of Puerto Maunabo, potassium feldspar is conspicuously absent, and only a trace of biotite is present; the only sulfide present is pyrite. The physical and chemical environment required to precipitate K^{+} ions, either as potassium feldspar or biotite, apparently is very similar to that required to precipitate base-metal sulfides. At Puerto Maunabo, these conditions evidently did not prevail, and potassium and the base metals may have been carried in solution to a more favorable environment.

The San Lorenzo batholith is exposed in southeastern Puerto Rico (fig. 1), and the somewhat smaller Utuado batholith is exposed about 75 km westward in west-central Puerto Rico. Between these two intrusive bodies, and bordered on the north and south by extensive fault zones is an area underlain chiefly by Cretaceous volcanic rocks that have been moderately folded, greatly shattered, penetrated by many small granitic stocks, and dikes, and locally completely altered by the action of hydrothermal solutions.

The metallogenic map of Puerto Rico (Cox and Briggs, 1973) shows that sulfide mineralization is common in Puerto Rico and that the largest base-metal deposits have been found along the southern border of the Utuado batholith. Geologic relations that may shed some light on the source of hydrothermal solutions that transport base metals have been observed in the Punta Tuna quadrangle in the southernmost exposures of the San Lorenzo batholith.

A narrow band of quartz oligoclase porphyry is exposed in a small group of hills near the village of Puerto Maunabo (fig. 2) in the southeast corner of Puerto Rico. The porphyry appears to be a late magmatic differentiate of the San Lorenzo batholith and may represent a source of mineralizing hydrothermal solutions. It occurs within an albitized quartz diorite

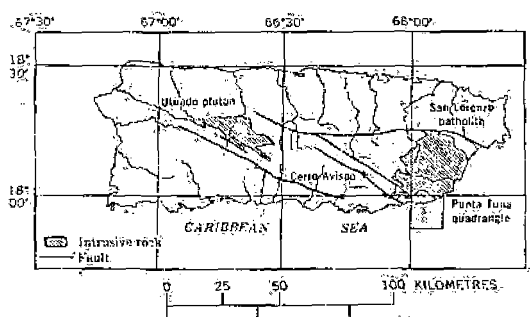

FIGURE 1.—Index map of Puerto Rico.

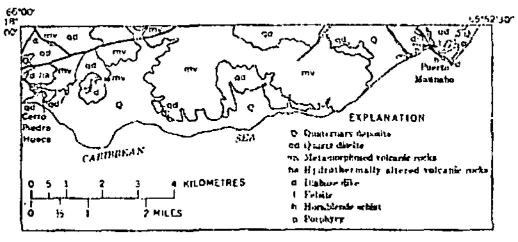

FIGURE 2.—Simplified geologic map of the Punta Tuna quadrangle, Puerto Rico.

body on the border of the batholith and has been hydrothermally altered. The albitized quartz diorite which shows evidence of deuteric alteration also is in contact with hydrothermally altered volcanic rock. The texture, mineralogy, and geologic environment of the porphyry are similar in many respects to those of intrusive porphyries associated with base-metal deposits in west-central Puerto Rico.

The age of the porphyry of Puerto Maunabo is not known, but if it is the same as the porphyries associated with base-metal deposits, as much as 20 m.y. may have elapsed, according to D. P. Cox (written commun., 1974), between emplacement of the San Lorenzo batholith and final emplacement of the porphyry.

GEOLOGIC SETTING

The San Lorenzo batholith of Late Cretaceous age is a crudely circular plutonic complex about 25 km in diameter. The southern part of the batholith includes the Yabucoa and Punta Tuna quadrangles (C. L. Rogers, M. H. Pease, Jr., C. M. Cram, and M. S. Tischler, unpub. data, 1976). The Yabucoa quadrangle is underlain mostly by granitic-textured rock intermediate in composition between hornblende-biotite quartz diorite and biotite-hornblende quartz monzonite. The Punta Tuna quadrangle is underlain mostly by albitized quartz diorite having extensive roof pendants of metamorphosed volcanic rock. The northern boundary of the albitized quartz diorite appears to be transitional and is covered by alluvium and colluvium at the southern border of the Yabucoa quadrangle.

Most of the metavolcanic rocks are uniformly dark greenish gray and in the epidote greenschist facies of metamorphism. They commonly retain faint relic textures and structures that attest to their origin as interstratified lava, tuff, and breccia. At Cerro Piedra Hueca, near the western edge of the quadrangle, an area of volcanic rock has been hydrothermally altered to a very light gray rock composed chiefly of finely divided quartz and sericite.

The quartz oligoclase porphyry crops out in a relatively narrow arcuate band that passes through Puerto Maunabo (fig. 3.). It is not a true porphyry; evenly distributed clots, as much as 30 mm in diameter, of quartz and oligoclase phenocrysts give to this rock the apparent coarse texture of a porphyry. The southern contact of the porphyry is defined by an abrupt increase of mafic silicates in the albitized quartz diorite; the northern contact is gradational, but an indefinite contact was delineated in the field, where pyrite is no longer present and the porphyritic texture is no longer conspicuous.

A section of stratified tuff and lava exposed in sea cliffs at Puerto Maunabo has been metamorphosed to dark-greenish-gray hornblende schist. Relic primary phenocrysts are preserved in the metalavas and thinly layered stratification containing graded bedding is preserved in the metatuffs. This section is about 85 m wide; it trends northward and terminates abruptly at the southern border of the porphyry. Lenses of pale-yellowish-brown layered felsite are exposed in two areas on the north side of the porphyry. One area is nearly on strike with the hornblende schist; the other is about 300 m west. Layering within the eastern lenses conforms generally to the attitude of relic bedding within the hornblende schist. In the second area of felsite, the layering trends in a north-northwesterly direction, and associated with lenses of felsite in this tongue are blocks of float and a few possible outcrops of dark-colored hornblende schist possibly interlayered with the felsite. The outlines of these felsite lenses are indistinct because they interfinger with albitic quartz diorite of similar color and composition. The layered structure and areal distribution of these felsite lenses suggest that they too represent bands of metamorphosed volcanic rocks, probably stratified tuffs.

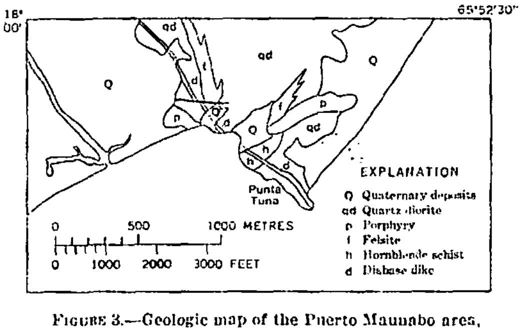

FIGURE 3.—Geologic map of the Puerto Maunabo area, Puerto Rico.

A medium-gray, commonly porphyritic, diabase dike forms the crest of the sea cliff at Punta Tuna; it transects the hornblende schist lens and the band of quartz-oligoclase porphyry and extends northwestward, where it is buried by alluvial deposits. This dike is about 20 m wide at Punta Tuna and thins northwestward; it is offset by faults of small displacement. Similar linear dikes also offset by minor faults intrude the southern border of the batholith at several localities.

PETROGRAPHY

Quartz oligoclase porphyry.—The quartz oligoclase porphyry is a light-gray siliceous rock containing almost no mafic silicates. Clusters of quartz and oligoclase phenocrysts are evenly distributed in a fine-grained matrix of quartz and oligoclase containing wisps of reddish-brown biotite and rare clinozoisite. Fine to coarse cubic pyrite amounts to as much as 10 percent of the rock.

The two distinct grain sizes in the quartz-oligoclase porphyry are evidence of alteration and partial replacement. The coarse constituents have been partly resorbed by later interstitial material. Turbid oligoclase crystals are deeply embayed and contain secondary inclusions of quartz and clear oligoclase; many of the large quartz grains are corroded, but others appear to have been enlarged by accretion of secondary quartz to form the phenocrysts that characterize hand specimens.

Albitized quartz diorite.—The albitized quartz diorite is variable in texture and composition, but in general is a medium-grained holocrystalline rock composed chiefly of median oligoclase, An-20, and quartz, and having interstitial subhedral hornblende and biotite. Oligoclase is turbid brown and altered; it commonly shows the relic twinning of a more calcic plagioclase. It locally forms myrmekitic intergrowths with quartz. No potassium feldspar remains in the rock, if it was ever present. Coarse anhedral crystals of quartz having irregular extinction compose as much as 50 percent of some specimens; fine-grained secondary quartz also is found in microveins and interstitially with albite. Most hornblende is partly or entirely altered to granular aggregates of biotite, chlorite, epidote, magnetite, and sphene. Much of the biotite, however, appears to be original and is partly replaced by clinozoisite and chlorite minerals.

Plutonic rocks just north of the porphyry are intermediate in the transition from albitized quartz diorite to porphyry, although they have not been mapped as a separate unit. Fine-grained interstitial quartz-oligoclase aggregate, identical with the fine-grained facies of the porphyry, occurs in irregular clots and veinlets in amounts less than 15 percent. Myrmekitic intergrowths of quartz and sodic oligoclase occur in large unevenly distributed patches. Mafic constituents, which consist of olive-brown biotite in fine aggregate clots associated with minor amounts of penninite, epidote, and clinozoisite, amount to less than 5 percent of the rock. Primary hornblende is rare or absent, and finely divided magnetite is ubiquitous. This rock evidently grades northward into typical albitic quartz diorite, but the transition cannot be observed, as the exposures are surrounded by a broad alluvial valley. Albitic quartz diorite exposed south of the porphyry shows no such transition and has the typical texture and composition of that exposed farther to the west and north.

Hornblende schist.—The hornblende schist exposed south of the porphyry consists of an intergranular mosaic of sodic andesine and quartz, having stubby subrounded grains of hornblende occurring in clusters and as discrete crystals. Probable pseudomorphs of pyroxene phenocrysts are represented by clusters of hornblende showing poorly defined crystal outlines bordered by magnetite dust. Relic plagioclase phenocrysts have been so nearly resorbed that, although their optical continuity is still apparent, their crystal outlines are obscure. Bedding in the tuffs is marked by light and dark mineral segregation and by abrupt and, in part, gradational changes in grain size parallel to bedding planes.

Felsite.—The microscopic texture of the felsite north of the porphyry is much like the fine-grained facies of the porphyry. It is a granoblastic mosaic of quartz and sodic oligoclase containing many patches of myrmekite. Sheaflike clusters of biotite compose about 2 percent of the rock, and magnetite is present. The primary stratification clearly apparent in hand specimen is almost entirely obscured on a microscopic scale because of recrystallization to grain-size diameters greater than primary bedding thickness.

Hydrothermally altered volcanic rock.—The hydrothermally altered volcanic rock exposed at Cerro Piedra Hueca is composed almost entirely of quartz and sericite in a ratio of about 3:1. Clinozoisite occurs in granular patches, and pyrite is present. In weathered outcrops, the rock is perforated with irregular-shaped pores amounting to about 20 percent of the rock, and most pores are lined with a thin rim of dark-reddish-brown hematite, probably after sulfides.

Diabase dikes.—The diabase dikes have a typical diabasic texture, although masked by deuteric alteration. Phenocrysts composing as much as 40 percent of the rock consist of strongly zoned intermediate plagioclase, An 40–60, which is sericitized and contains inclusions and veinlets of albite and hornblende. The hornblende is pseudomorphic after pyroxene and is partly altered to penninite, clinozoisite, and epidote. Relic pyroxene is rare. The groundmass consists of interlocking grains of quartz and sodic plagioclase having wisps and clots of hornblende, chlorite, clinozoisite, and, rarely, calcite.

MAGMATIC DIFFERENTIATION AND FORMATION OF HYDROTHERMAL SOLUTIONS

Exposures in the Punta Tuna quadrangle appear to demonstrate progressive stages in the formation of hydrothermal solutions from residual magmatic liquids emanating from late-crystallizing magma on the borders or near the top of the San Lorenzo batholith. The albitized quartz diorite appears to be the product of a residual melt derived from a parent dioritic to granodioritic magma by fractional crystallization in the presence of a water-rich vapor phase. By this process, K^{+} ions were entirely removed, Ca^{+2}, Mg^{+2}, and Fe^{+2} ions were depleted, and the breakdown of primary silicates resulted in the formation of hydrous silicates accompanied by an increase in the relative amount of free quartz.

The oligoclase-quartz porphyry represents a concentration of later crystallizing volatile-rich magma further depleted in basic constituents. A mush of coarse crystals having interstitial fluid magma evidently was squeezed upward as an east-trending dike along a fault or fracture. In the process of cooling and final crystallization, many of the early-formed coarse crystals of the mush were resorbed by reaction with the residual magma. Along the northern border of the porphyry, this residual magma penetrated for a considerable distance from the contact fractures and interstices in essentially crystalline albitized quartz diorite. Xenolithic lenses of metavolcanic rock also were almost entirely converted to oligoclase quartz felsite. Conceivably, these metavolcanic rocks had originally been basaltic in composition.

Evidence that suggests a basic volcanic origin for the felsite may be summarized as follows:

1. The felsite exposed north of the porphyry is distinguished from the enclosing albitized quartz diorite by a conspicuous layering very similar to that in the hornblende schist south of the porphyry.
2. The composition and microscopic texture of the felsite, however, is identical with the fine-grained clots and veinlets in the surrounding altered albitized quartz diorite just north of the porphyry.
3. Lenses of the eastern area of the felsite are nearly on strike with the hornblende schist to the south, and the layering is essentially parallel to the layering in the schist.
4. No felsite was observed south of the porphyry, but a few slabs of green hornblende schist float, perhaps preserved remnants, are associated with the western felsite area north of the porphyry.

During final crystallization of the porphyry the remaining water-rich vapor phase escaped, probably as hydrothermal solutions via fractures in the overlying volcanic rock, carrying released basic ions of Fe^{+2}, Ca^{+2}, and Mg^{+2}, and previously mobilized K^{+} ions. Evidence in the porphyry of the former presence of volatiles carrying these ions is indicated by the occurrence of ubiquitous pyrite, myrmekite, rare muscovite, and traces of reddish-brown biotite and clinozoisite.

Lateral and vertical distribution of these hydrothermal solutions appears to have been confined to open conduits within the zone of structural weakness that permitted emplacement of the porphyry. The hydrothermally altered quartz-sericite rock exposed at Cerro Piedra Hueca is roughly in line with this zone of structural weakness. The solutions that altered the porphyry at Punta Maunabo also may have altered the volcanic rock at Cerro Piedra Hueca.

This altered volcanic rock is at the eastern terminus of a belt of disconnected outcrops of hydrothermally altered volcanic rock (shown on the metallogenic map by Cox and Briggs, 1973), that extends northwestward toward Cerro Avispa (fig. 1). Iron sulfides have been found at several localities within this belt, and a potential ore deposit of quartz veins containing traces of gold and silver as well as minor sulfides is exposed in the Cerro Avispa area. These exposures of hydrothermally altered rock almost certainly are alined along a zone of faulting, not shown on the metallogenic map, that parallels the principal trend of mineralization in Puerto Rico.

The hydrothermal alteration appears to be older than the diabase dike that cuts the porphyry because the dike shows no evidence of alteration that cannot be ascribed to deuteric alteration.

ANALOGY TO ENVIRONMENT OF BASE-METAL DEPOSITION IN PUERTO RICO

Some of the geologic characteristics of copper-mineralized areas in Puerto Rico were presented at the Third Caribbean Geological Conference (Pease, 1966). This paper concluded that most deposits of economic interest are of the porphyry copper type. Among the essential features of this type of deposit in Puerto

Rico are irregularly shaped dikes of porphyritic quartz diorite within and alined roughly parallel to one or another of the major west-northwest- to northwest-trending shear zones of the island. Where not hydrothermally altered, this porphyritic intrusive rock consists of subhedral phenocrysts of albitized plagioclase, quartz, and olive-brown hornblende and biotite in a microcrystalline groundmass composed chiefly of albite, granular quartz, and chlorite. Plagioclase phenocrysts and mafic minerals both show evidence of deuteric alteration.

In mineralized areas, however, both the intrusive and the volcanic country rock are intensely fractured and hydrothermally altered. They are strongly silicified and sericitized and the primary silicates have been essentially destroyed. Quartz-sulfide veins and calcite veins fill the fractures. Some quartz veins, particularly within or closely associated with the intrusive rock, contain copper-bearing sulfides, and commonly these veins also contain adularia and magnetite. Sulfides are also disseminated throughout the highly fractured volcanic and intrusive rock, but copper sulfides appear to be concentrated along the borders of hydrothermally altered porphyritic quartz diorite. Finely divided reddish-brown biotite appears to be a hydrothermal mineral intimately associated with these copper sulfides.

The textures and composition of the quartz oligoclase porphyry at Puerto Maunabo have many of the characteristics and associations of hornblende-quartz diorite porphyry stocks associated with the porphyry copper-type mineral deposits of Puerto Rico (Cox, Larson and Tripp, 1973). They are highly siliceous porphyries that contain finely divided conspicuously reddish-brown hydrothermal biotite and no primary mafic silicates. The similarity is clearly apparent; the conspicuous differences are the absence of potassium feldspar and the absence of base metals at Puerto Maunabo.

The potassium feldspar, present in the San Lorenzo batholith, is not present in the albitized quartz diorite or in the quartz oligoclase porphyry. Yet the occurrence of myrmekite in the porphyry suggests that K^+ ions were present in the magma and were segregated out during late-stage deuteric alteration that accompanied the release of water-rich volatiles to form hydrothermal solutions.

Most of the porphyry-copper-type ore deposits in Puerto Rico, on the other hand, contain, in veinlets, hydrothermal biotite and potassium feldspar in addition to the base metals (Cox, Larson and Tripp, 1973). Although K^+ ions are not necessarily required to precipitate base metals from solution, the physical and chemical environment that causes the precipitation of K^+ ions, either as biotite or potassium feldspar, appears to be very similar to that required for precipitation of base-metal sulfides.

CONCLUSIONS

The quartz oligoclase porphyry exposed at Puerto Maunabo appears to be a late-magmatic deuterically altered phase of the San Lorenzo batholith and the source of hydrothermal solutions that have altered volcanic rocks at Cerro Piedra Hueca. A northwest-trending zone of fractures that extends from Cerro Piedra Hueca at least as far as Cerro Avispa evidently acted as an open conduit for passage of these hydrothermal solutions.

Hydrothermally altered rock found along many other northwest- and west-northwest-trending shear zones probably was altered by similarly derived hydrothermal solutions. Where the porphyry intrusive rock is exposed in these zones, it too is hydrothermally altered and contains sulfides. If hydrothermal potassium feldspar and biotite are present in veinlets in the highly fractured porphyry and adjacent country rock, the sulfides commonly contain base metals, but base-metal sulfides do not tend to precipitate if, as at Puerto Maunabo, K^+ ions have been driven off prior to crystallization and hydrothermal alteration.

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