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Sedimentary Rock-Hosted Disseminated Precious Metal Mineralization at Purísima Concepción, Yauricocha District, Central Peru

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Abstract

Sedimentary rock-hosted disseminated gold ores lithologically and chemically similar to those of Carlin-type deposits of the western United States are present in the Yauricocha district, central Peru. The Purísima Concepción deposit is located in the core of a steeply plunging anticline several hundred meters beyond large pipe-shaped Cu-Zn-Pb-Ag-Au replacement orebodies in limestone bordering a late Miocene granodiorite stock. The central part of the stock is potassium-silicate altered and contains high-salinity fluid inclusions.

Mineralized impure limestone is generally decalcified and silicified and appears to have been carbonaceous. Original laminated bedding and other sedimentary structures are locally preserved. Characteristic minerals include quartz, rhodochrosite, pyrite, calcite, sericite, and barite. Pyrrhotite, arsenopyrite, plagionite ($Pb_5Sb_8S_{17}$), and altaite (PbTe) have been recognized locally. Although the chemical composition of the ores is generally similar to that of the Carlin deposit, rocks of Purísima Concepción have higher Fe, Mn, Te, Ag, and Tl and lower Hg contents. Most of the Au-bearing rocks contain between 3 and 6 wt percent Fe, and Te ($\approx$4 ppm) and Mn ($\approx$4 wt %) are about two orders of magnitude higher than at Carlin. These elevated elemental concentrations are all epigenetic; there is no regional or local geologic or textural evidence for a syngenetic and/or diagenetic origin. The Ag/Au ratio of the ores is about 2.5. Gold correlates positively with Ag, As, Hg, Mo, Sb, Te, and Tl and Ag strongly with Mn. Porous, leached, but not silicified, beds tend to carry higher gold values than silicified rocks.

The presence of enargite, tetrahedrite, and high S copper sulfide minerals in the replacement ores and of pyrophyllite, diaspore, alunite, anhydrite, and high-temperature ($\geq$400°C), compositionally complex, hypersaline fluid inclusions in altered rocks bordering enargite veins in the stock, and the intense dissolution of limestone during deposition of the polymetallic orebodies suggest that the fluids initially had low pH and high f_{O_2} and f_{S_2} values. The magmatic hydrothermal system may have been similar to that of Julcani and other enargite-tetrahedrite districts in Peru, with the differences in ore types at least in part reflecting the carbonate composition of the host rock at Yauricocha.

The elemental chemistry of the Purísima Concepción ores can be qualitatively explained by a process of hydrothermal differentiation in which selective precipitation of base metal and Ag sulfides and sulfosalts depleted the fluids in these components and produced a decrease in Cu/Zn, Cu/Pb, As/Sb, base metal/precious metal, and Ag/Au ratios. The moderate pH and low f_{O_2} and f_{S_2} values implied by the mineral assemblage of Purísima Concepción presumably reflect in part the presence of carbonaceous material.

Similar deposits can be expected elsewhere in the Western Cordillera of central and northern Peru where hydrothermal fluids related to Neogene stocks encountered impure carbonaceous limestone beds of the Pariatambo and Jumasha Formations and other units. Certain sedimentary rock-hosted, disseminated Au-Ag deposits elsewhere may have a similar genetic relation to porphyry, skarn, and/or limestone-replacement systems.

Introduction

DURING the past two decades sedimentary rock-hosted, disseminated precious metal deposits have become an important source of gold, and to a lesser extent, silver. Although most known sedimentary rock-hosted deposits are located in the western United States, and particularly in Nevada (e.g., Radtke et al., 1980; Bagby and Berger, 1985; Bonham, 1985; Tingley and Bonham, 1986; Percival et al., 1988), similar deposits are present in other parts of the world, for example, China (Geng, 1985; Liu and Geng, 1985; Cunningham et al., 1987).

Central Peru, a major region of base and precious metal mining (Petersen, 1965), possesses impure carbonate rocks and calcareous siltstones and shales, some carbonaceous (Mégard, 1978b). These rocks, largely of Mesozoic age, occur in a transitional environment reminiscent of that of lithologically similar strata in the western United States (Stewart, 1980) and are cut by many stocks of Tertiary age (Mégard, 1978a and b). Units of relatively pure carbonate strata, sandstone, and shale—locally coal-bearing—are present in the section, but volcanic rocks are absent. The impure carbonate beds should be good exploration targets for disseminated precious metal deposits.

The purpose of this paper is to provide a preliminary geologic and geochemical description of the Purísima Concepción gold deposit and of the intimate spatial and temporal association of the deposit with a porphyry system and important polymetallic limestone replacement orebodies, features that are critical in providing insights into the origin of the deposit. Purísima Concepción, located in the Yauricocha district at an elevation of about 4,700 m in the Western Cordillera of central Peru (Fig. 1), is one of the first sedimentary rock-hosted, disseminated precious metal deposits to be recognized in the central Andes (Noble and Alvarez, 1988). This first report is based mostly on information obtained during mining, development, and evaluation activities, supplemented by small amounts of chemical and petrographic data obtained for this study.

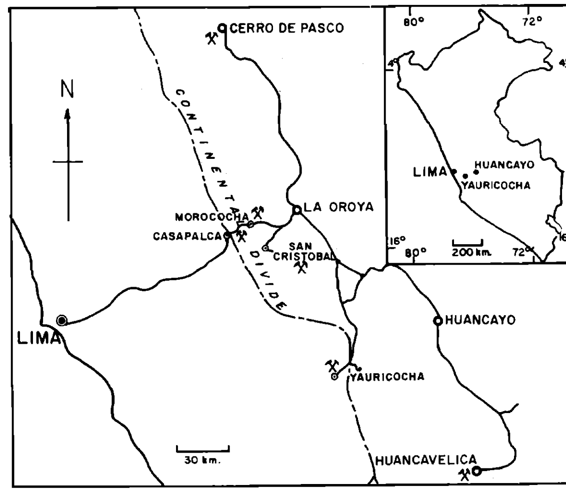

FIG. 1. Map showing the location of the Yauricocha district and certain other major mining districts in central Peru.

Geologic Setting and Associated Mineral Deposits

The geology and mineral deposits of the Yauricocha district have been described by Lacy (1949), Thompson (1960), Petersen (1965), and the Departamento de Geología de Cerro de Pasco Corporation (1970). The ore deposits of the district are spatially and genetically related to the Yauricocha stock, a composite intrusive body of granodioritic to quartz monzonitic composition (Fig. 2) that has been radiometrically dated at about 7.5 m.y. (Giletti and Day, 1968). The stock intrudes tightly folded beds of the Late Cretaceous Jumasha (Coniacian) and Celendín (Santonian) Formations and the overlying Casapalca Formation (latest Cretaceous and Paleocene?) (Mégard, 1978a; Noble et al., 1979).

The central part of the Yauricocha stock is affected by K silicate alteration. Abundant high-salinity and vapor-dominated inclusions are present, with the hypersaline inclusions commonly containing sylvite and carbonate daughters and in some cases one or more moderately birefringent minerals and chalcopyrite(?) in addition to halite. The K silicate-altered granodiorite contains 0.1 to 0.2 wt percent Cu and locally as much as 12 ppm Mo (Wright, 1966); veinlets in quartz-sericite-altered granodiorite exposed at the surface contain as much as 0.02 to 0.03 oz/ton Au and 0.5 to 1 oz/ton Ag.

The principal orebodies of the Yauricocha district, located near the western margin of the Yauricocha stock, are related spatially and genetically to the main body of the stock and to narrow fingers of granodiorite that presumably connect at depth to a western extension of the stock (Figs. 2 and 3). The orebodies consist of vertically elongate pipes composed largely of pyrite and other sulfide minerals that replace limestone of the Jumasha Formation. Skarn is developed adjacent to the stock but does not host appreciable amounts of ore. The pipes typically exhibit both vertical and radial zoning and there is a pronounced district zoning, with an inner zone of enargite (the principal copper mineral) giving way outward to an enargite-chalcopyrite-bornite zone, which in turn is succeeded to the west by zones characterized by sphalerite, galena, lead, and silver (Lacy, 1949; Thompson, 1970; Figs. 2 and 3).

Enargite veins that cut the Yauricocha stock (Fig. 2) are surrounded by granodiorite altered to a mixture of pyrophyllite, diaspore, alunite, and small amounts of anhydrite. Large quartz grains in these rocks also contain abundant secondary fluid inclusions, some which contain halite and as many as 14, and perhaps 16, other daughters, including two phases with extreme birefringence, probably carbonate, and a variety of other moderately birefringent minerals. Vapor-dominant inclusions accompany the daughter-bearing inclusions, and small amounts of liquid CO_2 have been tentatively identified in a few inclusions. Preliminary heating- and freezing-stage measurements (P. C. Gibson, pers. commun., 1988) reveal a strongly telescoped fluid inclusion assemblage, with one type of hypersaline inclusion having vapor homogenization temperatures in excess of 400°C and

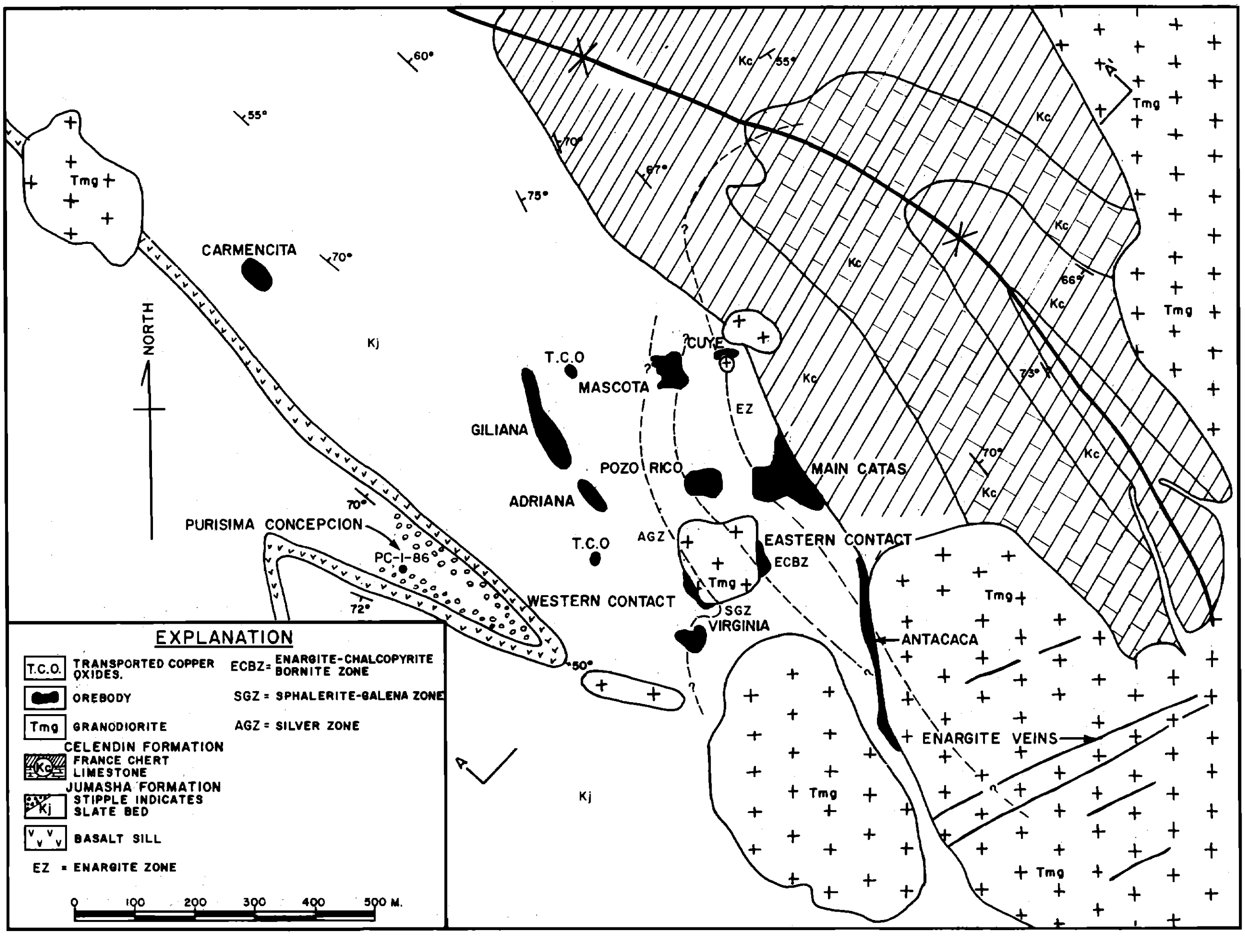

FIG. 2. Map showing the principal orebodies and zoning pattern of the Yauricocha district. Modified, with additions, from mapping by K. E. Siegrist (unpub.) and Thompson (1960). Line A-A' shows approximate zone across which the generalized cross section (Fig. 3) was drawn.

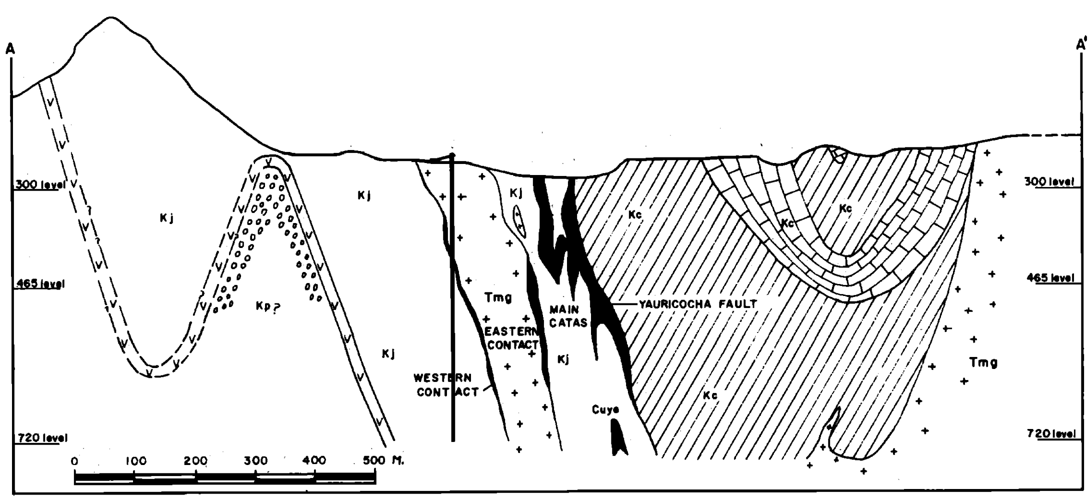

FIG. 3. Generalized cross section showing the geology and mineral deposits of the Yauricocha district. Modified, with additions, from Thompson (1960). See Figure 2 for symbols and abbreviations, Kp? possible Pariatambo Formation.

salinities of greater than 50 wt percent. These are accompanied by a variety of other inclusions having a very wide range of temperatures and salinities. Based on the alteration assemblage and the very complex cation and anion chemistry of the fluids indicated by the many daughters (cf. Metzger et al., 1977), the hydrothermal fluids responsible for the sulfide orebodies appear to have been relatively acid, oxidized, and rich in sulfur and probably CO_2. The alteration is an excellent example of advanced argillic alteration produced by hot, saline ascendant fluids which probably included an important magmatic component (cf. Bruha and Noble, 1983; Drexler and Noble, 1983).

The Yauricocha magmatic-hydrothermal system is interpreted as a high O_2 and S_2 fugacity system that was emplaced into carbonate strata rather than into dominantly quartzofeldspathic rock. The solutions were highly reactive and intensely attacked the carbonate wall rock, producing the pipe-shaped channels within which the rich sulfide orebodies were rapidly deposited (Lacy, 1949; Thompson, 1960). Base and precious metals were largely precipitated within several hundred meters of the stock rather than being carried upward along structures into an overlying genetically related volcanic pile as, for example, at Julcani (Petersen et al., 1977; Noble and Silberman, 1984).

Purísima Concepción Gold Deposit

The Purísima Concepción disseminated deposit (also known as Purísima Concepción Oeste), one of several bulk-mineable precious metal deposits in the Yauricocha district (Alvarez et al., 1989), is located outside of the sphalerite-galena and silver zones about 300 m from the outermost part of the enargite zone (Figs. 2 and 3). Although the orebody is in the early stages of exploration, about 200,000 metric tons at a grade of about 0.1 oz Au/metric ton have been proven. Column tests have yielded about 90 percent extraction of Au and 45 percent extraction of silver. Preliminary results of a pilot heap-leaching operation have been favorable.

Previous work

The first recorded study of the Purísima Concepción area was that of Iten (1952), who was principally interested in evaluating the potential for lead ores. Iten recognized that metal values were present in a subunit of impure limestone (the "slate bed") that forms the core of an anticline plunging about 50° to the southeast and were localized, particularly in crush and shear zones within the subunit. The slate bed is probably a subunit of the Jumasha Formation, but it may belong to the underlying Pariatambo Formation. Iten (1952) also obtained assays for Cu, Zn, Pb, Ag, and Au on 20 specimens that clearly showed elevated Au and Ag contents, high Au/Ag ratios, and low base metal contents.

On the basis of Iten's (1952) assays, CENTROMIN began a reevaluation of the Purísima Concepción zone in 1986. It was recognized that, in addition to the lithological control, the plunging anticline in conjunction with a sill of basalt and andesite and the shear zones provided structural control for the mineralizing solutions. The Departamento de Geología realized that the deposit had geologic and geochemical similarities to sedimentary rock-hosted deposits of the western United States.

Lithology and mineralogy

Carlin-type ores: The ores of the Purísima Concepción deposit are sedimentary rock-hosted, disseminated ores having physical characteristics typical of the Carlin-type subset of sedimentary rock-hosted, precious metal deposits of Bagby and Berger (1985). The geologic setting and the physical features of the deposit are inconsistent with a syngenetic or diagenetic origin such as that proposed for sedimentary rock-hosted, stratiform base metal deposits (e.g., Gustafson and Williams, 1981) or gold-bearing but base metal-poor massive sulfide deposits (e.g., Barnett et al., 1982).

The ores are largely unoxidized and consist mostly of decalcified and silicified impure carbonaceous limestone (cf. Armstrong et al., 1987), which in places is hydrothermally brecciated and/or sheared. Although some beds possess well-preserved thin bedding with certain laminae preferentially replaced by rhodochrosite (Fig. 4A), the deposit does not exhibit the textural and structural features, for example, sulfide banding, of sedimentary exhalative deposits. Oxidized zones containing abundant limonite also are locally present, but quartz veinlets and bodies of jasperoid are uncommon. It is not presently clear whether the oxidized ores are hypogene, supergene, or of mixed origin. The average grade for the deposit appears to be somewhat higher than the median (3.3 ppm) for the sedimentary rock-hosted deposits of the western United States (Bagby et al., 1986). About 5 percent of the ore consists of beds composed largely of soft, porous, fine-grained, decalcified but not silicified, and in part carbonaceous, material that commonly contains high pyrite contents (Fig. 4B). These rocks typically have higher gold contents than the silicified rocks.

Most mineralized rock is composed largely of quartz, with lesser amounts of very fine grained rhodochrosite, pyrite, calcite, and sericite ± barite and ± carbonaceous material and traces of detrital(?) tourmaline, sphene, and zircon. Preliminary X-ray diffraction study suggests that some or all of the sericite may be muscovite rather than illitic material. Quartz is typically very fine grained and apparently largely

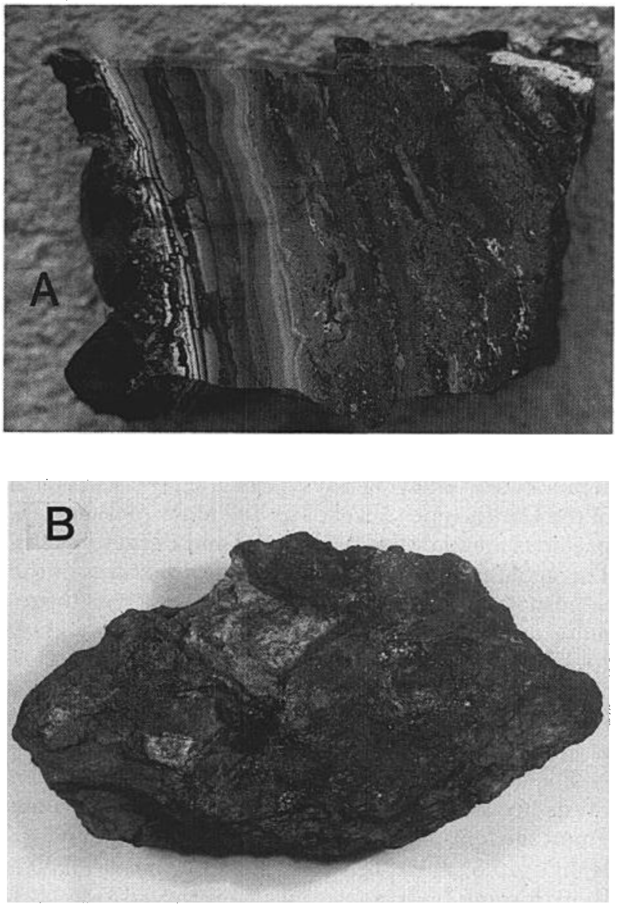

FIG. 4. Hand specimens of ore from the Purísima Concepción deposit. A. Finely bedded silicified rock containing light layers composed largely of rhodochrosite; specimen is 12 cm long. B. Porous decalcified rock; specimen is 10 cm long.

replaces carbonate removed by hydrothermal solutions. It is unclear to what extent carbonaceous material has been added to and/or redistributed within the deposit. Pyrite is the principal opaque mineral, occurring as small irregular grains, in part framboidal, disseminated within the rock. Inclusions of pyrrhotite have been identified in pyrite in one specimen. Hematite, limonite, and/or Mn oxides have been identified in several oxidized samples, and galena has been identified in several specimens. Grains of native gold 4 to 6 μm in diameter, associated preferentially with quartz and oxide minerals, have been observed in two of ten specimens of ore-grade drill core studied. A portion of the gold appears to occur along fractures and in other readily accessible sites.

Sulfide-quartz veinlets: In the southern part of Purísima Concepción the slate bed is cut by veins and veinlets composed largely of sulfide and sulfosalt minerals. A vein cut by drill hole PC-4-86 contains about 40 percent pyrite, 10 percent each of marcasite, arsenopyrite, and boulangerite, 2.5 percent each of pyrrhotite and galena, 1 percent chalcopyrite and altaite, and traces of sphalerite and native gold in a gangue composed largely of microfractured quartz. Plagionite also has been reported (Iten, 1952). The native gold, which occurs associated variously with the major minerals, in some cases fills fractures in quartz, pyrite, and boulangerite, suggesting late deposition and/or remobilization. It is unclear if these veins and veinlets, which do not comprise an economically important part of the deposit, were formed before, after, or contemporaneous with the disseminated ores.

Geochemistry

The following section summarizes the results of a large number of assays for the precious metals and a lesser number of analyses for the common base metals made during evaluation of Purísima Concepción plus a much smaller number of analyses for a wider range of minor elements obtained for geochemical characterization of the deposit. These results are compared with data available for the Carlin sedimentary rock-hosted deposit of the western United States (Radtke, 1985), for which the most comprehensive geochemical coverage in the public domain is available. It should be emphasized that the data base available for sedimentary rock-hosted, disseminated precious metal deposits suggests an appreciable range in trace element composition (e.g., Bagby and Berger, 1985). A more detailed discussion of the geochemistry of the Purísima deposit will be presented elsewhere.

Figure 5 summarizes analyses for Ag, Au, and a wide range of other minor elements obtained on 12 specimens of mostly unoxidized, decalcified, and silicified ore from diamond drill hole PC-1-86 in the northern part of Purísima Concepción and compares these data with average values reported for the Carlin deposit. (Although the Purísima data are not normally distributed, the arithmetic mean is used so as to provide a more direct comparison with those from Carlin.) Mean values for Bi and Cd at Purísima Concepción are 1.7 and about 0.5 ppm, respectively. Analyses for Cu, Pb, and Zn available for 33 specimens from other parts of the deposit confirm the very low contents of these elements. Concentrations of As, Cu, K, Mo, Pb, Sb, Se, and Zn are similar to those of the ores from the main pit at Carlin. Fluorine contents of a small suite of samples range from 0.06 to 0.46 wt percent, with a median of 1.10 wt percent. K/Rb ratios of about 500 are much higher than those of the metasomatized dacitic lavas that host enargite-tetrahedrite veins at Julcani (Scherkenbach and Noble, 1984).

Analyses for more than 150 specimens containing $\geq$0.01 oz/ton Au show that most of the mineralized rocks contain between about 3 and 6 wt percent Fe,

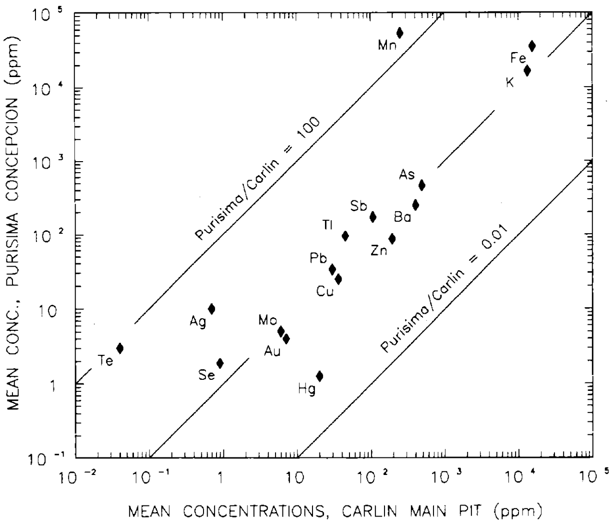

FIG. 5. Plot comparing mean concentrations of selected elements for the Purísima Concepción ore zone with mean values for the Carlin main pit (Radtke, 1985). The 12 Purísima Concepción specimens consist of silicified impure limestone from drill hole PC-1-86. The Te and Tl values for Purísima Concepción are the mean of duplicate analyses by Geochemical Services, Inc., and Bondar Clegg, Inc., and GSI and Barringer Laboratories, Inc., respectively. Other values are based on analyses by GSI, Hunter Mining Laboratory, Inc., and CENTROMIN-PERU.

several times the average of about 1.5 wt percent for normal ores from Carlin. The 12 core specimens of ore from PC-1-86 average 3.5 wt percent Fe. Manganese contents are more than 100 times higher than at Carlin (Fig. 5). The average for the 12 core samples, 5.3 wt percent, is supported by four analyses of other rocks ranging from 2.3 and 3.6 wt percent Mn. Based on XRD study of representative samples, the manganese is present mainly as fine-grained rhodochrosite. The high silica contents of the rocks are supported by routinely obtained insoluble residue values mostly between 60 and 80 wt percent.

The average Hg content of the core specimens is more than an order of magnitude lower than at Carlin and Ag, and to a lesser degree Ba, Se, and Tl, are higher. Tellurium ($\approx$3–4 ppm) averages about two orders of magnitude greater than the mean for Carlin, which is consistent with the presence of altaite. All the elevated concentrations, including those of Fe and Mn, clearly represent epigenetic addition of the elements.

The elements Ag, As, Hg, Mo, Sb, Te, and Tl show a positive correlation with Au in the small and spatially very restricted data set available from PC-1-86. The covariance is similar to that reported by Joralemon (1951), Wrucke and Armbrustmacher (1975) and Harris and Radtke (1976). Based on more than 200 fire assays, Au shows a general, but scattered, correlation with Ag, with samples with more than 0.1 oz/ton Au having an average Ag/Au ratio of about 2.5. Silver exhibits a strong positive correlation with Mn (Fig. 6). Manganese, most commonly as rhodonite, rhodochrosite, and/or alabandite, is typical of Ag-bearing veins in Peru, and the close relationship between Ag and Mn at Purísima suggests a close association of these elements during hydrothermal transport and deposition.

One bulk sample of soft, porous, and fine-grained black, barite-bearing material selected for chemical and metallurigical study contained about 2.7 oz/metric ton Au, 1.0 oz/metric ton Ag, 730 ppm As, 5.0 wt percent Ba, 10.4 wt percent Fe, 78 ppm Hg, 240 ppm Mn, 26 ppm Mo, 460 ppm Sb, 10 ppm Te, 0.23 wt percent noncarbonate carbon, and less than 10 ppm each of Cu and Pb. The thallium content is about 0.6 wt percent (based on replicate analyses by Geochemical Services, Inc., and Barringer Laboratories, Inc.); two similar rocks from other parts of the deposit have thallium contents of 2,600 and 3,800 ppm. Although the site of the thallium in not clear, these samples demonstrate that very high concentrations of thallium can develop in a disseminated form in fine-grained, homogeneous, and unfractured rock. The carbonaceous material is apparently active, because only 2 percent of the gold present was extracted during a standard cyanide roll test.

Discussion and Conclusions

Comparison with deposits in the western United States

The ores of the Purísima Concepción deposit are similar in general appearance, lithology, mineralogy and chemical composition to those of the sedimentary rock-hosted deposits of the western United States (e.g., Bagby and Berger, 1985; Radtke, 1985; Bakken

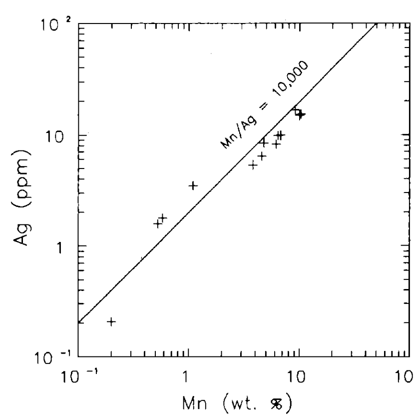

FIG. 6. Plot of Ag versus Mn for specimens from drill hole PC-1-86.

and Einaudi, 1986; Birak and Hawkins, 1985; Romberger, 1986; Johnson and Abbott, 1987; Percival et al., 1988). With an average Ag/Au ratio of about 2.5, the Purísima ores are similar to those of the Bald Mountain and Standard deposits, which provide a link between the typical sedimentary rock-hosted deposits of the western United States, in which gold greatly exceeds silver and silver-dominant systems such as Taylor (Bagby and Berger, 1985). Notable differences between Purísima Concepción and the U. S. deposits include the intimate association with pluton-related hydrothermal activity and large-scale base metal mineralization, and based largely on the data from Carlin, the higher concentrations of introduced Fe, and particularly, Mn and Te.

Model for the origin of the Purísima Concepción deposit

Although igneous rocks are exposed at or near most sedimentary rock-hosted deposits, the connection between igneous activity and mineralization is in many cases tenuous (e.g., Romberger, 1986; Percival et al., 1988). In contrast, at Yauricocha there exists a clear and compelling connection between magmatic activity and mineralization.

The low Ag to Au and base metal to precious metal ratios of the Purísima Concepción ores relative to the sulfide-rich orebodies of the district can reasonably be interpreted in terms of progressive differentiation of hydrothermal solutions. The enargite ores of the inner part of the zoning pattern contain Cu, with lesser amounts of Au, Ag, Zn, and Pb, and have an Ag/Au ratio of about 100, although enargite-rich specimens commonly have Ag/Au ratios of less than 20 (Table 1). Progressive removal of Cu, Zn, and Pb in the enargite, enargite-chalcopyrite-bornite, and sphalerite-galena zones could have largely depleted the solutions in base metals. Silver to gold ratios of 100 to 500 in the sphalerite-galena zone, and the presence of ores containing 10 or more oz/ton Ag and less than 0.02 oz/ton Au in the silver zone, suggest that the Ag/Au ratio of the solutions were progressively reduced as the ores were deposited. The relative abundance of silver in the Purísima Concepción deposit is consistent with the generally silver-dominant nature of mineral deposits in central Peru (e.g., C. E. Vidal and D. C. Noble, in prep.) and with the closeness of the deposit to the probable source of the hydrothermal solutions, which appear to have been saline and thus good carriers of Ag.

The elevated Te contents appear to reflect the close proximity to the Yauricocha stock (cf. Afifi et al., 1988). The stocks and associated volcanic rocks of the main part of the late Neogene magmatic arc are not alkalic, although alkalic rocks were erupted east of the volcanic front (Thompson, 1960; Noble et al., 1975; Noble and Bowman, 1976; Beckinsale et al., 1985). Although elevated Te contents are conventionally considered to be associated with alkalic rocks (e.g., Watterson et al., 1977; Bonham, 1988; Hastings,

TABLE 1. Average Compositions of Ores from the Enargite, Enargite-Chalcopyrite-Bornite, Sphalerite-Galena, and Silver Zones and the Purísima Concepción Orebody

	1	2	3	4	5	6	7
Au	0.35	0.038	0.049	0.061	0.030	0.020	0.12
Ag	5.9	3.4	4.3	6.8	4.6	16.5	0.30
Cu	16.4	2.4	1.7	1.2	0.68	0.4	0.0025
Pb		3.0	3.8	3.6	4.4	8.5	0.0035
Zn		4.3	6.5	7.5	7.9	8.1	0.009
As				0.43		0.16	0.046
Sb				0.05		0.05	0.017
Ag/Au	17	89	88	111	153	808	2.5
Ag/Cu*	1.2	4.9	8.7	19.4	23	141	411
Ag/Pb*		3.9	3.9	6.5	3.6	6.7	294
Au/Cu*	0.07	0.06	0.08	0.18	0.15	0.18	165
Pb/Cu		1.3	2.2	3.0	6.5	16	1.4
Zn/Cu		1.8	3.8	6.3	12	20	3.6
Pb/Zn		0.7	0.6	0.5	0.6	1.0	0.39
Sb/As	(very low)	(low)	(low)	0.12		0.33	0.38

Specimens: 1, mean of 12 bulk specimens of rich enargite ore, Main Catas orebody; 2, mean composition, Cuye orebody; 3, mean composition, Main Catas orebody; 4, mean composition, Eastern Contact orebody; 5, mean composition, Antacaca orebody; 6, mean composition, Western Contact orebody; 7, mean composition of 12 samples of Purísima Concepción ores cut by drill hole PC-1-86

Au and Ag in oz/ton, other elements in wt percent; data compiled from various sources; except as indicated values for columns 2 through 6 are calculated ore-block averages; Au, As, and Sb values for Eastern Contact and Western Contact orebodies are analyses of specially prepared composite samples; ratios are weight ratios, those marked with an asterisk have been multiplied by 1,000; the qualitative Sb/As ratios in columns 1, 2, and 3 are based on concentrate assay data

1988), it appears that a significant Te signature can develop in nonalkalic terranes (cf. Sillitoe, 1988).

Although we lack stable isotope data, the geologic relations, mineralogy, and chemistry of the deposit suggest that the initial fluids were largely of deep-seated origin which presumably mixed to greater or lesser degrees with meteoric fluids prior to and/or during differentiation. These evolved base metal-poor residual fluids were then structurally focused on a zone of relatively permeable and lithologically favorable strata. The local presence of pyrrhotite and arsenopyrite, the scarcity of arsenic sulfides (and the presumed presence of arsenian pyrite, arsenopyrite, and/or native arsenic; Rytuba, 1985), and the presence of carbonaceous material suggest that Au-Ag deposition took place under conditions of low S_2 and O_2 fugacities markedly different from those of the initial solutions.

The depth of formation was at least 400 m, because strongly glacially eroded remnants of Cretaceous strata reach elevations of greater than 5,000 m several kilometers north and west of the deposit. The coexisting hypersaline and vapor-dominated fluid inclusions in the Yauricocha stock suggest an even greater depth, which would be consistent with depths of 1,000 m or more inferred by some geologists from geologic and fluid inclusion data for certain of the sedimentary rock-hosted deposits in the western United States (Kuehn and Bodnar, 1984; Bonham, 1985; Schnorr et al., 1986).

Relation to contact metasomatic distal deposits

Sillitoe (1983, 1988) and Bonham (1985, p. 72) have discussed a class of bulk mineable contact metasomatic distal precious metal deposits "believed to be related to granitic intrusive rocks but which lie beyond the zone of well-developed skarn formation," as, for example, the gold deposits at Copper Canyon, Nevada (Blake et al., 1984; Theodore et al., 1986; Wotruba et al., 1986, 1988; see also Orris et al., 1987). Purísima Concepción would appear to blur the distinction between the "contact metasomatic distal deposit" and sediment-hosted disseminated precious-metal deposit categories (a possibility presciently recognized by Sillitoe, 1983), with the term applied reflecting the degree of association of the deposit with intrusive rocks, the nature of the host material, and the initial composition and degree of evolution of the hydrothermal solutions from which a given deposit was formed. Other examples of the close spatial and genetic relationship between sedimentary rock-hosted, disseminated ores, gold-bearing calc-silicate rocks, and high-level silicic intrusions are provided by the Bau district, Indonesia (Wolfenden, 1965; T. J. Percival et al., in prep.), and the Te-rich Star Pointer deposit (Smith et al., 1988), which is closely related to the Ruth (Nevada) porphyry system.

General implications for the origin of sedimentary rock-hosted deposits

Because of its clear association with a porphyry-skarn system and major polymetallic mineral deposits, Purísima Concepción has implications for the origin and evolution of the fluids from which certain of the sedimentary rock-hosted, precious metal deposits of the western United States and other regions were deposited. Ore solutions compositionally appropriate to form Au-, As-, Sb-, Tl- and Hg-rich and Ag- and base metal-poor sedimentary rock-hosted deposits can form from magmatically derived and/or closely related hydrothermal solutions by a process of hydrothermal differentiation (see, for example, Petersen et al., 1977; Hackbarth and Petersen, 1984). Derivation of metals and other components from metal-bearing carbonaceous or other sedimentary rocks (e.g., Dickson et al., 1979; Romberger, 1986) would not appear to be required for the formation of all sedimentary rock-hosted deposits. Admixture with meteoric waters could mask any high $\delta^{18}O$ fluids involved. The high Au/Ag ratios of many sedimentary rock-hosted deposits may largely reflect a combination of changes in the Au/Ag ratio produced during early base metal deposition and subsequent selective precipitation of low concentrations of silver in limestone (see below) and perhaps in other rock types that were not lithologically favorable for the deposition of gold. The presence of hypersaline fluid inclusions suggests a similar mechanism of formation for the Candelaria, Nevada, silver deposit (Foster et al., 1988). Boiling (e.g., Cole and Drummond, 1986) may not be required to explain the high Au/Ag ratios and very low base metal contents of many sedimentary rock-hosted deposits. The relative abundance of carbonate daughter minerals in the fluid inclusions observed in the potassium silicate-altered portion of the Yauricocha stock, and the local presence of pyrrhotite (cf. Rytuba, 1985), would appear consistent with the relatively high CO_2 contents of the solutions from which the Carlin and other sedimentary rock-hosted deposits in the western United States were deposited (Kuehn and Bodnar, 1984; Bagby and Berger, 1985; Schnorr et al., 1986).

Exploration for similar deposits in central and northern Peru

Prime exploration targets in the Western Cordillera include localities where thin-bedded, silty to sandy carbonaceous siltstone or carbonate rock of the Pariatambo and Jumasha Formations is cut or underlain by stocks or other Cenozoic intrusive bodies. However, the rich distal silver ores presently being produced at Colquijirca from the fresh-water Calera Limestone of Paleogene age (Vidal et al., 1984) and the range of lithologies known to host disseminated ores in the western United States together suggest that exploration should not be restricted to the Pariatambo and Jumasha Formations. Tellurium may be a useful addition to the standard geochemical exploration suite of Au, Ag, As, Sb, and Hg. Alteration and fluid inclusion features should allow the identification of productive stocks where they have been exposed by erosion. Plutons typically are exposed at high structural levels, and unexposed stocks may only be recognizable by geochemical or alteration features. Relatively pure limestone and other rocks near Purísima Concepción commonly have Ag, As, and perhaps to a lesser extent, Sb contents similar to those of the ores, and concentrations of these elements in lithologically unfavorable carbonate rock may prove helpful in locating hidden gold deposits, although presumably the fluids that deposited sedimentary rock-hosted deposits with very high Au/Ag ratios would not possess a silver halo. Such geochemical anomalies, which could guide the location of induced polarization and related surveys, also have the potential for locating base metal deposits. The Western Cordillera has been affected by several phases of complex compressional deformation during Cretaceous and Cenozoic time (Mégard, 1978b; Angeles, 1987) and the faults, fractures, and folds developed during these phases can be expected to have had as important an influence in the channeling of hydrothermal solutions there as they have in the western United States (e.g., Percival et al., 1988; Rota, 1988).

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