

GEOLOGICAL SETTING, DEPOSIT CHARACTERISTICS AND GENETIC MODELS, HUANCVELICA MERCURY DISTRICT, CENTRAL PERÚ

*Donald C. Noble **

ABSTRACT

The deposits of the Huancavelica district, the most important producers of mercury in the western hemisphere, may be interpreted as portions of an enormous geochemical anomaly situated at very high levels above one or more magmatic systems of general porphyry type. In this model, mercury was deposited along with Ag, As, Sb, Tl, mobilized hydrocarbons, and small amounts of base metals, including Bi, from highly differentiated hydrothermal solutions that previously had transported and deposited base metals. Gold contents of the mercury ores are extremely low. The enormous amounts of mercury deposited at high levels suggests that complementary lead, zinc, copper and precious metals at depth could comprise world-class ore bodies. Potential targets include vein, replacement, skarn and porphyry-type deposits.

An alternative interpretation involves leaching of metals and other components from basement rocks by a large, thermally-driven hydrothermal convection system and focussing of upwelling fluids within zones of structural permeability. Heat could have been provided by Miocene intrusives directly west of the belt of mercury deposits and anomalies. There is a lower probability of related polymetallic ores if the mercury deposits were formed by processes involving water-rock interaction. The existence at depth of Carlin- or Purísima-type sedimentary rock-hosted gold deposits is a possibility in either model, and their formation could explain the very low observed Au contents and very high Ag/Au ratios. Radiogenic and stable isotope data for ores, volcanic rocks and basement rocks may help to constrain genetic models.

INTRODUCTION

The Huancavelica district, central Perú, remains the largest producer of mercury in the western hemisphere. The famous Santa Bárbara mine, situated at an elevation of about 4,300 m above the city of Huancavelica, was by far the most important in the district. This paper presents some new geological and geochemical data and discusses possible origins of the mercury mineralization and the base-metal and silver potential of the district.

GEOLOGICAL SETTING

Deformed sedimentary rocks ranging from Paleozoic to early Miocene in age are exposed within and near the Huancavelica district (Narvaez & Guevara, 1968; McKee and Noble, 1982). These rocks were

tightly folded around north-south trending axes during the early Miocene Quechua I phase and earlier tectonic events (Yates et al., 1951; Fernández Concha et al., 1952; McKee and Noble, 1982; Mégard et al., 1984). Recent observations by the author in the northern part of the Huachocolpa district suggest that compressive deformation also affected the zone during the Quechua II phase about 10 Ma. The folded rocks are intruded and overlain with profound unconformity by younger lavas of dacitic composition. Although middle Miocene lavas are present, most of the volcanics within the district are of late Miocene age (McKee et al., 1986).

The Huancavelica district is located within the southern part of a major metallogenetic belt of middle to late Miocene (about 7 to 16 Ma) age that extends along the Western Cordillera from the southern part of central Perú to near the border with Ecuador (Noble et al., 1989). The district is surrounded by numerous

* Mackay School of Mines, University of Nevada, Reno, Reno, Nevada 89557, USA

mineral deposits and prospects and by a number of mercury occurrences. Important polymetallic and precious-metal mines of the Julcani, Huachocolpa and Castrovirreyna districts are located several tens of kilometers to the southeast, south and southwest (Fig. 1). Polymetallic veins and replacement bodies are exposed over a broad area in the Tinyaccla district to northwest of the Santa Bárbara mine (Fig. 1). Cinnabar, principally in stockwork veinlets developed in limestone, is found in the Manta area in the northwest part of the Tinyaccla district and at mina Torciopelo and the Cerro Chuñumayo area south of Santa Bárbara (Fig. 1).

MINERALIZATION

Almost all of the mercury produced in the Huancaavelica district was hosted by sandstone of the Gran Farallón member of the Goyllarisquizga Group of Early Cretaceous age. A small amount of ore was mined from deposits in Mesozoic limestone and dacite lava. At the Santa Bárbara mine, situated near the axis of a tight, faulted anticline, ore was mined from tabular to irregular ore bodies, mainly consisting of open-space fillings in Cretaceous sandstone and Neogene volcanic breccia, that extended for a vertical distance of about 300 m.

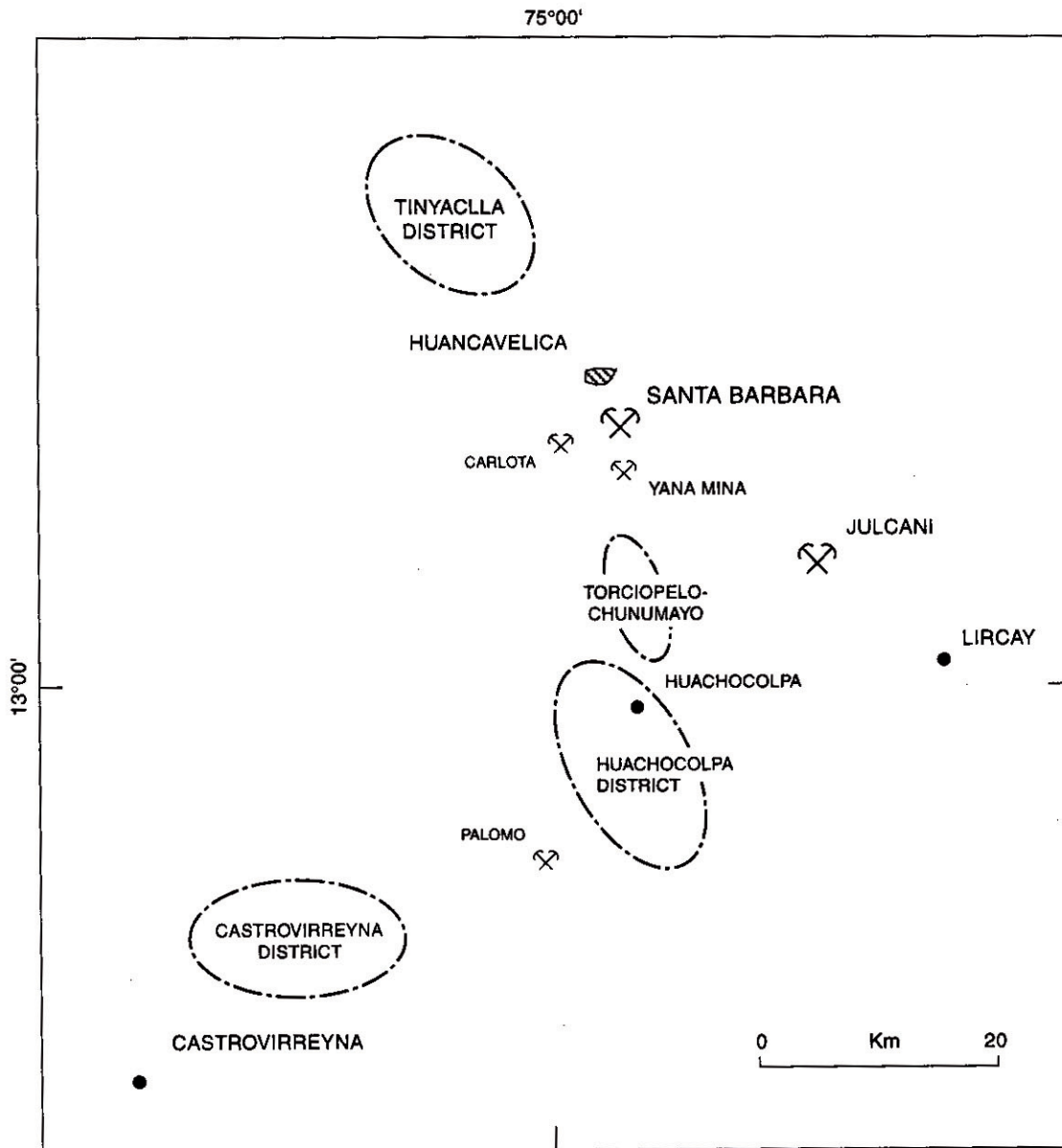


FIG. 1 GENERALIZED MAP SHOWING MINES AND OTHER FEATURES REFERRED TO IN TEXT.

It is clear that mineralization postdates the emplacement of the dacite lavas, which have been dated at about 7 to 7.5 Ma (McKee et al., 1986). An upper limit on the time of mineralization is given by an age of 3.3 ± 0.3 Ma on an unaltered dike that cuts altered and mineralized dacite and sandstone. However, because of the close relation inferred between magmatic and hydrothermal activity, mineralization probably took place very shortly after eruption of the dacite lavas. This age is within the period of from about 6 to 12 Ma over which polymetallic and precious-metal ores were deposited in the nearby Julcani, Huachocolpa and Castrovirreyna districts (Bruha et al., 1982; Noble and Silberman, 1984; E. H. McKee and D. C. Noble, unpub. data).

Both eruption of the late Miocene dacites and mineralization took place after major uplift and formation of the deep canyons that incise the high plateaus. The topographic relief of almost 1,000 m controlled the movement of the dacite lavas and almost certainly influenced the flow patterns of later high-level hydrothermal solutions.

Presently subeconomic polymetallic veins are common near, and locally within, the Huancavelica district. Pyrite and tetrahedrite are the most important minerals in the Ccollecemina and Farallón veins at the Santa Bárbara mine and at Yana Mina about four kilometers south of Santa Bárbara. These minerals are variously associated with galena, sphalerite, arsenopyrite, chalcopyrite, jamesonite, stibnite, quartz, barite and hydrocarbon and/or bituminous material (Yates et al., 1951; Fernández Concha et al., 1952).

The mercury ores of the Huancavelica district contain cinnabar and lesser amounts of native mercury closely associated with pyrite, realgar, orpiment, arsenopyrite and stibnite (Yates et al., 1951; Fernández Concha et al., 1952). Marcasite is present in some specimens, and may be the dominant iron sulfide phase in the district. Mercury appears to occur late in the paragenetic sequence. Base metals are present in generally low concentrations, but masses of galena 10 to 20 cm in diameter have been found in some places in the Santa Bárbara mine. The ores contain significant amounts of hydrocarbon and/or bituminous material. Mineralization was contemporaneous with and/or followed formation of innumerable narrow, curvilinear to irregular, commonly crosscutting fractures filled with small, angular fragments of quartz grains cemented by hydrothermal quartz. These fractures are similar to those observed in the sandstone-hosted gold deposits of northern Perú (Montoya et al., 1995). The origin of

these anastomosing structures is unclear, but the presence of fine-grained tuffisite dikes elsewhere in the district suggest that their formation at least in part may have involved the action of vapor or supercritical fluid under high pressure. Clay beds exposed within the zone of mineralization consist largely of kaolinite and quartz, although hydrothermal adularia has been recognized elsewhere within the district.

Geochemical analyses of several samples of low- to medium-grade ores from the Santa Bárbara mine suggest Cu, Mo and Bi contents, respectively, in the 5-15, 2-6, and 1-20 ppm range, with variable, but generally high (≈ 20) Pb/Cu ratios. Arsenic is in the range 100-400+ ppm and is generally more abundant than Sb; Se and Te are <1 ppm and Tl contents are 1-3 ppm. Silver is present in appreciable amounts, perhaps as tetrahedrite, and specimens can be readily found that contain several ounces Ag. Although silver is not cyanide soluble (Noble and Vidal, 1990), roasting liberates Ag, permitting cyanide recoveries of about 90 percent from re-ort tails. The ratio Hg/Ag varies widely, from <1 to >200 .

Even more remarkable are the extremely low gold concentrations of the mercury ores (Noble and Vidal, 1990). Gold contents are typically <1 ppb, with Ag/Au ratios of $>15,000$. Very limited and areally restricted sampling suggests that the entire district may be abnormally poor in gold. For example, several sulfide-rich samples from Yana Mina have highly elevated As, Sb, Bi, Hg and Tl and Ag/Au of from 2×10^4 to $\geq 10^6$. Samples with relatively low Ag/Au include an oxide-rich sample with Ag/Au of about 3,000 and a carbon-rich specimen with abundant base metals, As, Sb, Hg and Tl with Ag ≈ 40 ppm and Ag/Au ≈ 150 .

GENERATION OF METAL-BEARING HYDROTHERMAL SOLUTIONS

There are several potential methods for generating the hydrothermal solutions that formed the mineral deposits of the Huancavelica district.

MAGMATIC-HYDROTHERMAL ORIGIN

As discussed by Noble and Vidal (1990), the mercury ores of the Huancavelica district may be interpreted as having been deposited from distal solutions produced by hydrothermal differentiation (cf. Petersen et al., 1977; Petersen, 1990) from solutions of the same fundamental type that deposited the polymetallic and base metal-rich silver ores of the region. This interpre-

tation would appear to be supported by the new geochemical data and is consistent with the general relative abundance of mercury in various types of hydrothermal deposits (e.g., Soler, 1987) and with the fact that mercury is a highly mobile element that has been used as a pathfinder for various types of base- and precious-metal mineral deposits. Only where metals are precipitated rapidly and at considerable pressure, for example to form submarine massive sulfide deposits, are considerable amounts of mercury deposited with the common base metals.

Extending this line of reasoning, the mercury ores of the Huancavelica district can be interpreted as an enormous geochemical anomaly situated above a very large, unexposed complementary polymetallic (Cu-Zn-Pb-Ag) mineral system (Noble, 1994). Support for this interpretation is given by the fact that the distal or uppermost parts of certain polymetallic veins in this region, and elsewhere, contain appreciable amounts of mercury accompanied by arsenic and antimony. These include the outermost parts of certain of the veins in the Herminia zone of the Julcani district and the Carlota prospect west of the Santa Bárbara mine (Fig. 1). Specimens of rich Pb-Zn ore from narrow veins at Carlota are reported to contain about 4 to 7 oz/TM Ag, 0.02% Cu, 2 to 2.5 gm/TM Au, 2 to 4% Sb, 1 to 2% As and 20-80 ppm Hg.

The remarkable spatial and temporal association of Neogene polymetallic and precious-metal mineralization of the Western Cordillera with igneous activity (e.g., Petersen, 1965; Noble & Vidal, 1994), the common presence of hydrothermal breccias and tuffsite dikes and the local occurrence of hypersaline fluid inclusions (e.g., Shelnutz and Noble, 1985), and the conclusive demonstration by stable-isotope methods of the presence of magmatic fluids at the nearby Julcani district (Deen et al., 1994) all suggest that the polymetallic mineralization inferred to be present at depth would be genetically related to a large, and probably complex, magmatic system. Intrusives with porphyry texture are exposed about 15 km south of the Santa Bárbara mine (McKee et al., 1975) and at Luchito in the Huachocolpa district and Pb-Zn-Ag-Cu skarn deposits are related to intrusive bodies at Rifle in the southeastern part of the Tinyaclla district. The presence of bodies of hydrothermal breccia (Modelohuayco, Cabramachay, Ninabamba) with average diameters of about 0.5 km (Vidal & Cabos, 1984; Noble & Vidal, 1990) are consistent with a magmatic-hydrothermal origin, as are the moderately to highly elevated Bi contents and local Te concentrations of from 2 to >10 ppm in certain ores of the district. The Santa Bárbara ores

contain considerable amounts of mobilized carbonaceous material, suggesting the possibility of limestone replacement or skarn as well as vein-type deposits. Porphyry copper (\pm Mo, Au) deposits are also a possibility.

CONVECTIVE LEACHING OF BASEMENT ROCK

Is there some way that large amounts of mercury could have been deposited at high levels without deposition of complementary base metals at depth? Although there are several marked differences, notably the absence of gold and elevated silver, the presence of significant amounts of Bi and, in some rocks, Te, and the greater abundance of mercury, the geochemical signature of the Huancavelica ores is reminiscent of that of Carlin-type gold deposits (e.g., Hofstra et al., 1991). Another difference is that at least some Carlin-type deposits were formed at considerable depth (Bagby and Cline, 1991; Kuehn and Rose, 1995), in strong contrast to the very shallow level of mercury mineralization in the Huancavelica district. Models proposed for the formation of Carlin-type deposits range from magmatic-hydrothermal (e.g., Sillitoe and Bonham, 1990) to models in which gold and other metals are leached from enormous volumes of sedimentary rock by convecting meteoric, connate or other fluids driven by magmatic systems or regional heat flow and the resultant metal-bearing fluids focussed in structural or other zones of high permeability (Dickson et al., 1979; Radtke et al., 1980; Thorman et al., 1995).

The principal mercury deposits of the Huancavelica district are centered on a zone of tight folding and associated faulting. The N-S trending belt of mercury deposits and anomalies could reflect upward movement of hydrothermal fluids along such a structural zone, possibly when tectonic stresses had relaxed. The mercury belt lies along the eastern margin of a belt of major middle to late Miocene magmatic activity (Noble et al., 1975) that could have provided the necessary thermal input for convective fluid movement. Central Perú was under compressive stress intermittently during late Miocene time (Mégard et al., 1984), and a variant of the model would involve tectonic mobilization of deep, metal-bearing fluids. Alternatively, metal-bearing magmatic fluids could have episodically mixed to greater or lesser degrees with deeply circulating nonmagmatic waters that had interacted with wallrock. Hybrid models of this type could explain the varying amounts of Bi and Te in the Huancavelica ores and may be applicable to certain Carlin-type deposits, such as Betze and Meikle, that contain several ppm Te.

The modest amounts of gold found to date in the district provides perhaps a more serious objection to the hydrothermal leaching model than to the classic magmatic-hydrothermal mechanism. Hot circulating fluids containing modest amounts of reduced sulfur will efficiently leach gold from the rocks through which they pass. There is no reason to believe that the Mesozoic or Paleozoic rocks of the region, which are generally similar to those of similar age in the Great Basin of the western United States, should be devoid of gold. Such ready availability of gold would appear to require essentially total deposition of gold by fluid mixing, removal of reduced sulfur and/or other mechanism(s), while retaining sufficient Hg, Ag, As, Sb and other components to produce the known mineral deposits and geochemical anomalies. This could conceivably have been accomplished by the formation of sedimentary rock-hosted disseminated gold deposits of general Carlin type or, if a magmatic component is present, Purísima type (Alvarez & Noble, 1988) at depth.

SELECTING BETWEEN GENETIC MODELS

Is there a way, short of deep drilling, to evaluate the above models? One line of study involves characterization of the radiogenic and stable isotopic compositions of the rocks and ores. Base- and precious-metal mineral deposits related to magmatic activity typically are characterized by very small variations in $^{206}\text{Pb}/^{204}\text{Pb}$ and significant variations in $^{207}\text{Pb}/^{204}\text{Pb}$ and in some cases $^{208}\text{Pb}/^{204}\text{Pb}$, defining steep coherent arrays on standard lead evolution diagrams (e.g., Gunnesch et al., 1990; Tosdal et al., *this volume*). $^{206}\text{Pb}/^{204}\text{Pb}$ ratios show general, although not necessarily exact, relations to those of spatially and temporally associated igneous rocks. Ores containing lead from pre-Cenozoic rocks would be expected to have both a wider range in $^{206}\text{Pb}/^{204}\text{Pb}$ values and a greater difference in absolute isotopic composition from associated igneous rocks. Similar reasoning can be utilized for strontium isotopic composition, with strontium derived from carbonates or old clastic rocks having appreciably higher $^{87}\text{Sr}/^{86}\text{Sr}$ ratios than those of associated igneous rocks, which would probably be similar to the values of about 0.705 obtained for rocks of Julcani (D. C. Noble, unpub. data). However, the abundant hydrocarbon material in the mercury ores, implying that the solutions interacted with carbon-bearing rocks, suggests that even fluids of magmatic origin could have acquired significant amounts of wallrock Pb and Sr. Stable isotopic data can provide constraints on the source(s) of water and sulfur in the hydrothermal fluids (e.g., Landis & Rye, 1974).

EXPLORATION AND PRODUCTION CONSIDERATIONS

Petersen et al. (1990), noting the association of silver with mercury, pointed out the silver potential of the Huancavelica district, from which more than 50,000 metric tons of mercury were produced (Bailey et al., 1973; Rodriguez Hoyle, 1974). Many times this amount of mercury certainly was deposited in rocks of the district, and was variously lost to the surficial environment, eroded, or remains in undiscovered ore bodies and/or dispersed in subeconomic concentrations around the ore zones. Mercury is a relatively minor component of most ore fluids. If the magmatic-hydrothermal model is correct, the amounts of zinc, lead, copper and silver originally present in the initial, undifferentiated hydrothermal fluids of the Huancavelica district must be in the millions of metric tons. It would appear likely that complementary base- and precious-metal ore bodies would be centered approximately beneath or, considering the influence of the topography at the time of mineralization on fluid flow, slightly south of the most important mercury deposit of the district, that of the Santa Bárbara mine. Clearing and rehabilitating the Fernandini tunnel, which was driven in the early 20th century to access the lower part of the old mercury workings, would allow geochemical sampling and geological study, and would provide sites from which to carry out deep diamond drilling.

It would be relatively easy to explore for and mine ore bodies beneath the Santa Bárbara mine. The top of the mine is more than 650 meters above the valley of the Río Ichu near the town of Huancavelica. Because of the very rugged topography, a tunnel less than 3 km in length would extend beneath the Santa Bárbara mine. A major power line passes through Huancavelica, the administrative center of the province. The narrow-gauge Ferrocarril Huancayo-Huancavelica, which connects to a standard-gauge line at Huancayo, could readily be extended to a mill site and used to transport ore as well as concentrates.

ACKNOWLEDGMENTS

The thoughts presented in this paper are the outgrowth of work in central Perú and elsewhere at various times over the past several decades, done in part for Sociedad Minera «El Brocal», S.A. and Cía. de Minas Buenaventura, S.A.; we thank these companies for permission to publish. Some funding was provided by the U.S. National Science Foundation. Ing. Juan

Proaño of Brocal supported the most recent work at Huancavelica and Dr. Víctor Benavides contributed to bringing the present paper to print. Dr. César Vidal constructively reviewed the manuscript.

REFERENCES

- Alvarez A., A. & Noble, D. C. (1988)**
Sedimentary-rock-hosted disseminated precious-metal mineralization at Purfísima Concepción, Yauricocha district, central Peru. *Econ. Geol.*, 83: 1368-1378.
- Bagby, W. C. & Cline, J. S. (1991)**
Constraints on the pressure of formation of the Getchell gold deposit, Humboldt County, Nevada, as interpreted from secondary-fluid-inclusion data, in Raines, G. L., Lisle, R. E., Schafer, R. G. & Wilkinson, W. H., eds., *Geology and ore deposits of the Great Basin. Symp. Proc. Geol. Soc. Nevada*, 913-934.
- Bailey, E. H., Clark, A. L. & Smith, R. M. (1973)**
Mercury. *U.S. Geol. Survey Prof. Paper 820*: 401-414.
- Bruha, D. J., McKee, E. H. & Noble, D. C. (1982)**
Paragenetic, fluid-inclusion and geochronological study of the Teresita vein system, Huachocolpa district, Peru. *Geol. Soc. America Abs. with Programs*, 14: 152-153.
- Deen, J. A., Rye, R. O., Muñoz, J. L. & Drexler, J. W. (1994)**
The magmatic hydrothermal system at Julcani, Peru: Evidence from fluid inclusions and hydrogen and oxygen isotopes. *Econ. Geol.*, 89: 1924-1938.
- Dickson, F. W., Rye, R. O. & Radtke, A. S. (1979)**
The Carlin gold deposit as a product of rock water interactions, in Drew, J. D., ed. *Proc. Internat. Assoc. Genesis Ore Deposits (IAGOD): 5th Symp., II. Nevada Bur. Mines Geol. Rept.* 33: 101-108
- Fernández-Concha, J., Yates, R. G. & Kent, D. F. (1952)**
Geología del distrito mercurífero de Huancavelica, Perú. *Perú, Inst. Nac. Inv. Fomento Mineros*, 5: 56 p.
- Gunnesch, K. A. Baumann, A. & Gunnech, M. (1990)**
Lead isotope variations across the central Peruvian Andes. *Econ. Geol.*, 85: 1384-1401.
- Hofstra, A. H., Landis, G. P., Leventhal, J. S., Northrop, H. R., Rye, R. O., Doe, T. C., & Dahl, A. R. (1991)**
Genesis of sediment-hosted, disseminated gold deposits by fluid mixing and sulfidation of iron in the host rocks - Chemical reaction path modeling of ore depositional processes at Jerritt Canyon, Nevada, in Raines, G. L., Lisle, R. E., Schafer, R. G. & Wilkinson, W. H., eds., *Geology and ore deposits of the Great Basin, Symp. Proc. Geol. Soc. Nevada*, 235-237.
- Kuehn, C. A. & Rose, A. W. (1995)**
Carlin gold deposits, Nevada: Origin in a deep zone of mixing between normally pressured and overpressured fluids. *Econ. Geol.*, 90: 17-36.
- Landis, G. P. & Rye, R. O. (1974)**
Geologic, fluid inclusion and stable isotope studies of the Pasto Bueno tungsten-base metal ore deposit, northern Peru. *Econ. Geol.*, 69: 1025-1059.
- McKee, E. H. & Noble, D. C. (1982)**
Miocene volcanism and deformation in the Western Cordillera and high plateaus of south-central Peru. *Geol. Soc. America Bull.*, 93: 657-662.
- McKee, E. H., Noble, D. C., Petersen, U., Arenas F., M. & Benavides Q., A. (1975)**
Chronology of late Tertiary volcanism and mineralization, Huachocolpa district, central Peru. *Econ. Geol.*, 70: 388-390.
- McKee, E. H., Noble, D. C. & Vidal, C. (1986)**
Timing of volcanic and hydrothermal activity, Huancavelica mercury district, Peru. *Econ. Geol.*, 80: 489-492.
- Mégard, F., Noble, D. C., McKee, E. H. & Bellon, H. (1984)**
Multiple pulses of Neogene compressive deformation in the Ayacucho intermontane basin, Andes of Central Peru. *Geol. Soc. America Bull.*, 95: 1108-1117.
- Montoya, D. E., Noble, D. C., Eyzaguirre, V. R. & Desrosiers, D. F. (1995)**
Sandstone-hosted gold deposits: A new exploration target is recognized in Perú. *Eng. Mining Jour.*, 196, 6: 34-41.
- Narvaez, S. & Guevara, C. (1968)**
Mapa geológico de cuadrángulo de Huancavelica. *Serv. Geol. Min. Perú*, scale 1:100,000.
- Noble, D. C. (1994)**
Huancavelica revisited: The silver and base-metal potential at depth of the Santa Bárbara mine. *Unpub. Memo. to Alberto Benavides Q., Bernardo Alvarez Calderón and Raúl Benavides G.*, 2 p.
- Noble, D. C., Bowman, H. R., Hebert, A. J., Silberman, M. L., Heropoulos, C. E., Fabbri, B. P. & Hedge, C. E. (1975)**
Chemical and isotopic constraints on the origin of low-silica latite and andesite from the Andes of central Peru. *Geology*, 3: 501-504.
- Noble, D. C., Eyzaguirre, V. R. & McKee, E. H. (1989)**
Precious-metal mineralization in the Andes of Perú. in Ericksen, G. E., Cañas-Pinochet, M. T. & Reinemund, J. A., eds., *Geology of the Andes and its Relation to Hydrocarbon and Mineral Resources. Circum-Pacific Council for Energy and Min. Res. Earth Sci. Series*, 11: 207-212.

- Noble, D. C. & Silberman, M. L. (1984)**
Evolución volcánica y hidrotermal y cronología de K/Ar del Distrito Minero de Julcani. *Soc. Geol. del Perú, Vol. Jubilar LX Aniv.*, 5: 35 p.
- Noble, D. C. & Vidal, C. E. (1990)**
Association of silver with mercury, arsenic, antimony, and carbonaceous material at the Huancavelica district, Peru. *Econ. Geol.*, 85: 1645-1650.
- Noble, D. C. & Vidal, C. E. (1994)**
Gold in Perú. *SEG Newsletter*, 17.
- Petersen, U. (1965)**
Regional geology and major ore deposits of central Peru. *Econ. Geol.*, 30: 407-476.
- Petersen, U. (1990)**
Ore distribution, zoning, and exploration of hydrothermal ore deposits. *Econ. Geol.*, 85: 424-435.
- Petersen, U., Noble, D. C., Arenas F., M. & Goodell, P. C. (1977)**
Geology of the Julcani mining district, Peru. *Econ. Geol.*, 72: 931-949.
- Petersen, U., Vidal, C. E. & Noble, D. C. (1990)**
A special issue devoted to the mineral deposits of Peru, Preface. *Econ. Geol.*, 85: 1287-1295.
- Radtke, A. S., Rye, R. O. & Dickson, F. W., (1980)**
Geology and stable isotope studies of the Carlin gold deposit, Nevada. *Econ. Geol.* 75: 641-672.
- Rodriguez Hoyle, D., ed. (1974)**
Peru minero 1974. *Soc. Nac. Min. Pet.*, 301 p.
- Shelnutt, J. P. & Noble, D. C. (1985)**
Pre-mineral radial dikes of tourmalinized fluidization breccia, Julcani district, Peru. *Econ. Geol.*, 80: 1622-1632.
- Sillitoe, R. L. & Bonham, H. F. (1990)**
Sediment-hosted gold deposits; distal products of magmatic-hydrothermal systems. *Geology*, 18 : 157-160.
- Soler, P. (1987)**
Variations des teneurs en éléments mineurs (Cd, In, Ge, Ga, Ag, Bi, Se, Hg, Sn) des minerais de Pb-Zn de la province polymétallique des Andes du Pérou Central. *Min. Deposita*, 22: 135-143.
- Thorman, C. H., Brooks, W. E., Snee, L. W., Hofstra, A. H., Christensen, O. D. & Wilton, D. T. (1995)**
Eocene-Oligocene model for Carlin-type deposits in northern Nevada. *Prog. with Abs., Geology and Ore Deposits of the American Cordillera, Geol. Soc. Nevada and U.S. Geol. Survey*, A75.
- Tosdal, R. M., Gibson, P. C. & Noble, D. C. (1996)**
Metal sources for Miocene precious-metal veins of the Orcopampa, Shila, Cailloma and Arcata mining districts, southern Perú. *This volume*.
- Vidal, C. & Cabos, R. (1984)**
Estudio geológico y campaña piloto de geoquímica en el distrito minero Santa Bárbara, Huancavelica. *Unpub. Rept., Buenaventura Ingenieros, S.A. for Sociedad Minera «El Brocal» S.A.*, 59 p.
- Yates, R. G., Kent, D. F. & Fernández-Concha, J. (1951)**
Geology of the Huancavelica quicksilver district, Peru. *U.S. Geol. Survey Bull.* 975-A, 45 p.