Pueblo Viejo and highly sulfidized gold and copper deposits of the Caribbean Basin

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Abstract

The gold endowment of the Caribbean Basin currently totals 80 million ounces (Moz). Fully half of these ounces are located in the Pueblo Viejo district of the Dominican Republic where six highly sulfidized orebodies have produced over 5 Moz of gold from weathered and oxidized protore. The remaining sulfide resource is 35 Moz at a 1 g/t gold cutoff grade. Pueblo Viejo formed in a volcanic dome field within a chemically-primitive, intraoceanic island arc of Cretaceous age. Host rocks include thinly-bedded, carbonaceous, epiclastic sedimentary rocks and volcanic domes of basaltic andesite to dacite composition. Pueblo Viejo has been referred to as a hot spring deposit, as a massive sulfide deposit, as a high sulfidation deposit, and even as a Carlin-type deposit. In this paper, I refer to Pueblo Viejo as highly sulfidized, emphasizing the high sulfide sulfur content (8%) of the protore and the likelihood that sulfidation reactions were responsible for mineralization. Similar highly sulfidized gold deposits are found around the Caribbean Basin. Some occur in fragments of the same Cretaceous intraoceanic island arc that hosts Pueblo Viejo. The Cerro Quema gold deposit, located on the Azuero Peninsula of Panama, is scheduled to go into production in 2006.

Introduction

The geology of the Pueblo Viejo district has been described by Kesler et al. (1981); Cumming et al. (1982); Muntean et al. (1990); Kesler et al. (1991); Russell and Kesler (1991); Kettler et al. (1992); Vennemann et al. (1993); Nelson (2001); and Kesler et al. (2003). Readers are referred to these papers for an in-depth discussion of the regional and the local geologic setting, hydrothermal alteration, gold mineralization, and isotope studies.

Mining at Pueblo Viejo mine began in 1975 and continued until 1999 when falling recovery related to depletion of the oxide reserve resulted in closure of the mine and carbon-in-leach (CIL) mill. Ruiz (1997) reports total production through 1996 of 5,335,918 ounces gold and 24,422,758 ounces silver.

Table 1 provides information on the size of the sulfide gold resource at a number of different cutoff grades. Pueblo Viejo still contains close to 35 million ounces (1000 tonnes) at a cutoff grade of 1.0 g/t. Much of this resource (14.5 million ounces) is in the Moore deposit.

Table 1

Pueblo Viejo District Sulfide Resource*

Deposit size (Mt)	Average gold grade in g/t	Average silver grade in g/t	Contained gold in tonnes (Moz)	Cutoff gold grade in g/t
544.34	1.98	11.76	1078 (34.65)	1.0
321.42	2.50	14.47	804 (25.83)	1.5
188.92	3.06	17.63	578 (18.59)	2.0
69.81	4.17	25.13	291 (9.36)	3.0
28.30	5.29	33.98	150 (4.81)	4.0
12.99	6.31	41.94	82 (2.63)	5.0

*condensed from Ruiz (1997)

Most of the gold at Pueblo Viejo occurs as electrum along growth zones in pyrite (Kesler et al., 1985; Muntean et al., 1990). Gold also occurs as inclusions of native gold and calaverite in disseminated pyrite (Muntean et al., 1990; Kettler et al., 1992). Metallurgical challenges include encapsulation of gold (by sulfide minerals and by quartz), carbon competition for gold from the carbon content of the host rocks, high arsenic content, and local copper and/or zinc enrichment (which increases cyanide consumption).

District Geology

The Pueblo Viejo district occurs within the Los Ranchos Formation (Fig. 1), part of an Early Cretaceous intraoceanic island arc. Host rocks include basaltic andesite, andesite and dacite (Table 2). These rock units were spilitized by their interaction with seawater and were hydrothermally altered during gold mineralization. Figure 1 also shows the location of surrounding base and precious metal prospects.

Ore deposits in the Pueblo Viejo district are spatially associated with a series of volcanic domes (Nelson, 2001). These domes are shown on Figure 2 and extend well outside of the map area. Gold prospects elsewhere in the Los Ranchos Formation (e.g. Managua, Guaimarote) are also associated with volcanic domes.

Northwest-striking thrust faults are common in the Moore deposit and throughout the Pueblo Viejo district (Figs. 1 and 2). Both volcanic and sedimentary rocks exhibit penetrative cleavage and are locally recrystallized to phyllite. Bowin (1966) proposed that metamorphism occurred during the Eocene. Draper et al. (1996) argue that metamorphic recrystallization and cleavage development was a Cretaceous event but that related thrust faults were reactivated during the Tertiary. Metamorphism occurred during Aptian-Albian obduction of oceanic crust when a northwest-facing arc replaced an Early Cretaceous southwest-facing arc.

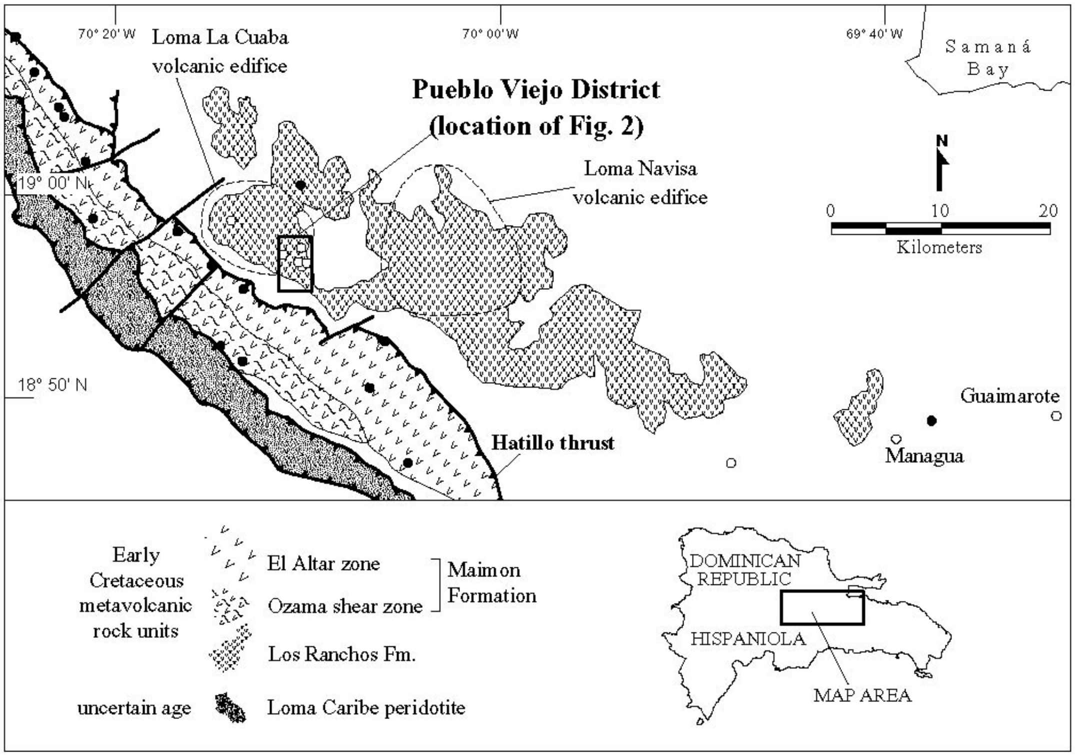

Fig. 1. Location map of the Pueblo Viejo district and nearby base and precious metal prospects. The regional distribution of the Los Ranchos Formation is from Mann et al. (1991). The Ozama shear zone, the El Altar zone and bounding thrust faults are from Draper et al. (1996). The thrust-faulted southwestern boundary of the peridotite is from Toloczyki and Ramirez (1991).

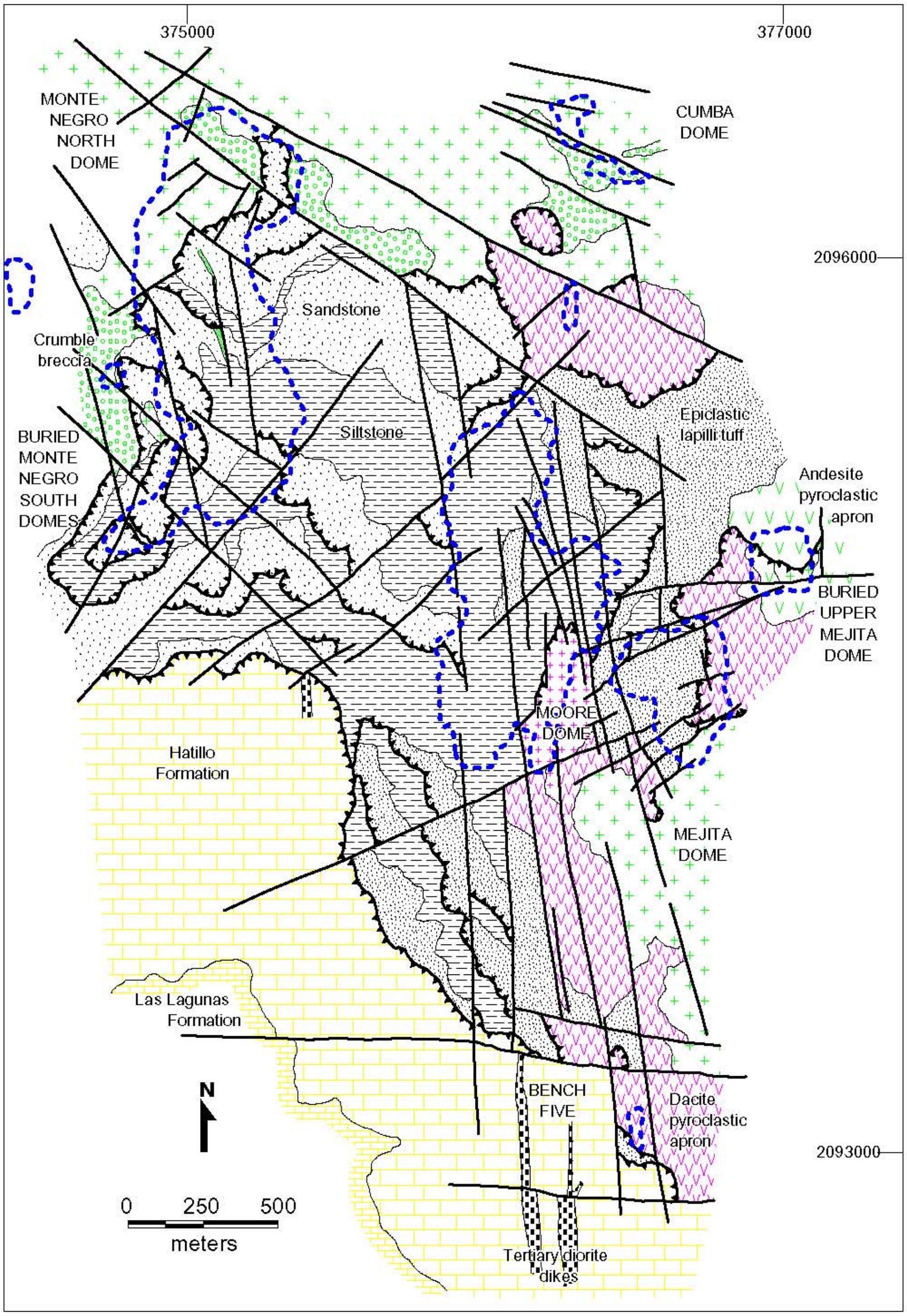

Fig. 2. Geologic map of the Pueblo Viejo district showing the location of volcanic domes and pit outlines (heavy dotted line). See Table 2 for an explanation of rock units. Strike and dip symbols are omitted for clarity; sedimentary units are subhorizontal. See Figure 3 for a detailed geologic map of the Moore deposit.

Moore Dacite Porphyry Dome and Vent Breccia

Geologic mapping by the author (Fig. 3) in the Moore gold deposit shows a dacite porphyry dome intruding epiclastic carbonaceous sedimentary rocks. Kesler et al. (1981) described this unit as quartz porphyry agglomerate. Muntean et al. (1990) and Russell and Kesler (1991) described this unit as a lapilli tuff.

The margin of the dacite porphyry dome is steeply dipping and a baked contact metamorphic aureole can be observed in the surrounding epiclastic carbonaceous sedimentary rocks. Carbonaceous siltstones dip steeply away from the dome margin suggesting that surrounding rock units were tilted as the dacite porphyry dome shouldered its way through the epiclastic section. Blocks (xenoliths) of carbonaceous siltstone can be observed within the dacite porphyry, especially near its contact with surrounding sedimentary rocks. All in all, evidence is strong that the dacite porphyry has an intrusive origin.

Quartz eyes are a distinctive characteristic of the dacite porphyry. The presence of bipyramidal outlines and resorbed borders indicate that most of the quartz eyes are phenocrysts. Although the dacite porphyry is generally massive, local flow banding and spherulitic devitrification can be observed.

The margin of the dacite porphyry dome is marked by an unsorted, unbedded breccia that contains abundant lapilli-size fragments of dacite porphyry, andesite, and epiclastic carbonaceous siltstone. Hydrothermally altered fragments and quartz eyes are common. The breccia is irregularly exposed around the margin of the dacite porphyry dome and is interpreted here as a hydrovolcanic vent breccia. A pyroclastic apron, consisting of bedded lithic lapilli tuff breccia of dacite porphyry compostion, is exposed at the top of the Mejita pit, 300 meters east of the Moore dacite porphyry.

Inclined core holes drilled in 1997 reveal a funnel-shaped contact (Fig. 3) with surrounding epiclastic carbonaceous sedimentary rocks, consistent with dacite porphyry intrusion. Elsewhere, the contact between dacite porphyry and carbonaceous siltstone is nearly horizontal (Kesler et al., 1981). There has also been offset of the dome by shallow dipping thrust faults. Drilling by Placer Dome in 2002 confirms the presence of an intrusive root to the dacite porphyry dome.

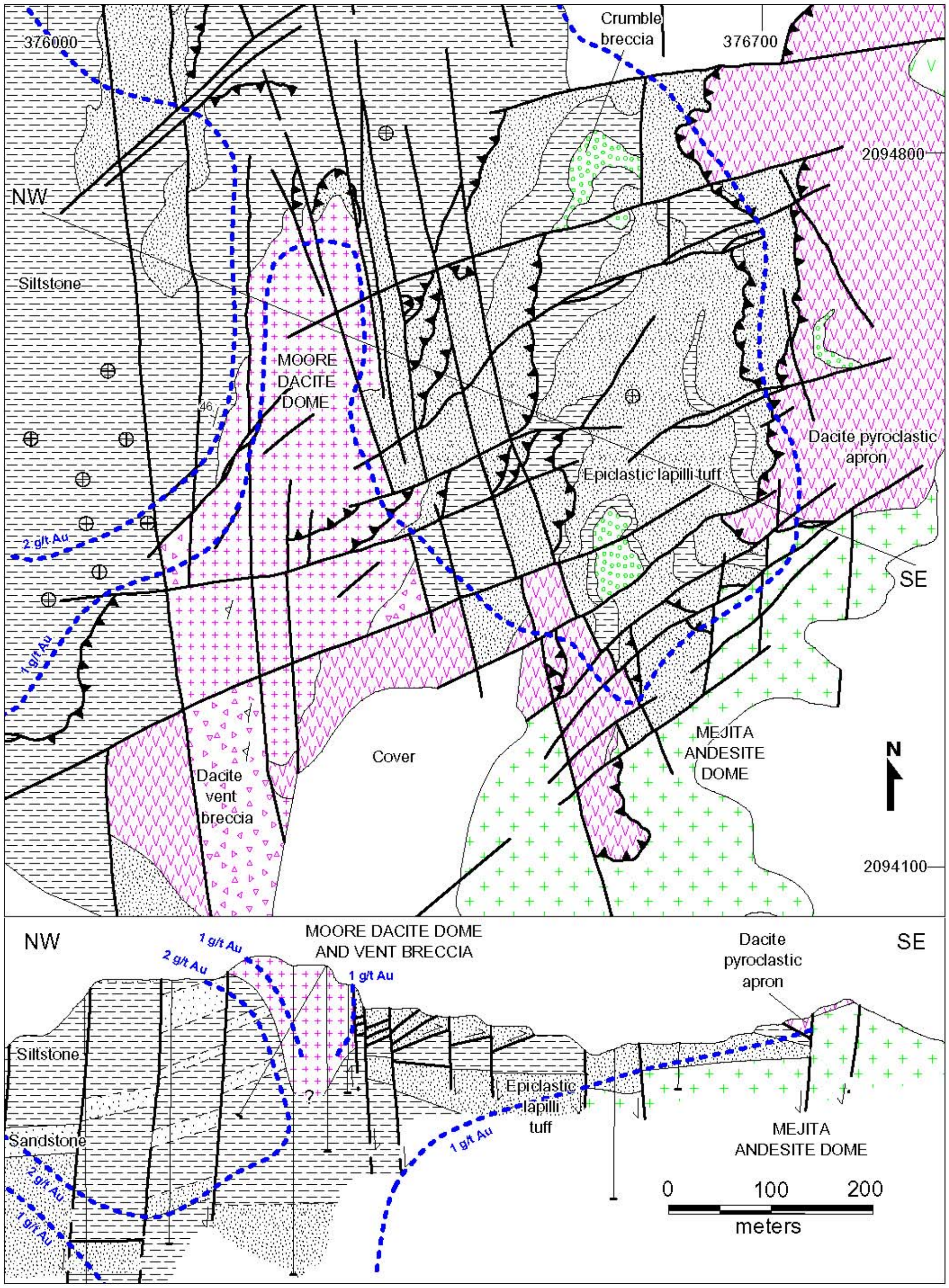

Fig. 3. Geologic map and cross section of the Moore deposit, Pueblo Viejo district. There is no vertical exaggeration. Rock units too thin to be shown clearly on the section are omitted. Drill hole locations are plotted on the section. Grade contours are shown as heavy dotted lines.

Epiclastic Carbonaceous Sedimentary Hostrocks

Thinly bedded, epiclastic, carbonaceous siltstones and sandstones surround the dacite porphyry dome in the Moore deposit. Bedding, clearly visible away from the intrusive contact, is obscured in the baked zone where siltstones exhibit a hardened, pale brown appearance. Carbonaceous sedimentary rocks are recrystallized but not silicified along the intrusive margin resulting in a lighter color that is easily confused with the dacite porphyry.

Epiclastic carbonaceous sedimentary rocks near the dacite porphyry dome contain detrital quartz eyes and lenticular debris flows of dacite porphyry. Detrital quartz eyes can be found in the epiclastic section up to 200 meters from the dome margin. These observations are not inconsistent with dacite porphyry intrusion. Early phases of the dacite porphyry dome must have been exposed to erosion while epiclastic carbonaceous sediments accumulated and dacite porphyry intrusion continued. Hydrothermal alteration was also ongoing at the time, as indicated by the presence of altered and mineralized clasts in both the dacite porphyry vent breccia and the epiclastic sedimentary section.

Epiclastic carbonaceous sediments in the Moore deposit contain terrestrial plant fossils and exhibit well-developed soft sediment deformation and dewatering structures. Sedimentary dikes and diapirs are common. These features indicate that the environment of deposition was subaqueous and that water depths were shallow. Pyroclastic “bombs” provide evidence for nearby explosive volcanic activity during sedimentation. Given the evidence cited above, volcanic dome emplacement, epiclastic sedimentation, hydrothermal alteration, and gold mineralization must have been coeval events and must have occurred in a shallow subaqueous setting.

Gold Deposition

Gold mineralization in the Moore deposit follows north-south striking, normal faults that offset both the epiclastic sedimentary section and the margin of the dacite porphyry dome. Thick envelopes (as much as 30 m across) of goldbearing disseminated sulfide minerals surround the high-angle feeder faults. Veins contain quartz, pyrite and variable amounts of sphalerite, galena and enargite. Gold is present as native gold, electrum and as calaverite (gold telluride).

Gold mineralization is associated with widespread secondary quartz and pyrophyllite, an advanced argillic assemblage according to Corbett and Leach (1998). Muntean et al. (1990) report that hydrothermal fluid temperatures locally exceeded 285° C based on the presence of pyrophyllite and coexisting diaspore. These temperatures are consistent with those reported by Vennemann et al. (1993) based on sulfur isotope geothermometry (over 250° C). Fluid-inclusion temperatures reported by Kesler et al. (1981) range from 135° to 195° C.

Sulfur isotope studies have drifted with time away from a marine origin (Kesler et al., 1981) towards a magmatic origin (Vennemann et al., 1993). Kesler et al. (1981) suggest that base and precious metals were leached from the Los Ranchos Formation by circulating hydrothermal fluids. Vennemann et al. (1993) suggest that gold in the Pueblo Viejo district was introduced during condensation of magmatic vapor. Circulating hydrothermal fluids may have leached gold from the glassy portion of an accumulating volcanic pile. Condensation of volcanic gas may have also provided sulfur if not gold to solution. In either case, precipitation appears to have been controlled by sulfidation reactions (Kettler et al., 1992) in which gold, carried in solution as a bisulfide complex, reacts with iron present in the host rocks to precipitate pyrite and gold.

$$FeCO_3 + \frac{1}{4}O_2 + Au(HS)^- + H^+ = FeS_2 + CO_2 + 1\frac{1}{2}H_2O + Au$$

Similar reactions govern gold precipitation in a wide variety of epithermal gold deposits (e.g. Carlin-type deposits).

Conclusions

Geologic mapping (Nelson, 2001) in the Pueblo Viejo district indicates that gold mineralization was an Early Cretaceous event, coeval with the emplacement of volcanic domes that vary in composition from andesite to dacite. This geologic setting differs from the maar basin proposed by Sillitoe and Bonham (1984) and later adopted by Russell and Kesler (1991). Maar eruptions certainly occurred in the Pueblo Viejo district but the large crater (2 km diameter) previously proposed is, instead, simply an embayment along the margin of a Cretaceous island arc. The contrasting models are compared in Figure 4.

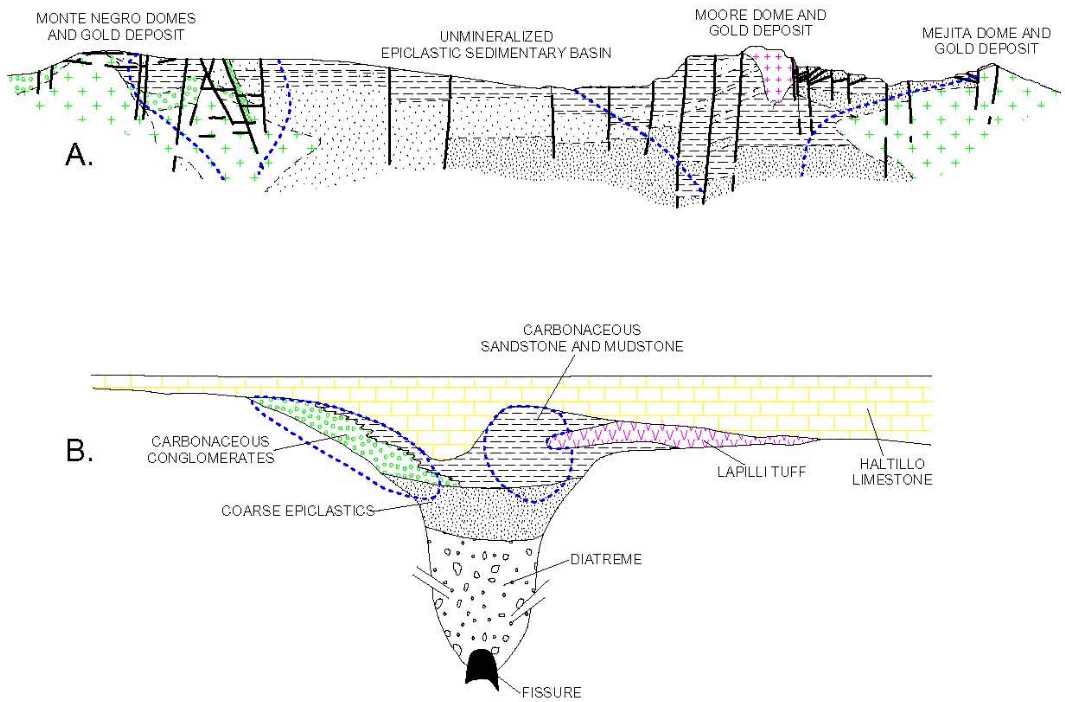

Fig. 4. Contrasting geologic models for the Pueblo Viejo district. A. Schematic cross section looking north and showing volcanic domes (this paper). B. Schematic maar-diatreme model from Russell and Kesler (1991, Fig. 5C). Ore deposits are shown as heavy dotted lines.

The volcanic dome field at Pueblo Viejo and a regional magnetic high beneath the adjacent Loma La Cuaba volcanic edifice provides strong evidence for an underlying magma chamber. However, there is as yet no evidence for an underlying porphyry copper deposit. Pueblo Viejo, instead, appears to be a shallow subaqueous hot spring deposit, transitional between the subaerial hot spring environment encountered in many modern geothermal fields and the subaqueous hot spring environment that is responsible for the deposition of volcanogenic massive sulfides.

Around the Caribbean Basin, approximately forty highly sulfidized gold occurrences have been recognized to date. Cerro Quema, on the Azuero Peninsula of Panama, is the first to be scheduled for production.

Acknowledgements

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References Cited

Bowin, C.O., 1966, Geology of the Central Dominican Republic (a case history of part of an island arc): *in* Hess, H.H., ed., Caribbean Geological Investigations: Geological Society of America Memoir 98, p. 11-84.

Corbett, G.J. and Leach, T.M., 1998, Southwest Pacific Rim Gold-Copper Systems – Structure, Alteration, and Mineralization: Soc. Economic Geology Special Publication No. 6, 237 p.

Cumming, G.L., Kesler, S.E., and Krstic, D., 1982, Source of lead in sulfide ore at the Pueblo Viejo gold-silver oxide deposit, Dominican Republic: Economic Geology, v. 77, p. 1939-1941.

Draper, G., Gutierrez, G. and Lewis, J.F., 1996, Thrust emplacement of the Hispaniola peridotite belt - Orogenic expression of the mid-Cretaceous Caribbean arc polarity reversal?: Geology, v. 24, p 1143-1146.

Kesler, S.E., Russell, N., Seaward, M., Rivera, J., McCurdy, K., Cumming, G.L. and Sutter, J.F., 1981, Geology and geochemistry of sulfide mineralization underlying the Pueblo Viejo gold-silver oxide deposit, Dominican Republic: Economic Geology, v. 76, p. 1096-1117.

Kesler, S.E., Kettler, R.M., Meyers, P.A., Dunham, K.W., Russell, N., Seaward, M., and McCurdy, K., 1985, Relation between organic material and precious metal mineralization in the Moore orebody, Pueblo Viejo, Dominican Republic: Denver Regional Exploration Geologists Society, Special Volume 2, p. 105-110.

Kesler, S.E., Russell, N., Polanco, J., McCurdy, K. and Cumming, G.L., 1991, Geology and geochemistry of the early Cretaceous Los Ranchos Formation, central Dominican Republic: *in* Mann, P., Draper, G. and Lewis, J.F., eds., Geologic and tectonic development of the North America-Caribbean plate boundary in Hispaniola: Geological Society of America Special Paper 262, p. 187-201.

Kesler, S.E., Russell, N., and McCurdy, K., 2003, Trace-metal content of the Pueblo Viejo precious-metal deposits and their relation to other high sulfidation epithermal systems: Mineral. Deposita v. 38, p. 668-682.

Kettler, R.M., Rye, R.O., Kesler, S.E., Meyers, P.A., Polanco, J. and Russell. N., 1992, Gold deposition by sulfidation of ferrous Fe in the lacustrine sediments of the Pueblo Viejo district (Dominican Republic) - The effect of Fe-C-S diagenesis on later hydrothermal mineralization in a maar-diatreme complex: Chemical Geology, v. 99, p. 29-50.

Mann. P., Draper, G. and Lewis, J.F., 1991, An overview of the geologic and tectonic development of Hispaniola: *in* Mann, P., Draper, G. and Lewis, J.F., eds., Geologic and tectonic development of the North America-Caribbean plate boundary in Hispaniola: Geological Society of America Special Paper 262, p. 1-28.

Muntean, J.L., Kesler, S.E., Russell, N. and Polanco, J., 1990, Evolution of the Monte Negro acid sulfate Au-Ag deposit, Pueblo Viejo, Dominican Republic: important factors in grade development: Economic Geology, v. 85, p. 1738-1758.

Nelson, C.E., 2001, Volcanic domes and gold mineralization in the Pueblo Viejo District, Dominican Republic: Mineralium Deposita, vol. 35, p. 511-525.

Ruiz, J.A., 1997, Partial privitization of Rosario Dominicana: Mining, Environment and Nature – Possibilities and Compatibilities (in Spanish): A seminar sponsored by CEDEMPRESA and the law firm of Russin, Vecchi, and Heredia Bonetti, Santo Domingo, March 7, 1997.

Russell, N. and Kesler, S.E., 1991, Geology of the maar-diatreme complex hosting precious metal mineralization at Pueblo Viejo, Dominican Republic: *in* Mann, P., Draper, G. and Lewis, J.F., eds., Geologic and tectonic development of the North America-Caribbean plate boundary in Hispaniola: Geological Society of America Special Paper 262, p. 203-215.

Sillitoe, R.H. and Bonham, H.F. Jr, 1984, Volcanic landforms and ore deposits: Economic Geology, v. 79, p 1286-1298.

Toloczyki, M. and Ramirez, I., 1991, Geologic map of the Dominican Republic 1:250,000 (in Spanish): Ministry of Industry and Commerce, Department of Mining, Geographic Institute of the Univerisity of Santo Domingo.

Vennemann, T.W., Muntean, J.L., Kesler, S.E., O'Neil, J.R., Valley, J.W. and Russell, N., 1993, Stable isotope evidence for magmatic fluids in the Pueblo Viejo epithermal acid sulfate Au-Ag deposit, Dominican Republic: Economic Geology, v. 88, p 55-71.