©2007 Society of Economic Geologists, Inc.
Economic Geology, v. 102, pp. 755–760

DISCUSSION

PUEBLO VIEJO HIGH-SULFIDATION EPITHERMAL GOLD-SILVER DEPOSIT, DOMINICAN REPUBLIC: A NEW MODEL OF FORMATION BENEATH BARREN LIMESTONE COVER—A DISCUSSION

John Muntean,†
Nevada Bureau of Mines and Geology, MS 178, University of Nevada Reno, Reno, Nevada 89557-0178

Gregory Hall,
Omaroo Pty. Ltd., P.O. Box 591, West Perth, Western Australia 6872, Australia

Stephen Kesler,
Department of Geological Sciences, University of Michigan, Ann Arbor, Michigan 48109

Andreas Mueller,
12a Belgrave Street, Maylands, Western Australia 6051, Australia

Darren O'Brien,
Terrane Metals Corp., 1500-999 West Hastings Street, Vancouver, British Columbia V6C 2W2, Canada

and Norman Russell
Apto. 710-3100, Santo Domingo de Heredia, Costa Rica

Sir: Sillitoe et al. (2006) suggest that the Pueblo Viejo Au-Ag deposit is younger than its Early Cretaceous Los Ranchos Formation host rocks. This interpretation contrasts with our earlier observations that the mineralization is coeval with the Los Ranchos Formation. Although a younger age would allow Pueblo Viejo to be conveniently grouped with many other high-sulfidation deposits in a subaerial calc-alkaline setting, evidence for it conflicts with geologic observations in and around the deposit.

The new interpretation of the age of mineralization depends largely on the contention that the Hatillo Limestone, which overlies the Los Ranchos Formation, was replaced along its basal contact by silica and magnetite that are coeval with Pueblo Viejo mineralization. In their figure 2 (p. 1429), Sillitoe et al. show two "silicified and iron-oxide–bearing zones along the poorly exposed base of the Hatillo Limestone outliers." One of these zones is along the southern edge of the Pueblo Viejo mine where mine workings and exploration drill holes immediately south of the contact provide good exposures. In this area the contact, which is tectonized locally, ranges from a basal conglomerate with silicified cobbles to calcareous sandstone-siltstone-mudstone with abundant marine fossils. Silicified cobbles require that silicification preceded deposition of the Hatillo Limestone. Similarly, carbonaceous sediments containing silicified boulders and cobbles and underlying fragmental rocks with clasts exhibiting different alteration assemblages are widespread in the mine area (Russell and Kesler, 1991, fig. 3). Sillitoe et al. (2006) do cite one outcrop containing veinlets of iron oxide (limonite) with marginal silicification (Russell and Kesler, 1991, p. 210–211) as evidence of "…silicification and iron oxides in the basal few meters of the Hatillo Limestone." They acknowledge, however, that we interpreted these features as (paleo)supergene, which they clearly are. Furthermore, they are hosted by clastic basal sediments beneath the Hatillo Limestone and bear no similarity to the type of magnetite mineralization proposed by Sillitoe et al. Elsewhere along the southern part of the mine area the base of the Hatillo Limestone is in direct contact with Eocene(?) diorite intrusions. Nowhere in the mine area is there evidence of magnetite or silicification as required by the Sillitoe et al. model.

In the absence of evidence in the mine area, Sillitoe et al. discuss two rock samples and a drill section from an area 4 km west of Pueblo Viejo in support of the newly proposed age. One sample (Sillitoe et al., 2006, fig. 3a), which is typical of brecciated Los Ranchos volcanic rocks on Loma La Cuaba, is claimed to be silicified limestone although no proof for this is given. Textures diagnostic of the origin (volcanic or sedimentary) of most totally silicified rocks are not common in the field, but thin sections of some rocks on Loma la Cuaba and in the mine area show remnant (feldspar?) phenocrysts indicating an igneous parentage. The other sample (their fig. 3b) is described as being from the base of the Hatillo Limestone, although its age, location, and status (float, outcrop) are not provided. In the drill section (their fig. 4), the upper 30 m of massive silicification are said to span the contact between the Los Ranchos and Hatillo Limestone Formations, although "the distinction is difficult to make." We agree. As shown, the hole contains a small piece, or "loose block," of limestone that is interlayered with quartz-pyrophyllite rock. Even if the

† Corresponding author: e-mail, munteanj@unr.edu

limestone were in place in the drill section, its position within altered Los Ranchos Formation precludes its being Hatillo Limestone and suggests, instead, that it should be correlated with Los Ranchos limestone lenses that occur just below the Platanal member in this area (Kesler et al., 1991, fig. 2, locality F1).

Then, there are the magnetite deposits, which Sillitoe et al. (2006, p. 1429) suggest formed as the distal part of Pueblo Viejo mineralization along the Hatillo-Los Ranchos contact. These deposits consist of boulders of magnetite, without associated silica, that are marginal to diorite of Eocene age over a 400 km^2 area that extends far beyond the Pueblo Viejo district (Fig. 1). Two of the largest deposits, Hatillo and Las Lagunas, were suggested as distal alteration related to Pueblo Viejo. Contact relations at Hatillo are not clear, but at Las Lagunas the magnetite occurs where diorite intrudes the Hatillo-Las Lagunas Formation contact and thus is far above the basal Hatillo contact, as required by the Sillitoe model. Similarly, magnetite at Sabana Grande is at the contact between diorite and Las Canas (now considered Hatillo) Limestone, and other deposits to the north are at the contact between diorite and limestone of the Maimon Formation. Piedra Imán, the only magnetite locality that is not clearly diorite-related, is associated with silicification of Los Ranchos rocks although its relation to Pueblo Viejo is not clear.

Sillitoe et al. (2006) also suggest that the shape of Pueblo Viejo orebodies and the presence of pyrophyllite support their new model. The shape of the orebodies is said to indicate that they were ponded beneath an overlying cap of impermeable Hatillo Limestone (Sillitoe et al., 2006, fig. 5). The Moore orebody had highest gold grades at the present erosional surface and so sheds no light on this question. But Monte Negro, which is shown by Sillitoe et al. as "ponded" beneath the limestone, actually has its highest grades well below the present erosional surface, along a zone of silicification that coincided with the contact between carbonaceous sediments and underlying volcanic rocks (Russell et al., 1986; fig. 5; Muntean et al., 1990, fig. 4). Sillitoe et al. also note that the formation of pyrophyllite at temperatures of 260ºC or higher requires generous assumptions about the amount of overburden that could have been present during mineralization, as we have indicated previously (Kesler et al., 2003).

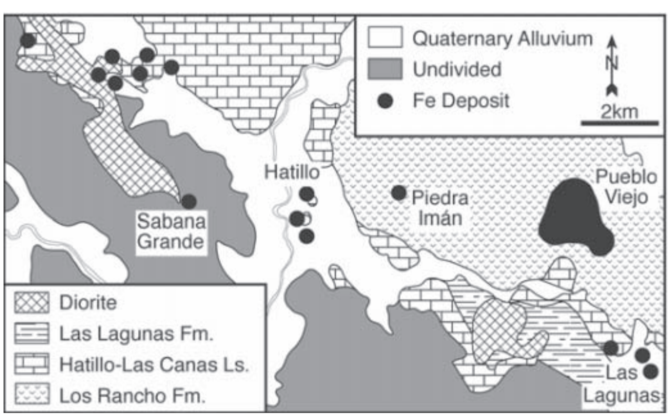

FIG. 1. Schematic geologic map of the central Dominican Republic showing location of iron deposits relative to Pueblo Viejo (modified from Bowin, 1966).

Pyrophyllite is paragenetically late, even crosscutting high-grade quartz-sulfide veins (fig. 5, Muntean et al., 1990), and could have formed during an unrelated, later event. Postore formation of pyrophyllite from kaolinite and quartz could have taken place in several ways, including thermal effects of as yet undocumented late Cretaceous intrusive activity, possibly in the Zambrana valley east of the mine area.

A postore thermal event that formed the pyrophyllite could have also reset the K-Ar and ^{40}Ar/^{39}Ar dates. This alternative is preferable to the suggestion of Sillitoe et al. (2006) that the ^{40}Ar/^{39}Ar dates on alunite of 62 to 68 Ma (Kesler et al., 1981) and 77 Ma (Kesler, 1998) "may very well approximately date the mineralization event rather than being random products of different degrees of postore resetting of an original ~111 Ma." Such a wide range of ages has not been observed in alunite from other high-sulfidation epithermal gold deposits and the range grows to a geologically unreasonable 30 m.y. if we include a 58 Ma ^{40}Ar/^{39}Ar age on sericite in the ore zone (Kesler et al., 2005) and 63.1 Ma (feldspar) and 46.1 Ma (sericite) K-Ar ages from a dike that cuts the Monte Negro orebody (Nelson, 2000). This dike provides strong additional support for an early Cretaceous age for mineralization. The dike is almost identical petrographically to spilite at Monte Negro, which it cuts at depth. However, it is altered to variable amounts of sericite, chlorite, and smectite but contains no pyrophyllite, whereas the surrounding wall rocks, including spilite, are intensely silicified and pyrophyllitized. The dike was described by Russell et al. (1986) as "…post-mineral and barren of precious metals." Subsequent drilling intersected a few zones of weak mineralization, including local sphalerite-pyrite-quartz veinlets, but Au grades in the dike are much lower (mostly <0.1 g/t Au) and have a distinctly different statistical distribution from grades in the wall rock (mostly >3 g/t Au). The difference in alteration mineralogy and gold grade between dike and wall rock indicate that the dike was emplaced after main-stage alteration but before the cessation of sphalerite-pyrite-gold mineralization. Single-grain zircon ID-TIMS analyses from this dike yield a U-Pb age of 109 Ma (Mueller and Nemchin, 2005), similar to but younger than any previously dated zircons in the Los Ranchos Formation (Kesler et al., 2005), clearly limiting Pueblo Viejo mineralization to an Early Cretaceous age coeval with the Los Ranchos.

The disagreement between field observations and ^{40}Ar/^{39}Ar and K-Ar age measurements at Pueblo Viejo has been a vexing aspect of Pueblo Viejo geology for many years. Outcrop relations and U-Pb ages in the mine area have shielded us from the tempting song of the Late Cretaceous Sirens; sadly, Sillitoe et al., working outside the mine area, were carried away.

May 30, 2007

REFERENCES

Bowin, C.O., 1966, Geology of the central Dominican Republic: Geological Society of America Memoir 98, p. 11–84.

Kesler, S.E., 1998, Geologic relations between Pueblo Viejo mineralization and Los Ranchos Formation: The status in 1997, *in* Feiss, P.J., ed., Mineral deposits of the Dominican Republic: Society of Economic Geologists Field Trip Guidebook, p. 31–36.

Kesler, S.E., Russell, N., Seaward, M., Rivera, J., Cumming, G.L. and Sutter, J., 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., Russell, N., Polanco, J., McCurdy, K., and Cumming, G.L., 1991, Geology and geochemistry of the early Cretaceous Los Ranchos Formation, central Dominican Republic: 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 deposits and their relation to other high-sulfidation systems: Mineralium Deposita, v. 38, p. 668–682.

Kesler, S.E., Campbell, I.H., Hall, C.M., Smith, C.N. and Allen, C.M., 2005, Age of the Pueblo Viejo gold-silver deposit and its significance to models for high-sulfidation epithermal mineralization: ECONOMIC GEOLOGY, v. 100, p. 253–272.

Mueller, A.G., and Nemchin, A., 2005, The zircon U-Pb age of an inter-mineral porphyry dike, Monte Negro orebody, Pueblo Viejo gold deposit, Dominican Republic: Unpublished report to Placer Dome Asia Pacific, 9 p.

Muntean, J.L., Kesler, S.E., and Russell, N., 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., 2000, Volcanic domes and gold mineralization in the Pueblo Viejo district, Dominican Republic: Mineralium Deposita, v. 35, p. 511–525.

Russell, N., and Kesler, S.E., 1991, Geology of the Pueblo maar-diatreme complex, Los Ranchos Formation, Dominican Republic: Geological Society of America Special Paper 262, p. 202–219.

Russell, N., Polanco, J., and Kesler, S.E., 1986, Geology of the Monte Negro gold-silver deposit, Pueblo Viejo district, Dominican Republic: Geological Association of Canada, Gold '86, Toronto, Proceedings Volume, p. 497–503.

Sillitoe, R.H., Hall, D.J., Redwood, S.D., and Waddell, A.H., 2006, Pueblo Viejo high-sulfidation epithermal gold-silver deposits, Dominican Republic: A new model of formation beneath barren limestone cover: ECONOMIC GEOLOGY, v. 101, p. 1427–1435.

PUEBLO VIEJO HIGH-SULFIDATION EPITHERMAL GOLD-SILVER DEPOSIT, DOMINICAN REPUBLIC: A NEW MODEL OF FORMATION BENEATH BARREN LIMESTONE COVER—A REPLY

RICHARD H. SILLITOE,[†]
27 West Hill Park, Highgate Village, London N6 6ND, England

DAVID J. HALL,
GoldQuest Mining Corp., 1480-885 West Georgia Street, Vancouver, British Columbia V6C 3E8, Canada

STEWART D. REDWOOD,
P.O. Box 0832-1784, World Trade Center, Panamá, Panama

AND ALISTAIR H. WADDELL
GoldQuest Mining Corp., 1480-885 West Georgia Street, Vancouver, British Columbia V6C 3E8, Canada

Sir: Muntean et al. (2007) are thanked for their long-anticipated discussion of our reinterpretation of the Pueblo Viejo high-sulfidation epithermal gold-silver deposit as a product of Late Cretaceous-early Tertiary rather than Early Cretaceous magmatism. The reinterpretation is based on evidence that the gold-silver mineralization post- rather than predated deposition of the thick, regionally extensive Hatillo Limestone (Sillitoe et al., 2006). Their discussion tries to diminish the significance of our new, district-wide observations, reiterates the limited evidence from the Pueblo Viejo mine, and presents a previously unpublished U-Pb zircon age (regrettably, without the supporting analytical data) and its interpretation. Here, we welcome the opportunity to restate the key district-scale features that led us to conclude that the gold-silver mineralization—along with formation of the adjoining 10-km-long Loma la Cuaba advanced argillic lithocap—took place beneath the Hatillo Limestone, before commenting on Muntean et al.'s (2007) main mine area observations and conclusions.

Muntean et al. (2007) infer that the silicification and associated iron-oxide replacement described from the base of the Hatillo Limestone is a local feature and possibly even a replacement of an older limestone bed in the underlying Los Ranchos Formation rather than of the Hatillo Limestone itself. Although we present in some detail the drill intercept from Piedra Imán as a type example of the replacement phenomenon, we nowhere imply that the silicification is merely a localized feature. In fact, quartz-iron oxide replacement along the base of the Hatillo Limestone is district-wide and exposed intermittently for at least 3 km along the basal contact of the Limestone with the underlying Los Ranchos Formation as well as occurring as erosional remnants on the dip slope exposed after Hatillo Limestone removal (see Sillitoe et al., 2006; fig. 2). Although outcrop is generally poor, especially near the Pueblo Viejo mine, small exposures and contiguous float trains are more numerous and widespread farther west and reveal unambiguous partial replacement of limestone by massive fine-grained silicification plus associated magnetite and derivative hematite. Breccia texture, like that shown in our figure 3a, and limestone cut by veins and pods of massive silicification, as illustrated by our figure 3b, are commonplace. There is no possibility that the limestone replaced is any other than the Hatillo. Nevertheless, as clearly stated, the silicification does extend from the limestone into the uppermost parts of the underlying Los Ranchos Formation, thereby making distinction of former limestone and volcanic rocks difficult.

Muntean et al. (2007) repeat the earlier conclusion that the magnetite is the result of contact metasomatism of limestone around diorite intrusions of Eocene age (Koschmann and Gordon, 1950; Bowin, 1966; Kesler et al., 1981; Russell and Kesler, 1991). However, most of the magnetite-hematite deposits are accumulations of boulders rather than in-situ replacements (Koschmann and Gordon, 1950). Moreover, the most important ones were largely mined out decades ago, thereby removing most of the geologic evidence. It is worth pointing out, however, that no calcic skarn has been recorded in association with any of the magnetite deposits. Furthermore, no magnetite is present at limestone-diorite sill contacts drilled by GoldQuest Mining Corp. on Loma la Mina, although minor pyroxene endoskarn was observed at a single contact. The largest magnetite accumulations were at Las Lagunas, adjacent to the Pueblo Viejo mine gate, and Hatillo. The latter was almost certainly an erosional product of magnetite replacements on Loma la Cuaba, like that drilled by GoldQuest Mining Corp. at Piedra Imán, and the source of the former, if it consisted of magnetite-hematite boulders (Koschmann and Gordon, 1950), may be inferred to be the former Hatillo Limestone cap to the Pueblo Viejo deposit.

We reiterate the new stratigraphic evidence from drill holes southwest of Pueblo Viejo in the Margajita valley and at Loma la Mina (see Sillitoe et al., 2006; fig. 2), which show that Hatillo Limestone conformably overlies the Los Ranchos Formation volcanic rocks rather than being separated from them by either a thrust fault or regional unconformity. The lower part of the Hatillo Limestone (or upper part of the Los Ranchos Formation) is a dark-colored, well-bedded limestone with black shale intercalations and a few tuff beds, which is gradational upward to the massive micritic limestone typical of the Hatillo. Consequently, it would be difficult, if not impossible, to generate the Pueblo Viejo orebodies and associated Loma la Cuaba lithocap between Los Ranchos and Hatillo Limestone times.

A key facet of our evidence, the identical lithogeochemistry of the quartz-iron oxide rock and the Pueblo Viejo orebodies,

[†] Corresponding author: e-mail, aucu@compuserve.com

except for the absence of appreciable gold in the former, was studiously ignored by Muntean et al. (2007). This distinctive Cu-Pb-Mo-Bi-As-Sb-Hg-Se-Te-Ba signature is surely the best evidence for a direct connection between hydrothermal fluid associated with the Pueblo Viejo orebodies and that responsible for the Hatillo Limestone replacement. The limestone-replacing fluid is interpreted as a distal equivalent of the ore fluid, which flowed laterally beneath the Hatillo Limestone aquitard. The geochemical anomalism associated with the base of the Hatillo Limestone extends west of Hatillo Lake, beyond the main Loma la Cuaba lithocap discussed by Sillitoe et al. (2006); therefore, it is unsurprising that magnetite occurrences occur in that area too, as reemphasized by Muntean et al. (2007). None of the massive silicification at Loma la Cuaba shows any sign of being supergene (or paleosupergene) in origin, as asserted by Russell and Kesler (1991) and Muntean et al. (2007) for an occurrence immediately beneath the Hatillo Limestone in the Pueblo Viejo mine area.

We accept the fact that the highest gold grades in the Monte Negro orebody at Pueblo Viejo were controlled by the contact between the carbonaceous sedimentary rocks and underlying volcanic sequence (Muntean et al., 1990, 2007). However, it also needs to be emphasized that the highest ground alongside the open pits, and immediately above the ore zones, is underlain by massive, cherty, hematitic silicification identical to that farther west on Loma la Cuaba. We interpret this silicification to have formed at the top of the Los Ranchos Formation, just below the Hatillo Limestone, which on geologic sections can be projected northward over the entire mine area.

Kesler et al. (1981) and Muntean et al. (2007) refer to cobbles of silicified rock in the Los Ranchos Formation within the Pueblo Viejo orebodies as evidence for broadly coeval sedimentation, alteration, and, by inference, gold-silver mineralization. In the open pits, we have observed sedimentary clasts in conglomerate that were preferentially silicified (or leached to produce vuggy quartz) during the ore-forming event; late-stage, strata-bound pebble dikes containing clasts of silicified rock that were presumably derived from elsewhere in the same orebody; and true sedimentary clasts of silicified rock derived from preexisting silicified zones. Before clasts of silicified rock can be used as evidence for broadly synsedimentary mineralization during the Early Cretaceous, their origin must first be confidently determined. Then the clasts that are truly of preexisting silicified rock must be shown to be gold-bearing prior to incorporation in the conglomerate horizon (no easy matter since they are part of the host rock to the gold-silver orebodies) as well as texturally identical to silicification developed during early stages of orebody formation rather than silicification that existed in some unrelated external source area. Such evidence, if it exists, has never been reported.

Muntean et al. (2007) describe a mafic dike that cuts the ore-bearing carbonaceous siltstone in the Monte Negro orebody at Pueblo Viejo as intermineral in timing because it has different alteration and a much lower gold content than the surrounding siltstone-hosted ore. These observations could, as they claim, be indicative of intermineral emplacement, following the main stage of gold-silver introduction, but they could equally well reflect the less receptive and/or less permeable nature of the dike vis-à-vis the thinly bedded and formerly carbonate-bearing siltstone. As Kirkham (1971) pointed out, intermineral dikes can only be confidently identified where they either clearly truncate veins or veinlets in the surrounding rock or contain xenoliths of previously mineralized rock. Neither of these criteria is satisfied by Muntean et al.'s description. Therefore, the 109 Ma U-Pb zircon age reported by Muntean et al. (2007) is not necessarily an intermineral age, but could equally well simply reflect the age of dike emplacement during the Early Cretaceous accumulation of the Los Ranchos Formation.

Muntean et al. (2007) restate the opinion of Kesler et al. (2005) that the range of $^{40}Ar/^{39}Ar$ ages (62–77 Ma) determined previously for alunite from depth in the Pueblo Viejo deposit must be due to different degrees of resetting of an original Early Cretaceous (~111 Ma) age by a postmineral thermal overprint, and cannot approximate the timing of the mineralization event because the hydrothermal lifespans of high-sulfidation epithermal deposits do not last for 15 m.y. Obviously, as they are well aware, we do not imply such longevity for the Pueblo Viejo system, but simply prefer the notion that the ages provide a rough estimate for the timing of the mineralization while accepting that the determinations, unlike those for alunite from most high-sulfidation deposits, fail to provide a precise age. One plausible interpretation would be that the mineralization took place at 77 Ma and that the younger ages, including the 58.0 and 46.1 Ma sericite ages cited by Muntean et al. (2007), are the products of subsequent argon loss or some other currently unknown factor.

Muntean et al. (2007) take issue with our assumed temperature of 285°C for the gold-silver mineralization at Pueblo Viejo and imply that the mineralization temperature may have been much lower and capable of generating only kaolinite as an alteration mineral rather than the widely observed pyrophyllite. They propose that the kaolinite (plus quartz) was subsequently transformed to pyrophyllite in response to heating by a Late Cretaceous intrusion. First, it should be emphasized that the assumed temperature was taken directly from Muntean et al. (1990), who documented gold deposition during the pyrophyllite and accompanying silicification stage. Second, the chances of billions of tons of kaolinite-bearing rock throughout the Pueblo Viejo orebodies and Loma la Cuaba lithocap being transformed to pyrophyllite during later epizonal intrusion are considered slight. We contend, of course, that the Late Cretaceous magmatic event that Muntean et al. (2007) invoke for this mineralogic transformation is, in fact, the mineralization event itself.

Therefore, in conclusion, we suggest that the district-scale evidence for post-Hatillo Limestone alteration and gold-silver introduction at Pueblo Viejo is difficult to ignore and is certainly not outweighed by the evidence mustered by Muntean et al. (2007) from the Pueblo Viejo orebodies. Muntean et al. (2007) rather facetiously suggest that we were bewitched by some previously undocumented genus of Late Cretaceous sea nymph, whereas in fact the district-scale evidence simply spoke for itself. May we remind them that the proper understanding of any mineral deposit depends on not just a detailed analysis of the ore zone itself but also its district setting; unfortunately, their studies were confined to the open pits. Porphyry copper-related lithocaps are commonly on the order of

10 to 25 km across, a scale consistent with the regional extent of silicification and magnetite in and around the Pueblo Viejo district. This fact is especially critical for those engaged in either green- or brownfield exploration. In this regard, it is encouraging to learn that direct application of our new Pueblo Viejo model elsewhere in the Dominican Republic recently resulted in the discovery of gold mineralization at the Juan del Bosque prospect, where the associated advanced argillic alteration and contained barite reportedly occur beneath the silicified base of a Cretaceous limestone sequence (Unigold Inc., press release, June 11, 2007). As always, the proof of the pudding is in the eating.

Acknowledgment

Thanks are due to Michel Gauthier for drawing Unigold's attention to our Pueblo Viejo model and for letting us know of the successful exploration outcome.

August 1, 2007

REFERENCES

Bowin, C.O., 1966, Geology of central Dominican Republic (A case history of part of an island arc): Geological Society of America Memoir 98, p. 11–84.

Kesler, S.E., Russell, N., Seaward, M., Rivera, J.A., 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., Campbell, I.H., Hall, C.M., Smith, C.N., and Allen, C.M., 2005, Age of the Pueblo Viejo gold-silver deposit and its significance to models for high-sulfidation epithermal mineralization: ECONOMIC GEOLOGY, v. 100, p. 253–272.

Kirkham, R.V., 1971, Intermineral intrusions and their bearing on the origin of porphyry copper and molybdenum deposits: ECONOMIC GEOLOGY, v. 66, p. 1244–1249.

Koschmann, A.H., and Gordon, M., Jr., 1950, Geology and mineral resources of the Maimón-Hatillo district, Dominican Republic: U.S. Geological Survey Bulletin 964-D, p. 307–359.

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.

Muntean, J., Hall, G., Kesler, S., Mueller, A., O'Brien, D., and Russell, N., 2007, Pueblo Viejo high-sulfidation epithermal gold-silver deposit, Dominican Republic: A new model of formation beneath barren limestone cover—a discussion: ECONOMIC GEOLOGY, v. 102, p. 755–757.

Russell, N., and Kesler, S.E., 1991, Geology of the maar-diatreme complex hosting precious metal mineralization at Pueblo Viejo, Dominican Republic: Geological Society of America Special Paper 262, p. 203–215.

Sillitoe, R.H., Hall, D.J., Redwood, S.D., and Waddell, A.H., 2006, Pueblo Viejo high-sulfidation epithermal gold-silver deposit, Dominican Republic: A new model of formation beneath barren limestone cover: ECONOMIC GEOLOGY, v. 101, p. 1427–1435.