Mineralium Deposita (2002) 37: 782–784
DOI 10.1007/s00126-002-0281-8

DISCUSSION

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Discussion on "Gold deposits of the Tapajós and Alta Floresta Domains, Tapajós-Parima orogenic belt, Amazon Craton, Brazil" by Santos JOS, Groves DI, Hartmann LA, Moura MA, McNaughton NJ (*Mineralium Deposita* 36:278–299, 2001)

Received: 13 December 2001 / Accepted: 13 December 2001 / Published online: 18 June 2002

Keywords Epithermal · Gold · Tapajós province · Amazon craton · Brazil

Concerning the recently published article by Santos et al. (2001), we would like to congratulate the authors in their effort to unravel the geological evolution of such a large and poorly known area of Brazil. As to the gold deposits of this region, we want to discuss some aspects about the deposits that Santos et al. (2001) describe as "intrusion-related epizonal quartz vein deposits" and in which they challenge our classification of two of these deposits (Dreher et al. 1998) as adularia–sericite epithermal types.

Firstly, we think it is appropriate to mention that our paper (Dreher et al. 1998) was written about 5 years ago and may contain typical uncertainties when given the level of knowledge available at that time on the Tapajós region geology, with particular reference to hard rock gold deposits. Having said that, we nevertheless stress that our paper was among the first to propose an epithermal origin for Proterozoic gold deposits of the Tapajós province. The Davi and Joel prospects, for instance, had been previously regarded as mesothermal (e.g., Pastana et al. 1994; Bastos Leal and Tassinari 1994). Santos et al. (2001) criticize our epithermal classification for these two deposits and include them in their "Korean-type, intrusion-related group". They fail to mention, however, that we consider the prospects as deep epithermal occurrences. This is particularly relevant here because the deeper parts of adularia–sericite epithermal systems may display features that resemble some of those that are characteristic of intrusion-related deposits (e.g., Robert et al. 1997). Other features may be different when compared with shallower, perhaps more classical, parts of epithermal deposits (e.g., Hedenquist et al. 2000), but, despite this, the deeper deposits still maintain the basic characteristics of the epithermal group, as discussed below.

An important point relates to the adularia content of the prospects. Santos et al. (2001) indicate that minor adularia is present in the Joel and Davi prospects. Underground workings at Davi, however, allowed us (Martini and Dreher 1996; Dreher et al. 1998) to verify that the main vein possesses a decimeter- to meter-scale alteration envelope containing patches and veinlets of reddish feldspar, which were later identified as hematite-altered albite and adularia. The amount of adularia is not minor. The mineral is an essential phase of a sizable alteration zone, particularly when considering that the main vein itself is never more than 50 cm in width. At the Joel prospect, adularia is not as abundant, but it occurs locally as a light pink or white mineral and may easily be mistaken for carbonate or quartz. In addition, it is well known that the scarcity or even absence of adularia, which is definitely not the case at the Davi and Joel occurrences, can not be used to disprove an epithermal origin for deposits (e.g., White and Hedenquist 1990).

Santos et al. (2001) also state that the epizonal gold of the Tapajós domain lacks many of the characteristics of epithermal deposits and refer to their Table 6 (Santos et al. 2001, p. 292) to prove this point. They mention, for instance, the absence of penecontemporaneous volcanic rocks. Epithermal deposits are, in fact, mostly associated with volcanic rocks, but they may also occur in other rock types at epizonal levels. Examples include gneisses (Tosdal and Smith 1987), metamorphosed basement rocks (White and Hedenquist 1990), intermediate to silicic intrusive rocks (Taylor 1995), and, actually, any rock type forming the basement to a volcanic regime (White and Hedenquist 1990; Robert et al. 1997). Also the geological setting of the prospects is referred to as hypabyssal and this is supposedly inadequate for epithermal deposits. However, in terms of depth, hypabyssal is synonymous with subvolcanic (Jackson 1997), which is indicated by Santos and coauthors in Table 6 itself as an appropriate setting for epithermal adularia–sericite deposits.

Santos et al. (2001) further mention that alteration in the deposits is restricted to a few meters from the ores. This does not seem relevant for the definition of the specific deposit type. According to Sillitoe (1993), low-sulfidation epithermals are characterized by "commonly restricted and visually subtle" alteration zones. Other workers (e.g. Panteleyev 1988; Hedenquist et al. 2000) have noted that the areal extent of alteration zones surrounding

Editorial handling: R.J. Goldfarb

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adularia–sericite epithermal deposits tends to be proportional to that of related orebodies. The one exception is possibly the argillic zone, within the upper parts of this type of deposit, which may attain a width of one to two orders of magnitude greater than the contained gold-bearing zone.

We concede that, on the other hand, only part of the mineral assemblage present in low-sulfidation epithermal gold deposits was observed in the prospects, although we do mention the presence of native silver in the Joel occurrence (see Dreher et al. 1998, p. 398). As for other "missing" ore or alteration minerals, this could conceivably reflect their lack of identification to date, or the fact that phases such as sellenides, cinnabar, kaolinite and alunite are usually absent in the deep parts of low-sulfidation epithermal deposits (e.g., Hedenquist et al. 2000), as we proposed in our model for the Davi and Joel prospects. Minerals such as sericite (as opposed to illite), carbonates, chlorite, and albite (e.g., propylitization), which are commonly found in deep epithermal deposits, were identified at the prospects. As to the apparent differences in metal association mentioned in Table 6 of Santos et al. (2001), these may be again a function of the depth within the hydrothermal system, where deeper parts lack anomalous Hg, Sb, and As and are enriched in base metals (Hedenquist et al. 2000).

Santos et al. (in their Table 6, 2001) also introduced our data on fluid inclusions. As shown, the temperatures obtained by us (220–340 °C; Dreher et al. 1998) overlap significantly with the higher ones typical of epithermal gold deposits. We see the temperature overlap as another good indicator of a deep epithermal situation.

Santos et al. (their Table 6, 2001) present Au:Ag ratios of ≥5:1 for Davi and Joel. If this is really representative of the average ore of the prospects, and not just determined from grab samples, then it still is a valid number for adularia–sericite epithermal deposits, in which maximum values for this ratio may reach 10:1 (Robert et al. 1997). We recognize, however, that the stated 5:1 ratio is problematic for the specific deep epithermal model because this ratio is more typical of the upper parts of such deposits (Hedenquist et al. 2000).

Santos et al. (2001) classify the deposits as Korean-type. We do not deny the possibility of occurrence of such deposit types in the region, as otherwise originally proposed by Robert (1996). Both types, Korean and epithermal, can occur together in the same region (Robert et al. 1997). We argue, however, that the Korean-type classification does not apply to the Davi and Joel prospects because adularia, which is consistently present in the prospects, is not mentioned at all in connection with Korean-type deposits (e.g., Robert et al. 1997; So and Shelton 1987). This points to the significance of identifying adularia, evidently along with other features, for genetic classification of the prospects.

Thus, taking into account the above discussion on the geological features, we see no reason to change our classification of the Davi and Joel gold prospects. It is essentially based on field, textural and mineralogical evidence, which have been considered appropriate for the characterization of epithermal deposits (White and Hedenquist 1990).

As for some possible "missing features", we adopt the view of Cox et al. (1992), according to which the features of a given type of deposit may not all be present in one single specimen of the group. This is reinforced with particular reference to epithermal deposits by Taylor (1995, p. 340) who states specifically that not all the diagnostic features of the type are to be always found in a given deposit. Of the diagnostic features cited by Taylor (1995), we were able to distinguish in the Davi and Joel prospects appropriate mineral assemblages, evidence of shallow emplacement, fluid inclusion data, and evidence of boiling (e.g., adularia), in addition to hydrothermal breccias and open space fillings.

Finally, it should be mentioned that Santos et al. (2001) say that only seven of the 140 primary gold deposits in the Tapajós province are hosted by subvolcanic felsic igneous rocks and, although this is a common ore host in epithermal systems, the subvolcanic rock-hosted deposits lack all other characteristics of epithermal deposits. It may well be the case for the deposits specifically considered by Santos et al. (2001), but, despite this, the geological environment is anyway permissive for epithermal gold, as we indicated by our classification of the Davi and Joel prospects. A confirmation of this is the recent discovery of both high- (alunite-bearing) and low-sulfidation (adularia-sericite) epithermal systems in the Tapajós region, as reported by Jacobi (1998), Lestra (1999), Nunes et al. (2000), Juliani et al. (2000), Nunes (2001), and Silva et al. (2001). These are located in volcanic rock-covered areas along the northern part of the Tapajós province, the same areas where Santos et al. (2001) say epithermal deposits do not exist. These discoveries probably represent the situation where the erosion levels were locally adequate for the preservation and exposure of entire epithermal systems.

In our view, the geological setting is the most important aspect for deposit classification. The (felsic) intrusive-volcanic setting of the Tapajós domain is permissive for epithermal gold deposits, and the preservation, at least in part of the region, of host rocks typically associated with these shallowly formed ore deposits allows for the preservation of the deposits themselves. The epithermal model was originally proposed by us for the Joel and Davi prospects and since then it has been shown to be applicable elsewhere in the province by the many new discoveries.

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