Gold deposit styles and placer gold characterisation in northern and east-central Madagascar

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Abstract: Microchemical characterisation of gold grains from orogenic lode and placer deposits from six gold districts within the Archaean domains and the intervening Neoproterozoic Anaboriana-Manampotsy belt of northern and east-central Madagascar show few opaque inclusions (e.g. pyrrhotite, Bi tellurides), localised Pd and generally low Cu contents, but a relatively wide range of Ag contents (≤40wt%). The distributions of silver contents show some samples to contain multiple populations of gold grains. These may be related to different host lithological associations, felsic magmatism, superimposed mineralization events, level of erosion and secondary processes. Some placer samples have a high proportion of gold with extremely low Ag contents (<0.5wt%). Close to the western contact with the Phanerozoic cover this is related to recycling of paleoplacers and erosion of post-Gondwana planation surfaces and indicates that some lode gold systems were already partially to wholly removed by erosion by the Permo-Triassic.

Keywords: Placer gold, microchemical characterisation, silver contents, Madagascar

1 Introduction and Results

Madagascar is a typical example of a country where historically the amount of placer gold recovered far exceeds the known bedrock resource. A number of different primary and secondary gold deposit types are known within the Precambrian basement and cover rocks of north and east-central Madagascar. Previous workers (Bournat et al. 1985; Premoli 1996; Rambeloson 1999; Peters et al. 2003) have linked these deposit styles to specific terranes but rarely take into account fully the geomorphic evolution, the mineralization styles and the possibility of superimposed metallogenic events linked to the polycyclic history of the basement. Recently completed geological mapping and laboratory studies by BGS/USGS *Projet de Gouvernance des Ressources Minérales* (PGRM) have led to a refinement of the various tectonic terranes, a better understanding of the geological evolution and controls of the gold mineralization (BGS-USGS-GLW 2008).

Northern and east-central Madagascar is made up of three Archaean crustal fragments separated by the Neoproterozoic Anaboriana-Manampotsy belt (Fig. 1). These Archaean domains exhibit a polycyclic orogenic history with deposition and tectonic emplacement of Proterozoic sequences. The main gold districts are associated with Neoarchaean 'greenstone' and Proterozoic metasedimentary belts (Rambeloson 1999). With the exception of the Andavakoera goldfield (Fig. 1) all the known primary gold deposits in the Precambrian metamorphic basement are orogenic lode gold deposits (Groves et al. 1998). However, in many cases there is a spatial, if not genetic, relationship with Neoproterozoic intrusions e.g. the Antalaha, Vavatenina and Itasy districts which suggest that intrusion-related gold deposits (Lang and Baker 2001) may be locally important.

Microchemical characterization of placer gold by electron probe microanalysis of the alloying elements (e.g. Ag, Cu, Pd and Hg) and included minerals within the gold grains has been shown to be an effective tool to distinguish different types of source mineralization, to detect zonation within a mineralized area and discriminate between gold of primary and secondary origin (e.g. Leake et al. 1992; Naden et al. 1994; Leake et al. 1997; Chapman et al. 2002; Potter and Styles 2003). Linkage of various styles of source mineralization with particular geological environments allows for more effective gold exploration targeting of bedrock mineralization and re-evaluation of well established alluvial goldfields. Twenty-one gold separates (3 bedrock and 18 placer samples) from 6 gold districts in the principal Archaean domains and Neoproterozoic Anaboriana-Manampotsy belt were used in this gold characterisation study (Fig. 1).

Clean gold separates were obtained by panning and hand picking composite samples. For statistical representativity a minimum of 30 grains (preferably 50) per sample are required for analysis. Five placer gold samples did not meet this criterion. Following optical examination under a binocular microscope the grains were mounted on polished thin sections and checked by reflected light microscopy for major internal inhomogeneities and micro-inclusions. The grains were

analysed for seven elements (Au, Ag, Pd, Fe, Cu, Hg, S) using a Cameca SX50 electron microscope fitted with three WDS spectrometers using the technique described in detail in Chapman et al. (2002) and Potter and Styles (2003). Detection limits were 0.02-0.08wt %.

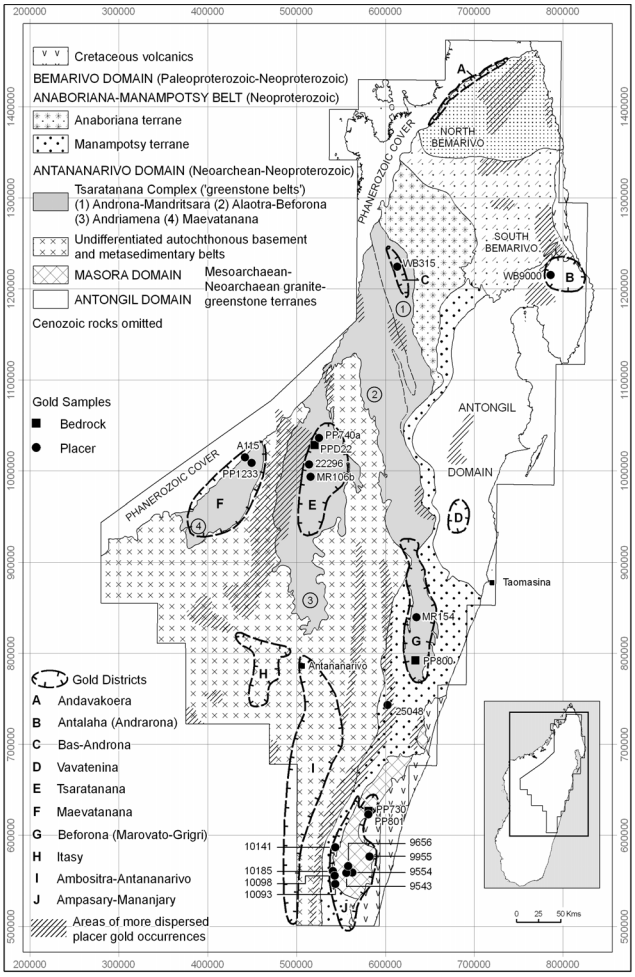

Figure 1 Map of the gold districts of northeast Madagascar showing the distribution of analysed bedrock and placer gold samples.

There is a general paucity of opaque mineral inclusions in all the gold samples. Detected mineral species include pyrrhotite, chalcopyrite, Bi tellurides, native bismuth and Fe±Mn oxides. This is consistent with the relatively simple inclusion assemblages reported in most orogenic gold deposits but may also be a product of increased transport and/or prolonged residence time in an oxygenated secondary environment. The grains were found to be simple Au-Ag alloys which varied from 0-10.6% Ag in the placer gold of the Maevatanana-Bas Androna districts to a maximum of 48wt% Ag in the other districts with ≥20wt%Ag in 17.5% and 3.4% of grains from the lode and placer gold respectively. Cumulative plots of the type presented in Fig. 2 where each gold grain is represented as a percentile and plotted against its silver content permit direct comparison of gold samples. Furthermore, modifications to the profile of the gold grain data for each sample provide a visual indication of the presence of more than one population of gold grains either due to contributions from different sources, multiple mineralization events and / or secondary processes. 57% of the analysed placer gold grains have a high fineness (≥990). A relatively small number of grains contain significant copper (6% with >0.5wt% and <2% with >1.0wt% Cu: Max 2.38wt% Cu) and palladium (1% with 0.20-1.88wt% Pd) whilst the concentrations of the other analysed elements were close to or below their respective detection limits.

2 Discussion

Lode gold sample PP730 from the Bebasy Mine in the Masora Domain (Fig. 1) has moderate Ag contents, (4.8-15.1wt%), a typical signature of 'greenstone belt' orogenic gold (Naden et al. 1994) whereas lode gold samples PP800 and PPD-22 from the Beforona and Andriamena belts respectively range to higher Ag contents (up to 40 wt%). Sample PP800 is a product of a two-stage paragenesis but appears to constitute a single population of gold grains relating to a single phase of gold precipitation. The fineness distribution of PPD-22, by contrast, clearly indicates two distinct compositional classes (10-20 and 25-40wt% Ag). The low fineness gold suggests a contribution (or overprint) from high level plutonic magmatic source or later phase of mineralization. This may be cogenetic with the late-Neoproterozoic? base metal (+ Ag) mineralization of the Ankisatra-Besakay orefield (Kabete et al., 2006).

More than 80% of grains in all alluvial placer gold samples from the Tsaratanana Complex (Fig. 1) contain <10wt% Ag. The gold in the alluvial placer samples preserves similar microgeochemical characteristics to the lode gold in the same district. Alluvial gold sample A115, downstream from a meta-BIF hosted auriferous vein source in the Maevatanana belt near the unconformity with the Phanerozoic cover (Fig. 1), exhibits a more truncated profile with over 60% comprising gold with <1wt% Ag. It is comparable to placer gold sample WB315 with >85% of high-fineness gold in the Bas-Androna goldfield. The extreme depletion in Ag is typical of redeposited authigenic gold formed near unconformities and suggests that a large proportion of this placer gold is recycled from paleoconglomerates. This has great significance in terms of the redistribution of secondary gold over much of the crystalline basement.

The Ampasary-Mananjary gold district is centred on the Archaean Masora domain and marginal Neoproterozoic Anaboriana-Manampotsy belt (Fig. 1) and lies to the east of a major regional east-facing escarpment. Three groups of placer gold samples taken from the different parts of the district show a marked increase in the relative proportion of gold with <1wt% Ag from ≤15% in the east to ≥70% in the west (Fig's 1 & 2). This zonation may be attributed to differing bedrock sources and / or secondary processes. The east coast lowlands of Late Cretaceous volcanic flows is most likely the oldest planation surface of a polycyclic landscape to the east of the main escarpment and drainage divide. Progressively younger landscapes are found moving inland toward the

modern escarpment. Higher levels of bedrock gold systems close to (or under) the Cretaceous volcanic cover will be better preserved than in the west of the gold district. The zonation may in part be due to increased unroofing of the gold systems further west or that there is a source of low-Ag gold to the west and that this mixes with locally derived low fineness gold that is the main component further east.

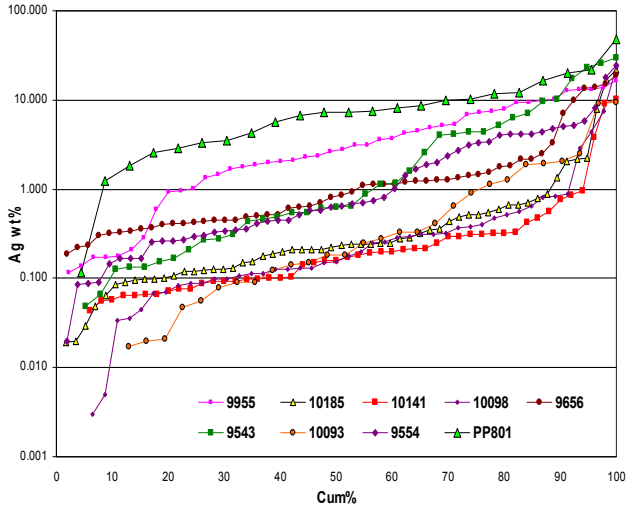

Figure 2 Ag contents of placer gold grains (spot analyses) within the Ampasary-Mananjary gold district, logarithmic scale on Y axis.

The four samples taken from the Ampasary-Mananjary river system on the western side of the district are largely derived from bedrock sources in the southern part of the Anaboriana-Manampotsy belt. The placer gold is distinctive not only by the extreme depletion in Ag but also the sporadic enrichment in Pd (0.42-1.36wt%) and Cu (0.51-2.38wt%). There is no appreciable change in the grain morphology nor detectable fining of the gold in 40km of river transport which suggests that recent riverine redistribution is not a significant factor. Placer gold sample 25048 sourced from the Manampotsy Complex and in the same geomorphic and tectonic setting to the north of the gold district exhibits similar characteristics.

The Antalaha gold district (Fig. 1) is underlain by a Paleoproterozoic shelf sequence, overlying a Neoarchaean granitoid complex and intruded by Neoproterozoic to Cambrian plutonic rocks (BGS-USGS-GLW 2008). It has been cited as one of the few areas where gold deposits may be associated with subalkaline plutonism (Peters et al. 2003). The consistent presence in the same goldfield of two different gold finenesses (975 and 850) has led to the proposal of a multiple origin of the gold (Premoli 1996). The present study showed a wide range of silver contents (0.3-33.3wt% Ag) with a significant proportion of grains with >20wt% Ag but the data is insufficient to confirm the bimodal nature of the gold fineness.

3 Conclusions

Opaque mineral inclusions are generally rare in the orogenic lode and placer gold from northern and east-central Madagascar and are therefore of limited use for characterisation of the placer gold. The plots of increasing Ag content show that some samples have multiple populations of gold grains indicating contributions from difference sources and / or multiple mineralization events. Placer gold with higher Ag contents may be inherited in part from the upper levels of felsic plutonic-hydrothermal systems.

The most conspicuous feature is the high proportion of the high fineness gold (i.e. ≥990) in many of the placer samples which can be linked to prolonged weathering and alluvial recycling of basal Karoo paleoplacers in the west and removal of Cretaceous erosion surfaces in the east. This suggests that the relative scarcity of known lode gold sources to a large extent can be attributed to their partial to wholesale removal by erosion.

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