'Invisible' gold in arsenopyrites of the auriferous zones of the Gadag gold field in Karnataka

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Electron probe microanalysis of arsenopyrites of the gold ore of western and middle auriferous zones of the Gadag gold field has revealed that it contains 'invisible' gold to the extent of 0.23 to 0.97 wt% (av. 0.63 wt%). This invisible gold appears to be present partly in solid solution and partly as ultrafine submicroscopic inclusions.

In the recent years, the so-called invisible gold present in sulphides has been receiving much attention all over the world. The invisible gold occurs as submicroscopic inclusions, and in solid solution or chemically bound state in the sulphides, thus rendering the gold refractory to the conventional cynidation process[1]. Although Indian gold mining provides some of the oldest mining activities in the world, very little attention has so far been paid to invisible gold and refractory gold ores of the country.

The Gadag gold field, covering an area of about 120 km^2 between Dambal and Doni (long. 75°34'–75°43'; lat. 15°20'–15°27'), has three almost parallel, tabular auriferous zones designated as western, middle and eastern zones. The western zone is hosted by pillowed schistose metavolcanic rocks, the middle zone is in both schistose metavolcanics and metasediments, whereas the eastern zone is hosted exclusively by metasediments. Gold mineralization of gold–quartz vein type is congruent to structural dilatant zones (shear zones and fractures) and is characterized by different degrees of chloritization, sericitization, carbonatization and silicification, with sulphide disseminations and bands[2].

Arsenopyrite is the most abundant sulphide mineral in the auriferous zones of metavolcanic suites, with the sulphide mineralogy represented by arsenopyrite + pyrite + chalcopyrite + pyrrhotite + sphalerite + galena, whereas in the auriferous zones of metasedimentary suite, pyrite dominates and the sulphide mineralogy comprises of pyrite, pyrrhotite, arsenopyrite and chalcopyrite in the order of decreasing abundance.

Examination of the Gadag gold ore samples, both under ore microscope and electron probe (JEOL-JCXA 733 Super Probe), has revealed that the gold in these ores is present in two distinct forms:

(1) As microscopically visible native gold.
(2) In microscopically invisible state within the homogeneous-looking arsenopyrite. The former occurs more commonly as irregular masses, stringers and droplets within or closely associated with arsenopyrite and less frequently as microfracture fillings in arsenopyrite and along the grain boundaries of pyrite. The latter, viz., the invisible gold, is present in ultrafine submicroscopic state. It is so fine that it remains undetected even under 20,000 times magnification. Both microscopically visible native gold and invisible gold in arsenopyrite have been analysed employing the said electron probe microanalyser, which has a detection limit of 0.05 wt% gold. While the microscopically visible native gold analyses showed 94.9 wt% Au and 5.1 wt% Ag, the arsenopyrite with invisible gold showed 0.23–0.97 wt% Au (av. 0.63 wt% Au); see Table 1. It is possible that at least a part of the invisible gold recorded in the arsenopyrite of Gadag gold ores is in solid solution and structure bound[3–5] and the rest is existing as ultrafine inclusions.

Finding specific explanations for the solid–solution relationship between Au and As within arsenopyrite structure is not an easy task since very little is known about the location and chemical state of Au in the mineral[5]. However, Boyle[6] has suggested that Au substitutes for As in arsenopyrite and this hypothesis is largely based on comparison of ionic radii of covalently bonded As and Au. John *et al.*[7] used electron probe data for gold-rich arsenopyrites (> 0.21 wt% Au) and stoichiometric calculations to propose that Au is substituting for the excess As, which actually is present at Fe sites. Cabri *et al.*[4] have reported the occurrence of 0.44 wt% structurally bound Au in the arsenopyrite of Sheba gold ore.

Table 1. Electron microprobe analyses of arsenopyrites from Gadag containing invisible gold (values in wt%)

	Western auriferous zone			Middle auriferous zone		Average
	1	2	3	4	5	6
As	43 88	44 19	43.78	42 91	43 22	43 60
Fe	34 15	35 48	34 48	34 88	34 70	34 94
S	20 46	20 66	20 37	21 11	21 40	20 80
Au	00 97	00 80	00 80	00 23	00 34	00 63
Total	99 46	101 13	99 43	99 13	99 66	99 97

There is a large number of publications dealing with the occurrence of invisible gold in arsenopyrite and other sulphides of gold ore[8-10] and different methods have been proposed (some of these are commercially adopted) for recovery of invisible gold in the refractory sulphide gold ores[11-15].

Factors that control the concentrations of structural or chemically bound gold in arsenopyrite include the gold content of the ore-forming solution, the prevalent physicochemical parameters during ore formation and subsequent metamorphism, the chemistry of the host rock and coprecipitation of gold together with arsenopyrite crystallization. The presence of submicroscopic intracrystalline inclusions of gold in arsenopyrite depends on the suitability of the host substrate for gold nucleation and on the initial gold solubility, which obviously decreases with changing conditions, leading to exsolution phenomena[3, 5].

It is needless to emphasize the economic importance of invisible gold in the arsenopyrite constituting the auriferous zones of Gadag as well as other gold deposits in the country, as the invisible gold may significantly account for the gold tenor. The fact that it is economically viable to extract ultrafine, invisible refractory gold adopting methods like bacterial leaching (as is presently being done in Wiluna mining operations in W. Australia[16], Santa Barbara mine in Brazil[17], Ashanti gold mine in Ghana[18], Barrik Goldstrike mine in USA[19] and Fairview mines in S. Africa[20]) or by additional treatment such as floatation coupled with smelting or oxidation of the concentrate and cynidation should stimulate a more detailed examination of the gold ores of our country to identify the quantum of invisible gold and its possible recovery.

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Heteropigmentation of plant impressions, Karai, Ariyalur, Tamil Nadu

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We present here the plausible causes for heteropigmentation of leaf impressions formed within the Karai-laminated clays. Geomorphic, mineralogical and sedimentological studies reveal that the different colouration of the leaf impressions are due to anaerobic, reducing, oxidizing, micro-environmental conditions formed in a shallow to deep, near-shore lake environment.

PLANT impressions, especially of the Upper Gondwana age, have played an important role in understanding the palaeo-vegetational canopy and palaeoclimate of sedimentary depositional basin. But not much work has been carried out in understanding genesis and colouration of the plant impressions. In this paper we have made an attempt to understand the plausible processes involved in pigmentations of the plant and palaeoenvironmental depositional conditions of sedimentations.

Karai is a small village lying 14 km west of Ariyalur (78°46'19":11°09'07") (Figure 1). Geomorphologically this area is dotted by isolated monadnocks and inselbergs of Archaeans lying towards the southwest of the study area. Presently, this area receives a mean annual rainfall of 800–1000 mm and the mean annual summer and winter temperatures vary between 20° and 28°C. The vegetational canopy is largely the subtropical plants. Karai is important because of the Karai clay mine, which is the chief source of clay for the ceramic industries.