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Nature of gold mineralization in certain areas in East Manipur, India, within the Indo-Burmese ophiolite belt

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Abstract: A probable plate-junction and ophiolite belt which run from Western China, roughly in a southern direction and extending up to the Andaman-Nicobar Islands in the Indian Ocean, is one of the least geologically known structures in the world.

Nearly all the rivers and streams flowing in this vast territory are known to carry minute amounts of placer gold. Our investigation of the source of this gold, in a very limited area of Eastern Manipur showed that primary gold mineralization took place in two phases—magmatic and hydrothermal. On the basis of the paragenetic mineral association, the magmatic phase can be further divided into two sub-phases—oxide phase, where the associated minerals are chromite and magnetite and the sulphide phase, where the associated minerals are pyrite, pyrrhotite and Co-Ni-Cu sulphides. In the oxide phase, gold occurs as minute blebs and flakes of gold-copper amalgam, sometimes as inclusions within chromite crystals and magnetite veins. In the sulphide phase, the presence of gold can be ascertained by chemical and other methods but visible gold particles are rare.

In the hydrothermal phase, gold occurs as auricupride within the serpentine veins, where the primary associated minerals are limonite-geothite; but the major source of gold is the high temperature quartz veins cross-cutting the ultrabasics and surrounding sedimentary rocks.

Some of the "granitic" rocks with which gold mineralization was formerly associated were found to be highly metamorphosed graywackes enveloped by ultrabasic rocks.

INTRODUCTION

In spite of a century old interest by geologists in the Indo-Burmese border regions (Mallet, 1882; Oldham, 1883), the region is geologically still one of the least known and least understood terrains in southeast Asia. Dense jungle, absence of road communication and political sensitiveness of the region have made the work of the geologists arduous. After (Staurt 1923), interest in the geology of this area has been renewed only in the early seventies. Work has been taken up on the Indian side by the Geological Survey of India, Nagaland Directorate of Geology and workers from Gauhati University. Recent published works (Duarah *et al.* 1983; Gossens, 1978; Mitchell & Mckerrow, 1975; Hutchison 1975; Deka, 1968 and 1969) on the region are mostly theoretical in nature and primarily based upon the earlier works, with little new information about the petrology, mineralogy and structure of the rocks of the region.

The mountain chain which runs roughly N-S in the Indo-Burmese border region which was originally considered as a southward bent arm of the Himalayas, and termed as "Burmese Arc", "Naga Range", Patkoi Range", "Khonjom Hills", "Arakan Yoma" etc. (Krishnan, 1956; Pascoe 1950) is now definitely known to be an independent structure. It begins in western China, runs southward and extends up to

Andaman-Nicobar islands in the Indian Ocean (Lee 1939, Deka, 1969). The present work is the result of a study of some very limited parts of this mighty range, confined mostly to the Ukhrul-Sirohi area of East District, and Moreh-Khudengthabi area of Tenganaupol District of the Manipur state. Ukhrul is the district head quarters of East Manipur District and Moreh is the border town situated just opposite the Burmese town of Tamu. The belt where these areas are situated has been identified as E.2. Naga hills belt by Hutchison (1975). Duarah *et al.* (1983) published a map of the area showing locations of ultrabasic massifs; which are unfortunately geographically inaccurate. Our investigation showed that the ultrabasic massifs are situated on the west of Moreh town; and ultrabasics in Ukhrul area are found both in east and west of the town of Ukhrul.

Gold in the Indo-Burmese border region

It has been known through the centuries that most of the rivers flowing out of these mountain ranges carry minute traces of gold which was panned by the agents of the kings of Assam, Manipur and Burma (Bion, 1913, Sarmah, 1951) and is still washed sporadically by the local people, specially in the west-flowing tributaries of Hukawng, Ningthi, Chindwin and Kabow rivers. Notwithstanding the knowledge of the geologists regarding the association of placer gold with the placer platinum group of minerals in this region (Mallet 1882, Maclaren 1904, Bion 1913, Chibber 1934, Pascoe 1950) no attention was given to the ultrabasic massifs and associated intrusives as the possible source of the placer gold. The author drew attention to the possibility in a seminar of the Geological Survey of India held in Shillong 1967 (Deka 1968).

Workers of the Directorate of Geology & Mining, Nagaland, first discovered the occurrence of traces of gold in the pyrite disseminations from a coarse grained gabbroic body located NE of Aniashu in the Tuensang District, Nagaland, during their 1974 field work (D.G. & M., Nagaland, 1978). The author first observed gold minerals associated with the oxide minerals (chromite and magnetite) and serpentine veins in 1979–80; gold minerals associated with sulphides in 1980–81 and gold-quartz veins in 1961–82 periods, in and around Sirohi and Khudengthabi ultrabasic massifs. On genetical considerations, the gold mineralization can be divided into two primary types: magmatic and hydrothermal. Magmatic gold minerals are found associated with the minerals chromite and magnetite which form an integral part of the intrusive ultrabasics, and with the flow type sulphide intrusives in the gabbro-pyroxenite complex. Hydrothermal gold is found in the serpentine veins formed due to the serpentinization of the ultrabasic intrusives, as auricupride and Au-Cu minerals; and in auriferous quartz veins as gold mineral having admixture of copper. These auriferous quartz veins are also found in the sedimentary country-rock adjoining the ultrabasic intrusive massifs.

General geology of the area under investigation

The area around the town of Moreh and Ukhrul comprises primarily of grey, slaty grey, reddish grey, brownish and buff coloured shale beds, collectively known as Disang shale of Upper Cretaceous to Lower Tertiary age, intercalated with sandy shale, sandstone, pelagic limestone, chert and cherty limestone. Duarah *et al.* (1983) reported radiolarian chert and beds of highly altered, black, glossy, crushed rocks which can be of volcanic origin. The rocks are highly folded, faulted and crushed in places. The general strike varies from NNE-SSW to NE-SW. The ultrabasic rocks are intrusive into them.

The rock suite can be safely considered to be an ophiolite belt as defined by Moore and Vine (1971), where the main intrusive rocks are peridotite, dunite, harzburgite, pyroxenite, gabbro and hornblende peridotite. The intrusive rocks form bodies varying in width from a few metres to several hundred metres. Lengthwise, individual exposures of ultramafic rocks may be traced for several hundred metres to several kilometres. These massive intrusive ultrabasic bodies are observed in Sirohi (Near Ukhrul), Gamnom, Khomjong, Kwatha, Khudengthabi (N.W. of Moreh) and Minou (S.W. of Moreh). Chromite-bearing Sirohi, Kwatha, Khudengthabi and Minou intrusives fall in a straight line N 8°E–S 8°W running for nearly 90 km. There may be many such intrusive massifs in the geologically unmapped areas of Manipur. These massive intrusives can be termed as "core ultrabasics' in the ophiolite belt. The pattern of rock distribution and mineralization in this belt conforms to that of a typical ophiolite belt, where Alpine-type podiform, nodular and stratified chromite are confined to serpentinised harzburgite. Peridotites are least serpentinised, pyroxenites are often schillerized. The basal part of the Khudengthabi is serpentinized and the upper part is mostly steatized. In Sirohi steatization is restricted but serpentinization is extensive. Veins of calcite and magnesite are observed in Sirohi rocks. The contacts between the ultramafic intrusives and the country rocks are mostly crushed and generally obscure. But in Khudengthabi area, half a kilometre south of the National Highway No. 39, in the mining road to quarry No. 1 the contact is well exposed where well stratified graywake beds and ultrabasic rocks are in normal intrusive contact. Within the contact zone, the ultramafic rocks are hornblende peridotite which in thin section shows hornblende crystals fraying out at the ends, implying intrusion in fluid or plastic state. Within the ultramafic intrusive itself the hornblende peridotite can be traced for nearly a metre. In this contact zone, finger-like remnants of recrystallized quartzo-feldpathic rocks are found within the hornblende peridotite, giving an appearance of quartzo-feldspathic intrusion within the ultramafics. These remnant graywakes, enveloped by ultramafics resemble typical granite in appearance, mineral content and texture. In the contact zone, the youngest continuous quartz veins cross-cut both the hornblende peridotite and graywakes. Quartz veins are by far more numerous in Sirohi massif, where in the field, they can be traced mostly as limonite-geothite veins with a central core of quartz. The quartz veins sometime follow the serpentine veins, silicifying serpentine, thereby proving themselves to be younger than the serpentinization phenomenon.

GEOLOGY OF THE GOLD MINERALS

It has been mentioned that the gold minerals are found associated with metallic oxide minerals, serpentines, sulphides and quartz veins. The mineralogy and textures of gold minerals of each of the paragenetic types differ significantly from each other.

Au with metallic oxides

In eastern Manipur, the dominant metallic oxide is chromite. Magnetite is mostly of secondary origin. Some small veins of magnetite are found in the western flank of

Khudengthabi massif. The chromite minerals are distributed in the intrusive as disseminated grains, pods, orbicules, nodules, pockets, massive short lenses and stratified settled layers. In Khudengthabi, high grade chromite occurs as massive, lensoid bodies of 4–6 metres length which are 20–70 cm thick in the middle and gradually tapers towards both end. Whereas low grade nodular and podiform chromite occurs in scattered pockets. In the Sirohi massif, settled texture in chromite is more common in the eastern and north-eastern flanks and nodular and podiform chromite in the western flank. In the southern flank of the Sirohi peak, a harzburgite block shows layered massive chromite at the bottom, nodular chromite in the middle and disseminated chromite crystals at the top in an unbroken succession.

The structures of chromite have been described in detail because only the massive chromite lenses or settled chromite layers and serpentine veins within these ore masses contain Au minerals. Study of nodular, podiform, and disseminated chromite ore and serpentine veins associated with these chromite ores under the ore microscope failed to reveal any Au minerals in them. Chemical probe also failed to reveal any trace of Au in them. In magnetite veins too, the presence Au is extremely rare and only in one instance positive identification was possible. Chromite-magnetite ores containing Au are generally encrusted with malachite and garnierite. This statement does not hold true to primary magnetite-free massive chromite, containing trace of Au.

Au minerals in chromite appear in polished section as extremely small yellow, pinkish yellow or cream yellow, round blebs of sizes varying from 10 to 50 μ having very high reflectivity, and are visible only under very high magnification. Distribution of such blebs is not uniform as they tend to occur as clusters within chromite grains. But as the chromite grains are crushed, such Au blebs were found to be not in contact with the chromite grain boundaries, thereby undeniably proving that they are inclusions within chromite crystals but these are extremely rare.

It is difficult to identify such small blebs conclusively, moreover Ramdohr (1969, p. 927) has observed that chromite crystals tend to contain fine blebs of sulphides. To remove this possibility, all such polished sections were etched with $AgNO_3$ (Ramdohr, 1969, p. 333) and as these minerals were unaffected, they are considered to be Au minerals. Subsequently this procedure of prior staining was abandoned as some grains were stained white (Schouten, 1962, p. 40; Deka, 1981). The yellow blebs have reflectivity much lesser than that of refined pure gold of 99.99 fine. Reflectivity measurement with absolute accuracy by photometer was found impossible due to the extremely small size of the blebs. By comparison method, reflectivity was found to be near 65% when red filter was used. The reddish tinge and comparatively lower reflectivity is probably due to the presence of copper in the gold in solid solution (Allman & Crocket, 1972).

Gold associated with serpentine

Gold mineralization in the serpentine veins is confined to the same ore bodies where Au mineralization is observed in oxide minerals, only in far greater abundance. Gold minerals observed in the serpentine veins texturally differ from Au minerals found in oxides. The former are of flaky nature, and even when they are globular in appearance, etching reveals this flaky texture. The size of individual flake is 0.1 mm or lesser, but as aggregates they can form globules or dendrites measuring up to 1.5 mm in size. Colour varies from reddish yellow, yellow to creamy yellow. Reflectivity is significantly lower than that of pure gold, varies widely from grain to grain but stays within the limit of 60–70 %. The mineral was identified as gold-copper mineral but the under oil lilac tinge described as characteristic of auricupride by Ramdohr (1969, p. 339) was found to be absent in freshly polished samples. Though they develop this tint within a few hours of exposure to air, after a few days exposure the "lilac tint" is observable even without oil immersion. Due to the quick tarnishing nature of the mineral, reflectivity decreases significantly with exposure. The mineral is weakly anisotropic which is observable even in air, bireflection is absent.

Ramdohr (1967) has identified three gold copper minerals in the serpentine veins cross-cutting ultrabasic rocks namely, Au_3Cu, Au Cu and $AuCu_3$ (auricupride). In the present case, it has not been possible to make such fine distinction but the anisotropic nature of the mineral indicates its possible composition to be CuAu, which crystallizes in tetragonal system (Allmann & Crocket, 1972).

Etching data of the minerals confirm the presence of Cu and Au. No reaction was observed with both concentrated HCI and HNO_3 up to one minute while prolonged exposure diminishes reflectivity. Aqua regia exposure up to five minutes results in the formation of green crusts, removable by light rubbing with cotton. This crust gives positive Au in benzedine tests. If aqua-regia etching is followed by $KMnO_4$ + KOH, the mineral edges turns brown and black, and the stains are not removed when rubbed with cotton. The contral part of the flakes are relatively unaffected, indicating that the copper percentage is higher near the edges of the flakes. This method of etching also makes the aggregate nature of the globules distinct (Deka, 1981). Prolonged exposure to $AgNO_3$ tends to form a white coating on the mineral, removable by light polishing.

Gold minerals associated with sulphides

The author does not have any direct knowledge about the field association of the sulphide ore bodies found in the Indo-Burmese ophiolite belt. Sulphide ore samples were provided by the courtesy of geologists of the Geological Survey of India and the Directorate of Industries, Government of Manipur.

The mineral association of the sulphide samples from the Sanalog gorge near the international border resembles the Cyprus-type sulphides as described by a number of authors (Panayiotou, 1979, Moore & Vine, 1971). The sulphides occur within the black, non-crystalline, ferromagnesian mass, which has been tectonically deformed. The metallic minerals identified are pyrrhotite, millerite, covellite and pyrite with small specks of gold electrum. According to S. Ghosh (personal communication) nickel mineralization is secondary, and is younger in age. Gold content in this type of ore varies from 7 to 10 ppm.

The second group of sulphide samples some from Longchow river valley, that is in the western flank of the ophiolite belt, where dominant minerals ore pyrite and pyrrhotite and where no Cu, Ni or Au minerals could be traced.

Gold mineralization in quartz veins

In the Indo-Burmese ophiolite belt, Disang shales, sandstones, pelagic limestones and graywakes are intersected by numerous quartz veins which are definitely younger in age then the ultrabasics. These veins from complex networks where individual vein may be hairlike or a few centimetres thick. The quartz veins may be milky-white, transparent or may be of bluish-white colour. Some of these veins, especially where the blue quartz veins intersect slightly crushed silicified limestone, are auriferous. The highest concentration of Au mineral was found along a fault plane near the 5 km post in the Ukhrul-Jasami road, which is 2 km east of the nearest visible ultrabasic dyke and 5 km west of the Sirohi massif.

The country rocks are limestone, shale and sandy shale. The rocks have been pulverised and silicified where ferruginous shales have been altered to jasper-like rock. The limestone patch is a few hundred metres in length, but the intersecting quartz veins continue in shales both towards north and south parallel to the ultrabasic intrusives. The quartz veins outside the limestone patch were found to be barren of Au mineral.

The limestone is crystalline and is often banded with secondary calcite veins. Calcite crystals are often seen prominently on the surface of the rock. Within the limestone, quartz veins form a fine network, chlorite is often present in the veins. The ferruginous minerals are magnetite, limonite and goethite.

Gold minerals are indiscernable in hand specimen, but becomes visible as bright spots even to the naked eye on a polished surface. The grain size is generally 1 mm or smaller but larger grains are also present. Gold minerals are observed only in the fine quartz veins, but never within calcite. Quartz veins of more than 5 mm thickness are also barren. Gold minerals are intimately associated with the magnetite grains present in the quartz veins, and sometimes even form partial encrustation on the magnetite crystals, thereby proving themselves to be younger than the magnetite. Goethite is younger to magnetite as it also develops in the fractures of the magnetite crystals, and sometime forms encrustration on the magnetite crystals. Au and goethite are sometimes deposited within cracks and fractured quartz grains.

Colour of gold minerals varies from yellow to pale yellow to creamy yellow. Reflectivity varies from 65–70 %. Lilac and reddish tints are much weaker than in gold-copper found in oxide minerals. Weak anisotropism is visible even in air. Polishing hardness is much higher than that of pure gold. Etching character are the same as those previously described for Au minerals in serpentine.

Genesis of Au minerals

Gold mineralization within the ophiolite belt is one of the least studied phenomena and hitherto gold mineralization in ophiolite has been reported mostly from sulphides and andesite rocks.

Ramdohr (1967, 1969) was the first to report gold mineralization genetically related to serpentinization.

In the Indo-Burmese ophiolite belt, each of the above mentioned types of Au minerals with different mineral paragenesis have different genetical history.

Au associated with metallic oxides

Au and Cu have very proximate melting points (Au = 1064°E, Cu = 1083°; Handbook, 1959) and they are also known to form solid solution both in laboratory and in nature (Handbook, 1959). Therefore the existence of Au-Cu blebs directly solidified from a magmatic melt raises no theoretical problem. It can be envisaged that still liquid blebs of Au-Cu were left as inclusions in crystallizing chromite and magnetite.

Thayer (1969) surmised that stratified structures in Alpine chromites were formed due to slow accumulation, over a long period of time by gravity settling. The existence of Au-Cu minerals only within the chromite-magnetite of the "stratified type" and their absence in the podiform and nodular chromite shows that Au-Cu gets separated from the magma by gravity settling along with the slow deposited, gravity-settled chromite-magnetite. Ramdohr (1969, p. 927) has described frequent occurrence of very fine sulphide blebs as inclusions within the chromite grains. One should not rule out the possibility that some of these inclusions are actually Au minerals because the oxygen-sulphur regime at high temperature as postulated by Betekhtin (1955) makes the possibility of the occurrence of sulphide minerals as inclusions within the high temperature oxide minerals quite slim. The same is supported by the sulphur solution theory in high temperature silicate magma as envisaged by Naldrett (1973).

Gold associated with serpentine

The deposition of Au-Cu minerals within the serpentine veins within the ultrabasic rock at a temperature below 390°C or probably considerably less has been established by Ramdohr (1967). Persistant association of geothite with the hydrothermal Au-Cu shows it to be a low temperature phenomenon. The deposition of Au-Cu is intimately related to the serpentinization, where the water entrapped in the sedimentary rocks would get heated during the intrusion of the ultrabasics and the hot water would circulate also within the ultrabasics, thereby serpentinizing the silicate minerals. The same water is capable of dissolving (flushing) Au from the metallic oxides and reprecipitation (Helgeson & Garrels, 1968). The carbon-rich solution responsible for the serpentinization is also capable of depositing copper as malachite.

T.P. Thayer (Personal communication) has suggested that the gold-copper blebs observed as inclusions in the chromite grains may be of replacement origin. This suggestion was not found acceptable because the Au minerals of different paragenesis have different textures (blebs/flakes) and the mineral equilibrium consideration shows that gold-copper cannot replace chromium or magnetite at such a low temperature where geothite is stable.

Gold in sulphides

The presence of Au with the sulphides of the ophiolite belt has been reported from various parts of the world (Thayer, 1976, Panayiotou, 1979 and Naldrett, 1973). Lack of direct knowledge by the author about this type of ore in the Indo-Burmese border region makes it difficult to throw any new light on this type of mineralization.

Gold in quartz veins

It is difficult to understand the genetical relationship between the auriferous quartz veins traversing the limestone, shales and ultrabasics and these of the massive ultrabasic intrusives of Sirohi and Khudengthabi. The ultrabasic complexes are the nearest visible intrusive bodies and some of the metallic oxides and serpentinite are auriferous. Gold as well as quartz could have been flushed out from the ultrabasics by the heated water during the emplacement of the ultrabasics or by subsequent hydrothermal activities (Helgeson & Garrels, 1968; Morey *et al.* 1962) and deposited in favourable host rocks. It is interesting to note that magnetite-bearing quartz veins are younger than the serpentinization process as shown by the silicification of serpentine veins. Gold and goethite are even younger than quartz and magnetite as the former minerals often develop along the fissures of quartz veins and form encrustation around magnetite grains.

Hydrothermal gold precipitation is generally associated with quartzo-feldspathic and andesitic rocks (Lindgren, 1933; Tatsch, 1975.) but in the present region, no quartzo-feldspathic rocks except metamorphosed graywacke have been reported to date.

Gold mineralization and plate tectonics

The present knowledge about the geology and structure of the Indo-Burmese ophiolite belt is too meagre to form any basis for a meaningful discussion on relationship between plate tectonics and gold mineralization.

A major school of geologists studying the metallogeny of sulphide mineralizations in respect to plate tectonics postulates that in such a belt the remelted crust is depleted in sulphur as they tend to settle down and the chromite-harzburgite fraction is left as refractory residium (Naldrett, 1973; Thayer, 1976). It is definite that the ultrabasic rocks are sulphur free but the occurrence of Au-Cu in chromite and serpentinitie indicates that metals of low melting points were not removed from the magma which gave rise to the chromite-magnetite harzburgite-peridotite rock complex, and only the sulphur was removed. Naldrett (1973) quotes Haughton and Shinner that raising the temperature of a basaltic melt from 1100°C to 1200°C causes a five-fold increase in sulphur solubility. The solubility of sulphur in a silicate melt is strongly dependent on temperature. Field and laboratory evidences gathered in the study of ultrabasics of Indo-Burmese ophiolite belt indicates that the above statement is true only for sulphur, but should not be extended to "sulphides". The analysis of malachite encrusted chromite-magnetite ore show the following concentrations of elements, Cu-1.04 %, Ni-trace, S-nil.

Thayer (1967) considered that the same Alpine mafic intrusives can give rise to stratified and podiform chromite and that stratification is due to gravity-settling. This is fully supported by the fact that Au-Cu minerals are found with the compact stratified chromite ore within serpentine veins of the lower horizon. Absence of Au-Cu in the podiform and nodular chromite in the serpentine of the upper horizon indicate that the Au-Cu minerals are the elements which settled along with the first batch of chromite crystals, forming lenses of stratified ore beds. Nodular, podiform and disseminate chromite are the aggregate of chromite grains which crystallize subsequently within the same intrusive mass.

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