Rare exotic mineral inclusions in Mesoarchaean Chromitites from Bangur, Orissa, India

Worldwide, chromitites compared to associated silicate rocks, are commonly characterized with elevated platinum group element (PGE) contents. The two prominent working chromite mines, Bangur and Baula in Orissa, were sampled to study the chromitite and the PGE relationship. The eastern part of the Indian Shield is composed of a high-grade metamorphic terrain known as the Chhotanagpur Craton in the north and a granite-greenstone terrain known as the Singhbhum Craton in the south. The latter is mainly composed of several granitoid batholiths, which are largely surrounded and intervened by supracrustal rocks. Both Bangur and Baula have been studied earlier, but petrological data (i.e. magma evolution and ore-forming processes) are scanty. We report here the presence of exotic minerals in chromitites obtained from drill cores of Orissa Mining Corporation (OMC) leased area. This may help in future studies to unravel the tectonometamorphic history.

The Southern part of the Baula Complex includes three main units, viz. chromitite-bearing ultramafic rock, Gabbro–Anorthosite unit and intrusive Bangur Gabbro, the last being a gabbro–norite with a porphyritic texture that locally cuts and incorporates the dunite and its chromitite layer. The dunite and chromitite inclusions are present within the gabbro[1]. The Bangur Gabbro also cuts the Gabbro–Anorthosite unit giving rise to a magmatic breccia (the Breccia zone). The age of Bangur Gabbro[2] is ~3.1 Ga. The Breccia zone is 1–40 m thick with a strike length of 2000 m[2] (ref. 3). The nature, size and shape originate from the different parts of the ultramafic unit. The matrix was predominantly gabbro and plagioclase pyroxenite corresponded to the Bangur Gabbro.

Various analytical techniques were applied to different types of samples to obtain relevant data. All mineralogical data were gathered at the Institute of Electron Optics, University of Oulu, Finland. Twenty polished mounts were studied. The accessory minerals and PGMs were investigated using both reflected light and field emission scanning electron microscopy (FESEM); FESEM–

Carl Zeiss ultraplus model and EPMA Jeol Super probe were utilized for this study. Chemical compositions were determined with an Oxford Inca energy-dispersive analytical system (EDS) attached to FESEM, operating at accelerating voltage of 20 kV, beam current of 2.9 nA and measurement time 60 s. Mineral phases were identified on the basis of quantitative EDS analyses. Atomic ratios were calculated with the ZAF-4 program, which performs the necessary corrections for the overlapping peaks of different elements.

During our recent studies on chromitites from Bangur, in addition to PGMs, unusual rare and exotic rare mineral inclusions were identified: chromite inclusion in zircon, galena in chromite, antimony and millerite. Galena and minor amounts of antimondes mainly occur in the chromite grains and in secondary silicates. Galena is present in minute amounts with size ranging from 3 to 20 microns (Figure 1 a).

Zircon is irregularly distributed in the chromitite samples. In four polished mounts, ca. 25–30 grains, with a diameter up to 50 microns were observed. Individual zircon grains (Figure 1 b) are aligned roughly parallel to the chromite bands. Most of the grains are subhedral to anhedral and occur as inclusions within chromite grains. No clear zoning is visible in zircon. It is noteworthy that zircon contains chromite inclusions (Figure 1 c). In six polished mounts, ca. 10 zircon grains were found that contain chromite inclusions up to >20 microns in size. Auge et al.[2] and Mondal et al.[3] have reported the presence of various PGE minerals in the sulphide-rich and sulphide-poor zones in the Bangur chromitites, including sperrylite, merenskyite, braggite, isoferroplatinum and ruarasite. We discovered the same minerals in our samples as inclusions in chromite (Figure 1 d). The capability of FESEM was utilized to analyse the PGMs with a size down to 0.2 microns with a reasonable accuracy.

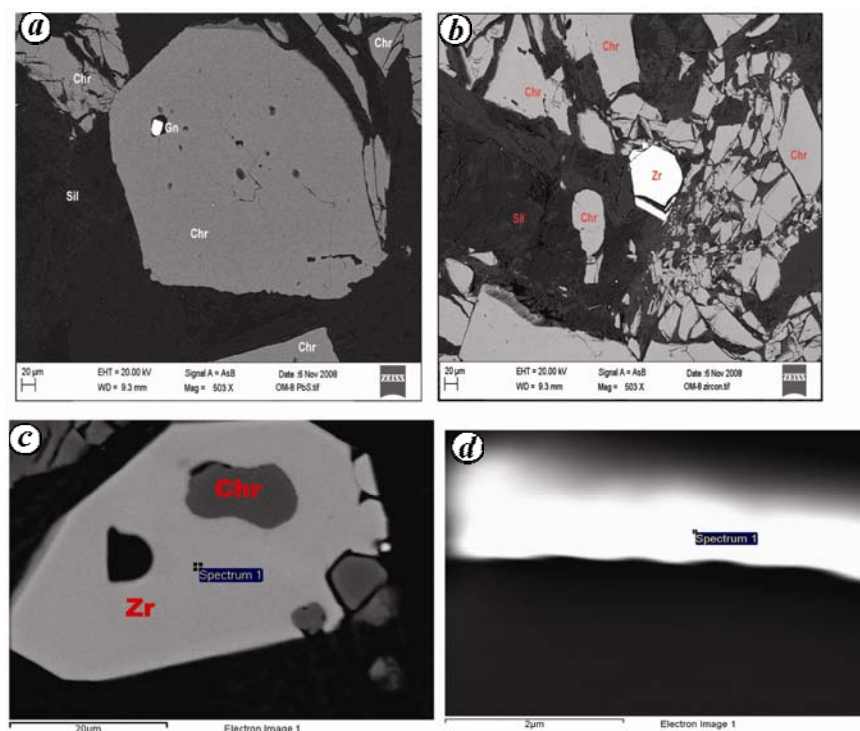The galena consists 86.18 to 88.58 wt% Pb with minor amounts of Fe up to 0.30 wt%, but no measurable Sb or

Figure 1. Field emission scanning electron microscope BSE image of (*a*) galena in chromite, (*b*) zircon in cataclasied chromite, (*c*) chromite in zircon, (*d*) sperrylite in chromite.

Ag. The mineral formula reflects to be pure galena, i.e. PbS. The galena bearing chromite and the adjacent chromite grains show a slight increase in chromium contents with traces of vanadium also. The zircon grains contain minor amounts of hafnium (~1.40 wt%) and thorium (~0.066 wt%). The zirconium oxide is ~68 wt% and silica up to 35 wt%.

The presence of exotic minerals like zircon or galena in chromitites has been reported earlier. Zircon as individual grains in the matrix between chromite and silicates was found in the Finero Complex in Southern Alps[4]. Small zircon grains as inclusions in chromites have been documented from typical layered intrusions such as the Bushveld Complex, South Africa (Plat-Reef[5], UG-2 and Merensky Reef[6,7], Kemi intrusion[8]) in northern Finland and Campo Formoso[9] complex in Brazil. Also, galena is present as inclusions in chromite grains from Kemi and Campo Formoso.

The inclusions present in our samples are: zircon in chromite; chromite in zircon; galena, silver, antimony and millerite in chromite. The most enigmatic problem is to explain how galena and zircon were formed within chromite or chromite within zircon.

The studies carried out on sulphides as a function of temperature by Barton and Skinner[10] demonstrated that galena needs higher $f S_2$ to form pyrrhotite. It is, therefore, not likely that it forms before pyrrhotite. The slope of the buffer lines indicates that at increasing temperature (i.e. magmatic conditions) the difference will get larger and no crossover (i.e. galena becomes stable at lower $f S_2$ than pyrrhotite) will occur. Galena melts congruently at $1127 \pm 5°C$ and pyrrhotite melts congruently at ~1190°C. At the moment when an immiscible sulphide melt forms, the much more common iron in the basaltic silicate melt will grab the sulphur before lead could. This strongly supports the hypothesis that the galena grains were formed by hydrothermal processes or as Irvine[11] reported that these types of inclusions may also represent droplets of trapped liquid from a contaminant salic melt. These were also confirmed by the recent studies[12], suggesting that these kinds of inclusions may also form due to specific chemical reactions between anhydrous silicates from the chromite-precipitating magma (olivine and pyroxene) and trapped volatile-rich silicate melt and fluids occurring inside the inclusions.

Pyrite is the common Fe–S compound in low temperature massive sulphide deposits, releases sulphur to form pyrrhotite, during the progressive regional metamorphism[13]. The auto regression of pyrrhotite will result to pyrite upon cooling[13,14], which implies that a sulphur-bearing fluid may be common part of peak and retrograde metamorphism assemblages.

In any case, pure galena cannot form from a basaltic magma and therefore has to be either hydrothermal in origin, or it is a relict of overprinted magmatic sulphide. If it would be overprinted magmatic sulphide, the galena could only be a very small fraction of the original sulphide inclusion. Sometimes, iron can be resorbed into the chromite[5,15]. There could not be a possibility of any crustal contamination as studied[3] from osmium isotopic studies. We conclude that galena and zircon are trapped melt inclusions in the chromitite.

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