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THE RAMPURA AGUCHA ZN-PB-(AG) DEPOSIT, RAJASTHAN, NORTH-WESTERN INDIA

von

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Rampura Agucha is a stratiform, sediment-hosted Zn-Pb-(Ag) deposit located some 220 km southwest of Jaipur in Rajasthan State, India. Since its discovery in 1977, Rampura Agucha has become one of the most significant base-metal deposits in India producing 900.000 t/a ore. Proven reserves are 39.2 Mt, probable reserves 13.8 Mt, and possible reserves 10.7 Mt (total 63.7 Mt) grading 13.6% Zn, 1.9% Pb, 9.58% Fe and 45 ppm Ag. The deposit occurs in the oldest part of the Bhilwara Belt at the contact with the Archean basement („Banded Gneissic Complex" - BGC). The Bhilwara Belt, consists of a pile of metasedimentary rocks intruded by igneous rocks. It developed as a result of crustal extension of the Archean basement about 2.0 Ga ago.

The deposit occurs in a doubly plunging synformal structure of elliptic shape, comprising a sillimanite-graphite-mica schist, which hosts the mineralization, enclosed in garnet-biotite-sillimanite gneiss with minor bands of amphibolite, calc-silicate rocks, leucocratic rocks and mylonites. The orebody is lens-shaped with a NE-SW strike length of 1600 m and a width varying from a few meters in the northeast to as much as 100 m in the central and SW section. The orebody dips between 50 and 80° SE and has been delineated by drilling to a depth of 370 m from surface. The deposit has an oxidized gossan and a small zone of partial oxidation between gossan and orebody.

The mineralization occurs predominantly in the graphite-sillimanite-mica gneiss, which consists of quartz, alkalifeldspar, plagioclase, sillimanite, graphite and various micaceous minerals (muscovite, biotite and chlorite). Sphalerite, the most important ore mineral, occurs with galena, pyrite and pyrrhotite in varying proportions. A large variety of minor sulfide phases has been identified within the ore, especially chalcopyrite, arsenopyrite and Ag-(Pb)-Sb sulfosalts. Ore microscopy of samples from 20 drill-core intersections from the orebody did not reveal any metal zonation within the orebody although the Zn/Pb/Fe ratio may vary within meters. Although sphalerite is the most important base metal sulfide at Rampura Agucha, small sections of the orebody can be dominated by either galena or pyrrhotite.

In the Late Proterozoic the lower crustal rocks of the BGC were thrust over the western margin of the Bhilwara Belt resulting in high grade metamorphism in the Rampura Agucha area. Peak metamorphic conditions of upper amphibolite- to granulite facies were estimated by garnet-clinopyroxene geothermometry (~700°C), sphalerite geobarometry (~7 kb) and fluid inclusion studies. Continuously zoned garnets with decreasing XMg towards the rim indicate a single-phase metamorphic event. The mineral assemblages of the country rocks still represent high grade metamorphic conditions; sericitization and chloritization are the only indicators of retrogression. The high-grade metamorphic event resulted in a high degree of recrystallization of the ore (coarse-grained sulfide aggregates with grain sizes exceeding 3 mm) and an obliteration of most of the primary sedimentary textures. Remobilization of galena and sphalerite and to a lesser degree of pyrrhotite into cracks of quartz and feldspar is widespread. In the course of this project, the approximate age of metamorphism of ~950 Ma has been determined by $^{39}Ar/^{40}Ar$ dating of metamorphic minerals: An amphibole age of 909 Ma, two muscovite ages of 888 and 874 Ma and two biotite ages of 797 and 788 Ma vary due to different closure temperature of the three minerals.
The Rampura Agucha deposit contains assemblages rich in Ag-(Pb)-Sb sulfosalts. Freibergite, pyrargyrite, stephanite, argentite, dyscrasite and various Pb-Ag-Sb sulfosalts occur either within or close to large aggregates of galena. Freibergite, pyrargyrite and stephanite are also present in galena-bearing veinlets in silicate minerals. Electron microprobe analyses reveal an average Ag-content of 31 wt.% in freibergite, whereas galena is devoid of Ag. The sulfosalts are Sb-rich end members of the respective solid-solution series with only limited As. The assemblages were affected by recrystallization and reequilibration during high grade metamorphism and subsequent cooling. Pyrargyrite presumably formed by replacement of freibergite and of Pb-Ag-Sb sulfosalts, stephanite by decomposition of pyrargyrite and argentite and dyscrasite by exsolution from galena.

The Rampura Agucha Zn-Pb-(Ag) deposit contains a number of rare oxide minerals. These have been formed as a result of high grade metamorphism. Gahnite is a common minor phase in the orebody and has formed mainly by desulfurization of sphalerite. Pyrophanite-ilmenite is very rare and occurs intergrown with rutile, the major oxide mineral. Two new compositional varieties of rare oxide minerals, a Cr-V-spinel and a Cr-V-oxide $(Cr,V)_2O_3$ have been determined. The compositions of these two minerals differ from known end-members because of considerable substitution of Cr for V. Similar oxide minerals have been reported from several high-grade metamorphic deposits and areas. The rare V-oxide schreyerite $V_2Ti_3O_9$ also occurs as exsolution lamellae in rutile at Rampura Agucha. These unusual compositions are attributed to the locally high V-contents in the precursor sediments; they further underline the isochemical nature of regional metamorphism of the orebody.

Dravite-rich tourmaline with Fe/(Fe+Mg) ratios around 0.02 occurs at the hanging wall contact of the orebody with the paragneiss and is clearly associated with the mineralization. Tourmaline from the stratabound ores is distinguished from schorl-rich tourmaline of two pegmatite samples which show Fe/(Fe+Mg) ratios of 0.43 and 0.62, respectively. At Rampura Agucha dravite-rich, pre-metamorphic tourmaline or its precursor mineral is very probably of exhalative origin, formed by the same hydrothermal fluid as the associated sulfide minerals and was later affected by recrystallization during high-grade metamorphism.

Fluid inclusions in quartz of the country rocks and dravite-rich tourmaline from Rampura Agucha deposit have been investigated by microthermometry and Raman microspectrometry. Four different main types of fluid inclusions in quartz can be distinguished: (1) gaseous (CO_2, partially mixed with CH_4-N_2), (2) low salinity aqueous inclusions (0-8 eq. wt.% NaCl), (3) CO_2-H_2O inclusions in dravite and (4) high salinity aqueous inclusions. Low density CO_2-rich and low salinity H_2O inclusions are contemperaneous and occur, as well as CH_4-N_2 inclusions, in close association with sulfide mineral inclusions. This indicates immiscibility between gaseous and aqueous phase and participation of these fluids during the remobilization of the ore. H_2O-CO_2 $\pm$ CH_4-N_2 inclusions in dravite-rich tourmaline represent the metamorphic fluid, trapped during metamorphic recrystallization. Raman spectra of graphite indicate upper greenschist-facies metamorphic conditions which suggests that graphite re-equilibrated with the CO_2-rich phase during retrograde metamorphism.

The deposit was formed by convective seawater circulation in zones of crustal extension, indicated by the occurrence of former subalkaline, tholeiitic ocean floor basalts at the deposit which may have contributed the heat for the convection cells. High graphite contents in the host rock and low $\delta^{13}C$ values indicate a reducing environment during precipitation of the sulfides. The predominance of former shales and only subordinate carbonaceous rocks suggests also a somewhat deeper, tranquil depositional environment, e.g. a third order basin. A Mid-Proterozoic age of 1.8 Ga has been suggested for the Rampura Agucha deposit.

Rampura Agucha has many features in common with other sediment-hosted deposits that are interpreted to be of submarine exhalative origin. Despite the close association of the orebody with amphibolites (former basalts) and felsic magmatites, Rampura Agucha can be regarded as a Sedex deposit due to the stratiform orebody, high graphite contents of biogenic origin and the predominance of former shales and minor marls and carbonates which point towards a tranquil, reducing, submarine basinal sedimentary environment.