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Role of $CuSO_4$ in the Oxidation and Secondary Enrichment Deposit Formation at Ambaji, Gujarat, India

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***Abstract*- Rocks of Todgarh Formation belong to the Kumbhalgarh Group are exposed in the study area, which are intruded by the granites at Gabbar hill and near Koteshwar. These intrusive become the source for the famous multi-metal deposits of Ambaji. A thin layer of malachite and limonite indicate the presence of buried wealth of sulphides at Ambaji. Oxygen and water are the powerful agents that react with the mineral pyrite (FeS_2) to form strong solvents like ferrous sulphate and sulphuric acid. Ferrous sulphate readily oxidized to ferric sulphate and ferric hydroxide, the former being further react with chalcopyrite to produce $CuSO_4$. Further with the natural salt like Na_2CO_3 role of $CuSO_4$ becomes crucial, which give rise to mineral malachite. The down trickling solutions contain metallic ingredients, deposited as oxidized ore deposits above the water table and as secondary sulphides below the water table.**

***Key words*- Ambaji, Deposits, Multi-metal, Oxidation and secondary enrichment, Sulphides.**

I. Introduction

Physiographically, the state of Gujarat comprises of three distinct zones such as Mainland Gujarat, Saurashtra and Kachchh. The Mainland Gujarat is further divisible in to two well defined sub-zones named as Eastern rocky highlands and Western alluvial plains [1].

Ambaji– part of Eastern rocky highlands is a holy town of Danta taluka, located in northeast part of Gujarat state in Banaskantha district. It is situated about 180 km in north direction from Ahmedabad with 24° 21' N latitude and 72° 15' E longitude. It is famous for its Ambaji temple, natural beauty as well as for marble and multi-metal deposits. It is well connected to the other cities of Gujarat by road network. Figure 1 shows the location of Ambaji area in Banaskantha district of Gujarat.

II. Geology Of The Study Area

Gujarat state exposes the rocks of Precambrian, Mesozoic and Cenozoic eras. Hard rocks are covering about 49% of the total area of Gujarat. Ambaji area comprises of rocks of Precambrian metamorphites and associated intrusives. In the northeastern part of Gujarat Precambrian rocks are represented mainly by Proterozoics, which is divided in two parts – Palaeoproterozoic and Palaeoproterozoic-Mesoproterozoic. Aravalli Super-group of rocks belongs to Palaeoproterozoic and represented by mica schist, phyllite, and quartzite etc rocks. Delhi Super-group is subdivided in to Gogunda Group, Kumbhalgarh Group and Sirohi Group, which are intruded by Phulad Ohiolite suite, Sendra-Ambaji Granite, Godhra Granite, Erinpura Granite and Idar Granite [2].

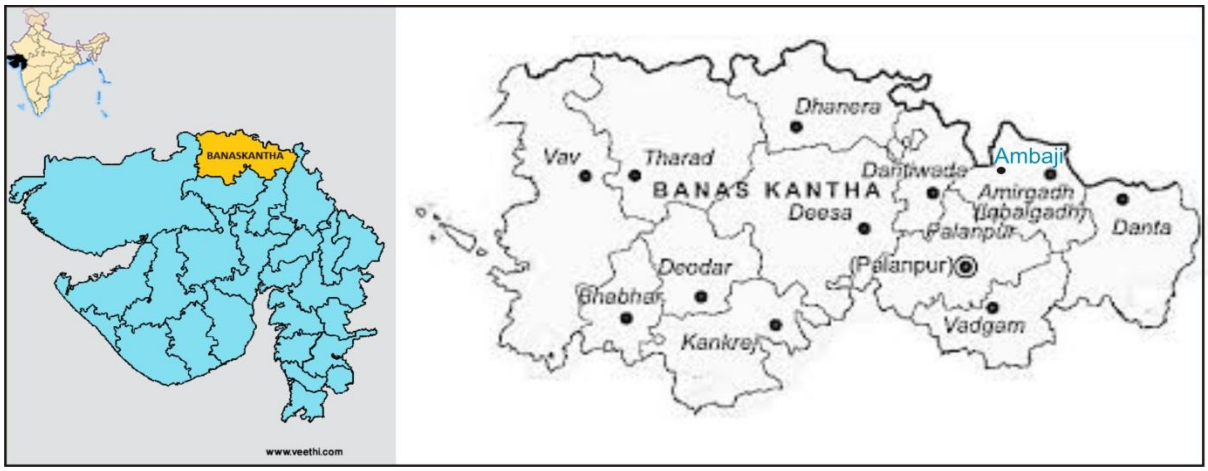

Figure 1: Location Map of the study area.

Study area comprises rocks of Kumbhalgarh Group ($pt_{12}dk$) and is intruded by Sendra-Ambaji Granite (ypt_2sa) intrusive, which is famous as Gabbar hill (Fig. 2).

Rocks of Kumbhalgarh Group dated, based on Rb-Sr dating as 1800-2000 Ma age and Sendra-Ambaji Granite as of 1228 Ma age [3].

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Rocks of Todgarh Formation belong to the Kumbhalgarh Group are exposed in the study area. Biotite gneiss, mica schists, marbles, amphibolites etc are the rocks, which are intruded by the granites at Gabbar hill and near Koteshwar. Koteshwar microgranite is dated as 756 ± 56 Ma age [4]. These intrusive become the source for the famous multi-metal deposits of Ambaji, which contains chalcopyrite ($CuFeS_2$), galena (PbS) and sphalerite (ZnS). Gujarat Mineral Development Corporation (GMDC) holds a mining lease at Ambaji since 1973.

These deposits constitute about 8 million tonnes of reserves of sulphides of copper, lead and zinc with about 10% of total metal content.

III. Geochemistry Of The Deposits

Gossan is a Cornish word used to name the peculiar oxidized outcropping cellular mass of iron oxide such as limonite and gangue. A thin layer of malachite [$CuCO_3Cu(OH)_2$] and limonite [$2Fe(OH)_3$] is found to overlie the subsurface sulphide deposits of Ambaji. These disseminated deposits are the indicators that point to what lies beneath the surface. Limonite is almost universally present in gossans in a variety of positions, forms and colours. Most ore deposits usually sulphides, are found capped by Gossans. Hence, the finding of malachite and limonite indicate the presence of buried wealth of sulphides at Ambaji.

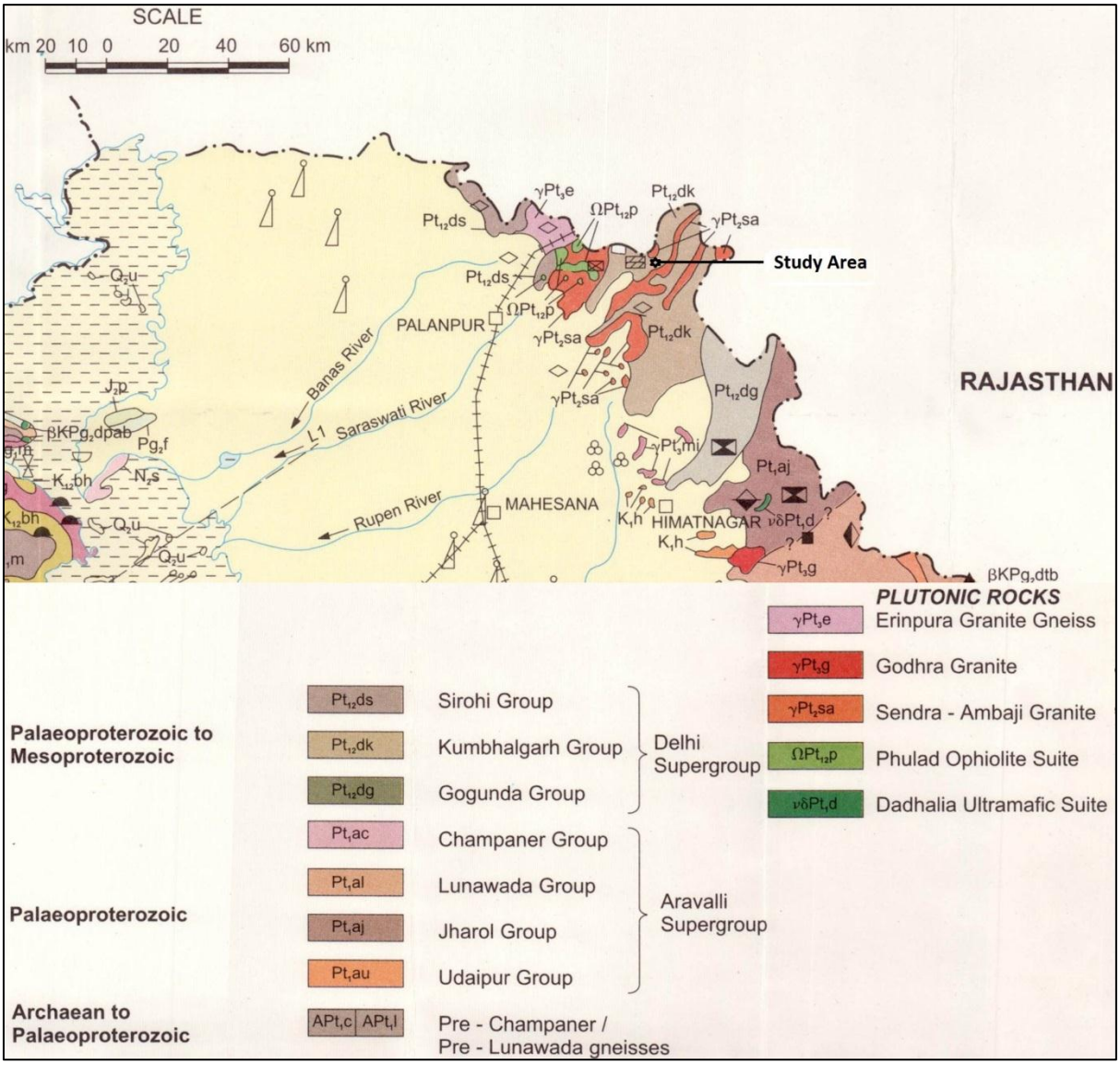

Figure 2: Geological Map of the study area (Modified from GSI map).

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When the ore deposits become exposed to atmosphere by erosion, they are weathered along with enclosing rocks. Oxygen and water are the powerful agents of weathering and when they are combined with the constituents of ore deposits, a natural chemical process is started. In the initial stage through oxidation minerals are altered and solutions are formed in the zone of oxidation. These agents react with the mineral pyrite (FeS_2) to form strong solvents like ferrous sulphate and sulphuric acid. Ferrous sulphate readily oxidized to ferric sulphate and ferric hydroxide.

$$FeS_2 + 7(O) + H_2O \rightarrow FeSO_4 + H_2SO_4$$

$$6FeSO_4 + 3(O) + 3H_2O \rightarrow 2Fe_2(SO_4)_3 + 2Fe(OH)_3$$

The part played by $Fe_2(SO_4)_3$ as a solvent with pyrite and chalcopyrite, which are present at Ambaji can be seen in the following equations.

$$FeS_2 + Fe_2(SO_4)_3 \rightarrow 3FeSO_4 + 2S$$

$$CuFeS_2 + 2Fe_2(SO_4)_3 \rightarrow CuSO_4 + 5FeSO_4 + 2S$$

General tendency of the chemical changes in the zone of oxidation is to break down complex minerals and form simple ones.

Further in the presence of natural salt like Na_2CO_3 role of $CuSO_4$ becomes crucial, which give rise to malachite [$CuCO_3Cu(OH)_2$] mineral.

$$2CuSO_4 + 2Na_2CO_3 \rightarrow CuCO_3Cu(OH)_2 + 2Na_2SO_4 + CO_2$$

The down trickling solutions contain metallic contents which may be deposited within the zone of oxidation and give rise to oxidized ore deposits. For the most part, the ores are deposited in the lower part of the zone of oxidation. The metals in solution that escape in the zone of oxidation, trickle down to the water table, where there is no available oxygen and hence are deposited as secondary sulphides. The metals removed from above are thus added to those existing below, thereby enriching the upper part of the sulphide zone. Schematic diagram of deposits formed due to oxidation and secondary enrichment process is shown in Fig. 3. This process repeated from time to time because of progressive erosion. Thus, because of secondary enrichment, poor deposits are made richer, unworkable deposits are made workable and the richer ones are enriched more.

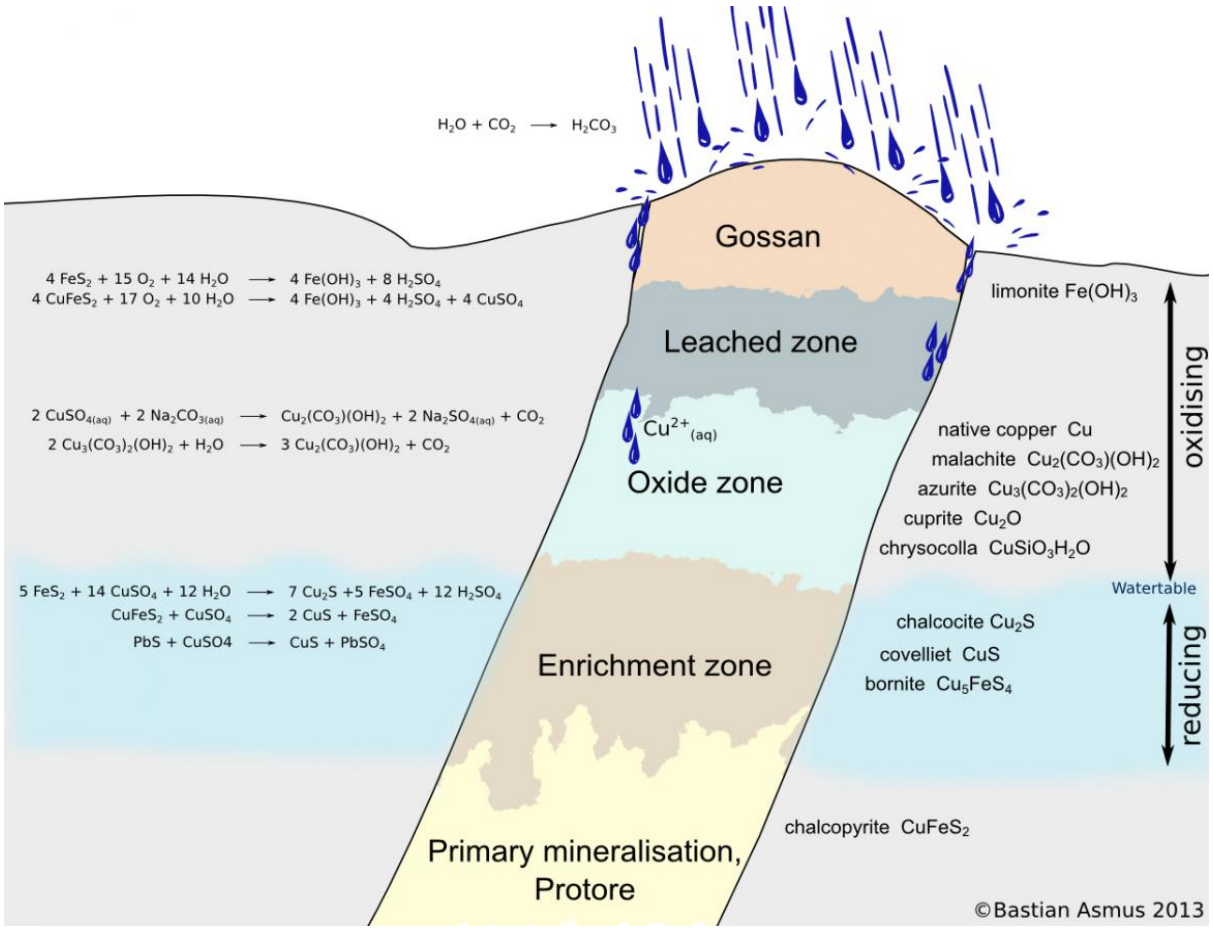

Figure 3: Schematic diagram of deposits formed due to oxidation and secondary enrichment (after Asmus, 2013).

IV. CONCLUSIONS

Ambaji area comprises of rocks of Todgarh Formation belong to the Kumbhalgarh Group of Delhi Supergroup. Talc-Tremolite schist is the host rock for the sulphide deposits of Cu, Pb and Zn. Malachite, azurite and limonite are capping over the subsurface sulphide deposits of Ambaji. Oxygen and water are the powerful agents of weathering that react with metals like pyrite and chalcopyrite to produce $CuSO_4$. Role of $CuSO_4$ becomes crucial with natural salt like Na_2CO_3, which give rise to malachitedeposits at the surface – Gossan. The down trickling solutions contain metallic contents that give rise to oxidize and sulphide ore deposits at depth.

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