Discussion on a Possible Genetic Model for the Mineralization

Banded iron-formation hosted iron ore deposits of Gandhamardan Hill (Lat.21°36'0" and 21°40'30"; Long 85°29'0" and 85°31'32") exposes a part of Iron Ore Group of rocks which occur as a horst-like block truncated in the east and west by two N-S trending faults (Figure 2.1). The Gandhamardan hill, a 1200 ft high elliptical plateau, the foothill part of the Gandhamardan hill is covered with succession of amygdular basaltic to andesitic volcanic flows, layered pyroclastic rocks and lenticular ferruginous chert bands. Towards top of the hill the pyroclastic rock are interlayered with cross-bedded sandstone and ferruginous shale and overlain by a thick banded iron-formation horizon. The banded iron-formation is represented by micro and mesobands of jasper and iron oxide minerals. The volcano-sedimentary unit forms a right side up succession and is undeformed and unmetamorphosed. The banded iron-formation lying at the top contains stratabound fracture filling and replacement vein-type iron ore bodies with irregular outline. Further up section, the iron ore bodies grade to barren banded iron-formation, which continues for 60 to 100m. Near the top of the hill the banded iron-formation is overlain by a sheet like low easterly dipping iron ore body (10 to 30m thick), which is ultimately capped by ferruginous laterites (Figure 2.2A).

There are some sag-folds developed within banded iron-formation, near the top of the Gandharmadan Hill, which are interpreted as ‘Karst folding’ developed due to down-sagging during Karst development.
The regional geological map (Figure 2.1) shows that the thick volcanic rock of basalt to basaltic andesite in composition (Figure 2.7, 2.13 and 2.14) forming the base of Gandhamardan succession, forms a part of the regionally developed Malangtoli lava. The geochemical data indicate that the basal igneous suite is a high Fe-tholeiite in nature (Figure 2.10, 2.11) and show a mixed character between LKT and OFB (Figure 2.10). The different discrimination diagrams for the classification of rocks and their magma-tectonic setting are chosen based mainly on the high-field strength (HFS) elements viz., REE, Y, Sc, Zr, Hf, Ti, Nb, Ta, P, Th, etc. From the plots in different discrimination diagram it is concluded that the basal volcanic flows represent either Ocean Floor Basalt (OFB) type or Within Plate Basalt (WPB) type (Figures 2.18, 2.20 and 2.24 to 2.32). Enrichment of LREE with respect to HREE in C1-Chondrite normalized REE plot (Figure 2.13) of the studied volcancics advocate strongly in favour of an OIB suite with E-MORB affinity.

The sedimentary succession below Gandhamardan iron-formation contains sand-silt alternation, ferruginous clay, thick massive sandstone and tuff. The sandstone is a silica cemented subfeldspathic arenite. It is composed mainly of rounded to sub-rounded feldspar (cf. K-feldspar) and quartz grains. Silica overgrowth with optical continuity is very common in the quartz grains. Profuse crystals with overgrowth indicate that the pore-fluid/basinal brine was silica enriched and acidic in nature. Abandoned polycrystalline fragments of silica (sub-rounded chert fragments) and rounded grains of martitized hematite are also very common. These indicate the presence of an ancient mineralized banded iron-formation horizon, which acted as one of the provenance components for the sandstone. A thick tuff bed overlies the sandstone. The change over from sandstone to tuff is represented by volcaniclastics mixed sandstones. The overlying tuff beds are andesitic in nature and composed of purely volcanic material with angular glass shards occurring within cryptocrystalline groundmass.

In absence of primary sedimentary structures of shallow water origin (e.g. wave ripples) in sandstones, it can be assumed that the volcano-sedimentary succession was deposited at least beyond fairweather wave-base. The sorted texture of the sandstones, further suggest that they are not the product of turbidity current deposition in deep water basin. Hence, it can be postulated that the succession might
have developed in a basinal part which was relatively deeper than shallow marginal part, preferably outer shelf part of a marine basin. The presence of subrounded chert fragments and martitized hematite grains in the sandstone suggest presence of another older iron ore bearing banded iron-formation in the nearby provenance area and the overlying Gandhamardan BIF hosted iron ore body was originated in the younger phase of the depositional history of the basin.

The banded iron-formation, representing the youngest member of the studied succession, is represented by oxide and silicate facies iron-formations and shows close affiliation to chemical precipitates sourced by hydrothermal basinal fluids.

The iron ores of Gandhamardan Hill show two different types of mineralization - one is a replacement vein type iron ore deposits developed near the lower part of the banded iron-formation horizon, close to vertical faults and are exposed along the western slopes of Gandhamardan Hill and the other is a blanket type ore developed over the banded iron-formation and is capped by a lateritic cover (Figure 2.1).

Depending on mineralogy and physical attributes like hardness, porosity and friability, the iron ores of Gandhamardan Hill are grouped into four ore types, viz. hard martite-hematite ore, soft friable/flaky martite-hematite ore, hard goethite-hematite ore and unindurated martite-hematite blue dust (Figure 4.12). Petrographically the high grade hard hematite ores are dominantly composed of martite, microplaty and cryptoplaty hematite, with some primary magnetite and at places late goethite (Figures 4.13A and B). They are either massive or laminated ores (Figure 4.13A –Massive ore and 4.13B – Laminated ore). Highly porous flaky ores contain thin flakes of massive ore in a matrix of microplaty hematite (Figure 4.12D). The hard goethitic ores with partially reduced porosity are produced by replacement of early martite or microplaty hematite by goethite (Figures 4.13E and F). The blue dust is completely unindurated and composed of loose grains of microplaty, microcrystalline hematite and martite.

Porosity is an important criterion to distinguish ore from mineralised BIF. Porosity in goethitic ore is partially reduced due to filling of pore spaces by late goethite. Goethite may be formed by replacing martite grains (Figure 4.13E) or by the
development of isopachous cement within interstices of microplaty hematite grains. Change of porosity of slope ore is also evident by the neo mineralization within mineralized BIF (Figure 4.14). Transformation of mineralized BIF to iron ore through replacement of silicate by iron-oxide minerals is common in both slope ore and top ore (Figure 4.15).

A Comparative geochemical study indicates that slope ore is enriched with Sc, V, Cr, Y, Zr, Hf, Ta, Th and U, whereas, compared to slope ore, top ore is enriched with Co, Ni, Cu, Zn, Ga, Rb, Sr and Cs. In the plots of PASS normalized REE diagram (Figure 4.20), the enrichment of REE from Normal BIF to ore through mineralized BIF indicates a gain of REE related to hydrothermal mineralization. Slight depletion of REE in top ore is possibly related to removal during late near-surface weathering process. Such REE distribution pattern reveals a continuous process of ore formation through replacement of BIF by iron bearing hydrothermal fluid.

The replacement of BIF by iron bearing hydrothermal fluid is expressed by mineralogy and texture of the iron ores. Formation of BIF breccia by hydrothermal brecciation and filling of the gaps by iron ore minerals is a characteristic feature in Gandhamardan iron ore deposits, particularly slope ores (Figure 4.8). Further, presence of core stone BIF occurring as undigested body within massive iron ore indices replacement of BIF by iron rich hydrothermal fluids (Figure 4.4). Such features are largely modified by late supergene processes in case of top ore horizon. The jasper fragments in breccias show mismatching clast boundaries indicating their transportation and locally such jasper clasts show normal grading (Figure 4.6). Such grading of jasper clasts definitely indicate transportation of the clasts with iron rich fluid and their deposition as suspension fall-out from the flowing fluid due to capacity failure and later the gaps were filled-up with iron oxide minerals crystallised from iron-rich hydrothermal fluid. Ultimately, breccia is totally replaced by iron oxides to form iron ore (Figure 4.12F).

Petrology of the litho-units indicates that the depositional environment of the volcano- sedimentary succession was developed in ocean island to back-arc basinal setting. A series of vertical to subvertical faults were developed in the basin partly due to sagging or due to tectonic strain developed within back-arc setting. Closeness
of the ore deposits to the fault planes also suggests that the faults might have acted as conduits for movement of ore solution which precipitated iron ore through replacement of silica in two different levels in the thick BIF horizon (Figure 5.1). Both the iron ore mineralizations have formed deposits of economic grade. When the lower iron ore deposit retains its hydrothermal characters, the upper ore deposit loses its pristine characters when subjected to near-surface supergene processes.
**Figure 5.1**
Schematic model for the evolution of the Gandhamardan Hill iron ore deposits.
A. Development of intrabasinal faults. B. Upward migration of basinal iron rich fluid (ore brine) along faults. C. Formation of iron ores through replacement of BIF adjacent to faults. The top ore might represent a hydrothermal ore body which recorded some change in chemistry and mineralogy due to near surface supergene processes.