chapter vii

CONCLUSIONS

The Jamnagar district forms the south-west part of the Kathiawar or Saurashtra peninsula of Gujarat State. Saurashtra has a well developed and well preserved geological record from Middle Jurassic to Holocene. The major occurrences of bauxite deposits associated with laterite in Kalyanpur taluka of Jamnagar district was well known even three decades ago. The laterite/bauxite belt runs in a north-south direction over a length of 50 km from Virpur near the Gulf of Kutch in the north to Gandhvi on the coast of the Arabian sea in the south. The belt attains a maximum width of 6 km in the northern part near Mahadevia, Ran and Mewasa, while the average width remains about 1.5 km. It covers parts of Survey of India toposheet numbers 41 F/4, 41 F/7, 41 F/8, 41 G/1, 41 G/5 and 41 G/9, and practically marks the border zone between the Deccan Trap basalt exposed in the east, and the Tertiary sediments (Gaj series) in the west.

This research was taken up with an aim to make an in-depth study of the occurrence, geology, geo-chemistry, and then to postulate a genetic model for bauxite dependent upon, the then prevalent palaeoclimate, topography, geography and the geo-chemical environment.

Field work in the bauxite areas included critical examination of all available mine-, pit-, river- and hill-sections, and this was followed by systematic sampling. The field characters and the nature of occurrence of bauxite pointed towards the in-situ nature of these deposits. This was supported by chemical analyses, XRD and trace element studies. Both the field characters and the laboratory studies indicated that there had been both vertical and lateral differentiation of major elements within the in-situ weathering profiles developed over the Deccan Trap basalts, leading to the enrichment of Al, thus forming bauxite deposits.

Fedden (1884), gave the first detailed and systematic geological account of the Saurashtra peninsula. He clearly recognised and described the major stratigraphic units of Saurashtra and gave the following succession:

Formation		Approximate geological position
Alluvium		Recent and sub-Recent
Dwarka beds		Higher Tertiary or Post-Pliocene.
Gaj beds	?	Upper Miocene (Lower Manchar in parts, and Gaj of Sind.)
Lateritic rocks	?	Lower Eocene [Sub-nummulitic (Wynne) of Kutch, and
	?	High level laterite of Deccan.]
Traps		Cretaceous-Eocene (Deccan Trap)
Trappean grits	?	Cretaceous [Infra-Trappean grits (Wynne) of Kutch.]
Wadhwan Sandstone	?	Cretaceous Infra-Trappean of India.)
Umia beds		Jurassic (Upper Gondwana)

The generalised stratigraphy of the Jamnagar district of Saurashtra is as follows :

Age	Group	Litho-unit
Recent		Soil and alluvium
Pleistocene to sub-Recent		Milliolite limestone (oolitic) [base often conglomeratic]
	Unconformity overlap	
Mio-Pliocene	Dwarka beds	Shell limestone and marl
	Disconformity	
Lower Miocene	Gaj series	Shell limestone, concretionary limestone (foraminiferal) with calcareous clay, mudstone, marl, calcareous clay (frequently fossiliferous), mudstone, mixed clay zone (impersistent), black shale (grading to grey shale, rarely fossiliferous and gypseous, often pyritiferous), transported bauxite, mixed clay zone, conglomerate
	Unconformity	
Palaeocene to Lower Eocene	Weathered zone of Deccan Trap	Laterite-bauxite, lithomargic zone, rare volcanoclastic lithomarge, basaltic saprolite, purple spotted clay (montmorillonitic), chocolate brown clay (ferruginous).
Upper Cretaceous -Palaeocene	Deccan Trap	Basalt-dolerite dyke, gabbro boss, amygdular porphyritic, olivine basalt (flows). (base not encountered).

Study of different mine and quarry sectinns, and exposures of bauxite, shows that there are two distinct modes of occurrence of bauxite in the area viz. the *in situ* type and secondary type. While most of the deposits in the area are of *in situ* type, there are typical instances of redeposited bauxite corresponding to talus accumulations of material eroded and transported from the *in situ* deposits.

The generalised profile exhibited by a majority of the bauxite sections is as follows:

Soil	A	
Horizon rich in oxides	B_{ox}(Fe,Al)	Laterite/bauxite
Horizon rich in silicates	$B_{(sap)}$	Kaolinite/bentonite
Horizon of fresh rock	C	Deccan Trap basalts

The *in situ* deposits of bauxite occur on the gentle, dip slopes of the laterite ridges and show all gradations to the underlying lithomarge on one side and to the hard laterite on the other. The deposits are lenticular and may be repeated laterally, connected by thin necks, but they are never repeated vertically. They show a typically disaggregated nature. The whole bauxite deposits look like a conglomeration of highly fragmented, disaggregated, flat, lenticular bodies. Angular, subrounded, ellipsoidal blocks of longest dimensions occur together with small nodules of bauxite, kaolinite, ferruginous and bauxite clay are seen in between the blocks. Abundant infiltration of calcareous materials is seen to have taken place in the bauxite along the cracks from the overlying calcareous rocks of the Gaj series. The bauxite in the *in situ* deposits is usually compact and massive with gradations to a nodular zone towards the top and an earthy, clay-rich zone towards the bottom. The nodular zone at the top consists of nodules of bauxite, set in a clayey matrix. The earthy, clay-rich zone consists of sporadic pisolites and nodules of bauxite. Formation of pisolites and oolites of bauxite is seen in all the zones. The bauxite zone grades laterally into the mottled laterite, and vertically downwards into the basaltic saprolite. This clearly points to in situ bauxitisation, by prolonged chemical weathering of the source rocks viz. Deccan Trap basalts. All the zones in the in situ deposits are more or less characterised by oolitic and pisolitic structures. Bauxite is disaggregated dominantly along the subhorizontal planes (sheets of weathering), and to some extent, moderately inclined lenses are observed at a number of places.

Outcrops of transported bauxite deposits are rare. Evidence of partial erosion and redeposition of bauxite are very near to the in situ deposits. They occur as scree or talus accumulation and show a conglomeration of high and low-grade bauxite with a loose clastic texture. Infiltration of calcareous materials in these deposits from the surrounding limestone country is a characteristic feature. The transported bauxite exhibits more than two generations of enrichment, in both the fragments and pebbles of bauxite, as well as in the clayey matrix.

The transported deposits are, therefore, alluvial deposits occurring at or near to their in situ counterparts. While the in situ deposits show a general upgrading of the ore towards the middle and lower parts of the gentle slopes, transported deposits to do not have such a relation with the slope. They do not show a regular gradation into an upper laterite mantle and lower earthy zone of lithomarge.

Sampling was done systematically from various bauxite profile in Jamnagar district so as to ensure that the minutest chemical variation could be monitored.

These samples were then chemically analysed using ICPS, so that both major and trace elements could be determined. The qualitative mineralogy of each of these samples was confirmed by X-ray diffraction.

The interpretation of chemical and X-ray data point towards the residual nature of these bauxite deposits, formed by the weathering of the Cretaceo-Eocene Deccan Trap basalt. Secondary deposits of bauxite were also discernible from the laboratory investigations.

GENESIS OF BAUXITE

Bauxite is an Al-rich rock formed by in situ weathering / reworking of diverse parent rocks. To arrive at such a selection, several physical and chemical factors come into play, and they are:

(a) climatic conditions, (b) morphology, (c) parent rock, (d) chemistry of weathering of parent rock and (e) the process of bauxitization.

The genetic model for the Jamnagar bauxites has been made after a critical appraisal of each of the above mentioned factors.

Traditional studies have shown that laterization/bauxitization can take place only in warm and humid climates of the inter-tropical zone. For this purpose, palaeoclimatological data and reconstruction of the palaeoposition of the Indian plate during the Palaeocene times was made. This revealed that the study area, in fact the western part of India, had a tropical monsoon climate, which was supposedly conducive for bauxite formation. Recent studies have shown that global bauxite formation maxima shows a progressive increase to present time. This poses a severe problem of explaining this general increase, particularly since the Oligocene, the conditions for bauxitization have been effectively deteriorating.

Morphologically, the study area is composed of numerous small hillocks aligned in a NW-SE direction separated by intermittent flat land. Recent review of the relief with which bauxite is associated has now made it clear that very low relief is by no means favourable. Topographic situations conducive to freedom of drainage, constitute an important control on the chemical routes taken during bauxitization. Since bauxitization is a separate chronological event from lateritization elevation of a low relief, lateritized surface, and its incision, would revive vadoze conditions and initiate the necessary leaching aggression by lowering the water table. Thus bauxitization would post-date the surface with which it is associated.

The drainage of the study area is composed of small seasonal streams. Most of the laterites of Gujarat State ,including those of Jamnagar district, are found at the leading edge of the Deccan Trap basalts. This is an indication that the alteration of the Deccan Trap basalt took place in a near-shore environment. The leading edge of the Deccan Trap basalt which came into contact with the early Tertiary sea, developed numerous cooling structures and joints, thus affording a high degree of free drainage.

Lateritization/bauxitization can occur on diverse rock types as well as showing areal anomalies, wherein Fe/Al enrichment is favoured by a particular lithology, while in another, the enrichment is apparently inhibited by the same lithology. This suggests that other environmental factors are operative if not dominant in its development. This is especially true of Jamnagar, where only the edge of the basalts have undergone weathering, whereas the other areas remain unaffected, despite experiencing the same climatic conditions. As explained earlier, this is due to the profusion of cooling structures and joints on the leading edge of the basalts.

The main minerals present in the Deccan Trap basalt are augite, plagioclase felspars and olivine. Studies have shown that the first stage of alteration of these minerals has been one or the other member of the montmorillonite clay family. In the field, this is supported by the presence of sticky clays at the base of the profiles. The next stage, has nearly always been the formation of kaolinite, or sometimes a zone of iron or alumina enrichment. The study area shows all variations, with some profiles showing intermediate clayey zones followed by Fe/Al rich zones, and some without the clayey horizons. This is entirely due to topographical conditions, with profiles having clayey horizons predominant in low-lying areas, suggestive of sluggish leaching, and those without the clayey zones, in relatively elevated areas, suggestive of enhanced leaching.

Field observations have revealed that both relative and absolute enrichment of both Fe and Al had taken place, with the high degree of jointing and numerous fractures making the narrow belt of basalt prone to intensive geochemical weathering Ti-retained mass-balance models of the various complete profiles in the area have shown that there was a considerable elevational loss from the Palaeocene times to the present.

The rain water initiated the weathering of the basalt, producing Mg, Fe, Al, montmorillonite minerals. As the weathering front lowered below the ground water table, the montmorillonite above the water table started decomposing into kaolinite due to free drainage conditions, by intra-crystalline leaching of interlayer cations and tetrahedral silica layers. The formation of the kaolinite marked the threshold for lateritization. The removal of quartz from the kaolinite is common to both iron and aluminium enriched residua. For the development of an aluminium-riched residua, kaolinite is incongruently dissolved, Si is leached out and Al remains as gibbsite. This is accompanied by leaching of Fe. The co-removal of Si and Fe is not possible geochemically. Further, it has been found that Fe and Al are inseparable yet in nature Fe and Al behave antipathetically. Hence, it is suggested that Fe enrichment came first (laterite), followed later on by Al enrichment (bauxite), due to favourable conditions.

Failure of geochemical explanations for the mobilities of Fe and Al following kaolinite dissolution, leads one to point towards an important biological control. Geochemical constraints do not apply to Si, Fe and Al co-mobilities when biologically complexed material come into the picture. The ability of the microbial population in a laterite profile to attack already formed iron hydroxides, results from the secretion of special chelating agents with a high specific affinity for iron. This results in the formation of pockets of bauxite within the laterite, forming primary *in situ* deposits. When these deposits are reworked, secondary deposits of bauxites are formed.