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ORIGIN OF AZAD KASHMIR BAUXITE

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ABSTRACT

Bauxite and the associated rocks from seven different localities in Muzaffarabad and Kotli areas of Azad Kashmir have been investigated for their clay and non-clay mineral composition.

Rocks in contact with the bauxite are the fire clay at the base and Eocene shale at the top. The fire clay overlies the precipitation breccia of Permo-Carboniferous age.

No relationship could be established between the precipitation breccia and the bottom of the overlying fire clay. The undulatory contact between the fire clay and the bottom of the bauxite which grades upward into highly pisolitic variety indicates their common parentage in alkaline igneous and metamorphic rocks exposed to the north and north-east of Muzaffarabad Trough. The environment and cycle of deposition of the bauxite and the fire clay were also similar with some break and changes when the pisolites of the bauxites were being formed.

INTRODUCTION

The study of origin of the bauxite whether residual or detrial is not an easy task. The problem becomes more complicated when the contact and the vertical gradation between the bauxite and the underlying rock is not exposed. The difficulty is further enhenced if the bauxite is filling karst depressions. The karst depression filling bauxites were considered as solution residue of limestone till BRIDGE [1950] showed from a study of the bauxite deposits associated with limestone in Georgia and Alabama, ROCH [1956, 1957] from the French deposits, GOLDICH and BERQUIST [1947, 1948] from Haiti and Dominican Republic bauxites and ZANS [1952, 1956, 1959] from Caribbean bauxite deposits in general and Jamaican bauxite deposits in particular, that the source material is not the limestone but some alumino-silicate rocks exposed in the vicinity. Likewise BUSHINSKY [1958] also came to the same conclusion after studying the red bauxites of the Urals. However, it is still a controversial topic and requires more work to solve the problem. The present article comprises a mineralogical study of the bauxite and the associated rocks of Muzaffarabad and Kotli areas in Azad Kashmir which also do not have simple type of contacts. The contact between the bauxite and the underlying fire clay is undulatory and shows vertical gradation into each other. The precipitation breccia underneath the fire clay fills the karst depressions of Muzaffarabad Formation. Hence attempts have been made to determine the source rocks and to reconstruct the depositional environment of the bauxite and the associated rocks in these areas.

It is assumed that kaolinite is stable in low pH range (neutral to acidic) and active leaching with alkalies and alkaline earth removed. The presence of calcium hinders kaolinite formation. Illite is stable in an alkaline environment, and poor leaching with the presence of potassium. Similarly montmorillonite is stable in an alkaline environment and poor leaching with the presence of Mg [GRIM, 1951 and

KELLER, 1956]. Although the complex situation in nature will not make this assumption rigorously true for each bauxite deposit, the over all effects as judged from many samples may give a good indication of the composition of the parent rock.

The presence of minerals mentioned above is expected to indicate consistent mineralogy or a range of mineral variation for a particular rock subjected to bauxitization, provided there is no contamination through other sources. Any radical change in the clay minerals would be a cause of variation like the change in chemical environments and rock contamination of different composition.

The clay minerals as determined in the bauxite and the associated rocks by DTA method show that kaolinite is common in fire clay and the bauxite. The Eocene shale overlies the bauxite and contains kaolinite and halloysite. The precipitation breccia underneath the fire clay shows the presence of quartz only. Hence the clay minerals can be good indicators for distinguishing between the bauxite and the associated rocks of the various localities, as well as in determining the degree of correspondence between them.

Likewise similar and dissimilar non-clay minerals of the bauxite and the associated rocks were studied microscopically to determine the mineralogical correspondence between the composition of the bauxite and the associated rocks. This study is also expected to help in tracing the source rocks of the bauxites.

GENERAL GEOLOGY

General geology of these areas has been described in reports from time to time but no petrographic or mineralogical work on the bauxite and the associated rocks with the above objectives in mind has yet been done.

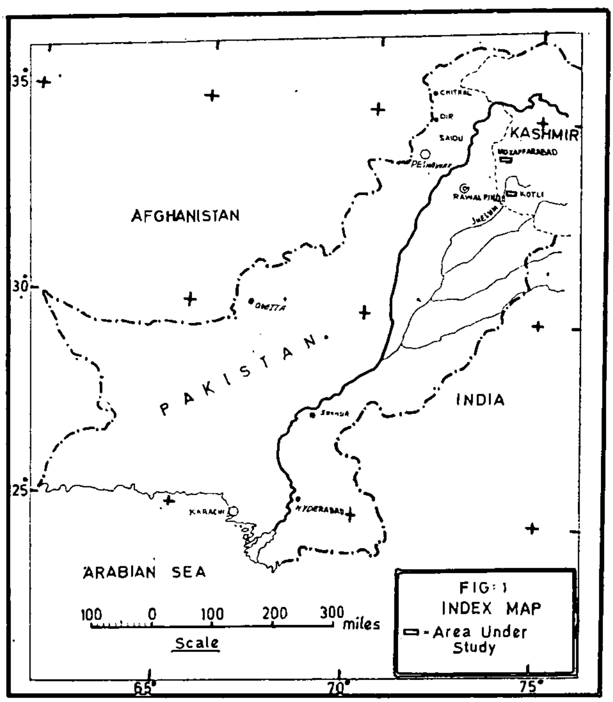

FIG: 1
INDEX MAP
▭ - Area Under Study

The localities discussed in this paper are Batmong and Khilla in Muzaffarabad and Sawer Guniamalni, Khander, Kamroti, Nikial, and Salhun in Kotli Thesil of Azad Kashmir territory *(Fig. 1)*. The rocks exposed in the areas of study are Muzaffarabad Formation, the fire clay, the bauxite and the Chhalpani Formations in their chronological order.

Muzaffarabad Formation of Permo-Carboniferous age consists of limestone, dolomite and precipitation breccia. The limestone is thinly bedded, light gray to mottled gray and white in colour, fine grained, hard and partly dolomitic. Joints and fractures are common.

Above the limestone is the dolomite and the top is precipitation breccia. The dolomite is thinly bedded, dark gray to black, hard compact, brittle, and wheathers to gray or dark gray. The precipitation breccia is colourless to white, hard and compact and very resistant to weathering.

The fireclay and the bauxite are Palaeocene in age and overlie the precipitation breccia of Muzaffarabad Formation. The bauxite is light to dark gray, yellow, brown and dirty white in colour and occurs in small pockets and lenses in association with the basal bed of gray and dark gray fire clay. The top of the bauxite bed is pisolitic and grades into non-pisolitic at the bottom. Average thickness of the pisolitic bauxite is 0.79 m and that of the underlying fire clay is 1.5–3 m. At some places the pisolitic bauxite has been completely eroded and only the poorly pisolitic part at the bottom is exposed.

The Chhalpani Formation of Eocene age is composed of dark carbonaceous light gray to olive and yellowish colored calcareous shales; light gray medium grained sandstone; and dark gray to almost black nummulitic limestone. The dark carbonaceous shale of Eocene age above the pisolitic bauxite contains the coal seams.

The main structure in Muzaffarabad area is a recumbent anticline in the east of Muzaffarabad proper. The regional structure in Kotli area is a pitching anticline, but not very tightly folded and turned into a recumbent fold as in Muzaffarabad area.

CLAY MINERALS IN THE BAUXITES AND THE ASSOCIATED ROCKS

Table 1 shows the vertical column of the major rock types, their stratigraphic succession and the types of clay minerals as determined by the differential thermal analysis method.

Fire-clay 1 & 2 and bauxite 1 & 2 (Table 1) represent the bottom and top of the respective beds. Megascopically the bottom of the fire clay can be distinguished from the top mainly by its color. The bottom of the bauxite bed is dark gray and poorly pisolitic while the top of the bed is dark gray to black and highly pisolitic.

Separate samples were collected from the top and the bottom of the beds to study the differences and similarities in clay mineral composition within the bed and also between the beds which appear to be conformable in the field.

The precipitation breccia appears to be very consistent in its chemical composition and no other mineral but quartz is present in each locality. In Kamroti, however, precipitation breccia is missing and the bottom of the fire clay is apparently in contact with the dolomite of Muzaffarabad Formation (Table 1).

The thin sections of the Muzaffarabad dolomite show clustering of grains which is usually more pronounced in the coarser grains and exhibits granular texture. The cementing material between the grains is scanty and the grains lie in random orientations. Conspicuous partings and cleavage directions are present

(*Fig. 2a*). In some of the grains rhombic cleavages are quite pronounced. It appears that the dolomite is product of inter-action between the limestone and the sea water.

In thin sections of precipitation breccia the grains of quartz appear to dominate the rock body. The cementing material between the grains is very scanty and the texture is quartzitic (*Fig. 2b*). Few grains of orthoclase and albite showing kaolinization and sericitization effects were also found.

TABLE 1

Clay minerals in the bauxite and the associated rocks

Stratigraphic succession	Localities					
	Batmong	Sawer Gunimalni	Kamroti	Nikial	Khander	Salhum
Eocene Lms.	—	Calcite	Calcite	Calcite	Calcite	
Eocene Sh.	Halloysite	Halloysite	Halloysite	—	Kaolinite	
$Bauxite_2$	Kaolinite	Kaolinite	Diaspore & Kaolinite	Diaspore or Boehmite	Kaolinite	
$Bauxite_1$	Kaolinite	Diaspore or Boehmite	Kaolinite	Kaolinite	Diaspore or Boehmite	Diaspore or Boehmite
Fire $Clay_2$	Kaolinite	Diaspore or Boehmite	Raolinite	Kaolinite	Kaolinite	Kaolinite
Fire $Clay_1$	Kaolinite	Kaolinite	Illite	Diaspore or Boehmite	Diaspore or Boehmite	Diaspore or Boehmite
Muzaffarabad Precipitation Breccia	Quartz	Quartz	—	—	Quartz	Quartz
Muzaffarabad Dolomite	—	—	Dolomite	—	Dolomite	—

At Khander lateritic patches lie between the precipitation breccia and the fire clay. The laterite is reddish-brown to dark brown in color and exhibits coarse to medium grained texture. No minerals could be identified in the hand specimens due to coatings of iron oxide on the grains.

The thin sections of the samples of laterite show the dominance of orthoclase and albite grains embedded in ferruginous matrix. Some grains of plagioclase and quartz were also found but they are not very common. Usually the grains of feldspars are angular to subangular in their shapes. Most of the grains are kaolinized and sericitized along the margins and cracks but the degree of alteration in feldspar grains present in this section of the laterite samples (*Fig. 2c, d*) show kaolinization effect very conspicuously due to diagenesis.

The study of the thin sections of the fire clay show the presence of the grains of quartz, kaolinized and sericitized albite and orthoclase embedded in blackish brown argillaceous matrix. Few grains of ferromagnesian minerals of pyroxene and amphibole groups were also found in altered condition. The alteration products of these minerals are biotite, epidote and some clay minerals which appear dirty white and cloudy in thin sections (*Fig. 2e*). Flakes of biotite, few grains of apatite,

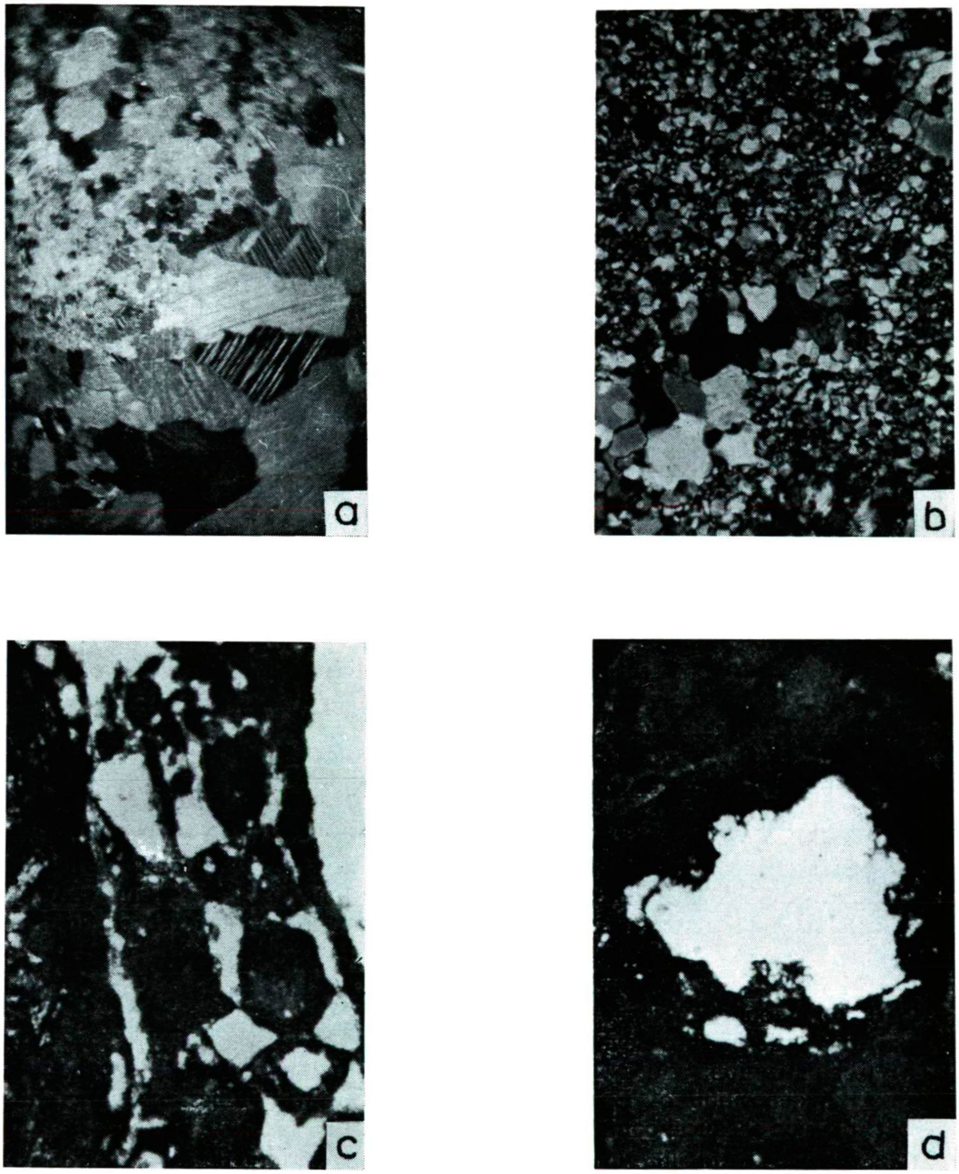

Fig. 2.

a) Fine to coarse grained aggregate of dolomite crystals from Khander, Azad Kashmir 50.4 X, crossed polarizers.

b) An aggregate of anhedral crystals of quartz in precipitation breccia, from Khilla, Azad Kashmir, 50.4 X, crossed polarizers.

c) Feldspar grains embedded in ferruginous matrix of laterite from Khander, Azad Kashmir 50.4 X, polarized light.

d) Kaolinized feldspar grain surrounded by ferruginous matrix of laterite from Khander, Azad Rashmir, 50.4 X, polarized light.

anatase and epidote were also seen under the microscope. Exact identification of the mafic minerals is not possible due to intense decomposition of the mineral grains. However, their outline, the development of craks and the black specks of iron oxide in the body of the grains are quite pronounced. Calcite and muscovite are common. Small specks of iron oxides with random distribution are of common occurrence in the main body of the rock. In all the samples of fire clay from the various localities of Muzaffarabad and Kotli Tehsil, banded structure is quite common and well pronounced *(Fig. 2f)*.

The thin sections of bauxite samples show the presence of argillaceous and ferruginous matrix in which grains of orthoclase, albite, quartz, flakes of muscovite and biotite are embedded. Few grains of anatase, apatite and calcite were also found. Specks of iron oxides were also seen under the microscope.

The grains of albite and orthoclase are angular to subangular in shape. These mineral grains are kaolinized and sericitized though their outlines are quite prominent. Generally in thin sections of the pisolites the mineral grains show their outlines quite conspicuously, but in some cases the grains are so intensely decomposed that the study of the shape is difficult *(Fig. 2g)*. In some of the pisolites few laths of feldspars appear as trapped grains in carbonaceous and argillaceous matrix. In others the rim is lined by altered grains of feldspars, and the internal material is carbonaceous to argillaceous with few grains of decomposed feldspar. In such pisolites the pisolitic structure is not well developed. Some of them exhibit random setting of non-clay mineral grains specially feldspars in them.

In non-pisolitic bauxite samples also some grains of feldspar and other minerals mentioned above, are present, exhibiting the same degree of decomposition of the mineral grains as in the pisolites. In some cases the altered feldspars appear to dominate over the matrix *(Fig. 2h)*.

ENVIRONMENTAL INTERPRETATION

The common occurrence of dolomite in the middle and precipitation breccia at the top of the Muzaffarabad Formation, kaolinite in the fire clay and the bauxite beds, halloysite in Eocene shale and calcite in the limestone alternating with the shale in Azad Kashmir area, suggests that there were at least five phases of sedimentation, namely:

i) dolomitization of Muzaffarabad limestone,
ii) formation of precipitation breccia,
iii) deposition of fire clay,
iv) bauxitization, and
v) the deposition of Eocene shale interbedded with limestone in varying physico-chemical controls of the environment.

The occurrence of illite in Kamroti locality only can not be explained on the basis of observations of MILNE [1958], BURST [1958] and WHITEHOUSE [1965] who reported the formation of illite from montmorillonite in marine condition, because no evidence of marine deposition of the fire clay of Azad Kashmir was found during the present investigations.

The presence of illite only at the bottom of the fire clay of Kamroti locality can be explained as detrital or derived from muscovite or montmorillonite due to petrodiagenesis.

WEISSE [1948] suggested that gibbsite generally occurs in deposits of Tertiary age, boehmite in deposits of Mesozoic age and diaspore in deposit of Paleozoic age.

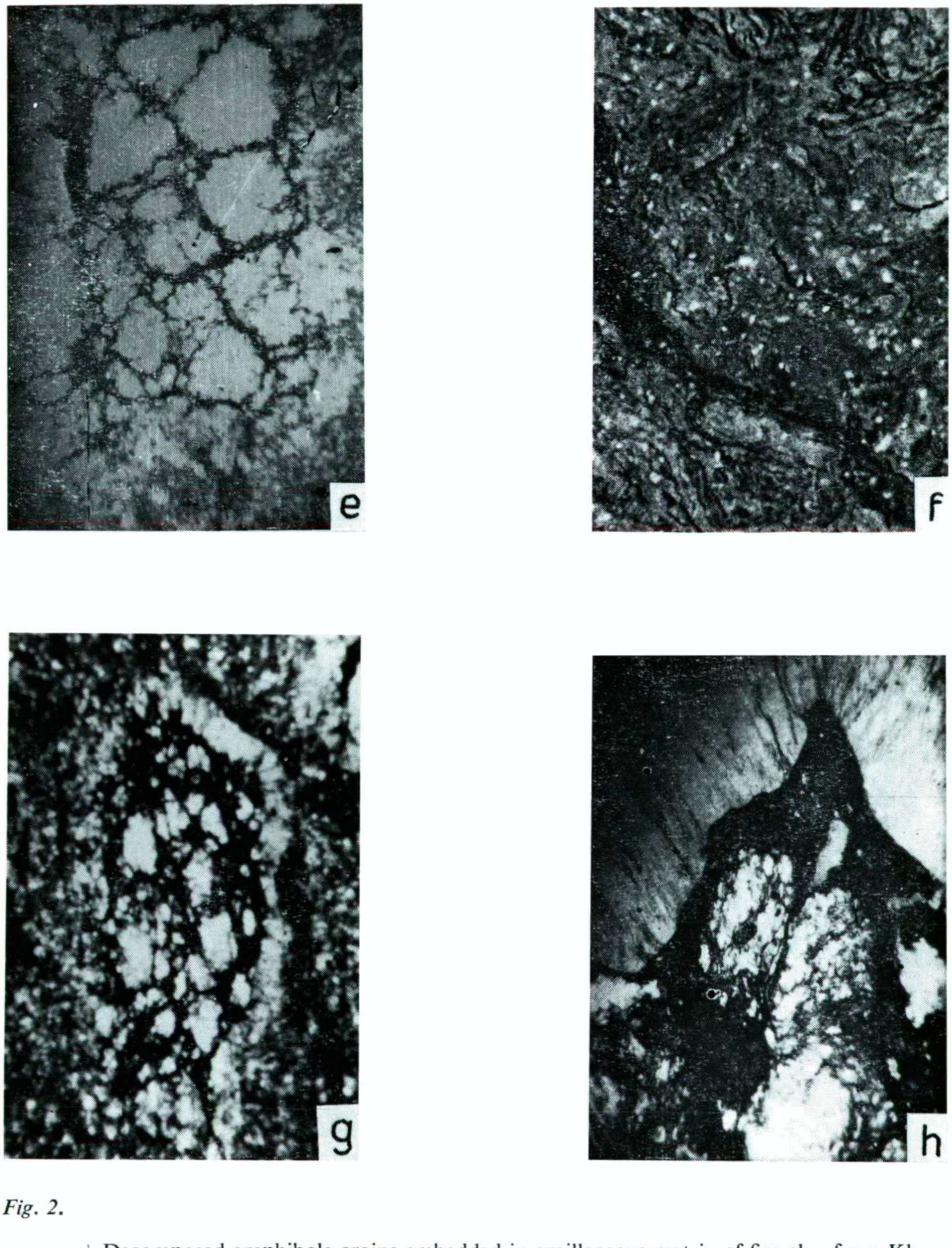

Fig. 2.

e) Decomposed amphibole grains embedded in argillaceous matrix of fire clay from Khander, Azad Kashmir, 50.4 X, crossed polarizer.

f) Banded algal structure with small feldspar grains in the fire clay from Khander, Azad Kashmir. 50.4 X, polarized light.

g) Pisolite of bauxite with decomposed feldspar grains from Batmong, Azad Kashmir, 80.0 X, polarized light.

h) Kaolinized feldspar grains trapped in argillaceous matrix of non-pisolitic bauxite from Khilla, Azad Kashmir, 50.4 X, polarized light.

This age relationship shows that with the geologic time gibbsite is dehydrated and altered to boehmite and boehmite is further altered to diaspore. Increase in pressure and temperature above those that exist at the surface does not appear to be necessary for the formation of these minerals.

BRACEWELL [1962] states that boehmite and diaspore may also be formed by the thermal metamorphism of gibbsitic bauxite or laterite.

J. DE LAPPARENT [1936] considers that boehmitic bauxites are formed at the ground water-table in the presence of humic acid water level and diasporic bauxite below it, where a higher geothermal gradient prevails.

The absence of gibbsite and random distribution of boehmite or diaspore in the bauxite and the associated fire clay of Azad Kashmir make the explanation given by WEISSE [1948] a paradoxical one. It is possible that all the gibbsite present at the beginning of sedimentation has been dehydrated into diaspore or boehmite due to intense tectonic movements to which those rocks were subjected during various phases of Himalayan uplift.

It is likely that the diaspore or boehmite are among the detrital sediments, and so the distribution of these minerals is random. But this seems less probable because diaspore and boehmite are usually the products of petrodiagenesis.

The thermal origin of boehmite and diaspore as suggested by BRACEWELL [1962] does not seem possible in case of the Azad Kashmir bauxite because no field indications or petrographic evidence of igneous activity were found in the bauxite and the associated rocks.

The formation of boehmite and diaspore in Azad Kashmir bauxite and fire clay seems compatible with the observation of DE LAPPARANT [1936] that the action of ground water together with humic components in the water draining from neighbouring peaty forests acted upon the gibbsitic bauxite and produced boehmite and diaspore. The humic component in Azad Kashmir bauxite could have been added from the carbonaceous material which is now present as a coal seam in Eocene shale above the bauxite lenses. Besides, the whole area is covered with pine forest and so the decomposition of the pine trees keep adding humic acid to the bauxite body.

The occurrence of halloysite together with kaolinite in the Eocene shale favours the acidic and oxidizing physico-chemical control of the environment. Therefore, it is further confirmed that acidic environment was responsible for this mineral assemblage.

The formation of clay minerals in the bauxite after the removal of non-aluminous materials is a complex process and it is not well understood. The dominant clay minerals in the fire clay and the bauxites of Azad Kashmir are kaolinite and boehmite or diaspore (Table 1). The kaolinite present in the fire clay and the bauxite is probably a transported material. The result of the present study is compatible with the conclusions reached by PATTERSON [1967], who described extensive transported kaolin deposits underlying or associated with some of the bauxites in Arkansas, the coastal plains of Georgia and Alabama, Guayana and Surinam.

The process of resilicification for the formation of kaolinite as suggested by BUSHINSKY [1964] does not seem to be very active in case of Azad Kashmir bauxite, because halloysite a member of kaolin family is present in Eocene shale which overlie the pisolitic bauxite. If there had been an active process of resilicification then the top of the pisolitic bauxite and the Eocene shale would have shown less percentage of silica and presence of clay minerals like gibbsite, boehmite or diaspore only. But such indications were not found in any of the localities of the present study. Besides, the chemical analyses of the bauxite and the fire clay samples do not show any appreciable change in their silica content from the top to the bottom of either beds [MALLICK and VALIULLAH, 1974].

The absence of gibbsite and occurrence of boehmite or diaspore in the fire clay and the bauxite is probably due to the effects of tectonic disturbances caused by Himalayan orogeny which changed gibbsite into the two minerals mentioned above through the process of dehydration and structural compaction.

Besides the evidence based on the study of clay minerals, the presence of altered angular to subangular grains of feldspars, ferromagnesian minerals probably of amphibole group, the quartz grains in the argillaceous matrix of the fire clay and the pisolitic bauxite reveal their transported nature and a common source. The presence of lateritic patches containing comparatively fresher grains of minerals than in the fire clay and the pisolitic bauxite, and its position between them further indicate immature state of the material which formed the two beds.

The negative correspondence of the fire clay and the pisolitic bauxite with the associated underlying precipitation breccia of Muzaffarabad Formation is clearly indicated by the microscopic examination of the thin sections.

The banded structure is probably an indication of the transportation of algal material along with the argillaceous sediments in the basin of deposition. It is also possible that the algal material was present in the basin of deposition, and so, when the transported sediments came in contact with the algal materials, both were deposited together and formed the bed of the fire clay.

It appears from the study of the internal structure of the pisolites that the local disturbances in the environment of bauxitization and pisolite formation were active and caused irregularities in the internal structure and setting of the mineral grains in them. Probably the disturbance in the supply of organic matter and the sediments were more intense at the time of bauxitization.

The provenance of the fire clay and the pisolitic bauxite was most probably in the north and north east of Muzaffarabad Trough which is occupied by the gneisses, schists, slates and the early Tertiary instrusions of granite, syenite, granodiorite and diorite. The positive correspondence between the fire clay and the pisolitic bauxite, on the basis of their mineral assemblage is probably due to their common provenance. The cycle of deposition also appears to be the same with some fluctuations in sedimentation and shallowing of the depositional basin when the pisolitic bauxite was in the process of formation.

While studying the bauxites from occupied Jammu province, ASHOK [1967] concluded that the provenance of the bauxites is in Pir Panjal Trap which is situated further north from the localities of the bauxite deposits. But the present study reveals that the source rocks of Azad Kashmir bauxites are the alkaline igneous and metamorphic rocks as mentioned above and is discussed below:

GEE [1957] is of the opinion that the basin structure of West Pakistan was emerging from the north and was submerging in the south during Mesozoic and Tertiary times. This statement further supports the possibilities of the source rocks for the fire clay and the bauxite deposits to be in the north.

The dominance of feldspar grains in the fire clay and the bauxite samples as compared to silica is probably because of the dominance of alkaline rocks in the provenance.

LOUGHNAN and BAYLISS [1961] described a large deposit of bauxite near Weipa, Queensland, Australia which formed from quartzose rocks containing less than 4 percent alumina.

The fire clay and the bauxites of Muzaffarabad and Kotli Thesil do not show any degree of positive correspondence with the immediate underlying precipitation breccia of Muzaffarabad Formation, as suggested by LOUGHNAN and BAYLISS for the origin of Weipa bauxite of Queensland from quartzose rocks.

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