MINERALOGICAL EVIDENCES FOR CLIMATIC VICISSITUDES IN INDIA DURING GONDWANA TIMES

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ABSTRACT

An account of palaeoclimatic reconstruction based on mineralogical parameters during Gondwana times is given. Importance and limitations of different mineralogical parameters, i.e. mineralogical association, colour, pebble study, heavy minerals, quartz grain surface features, felspar content, and clay minerals are discussed. The Gondwana sedimentation started with extensive glacial activity on the peninsular India depositing Talchir sediments. In the upper part of Talchir sediments fluvial action already started due to slight warming up of the climate. At the beginning of Barakar sedimentation climate was cold temperate with impeded drainage. Gradually the climate became warmer and drainage improved, and the upper part of Barakar was deposited in tropical climate with excellent drainage. Deposition of Barren Measures took place in pene-planed flood basin with lakes in subtropical to tropical climate. Raniganj sediments were also deposited in subtropical to tropical climate but with impeded drainage. During Panchet times, tropical humid climate of Damuda times changed to subtropical climate with prolonged seasonal droughts of high temperature, and continued into Mahadeva. At the time of sedimentation of Rajmahal intertrappeans the climate again switched over to tropical with excellent drainage. The seasonal variations became insignificant. This tropical climate with good to excellent drainage continued into Jabalpur and Umia times.

INTRODUCTION

The climate is essentially a combination of temperature, pressure, wind and rainfall/snowfall and has a strong control over the environment with its flora and fauna. In other words, climate strongly controls the weathering in the source area and the nature of deposits at the site of sedimentation. The human being has always been aware of the climate around him. Thus, it is natural to enquire about the climatic changes which have taken place during the long geological history of the earth, covering millions of years. For the interpretation of climate in the past, various parameters like fauna, flora, lithology, mineralogy, geochemistry, palaeo-magnetism, etc. have been used.

In marine environment the effect of climate is less pronounced, and leave little impact on its deposits, except for the coastal facies. The continental inland deposits, on the other hand, are more susceptible to climatic changes, and even changes of lesser magnitude shall be recorded in the continental deposits. The Gondwana sediments in India are essentially fresh-water deposits laid down inland of the Indian Peninsula (except for few coastal deposits along the east coast and western India). Thus, they are well-suited for the determination of palaeoclimate in the peninsular India during Gondwana times. It should be borne in mind that nowhere the complete succession of Gondwana sediments is developed. The Gondwana sediments of different ages occur in scattered outcrops distributed over a wide area in the Central India. Therefore, the interpretation of palaeoclimate of a certain horizon may not be true for the whole area of Indian continent.

In the present paper, various mineralogical parameters, which are helpful in the interpretation of palaeoclimate in Gondwana sediments, have been discussed and based on the

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mineralogical data a tentative palaeoclimatic evolution through Gondwana times has been given.

MINERALOGICAL PARAMETERS IN THE INTERPRETATION OF PALAEOCLIMATE

A sedimentary rock is made up of mostly particles derived during weathering processes in the provenance, and the sediments produced within the basin of deposition under the influence of environment. Thus, the nature of sediment particles is directly controlled by the climate. From time to time various mineralogical parameters have been used in the palaeoclimatic studies with a varying degree of success. The more important mineralogical parameters are discussed below.

General Mineralogical/Lithological Associations

Occurrence of certain minerals in a succession is a good indicator of the climate. For example, gypsum, salt indicate warm, arid climate with evaporitic conditions. Horizons of lateritic soil suggest a warm humid climate. Presence of Kankar horizons in flood plain deposits of a fluvial sequence suggests that the area suffered, at least, seasonal droughts, so that the lime-rich ground water, brought near the surface by capillary action due to excessive evaporation, leads to deposition of calcium carbonte concretions. Kankar horizons are quite common in the present-day Gangetic Alluvium, indicating that the climate of Ganga basin is well-suited for the genesis of Kankar. The climate is marked by a 3-4 months of rainy season alternating with 8 months of dry period, when for few months temperatures comparable to those of arid zone are reached.

Colour of Sediment

The colour of sediment is controlled by the chemical milieu of the depositional basin. Iron minerals are most important in imparting the colour to a sediment. Fe^{3+} imparts a brown to red colour, while iron in reduced state (Fe^{2+}) gives green to gray colouration. The red colouration of sediments is due to presence of hematite and iron pigments as matrix around the sediment grains, and indicate deposition in oxidizing milieu. However, exact climatic conditions for formation of red coloured sediments is disputable. One group thinks that red coloured sediments develop only in humid tropical climate (Krynine, 1949); others believe that red coloured sediments originate in desert climate (Walker, 1967). Van Houten (1961, 1968), and Glennie (1970) provide good texts about red beds. As shall be discussed later, Triassic Gondwana sediments are marked by abundance of red beds and have been traditionally assigned arid climate, though no aeolian sand deposits are recorded, and the sediments exhibit all the characteristics of water-borne sediments.

The red coloured sediments of warm, humid climate can be distinguished into two types :

(i) The sediments are red throughout; both sandy and muddy facies are red coloured. This type of red coloured sediment is often associated with coal measures and according to Van Houten (1961) has accumulated in warm, humid climate with insignificant seasonal dryness.

(ii) The red colouration is facies controlled, viz. the sandy facies shows gray, green colouration, while the muddy facies exhibits red colour. This type is extensively devloped in Siwalik sediments of Himalayas. The gray-green sandy facies represents channel sand deposits of a river system, where due to rapid rate of sedimentation iron is retained in reduced form (Fe^{2+}) giving greenish colour. The red coloured muddy facies represents flood plain deosits, where rate of sedimentation is very slow and the surface remains exposed to air, and Fe^{2+} changes to Fe^{3+} causing a change in colour from greenish-gray to red. In the Gangetic Alluvium also, the sandy facies is gray coloured, while the muddy facies is dark yellow to light brown in colour (SINGH, 1975b). Thus, this type of red coloured sediments develop in subtropical climate with marked dry seasons. This type of red coloured sediments are not associated with lateritic weathering and kaolinite. This type shows illite and chlorite as major clay minerals. Siwalik sediments and present day Gomti River sediments possess mainly illite and chlorite as clay minerals (MISRA *et al.*, 1971; SINGH, 1972 and unpublished data).

NATURE OF COARSE FRACTION (PEBBLES)

Angularity, shape, composition of pebbles provide information about the provenance, environment of deposition, and to a certain extent on the climate. For example, pebbles of pentagonal shape, striated pebbles are characteristic of the glacial climate; many-faceted pebbles—ventifacts are typical of desert environment, i.e. arid climate. Dominance of angular rock fragments of unstable composition, e.g. metamorphic rock fragments, indicates lack of chemical weathering in the provenance, and in the basin of deposition. This happens mostly in very cold climate and to a lesser degree in arid climate. Sedimentary tectonics play an important role in determining the nature of sediment grains. For example, if the rate of sedimentation is fast, sediment grains of unstable composition can be preserved in the rock in appreciable amounts.

COMPOSITION OF HEAVY MINERALS

Heavy minerals are helpful mostly in determination of provenance and in palaeogeographic reconstruction. However, in glacial climate, due to lack of chemical weathering, unstable heavy minerals are present in appreciable amounts and are fresh in appearance. Nevertheless, heavy minerals are not very sensitive parameter. If the rate of weathering is high in the provenance, transport is short and the rate of sedimentation is quick, unstable heavy minerals can be preserved in even tropical to subtropical climate. In Gondwana sediments above factors have been operating, thus the heavy minerals do not shed any light on the palaeoclimate. The heavy mineral assemblage of different rock units deposited under different climatic conditions, shows the same characteristics (SINGH, 1975a).

QUARTZ GRAIN SURFACE FEATURES

CAILLEUX (1942) proposed a scheme for distinguishing glacial, aeolian, and water-worn sediments by the study of quartz grain surface features. More recently SEM (Scanning Electron Microscope) has been successfully utilized for the sudy of microtextures of quartz grain surface, in order to distinguish depositional environment and climate (CAILLEUX & SCHNEIDER, 1968; KRINSLEY & MARGOLIS, 1969). Quartz grains of glacial climate are generally very angular and show features like very high relief, large variation in size of conchoidal fractures, semi-parallel steps, parallel striations etc. Water-borne sediments of somewhat warmer climate in fluvial environment are marked by rounded to subrounded outline, moderate to low relief etc. (SINGH, 1974a).

FELSPAR CONTENT

It is widely believed that fresh and unaltered felspars indicate glacial or arid climate. However, it may be pointed out that beside the climate, relief of the provenance, rate of erosion in the provenance, environment in the depositional basin, sufficiency of time, play important roles in determining the weathering of felspars. KRYNINE (1935, 1936) pointed out that arkose with high felspar content accumulate in tropical climate with heavy rainfall. It seems that in areas of high relief and rapid erosion, felspars are eroded away before they are decomposed, even though climate favours the alteration of felspars. This process is especially effective in areas of warm and humid climate. In such cases usually a mixture of fresh and altered felspars is present (VAN HOUTEN, 1961).

A study of present day sediments of Gomti river in Gangetic Alluvium depicts that felspar is an important constituent of the sands. Moreover, both alkali felspars and plagioclases are present in appreciable amount. In silt fraction sometimes plagioclases are more than alkali felspars, and quartz/felspar ratio is rather low. Felspars are present even in the clay fraction of the samples. This example further demonstrates that presence of felspars alone in a rock cannot be taken as a conclusive evidence in favour of glacial or arid climate. Most probably, a climate with prolonged seasonal droughts also favours preservation of felspars in appreciable amount (the climate of Ganga basin).

Plagioclase felspars are more sensitive and preserved mostly in glacial climate, rarely in warmer climates. However, alkali felspars are not at all a sensitive parameter in determination of palaeoclimate; they can be quite abundant in rocks of tropical climate. Moreover, felspar content of sand fraction is more susceptible to climate than that of silt fraction (see SINGH, 1976).

Clay Mineral Assemblage

Clay minerals are the stable alumino-silicates produced primarily during weathering and pedogenesis as a result of alteration of silicates, and their nature is directly controlled by climatic conditions. Important factors controlling genesis of clay minerals are hydrolysis, lessivage and vegetation, all of which are directly controlled by climate. Two clay minerals are especially good indicators of climatic conditions—kaolinite and montmorillonite. If the drainage is restricted montmorillonite is neoformed. This takes place more effectively in temperate climate, where, due to low temperature and low humidity, hydrolysis is incomplete. However, montmorillonite is also produced in warmer climate if drainage is impeded. If the drainage is good to excellent, and temperature is high, hydrolysis of silicates is complete and kaolinite is produced in abundance. In tropical climate, where lateritic soils are generated due to complete hydrolysis of silicates, thick deposits of kaolinite develop. Moreover, the iron released during hydrolysis may get deposited as layers of iron oxides.

Chlorite and illite are the other common clay minerals present in the sediments. They are regarded as inherited clay minerals. Dominance of chlorite and illite in soils suggests that neoformation of clay minerals is not actively taking place in the area, most probably due to rapid rates of erosion and deposition and inert nature of the environment. MILLOT (1970), and SINGH (1974b) discuss the climatic significance of clay minerals in the sediments.

Clay minerals produced during pedogenesis are transported to the basin of deposition and may undergo changes due to different chemical milieu of the basin of deposition, and later during diagenesis. Palaeoclimatic interpretation based on clay minerals is significant only if there are no mineralogical changes in the basin of deposition and later during diagenesis. Fresh water sediments, like Gondwana sediments, are well-suited for the interpretation of palaeoclimate from clay mineral assemblage, because they represent essentially the same clay mineral assemblage, as produced during pedogenesis.

There is dearth of mineralogical data about Gondwana sediments which can be utilized in the interpretation of the climate. Recently a detailed mineralogical study of the Talchir-Barakar sediments of the Korba Coalfield, Madhya Pradesh was made (SINGH & SHARMA, 1973; SINGH, 1974a, b, 1975a, 1976). In the following the mineralogical characteristics of various units of Gondwana sediments is given along with a tentative palaeoclimate (Table 1). It can be emphasized that only the interpretation of Talchir-Barakar succession of Korba Coalfield is based on detailed mineralogical study, while the palaeoclimatic reconstruction of other Gondwana sediments is based on highly scanty data and should be treated more as speculative and tentative. Lithological description of various Gondwana units is based mainly on PASCOE (1968) and ROBINSON (1967).

Table 1. Palaeoclimate of various stratigraphic units of Gondwana sediments based on mineralogical parameters. Data about Talchir and Barakar after SINGH (1974b)

Geologic Age	Stratigraphic Unit		Palaeoclimate from mineralogical evidences
Lower Cretaceous	Umia		Tropical humid; good drainage.
Upper Jurassic	Jabalpur		Tropical humid; excellent drainage.
	Rajmahal		Tropical humid; excellent to good drainage.
Upper Triassic	Mahadeva		Subtropical with pronounced seasonal droughts.
Lower-Middle Triassic	Panchet		Subtropical with pronounced seasonal droughts.
Upper Permian	Raniganj		Subtropical to tropical humid; moderate drainage; gentle landscape.
Middle Permian	Barren Measures		Subtropical to tropical humid; moderate to poor drainage in a flood basin landscape with extensive lakes.
		Zone E	Tropical humid; excellent drainage
Lower Permian	Barakar	Zone D	Warm temperate to sub-tropical; moderate to good drainage.
		Zone C	Temperate; moderate drainage.
		Zone B	Cold temperate; impeded drainage.
Upper Carboniferous	Talchir	Zone A	Glacial.

TALCHIR

Talchir sediments have been investigated from early times and have been considered to be the deposits of glacial environment due to presence of tillite, varves, glaciated pavements, striated pebbles. In Korba Coalfield it corresponds to the mineralogical *Zone* A (Palynological Zone I A). Glacial climate is supported by following mineralogical observations.

(i) High content of angular rock fragments of metamorphic rocks in the fine-grained matrix.

(ii) Presence of both plagioclase and alkali felspars in the sand as well as silt fraction. In lower part of this zone plagioclases are more in number and fresh, while in upper part they are partly altered. This suggests a less intense cold climate in the upper part of Zone A.

(iii) Dominance of glacial features on the quartz grain surface as revealed by SEM study. The quartz grains from lower part exhibit exclusively the glacial features, produced by mechanical breaking during ice transport. These features are large scale variation in size of conchoidal breakge patterns, very high relief, semi-parallel steps, parallel striations, curvilinear ridges, 'cirque' like depressions, fracture planes arranged like petal of flowers etc. (SINGH, 1974a, Plate 1). The quartz grains from upper part exhibit glacial features, but the outline has been modified by fluvial action leading to slight rounding of sharp edges and corners. Thus, suggesting fluvio-glacial environment for the upper part of the Zone A, indicating slight increase in the temperature.

(iv) The clay mineral assemblage is dominated by montmorillonite ∴ Low temperature of glacial environment inhibits genesis of clay minerals. On the contrary, montmorillonite is a rather highly evolved clay mineral. It has been suggested that pedogenesis during pre-glaciation period favoured development of montmorillonite in mild alkaline milieu. During glaciation the soil cover was removed by the glacial action and deposited with the unsorted tillite.

BARAKAR

The Barakar sediments are made up of sequences of sandstone, shale and coal. Thick sandstone horizons are overlain by thin shale-coal-sandstone alternations and repeated cyclically. Thick sandstone bodies can be considered as channel deposits, whereas, fine grained shale-coal succession represents flood plain deposits. The sandstone is typically an arkose—arkose-wacke. High content of felspar in these sandstones suggests a high relief and rigorous erosion in the provenance. These sediments indicate a short transport history and quick deposition. The heavy mineral assemblage is the same throughout the succession and contains in abundance the unstable minerals like garnet, apatite, epidote along with zircon, tourmaline and rutile. This points to quick sedimentation without significant reworking, while the provenance remained the same. The Barakar succession of Korba Coalfield is divisible into four mineralogical zones, each with a distinctive mineralogical assemblage and climate.

Zone B—The sediments are coarse-grained sandstone, shales and minor coal seams; they are deposits of fluvial environment.

(i) Metamorphic work fragments are absent, indicating more intense weathering in the source area. The large quartz grains are subangular to subrounded, indicating a short transport.

(ii) Sand fraction contains only alkali felspars, while the silt fraction contains both alkali and plagioclase felspars. This suggests a cold climate, though warm enough to destroy the plagioclases of the sand fraction.

(iii) Quartz grains depict glacial features on which fluvial features have been superimposed. This is especially true for the lower part of the Zone B. This suggests that material was derived from glacial environment, and was desposited under fluvial conditions only after slight reworking.

(iv) Clay mineral assemblage is marked by the abundance of montmorillonite, which has been derived partly from pre-glaciation soils, and partly developed in the cold temperate climate after the glaciation (SINGH, 1974b, Text-fig. 1).

It is suggested that during deposition of Zone B sediments, climate was cold temperate, and the material was partly derived from glacial sediments.

Zone C—The sediments are thick coarse-grained sandstone units with coal, shale intercalations near the top.

(i) No rock fragments. The sand and silt fractions contain only the alkali felspars.

(ii) Quartz grains depict fluvial features, viz., rounded to subrounded outline, moderate to low relief, and few irregular surfaces.

(iii) Kaolinite is the main mineral with lesser amounts of montmorillonite and illite. Towards the top, content of montmorillonite decreases ultimately grading into mixed layer minerals (SINGH, 1974b, Text-fig. 1). Presence of kaolinite in appreciable amounts indicate a humid and moderately warm (temperate) climate and moderate drainage.

Zone D—This zone is also made up of thick sandstone units with thin coal/shale/sandstone intercalations.

(i) No rock fragments. The sand and silt fraction contain only the alkali felspars. Quartz grains show fluvial features.

(ii) The clay mineral assemblage is lithologically controlled. Sandstones contain kaolinite along with chlorite and illite. Shales contain mixed layer mineral and kaolinite. Kaolinite is ubiquitous and the mainmineral. In lower part of this zone mixed layer mineral is of illite-chlorite-montmorillonite type; upwards it becomes illite-montmorillonite type. Near the top amount of montmorillonite in mixed layer mineral is low The clay mineral assemblage indicates a warm temperate to subtropical climate with moderate to good drainage. Temperature increases along with improvement in the drainage towards the top of this zone.

Zone E—This zone contains thick sandstone bodies, few metre thick shale/coal intercalations, and thick coal seams.

(i) No rock fragments. The sand and silt fraction contains only alkali felspars. Quartz grains show fluvial features (SINGH, 1974a, Pl. 2).

(ii) The clay mineral assemblage marked by the abundance of kaolinite, with minor amounts of illite and chlorite. Both sandstone and shale show same clay mineral assemblage. Kaolinite is very well crystallized. During deposition of this zone, climate was well-suited for the development of kaolinite, thus suggesting a humid and warm climate, almost subtropical to tropical, with excellent drainage.

BARREN MEASURES

The sediments of Barren Measures (=Ironstone shale) represent a thick succession of dark gray or black, carbonaceous shales with numerous bands and nodules of argillaceous iron ore varying in thickness upto about a foot (PASCOE, 1968). The clay-ironstone is actually siderite, which upon oxidation produces reddish brown colour. In the lower part of the sequence micaceous, sandy horizons are also present. The contact between underlying Barakar and Barren Measures is a gradational one. KAR *et al.* (1964) studied heavy minerals of lower Gondwana sediments of Bokaro Coalfield and found that heavy mineral assemblage of Barakar and Barren Measures is the same, viz., zircon, tourmaline, biotite, chlorite. Siderite development has not taken place in Barren Measures of all the basins. Siderite layers are well developed only in Raniganj Coalfield. In other basins it is often represented by carbonaceous shale, fine-grained sandstone succession.

According to BERNER (1971) siderite forms when Eh is low, pH high, and a high Co_2. Thus, siderite developes in lakes, which are low in dissolved sulphate and high in organic matter, and have high concentration of iron. It is postulated that during deposition of Barren Measures extensive development of lakes with impeded drainage took place in which mainly carbonaceous shales along with siderite were deposited. In some of Gondwana basins, lake development did not take place, with the result, these basins do not show recognizable Barren Measures facies.

In other words, the special lithological and mineralogical characteristics of Barren Measures is a result of environment of deposition, and not of the climate. Most probably subtropical to tropical climate of Barakar times continued into Barren Measures times. Due to extensive chemical weathering much iron was made available which was deposited in lakes as siderite.

Raniganj

The Raniganj succession is marked by the presence of thick sandstone, shale and coal sequences, which are repeated in cyclic nature. The sandstones are greenish to grayish in colour, fine to medium-grained, with alkali felspars. They can be designated as arkoses. Intercalated within sandstones are fine-grained sideritic sandstone. Shales are usually of sandy shale, gray shale or carbonaceous shale types. There are no beds of white, kaolinitic clays. The heavy mineral assemblage is made up of garnet, zircon, tourmaline, apatite etc., which suggest derivation from a Pre-cambrian basement complex with igneous and metamorphic rocks. Abundance of unstable heavy minerals, along with the presence of felspars indicate a quick burial of the weathered material with little reworking. The sandstones of Raniganj are finer-gained than the Barakar sandstones in Raniganj Coalfield. This suggests a peneplaned landscape with slow-moving streams. According to Karuna Karan and Mukherjee (1969) sediments of Raniganj age are marked by 30-50% kaolinite, 20-40% montmorillonite, 30-35% illite, and 10-15% chlorite. It seems that during deposition of Raniganj sediments warm humid climate (subtropical to tropical humid) was present; however the drainage was moderate, on a peneplaned, gentle landscape. Locally in marshes the iron released during weathering got precipitated as thin bands of siderite. Due to impeded drainage in warm humid climate, montmorillonite developed in appreciable amounts, along with the kaolinite.

In Godavari Valley, Kamthi sediments are equivalent to Raniganj. However, they are marked by coarse-grained sandstones, conglomerates, and absence of coal seams. These sediments represent deposits of a high relief area by rapidly flowing rivers. It is quite likely that in this area the climate was somewhat less humid than in the Damodar Valley.

Panchet

Panchet succession is made up of alternations of thick beds of light coloured coarse sandstone (arkose) alternating with relatively thinner beds of red coloured shales. Carbonaceous shales are absent. The content of felspars in the Panchet sandstone is much higher than in the underlying Raniganj sandstone. The felspar content is about 20-40% mostly the alkali felspars. The red coloured shales often include irregular carbonate nodules. The sandstone is rich in felspar content and mica. No coal seams are developed. There are also thin bands of limestone. The lower part of Panchet is made up of greenish silty shale and thin bands of brown, micaceos sandy shale. X-ray analysis of clay fraction of Panchet sediments shows that illite and kaolinite are the main clay minerals (Balasundaram *et al.*, 1970).

The Panchet succession is developed as red-bed facies, and can be described as piedmont valley flat type of red beds because they represent arkose-variegated/red shale association (Van Houten, 1961).

The Panchet sediments depict sedimentary structures, which point to their deposition by swiftly flowing rivers in a moderate relief area. The rate of sedimentation was fast, so that labile components, e.g. felspars were preserved. Grain size distribution also points to a fluvial environment of deposition (BALASUNDARAM *et al.*, 1970). Bones of vertebrates occur in localized lenticles in the sandstones in the form of channel lag deposits.

In the literature, Panchet are considered mostly as deposits of arid (PASCOE, 1968; WADIA, 1961) or semi-arid climate (TRIPATHI & SATSANGI, 1965). ROBINSON (1967) regards them to be deposits of monsoon type of climate, with heavier and longer seasonal rainfall. Panchet sediments show exclusively fluvial characteristics; nowhere aeolian sand deposits are present.

The red colouration of Panchet is facies controlled, and as discussed earlier points to deposition in a subtropical climate, with prolonged seasonal droughts associated with high temperatures. The climate comparable to that of Ganga basin must have existed during deposition of Panchet. Presence of illite in appreciable amount , high content of felspars also point to weak chemical weathering due to seasonal droughts. Abundance of kankar horizons in red shales is a further evidence of seasonal droughts of the type one has in Ganga basin.

With the onset of Panchet sedimentation tropical, humid climate(without seasonal variations) of Raniganj times changed gradually to subtropical climate with prolonged seasonal droughts of high temperatures.

MAHADEVA

Mahadeva succession include Pachmarhi beds, Denwa beds and Bagra beds and is best developed in Pachmarhi hills. The sediments are dominated by coarse-grained sandstones and conglomerates. The sandstone is white coloured with appreciable amount of felspar grains. MEHROTRA *et al.* (1971) investigated Mahadeva sediments of Palamau, Bihar and point out that they contain 10-30% felspars. The shales, wherever present, are always red coloured. The shaly facies of Mahadeva is made up of thick successions of red coloured to variegated shales, interbedded with the bands of white sandstone, which at places can be conglomeratic. The variegated shales are characterized by the abundance of carbonate nodules (Kankar). No coal seams are present. The clay mineral association is made up of 40-60% kaolinite, 20-40% illite, 10-20% chlorite, 0-25% montmorillonite (KARUNAKARAN & MUKHERJEE, 1969).

Sedimentary structures of Mahadeva sediments point to deposition by rapidly flowing rivers. The red-beds are facies controlled, i.e. shales are red coloured, and must have been laid down in more or less the same type of climate as the Panchet (subtropical climate with pronounced seasonal droughts).

Red coloured sediment which originate on piedmont valley flats are mostly associated with subtropical climate with prolonged periods of seasonal droughts. Such red beds are rich in labile components like felspars and rock fragments. The shale facies (Flood basin deposit) mostly shows development of carbonate nodules (Kankar). The clay fraction contains inherited clay minerals, i.e. illite and chlorite in appreciable amounts. Moreover, these deposits mostly lack any significant coal seams. It seems that a climate with prolonged seasonal droughts (Ganga basin climate) inhibits development of coal beds. The Siwalik succession, which also represent deposits of such climate, lacks any significant coal beds. The Gangetic alluvium also lacks any significant peat deposits, though it is fairly vegetated.

RAJMAHAL

The sediments of Rajmahal succession occur as intertrappeans within the Rajmahal traps, and are composed of chiefly white to gray shale, white to gray sandstone, carbonaceous shale and hard quartzose grit (PASCOE, 1968). The white shale is quarried for the porcelain industry, and is made up of chiefly kaolinite, with minor amounts of illite and montmorillonite (KARUNAKARAN & MUKHERJEE, 1969).

Locally iron rich bands are present showing oolitic (?) structure. They are very friable and made up of iron oxides and hydroxides (S. N. SINGH, personal communication).

Presence of thick units of kaolinitic clays suggests lateritic weathering in tropical humid climate under conditions of good drainage. Separation of iron is almost complete, as it occurs concentrated separately, precipitated most probably by biochemical processes. It is postulated that subtropical climate of Mahadeva times, which was marked by prolonged periods of seasonal droughts, gradually changed into tropical, humid climate during deposition of Rajmahal intertrappeans.

JABALPUR

The Jabalpur succession is characterized by coarse-grained to fine-grained soft sandstones, alternating with soft white clays. The sandstones are light coloured often quite mature, made up of mostly quartz grains. Sometimes minor amounts of altered felspars are present. The heavy minerals are dominated by zircon and tourmaline, along with garnet, suggeing an igneous—metamorphic provenance. Thin coal horizons and carbonaceous shales are intercalated. Locally ferruginous material occurs as thin bands and lenticular patches parallel to the bedding plane. White clays occur in thick units and are poor in ferruginous material. These clays are made up of essentially kaolinite with only traces of montmorillonite and illite (BAHL, 1964) and is used in ceramic industry. The kaolinite is well crystallized.

The mineralogical and lithological characteristics of the Jabalpur succession indicate that deposition of Jabalpur sediments took place in a tropical climate with heavy rainfall and excellent drainage conditions. Under such conditions chemical weathering is very intense leading to complete leaching of silicates into iron, silica etc. Iron was deposited in certain localized patches only, while in the soils mostly kaolinite developed and was accumulated in low-energy areas (e.g. flood basin) of the river system. The seasonal variations in the climate were insignificant.

UMIA

The Umia succession represents the uppermost unit of the Gondwana succession in peninsular India. It occurs interstratified with the marine sediments in Cutch area. The fresh water Umia sediments are made up of mostly white clay beds, along with light-coloured sandstones and sandy shales. Some of the sandstones are associated with extremely ferruginous bands. Few shale bands are also extremely ferruginous containing high amount of ironoxides and hydroxides. Some of the sandstones are very mature and pure and are utilized for making glass. Thin bands of coal are also present. The white clay often occurs in thick units and is employed for the manufacture of refractories. Though, no clay mineral analysis is available, it seems that clays are mostly kaolinitic.

It seems that tropical, humid climate of Rajmahal and Jabalpur times continued also during depostion of Umia sediments and led to extensive chemical weathering of the rocks producing highly evolved clays, mature sandstone and separation of iron to make iron-rich units.

CHANGES IN PALAEOCLIMATES DURING GONDWANA TIMES

From the foregoing discussion it is quite evident that during Gondwana times climate witnessed definite changes, which are well reflected in the mineralogical composition of the sediments. Though, we have meagre mineralogical data about different units of Gondwana deposits, it is quite evident that parameters like kankar horizons, colour, maturity of sandstone, felspar content, and clay mineral composition are rather useful in interpretation of palaeoclimates of the Gondwana sediments.

After a prolonged period of non-deposition, peninsular shield of India witnessed glacial activity at the onset of Gondwana sedimentation. Cold glacial climate of Talchir times gradually changed to subtropical to tropical climate during Barakar times, and continued into Barren Measures and Raniganj times. The climate during sedimentation of Damuda succession was lacking in seasonal changes (seasons of rainfall and dryness); the total rainfall must have been uniformly distributed throughout the year. Though, the general climate during Damuda times remained the same, the relief development and the drainage affected the mineralogical composition of the sediments.

Beginning of Panchet succession marked a significant change in the climate, i.e. the tropical, humid climate of Damuda times, where there were no seasonal changes, gradually gave way to a subtropical climate with pronounced seasonal changes. Rainfall, though relatively high was restricted to few months, which alternated with several months of dryness. During these drought months temperature comparable to those of arid climate must had been reached. This climate is well comparable to the climate of present day Ganga basin. Red colouration only in shale facies (sand facies is white), and kankar development in the shales further manifest seasonal droughts. The same type of climate continued during deposition of Mahadeva succession.

During sedimentation of Rajmahal intertrappeans, seasonal changes of the climate again disappeared, and a tropical climate with heavy rainfall distributed all the year round became established. This tropical climate continued upwards in the time during sedimentation of Jabalpur and Umia sediments.

CONCLUDING REMARKS

To sum up, it may be stated that we know very little about the mineralogical composition of the Gondwana sediments. The palaeoclimatic interpretation of Gondwana sediments based on mineralogical parameters as given in the foregoing pages must be regarded as tentative; it may be revised as soon as we get more detailed information about mineralogy, especially the clay mineralogy. Moreover, an integrated approach incorporating lithological, mineralogical, palaeobotanical, palaeontological, palaeomagnetic, geochemical information, along with facies and environmental analysis, would help us to obtain a clearer picture of climatic changes during Gondwana times.

It is evident from the scanning of the literature that most of the studies have been carried out in Talchir-Barakar succession. So far little emphasis has been placed on the study of Panchet, Mahadeva, Rajmahal, Umia successions from the view point of palaeoclimatic reconstruction.

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REFERENCES

Bahl, D. P. (1964). Origin and significance of the Upper Gondwana kaolinite beds of Jabalpur, Madhya Pradesh, India. *22nd Internat. geol. Congr. New Delhi.* **9**: 283-289.

Balasundaram, M. S., Ghosh, P. K. & Dutta, P. K. (1970). Panchet sedimentation and origin of red beds. *Second Gondwana Symposium, South Africa Proc.* : 293-301.

Berner, R. A. (1971). *Principles of chemical sedimentology.* McGraw-Hill Book Company, New York.

Cailleux, A. (1942). Les actions eoliennes peri-glaciaires en Europe. *Mem. Soc. Geol. France.* **46**: 1-176.

Cailleux, A. & Schneider, H. (1968). L'usure des sables vue au microscope electronique a balayage. *Sci. Prog.* 3395: 461-469.

Glennie, K. W. (1970). *Desert Sedimentary Environments.* ***Developments in sedimentology*** Vol. **14,** Elsevier, Amsterdam.

Kar, P., Banerjee, A. K., Banerjee, S. P. & Jhala, S. V. (1964). Heavy mineral assemblages and their significance in Lower Gondwana sediments of West Bokaro Coalfield. *22nd Internat. geol. Congr. New Delhi.* **9**: 290-302.

Karunakaran, C. & Mukherjee, B. (1969). Clay minerals in argillaceous sediments of Gondwanas in parts of Peninsular India. *Gondwana Stratigraphy, IUGS Symposium, Buenos Aires,* 1967: 675-608.

Krinsley, D. & Margolis, S. (1969). A study of quartz sand grain surface textures with the scanning electron microscope. *Trans. N. Y. Acad. Sci.* **31**: 457-477.

Krynine, P. D. (1935). Arkose deposits in the humid tropics. *Amer. J. Sci.* **29**: 353-363.

Krynine, P. D. (1936). Geomorphology and sedimentation in the humid tropics. *Amer. J. Sci.* **32**: 297-306.

Krynine, P. D. (1949). The origin of red beds. *Trans. N. Y. Acad. Sci.*, Ser. 2, **11**: 60-68.

Mehrotra, M. N., Singh, D. & Chandra, M. (1971). Textural analysis of the Upper Gondwana sandstones of Latehar, district Palamau (Bihar) and its significance. *Gondwana System, a symposium. Annals Geol. Dept. AMU, Aligarh.* **5-6**: 178-190.

Millot, G. (1970). *Geology of clays.* Masson et Cie, Paris.

Misra, R. C., Singh, I. B. & Kumar, S. (1971). A note on the sedimentological study of Gomti River, Uttar Pradesh, India. *Geophytology.* **1**: 151-155.

Pascoe, E. H. (1963). *A manual of the geology of India and Burma,* Vol. **2**. Govt. of India press, Calcutta.

Robinson, P. L. (1967). The Indian Gondwana formations—A review. *Reviews first Symp. Gondwana Stratigraphy Argentina*: 201-268.

Singh, I. B. (1972). Ablagerungsvorgänge in Flüssen am Beispiel des Gomti in Indien. *Naturu. Museum.* **102**: 50-62.

Singh, I. B. (1974a). Mineralogical studies of Gondwana sediments from Korba Coalfield, Madhya Pradesh, India. Part II-Scanning electron microscopy of sand grain surface features. *Geophytology.* **4**: 60-82.

Singh, I. B. (1974 b). Mineralogical studies of Gondwana sediments from Korba Coalfield, Madhya Pradesh, India. Part III—Clay mineralogy. *Geophytology.* **4**: 196-220.

Singh, I. B. (1975a). Mineralogical studies of Gondwana sediments from Korba Coalfield, Madhya Pradesh, India. Part IV—Study of heavy minerals. *Geophytology.* **5**: 61-71.

Singh, I. B. (1975b). A sedimentation model for the Siwalik sediments. *Chayanica Geologica.* **1**: 91-98.

Singh, I. B. (1976). Mineralogical studies of Gondwana sediments from Korba Coalfield, Madhya Pradesh, India. Part V—Mineralogy of silt fraction, coarse fraction study, and petrography. *Geophytology.* **6**: 46-62.

Singh, I. B. & Sharma, K. K. (1973). Mineralogical studies of Gondwana sediments from Korba Coalfield, Madhya Pradesh—I. X-ray mineralogy of the bulk samples, and optical mineralogy of the sieve fraction (0.1-0.2 mm). *Geophytology.* **3**: 195-204.

Tripathi, C. & Satsangi, P. P. (1963). *Lystrosaurus* fauna of the Panchet series of the Raniganj Coalfield. *Mem. geol. Surv. India. Palaeont. Indica.* **37**: 1-53.

Van Houten, F. B. (1961). Climatic significance of red beds. In: Nairn, A. E.M. (editor), *Problems in palaeo-climatology.* 89-139. Interscience Publisher, New York.

Van Houten, F. B. (1968). Iron oxides in red beds. *Bull. geol. Soc. Am.* **79**: 399-416.

Wadia, D. N. (1961). *Geology of India.* Mcmillan, London.

Walker, T. R. (1967). Formation of red beds in modern and ancient deserts. *Bull. geol. Soc. Am.* **78**: 353-368.