A STUDY ON THE DEPOSITIONAL PROCESSES AND HEAVY MINERAL ASSEMBLAGE OF THE QUATERNARY SEDIMENTS FROM MURSHIDABAD DISTRICT, WEST BENGAL

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Quaternary sediments designated as the Bhagirathi formation and occurring in Murshidabad district of the lower Ganga valley of West Bengal consist of a succession of clay, silt, sand, pebbly sand and pebble. The pebbly sand and pebble form a coarse substratum at the base of the Quaternary sequence resting upon a Tertiary basement. Log-probability plot of the grain size distribution indicates three well-defined populations such as suspension, saltation and surface creep or bed load. Textural pattern of these populations suggests that the sediments were deposited under fluvial conditions. The C-M pattern diagram also reveals characteristics which are typical of river deposits. The sediments are characterised by a varied and rich suite of heavy minerals consisting of garnet, tourmaline, hornblende, zircon, kyanite, staurolite, rutile and sillimanite suggesting a Recent or Late Quaternary age.

INTRODUCTION

Murshidabad district forming a part of the Lower Ganga valley of West Bengal is covered by extensive deposits of Quaternary alluvium. The eastern part of the district was explored for ground water during the sixties by drilling a large number of boreholes which yielded a vast amount of subsurface geological data. These borehole samples were analysed in the sedimentological Laboratory of the Eastern Region, Geological Survey of India during 1973–74 and were interpreted for deciphering the mode of transport and depositional history of the Quaternary sediments. Heavy mineral assemblages were studied for correlation and identification of the provenance of the sediments.

No systematic work had previously been done on these sediments. There is, however, a reference to a few boreholes of this area in a treatise on groundwater conditions of Greater Calcutta Industrial Area (Chaterji *et al.* 1964).

The area of study (Fig. 1), about 500 sq km in areal extent, lies about 350 km north of the Bay of Bengal and is drained by the Bhagirathi river in the western part and by the Bhairal river in the central part. The Sialmari river flowing through the eastern part has shallowed up; it is now mere a spill-way channel for flood water during monsoons. These are tributaries of the Ganga (also called Padma) which flows about 15 km to the north of the northern limit of the area. These rivers are meandering in nature and have shifted their courses many times during the period of alluviation as indicated by numerous river scars left on the surface in the form of river cut-offs, ox-bows, etc.

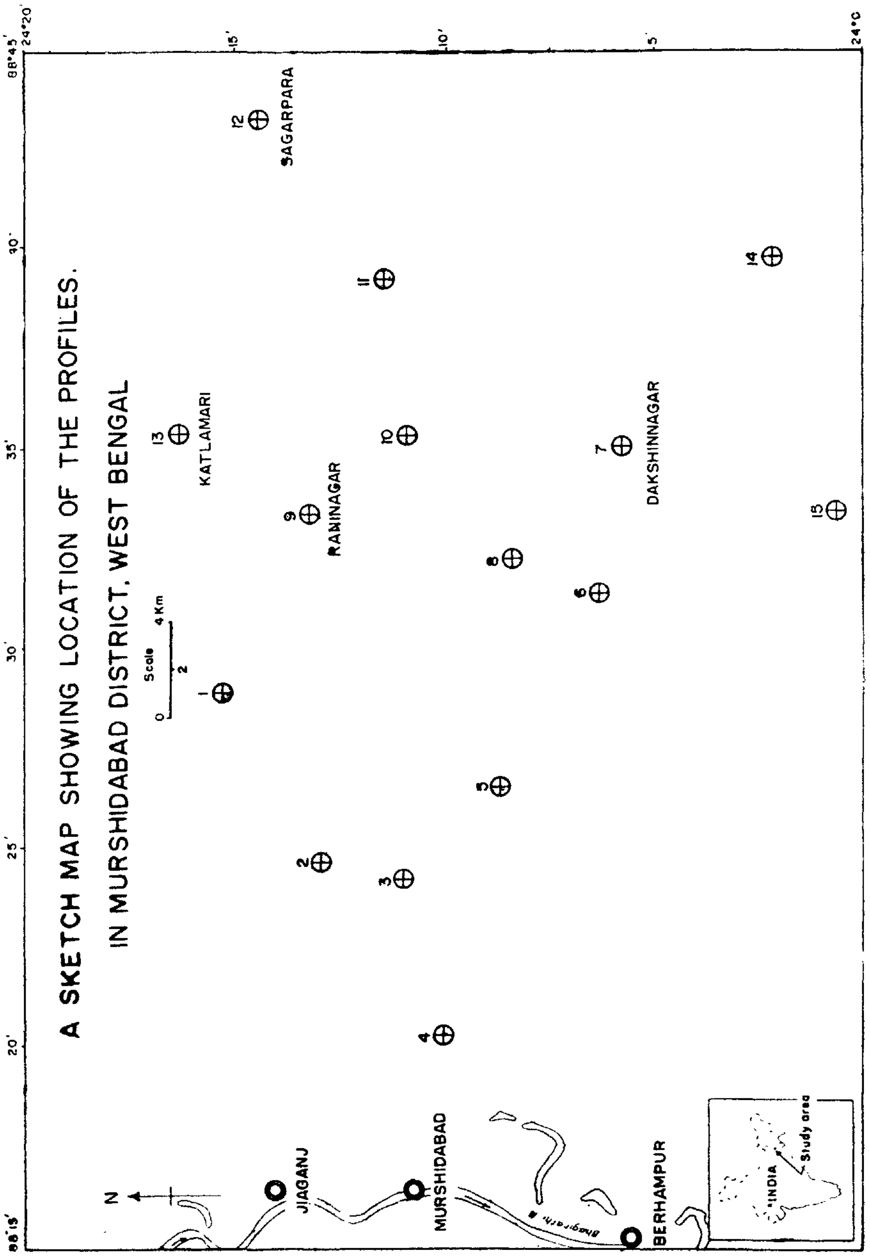


FIG. 1. A sketch map showing the location of boreholes in Murshidabad district, West Bengal, India from which vertical profile sampling has been done.

About 250 borehole logs were studied for a synthesis of the lithological sequence and samples from 15 key boreholes were subjected to sedimentological analyses for determination of grain-size parameters and heavy mineral suites.

GEOLOGICAL SET-UP

Geomorphologically, the area is a featureless plain and forms a part of the Late Quaternary alluvial plain which has also been referred to as the Younger Deltaic Plain by Mallick and Niyogi (1972). This plain is characterised by a gentle southerly master slope, and all the rivers draining the area have also a general southerly flow. The flatness of the plain is remarkable and its general elevation ranges from 12 to 15 metres above the mean sea level, which is in marked contrast to the Older Alluvial Plain (Early Quaternary) lying to the west of the study area. The elevation of the Older Alluvial Plain is much higher being 30 to 15 metres above the mean sea level, and the plain is characterised by a rolling topography. The soils of the Older Alluvial Plain are more mature and have undergone oxidation to various degrees and are much impregnated with nodules of calcium carbonate. Surfacial material of the Late Quaternary plain is free from calcareous matter, and is less mature and consists of sandy to silty loam.

The development of the alluvial plain is related to the world-wide phenomena of glaciation and deglaciation during the Quaternary period resulting in eustatic changes in sea level and concomitant transgression and regression of the sea. During the Late Pleistocene period the sea retreated and new areas emerging from the sea were thrown open to the rejuvenated river system and a new cycle of fluviatile sedimentation commenced. The sediments occurring in the area are the results of valley alluviation during the Late Quaternary period.

Study of the lithological logs and subsurface samples collected from nearly 250 boreholes drilled in the area reveals that the geological sequence consists of a succession starting with a basal silty clay and overlain by silt, clay, sand and pebble at least down to a depth of 300 metres. The basal silty clay has been established to be of Upper Tertiary age (Miocene) on the evidence of microfossils (Chaterji *et al.* 1964). On this Tertiary clay base, the Quaternary sediments have been deposited with a coarse substratum represented by pebble at the base which is followed upwards by sand, clay and silt. This coarse substratum is related to the lowering of sea level in the Late Quaternary period and consequent increase of the stream gradient resulting in greater erosive activities of the stream system. On geomorphic criterion these sediments appear to be definitely younger than the sediments associated and underlying the Older Alluvial Plain, which is considered to be of Pleistocene age (Mallick & Niyogi 1972). So these deposits are considered to belong to a later Quaternary period (Late Pleistocene to Recent), and have been designated as Bhagirathi formation to distinguish them from Pleistocene alluvium.

Fig. 2 gives a general index of symbols for various illustrations. To bring out the subsurface configuration of the different lithological units a fence diagram has been prepared on the basis of lithological logs of selected boreholes (Fig. 3). The diagram reveals that the pebble substratum is generally 10 to 20 metres thick and occurs below a depth of 60 to 70 metres. It is fairly persistent except in a

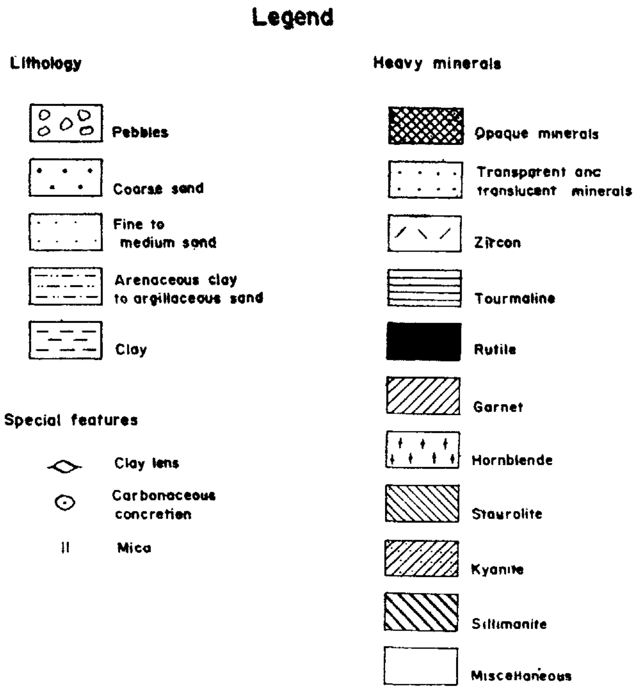


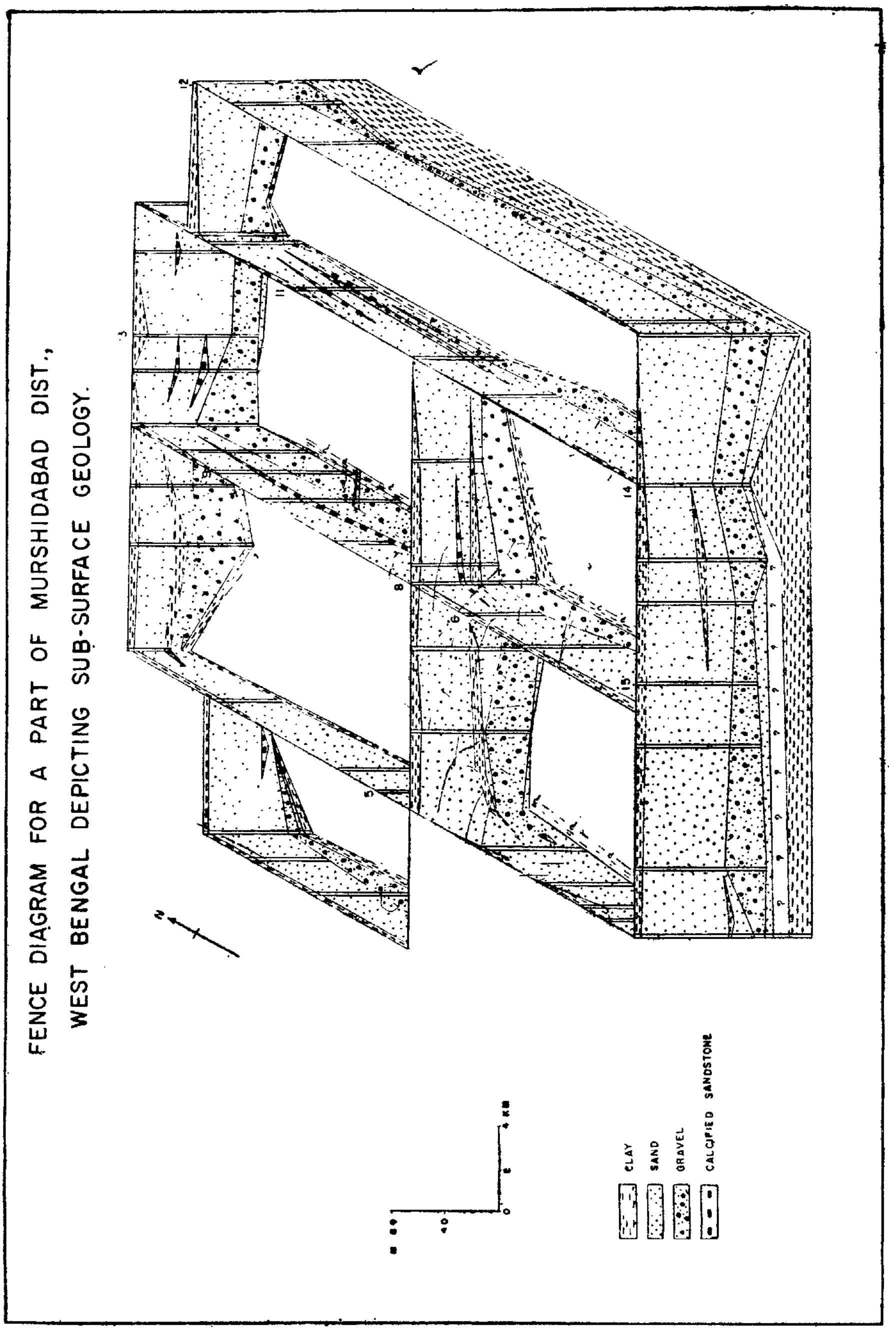
FIG. 2. A general index for symbols used in the various illustrations.

western sector of the diagram and appears to have a sheet-like disposition. Apart from sand, silt and clay are the other clastic elements. Clay occurs as a lensoid body in the upper part of the sand sequence in isolated cases. Silt, silty clay and fine sand occur in the upper part of the deposit. Fine to coarse sand occurs throughout the sequence. The colour of the sand is generally light grey, while the clay is dark grey. Nonclastic sediments are represented by calcium carbonate occurring as rare nodules. A thin zone of calcified sand occurs amidst the sequence of sand in the northern and eastern parts of the area. This zone is very compact owing to the sand being cemented by the circulating solution of calcium carbonate.

These sediments occur in a loose and unconsolidated state and are of fresh water origin as indicated by freshwater molluscan shells of Recent age. No fossil with marine affinity has been recorded in the sediments overlying the Tertiaries. Although the pebble bed is characterised by a sheet-like disposition, it thickens and thins out in places and is marked by lenticularity in the western part. Textures of sand also show considerable lateral variation. The sheet like feature of pebble bed has perhaps resulted from fusion of individual beds deposited by an anastomosing net-work of palaeochannels.

GRAIN-SIZE PARAMETERS AND DEPOSITIONAL PROCESSES

Grain-size distribution plays an important role in the identification of dynamic processes governing the transport and deposition of sediments. Although the genetic



G.S.I. E.R.O. CALCUTTA. DRAWING NO. 168/74.

FIG. 3. A fence diagram showing the subsurface geological formations of Murshidabad area.

significance of grain-size parameters is now better understood as a result of work by Doeglas (1946), Inman (1949), Passega (1957, '64), Moss (1962, '63), Spencer (1963), Friedman (1961, '67) and Visher (1969), textural criteria may not be conclusive enough for environmental reconstruction.

Grain-size distribution of about 100 samples collected from 15 selected bore-holes was determined by conventional method of sieving. Wentworth scale of classification with the corresponding phi conversion was adopted in the analysis and description of the sediments. For those samples which contain both pebble and sand, sand fraction was separately analysed. The frequency of the pebble population was determined by counting. The size frequency data were utilized in determining various quartile measures. Graphic parameters such as inclusive graphic mean size (Mz), graphic standard deviation (σ_1), graphic kurtosis (K_G) and skewness (SK_I) were determined by following the method of Folk and Ward (1957).

To understand the depositional mechanism and environments of the sediments under study the mechanical analysis of about 50 samples are plotted on arithmetic probability paper in phi-scale following the technique of Visher (1969). According to Visher textural response to environment is reflected in the shape of the log-probability curves and in the position of the truncation points between different populations making up the sediment which provide valuable clue for identification of depositional environments. In all the curves studied three straight line segments are identified representing suspension, saltation and surface creep or bed load population (Fig. 4).

On the basis of the analysis of the shape and characteristics of the log-probability curves two types of distribution can be recognised. One type of distribution is characterised by a well-developed suspension population varying from 20 to 26 per cent with the truncation point being located at 2 to 3.5 phi. The saltation population has a size range of 1 to 3.5 phi and is well sorted as indicated by the slope of the curves. The bed-load population is very insignificant being 0.2 to 1.2 per cent generally. The break between the saltation and the bed-load occurs at 1 phi. The characteristics of this distribution are more or less similar to those of fluvial sediments described by Visher (1969, p. 1903).

In the second type the suspension population is variable from 1 to 5 per cent. The truncation between the suspension and saltation population is at 2.5 to 3 phi. The bed-load population is very well developed varying from 30 to 74 per cent. The break point with the saltation population lies at 1 phi. The grain size range of the saltation population is 1 to 3 phi. In this distribution the saltation population is less in quantity and is less sorted compared to the former type of distribution. Visher (*op cit*) postulated that bed-load population in fluvial sediments is controlled by provenance and current competency of the transporting media. Bed-load population may or may not be present, when present, it is coarser than 1 phi. The shape of the curves of the second type of distribution, bears certain similarity with those described by Visher (1969, p. 1092, Fig. 14D) in respect of the sediments of the Altamaha river.

The grain-size analyses of the samples under study are also represented by the C-M pattern technique of Passage (1957, '64) by plotting C (one percentile particle diameter) against M (median) on arithmetic graph paper, for understanding

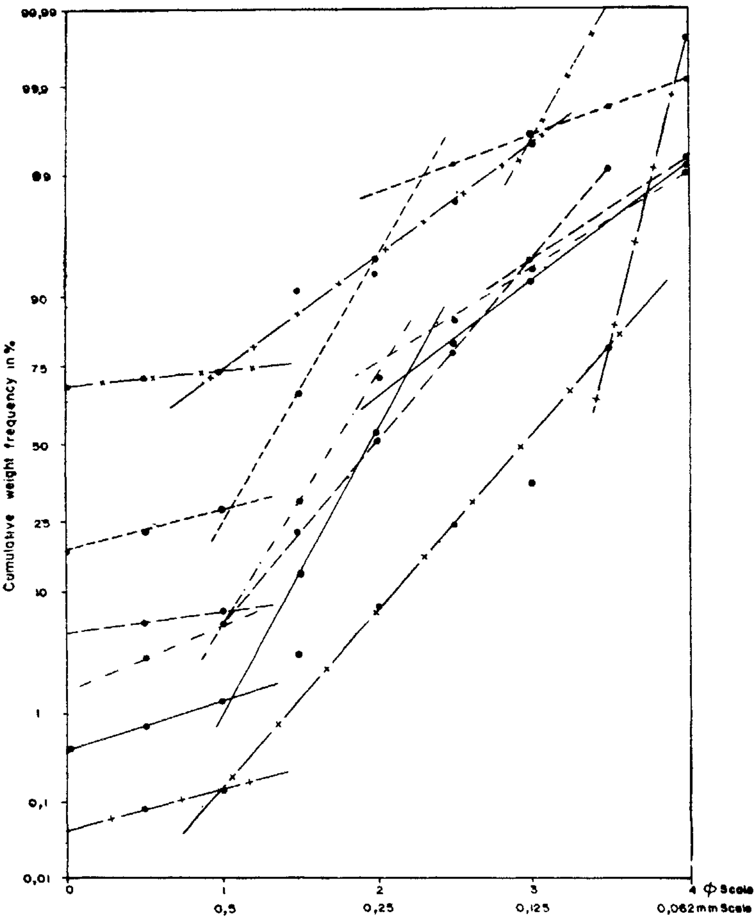


FIG. 4. Log-probability curves of a few representative samples from Murshidabad area.

the depositional mechanism (Fig. 5). Passega has built up a number of models by plotting C and M values of a large number of sediments collected from various environments and has established a correlation between C-M pattern and mode of transportation of sediments by tractive currents. Rivers, marine currents and waves touching bottoms are tractive currents. The model of a complete tractive current deposit (Passega, 1964, p. 831, Fig. 1) is designated by N—O—P—Q—R—S segments representing different modes of transport such as pelagic, uniform suspension, graded suspension, bottom suspension with rolling and rolling.

The C-M diagram (Fig. 5) of the samples under study has marked resemblance with the PQ and QR segments of the Passega's tractive current model. The lower part of the Fig. 5 is very close to the limit C-M and is almost parallel to it like the segment PQ of Passega's model suggesting thereby that the sediments were deposited as graded suspension The upper part of the Fig. 5 is almost straight like the segment QR of Passega's model. A deposit showing such a pattern is

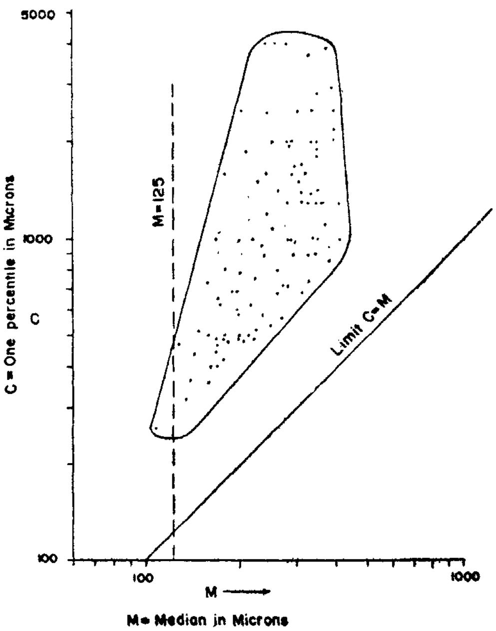


FIG. 5. C-M pattern diagram.

formed by graded suspension to which a small amount of coarse material has been contributed by rolling. The values of C's of the samples of graded suspension range from 400 to 1000 microns, while those of the graded suspension and rolling show a range from 1300 to 4000 microns. The C-M pattern diagram of the Murshidabad sediments is comparable with those of fluvial sediments described by Passega (*op cit.*). The finer sediments were deposited as graded suspension, while the coarser ones were deposited as graded suspension and rolling.

Graphic parameters of Folk and Ward (1957) and Quartile measures after Trask (1932) have also been determined for these samples. The graphic parameters are represented by two scatter diagrams prepared on the basis of inclusive graphic mean size *vs.* graphic standard deviation (Fig. 6) and graphic kurtosis *vs* inclusive graphic skewness (Fig. 7). The quartile measures of Trask are depicted in one profile of a representative borehole (Fig. 8).

When expressed in graphic parameters, a perfectly normal distribution will be characterised by 0.00 skewness and 1.00 kurtosis. Study of the Fig. 7 shows that 50 per cent of the samples under study show nearly symmetrical distribution, while a group of 20 per cent is positively skewed, while another 20 per cent shows negative skewness. According to Friedman (1967) continental sediments like river deposits and inland dunes containing an excess of fines are generally positively skewed. For sediments like coarse sand and graval in which fines are removed may be either positively or negatively skewed and its relationship is unpredictable. About 50 per cent of the samples are leptokurtic and the remaining samples are

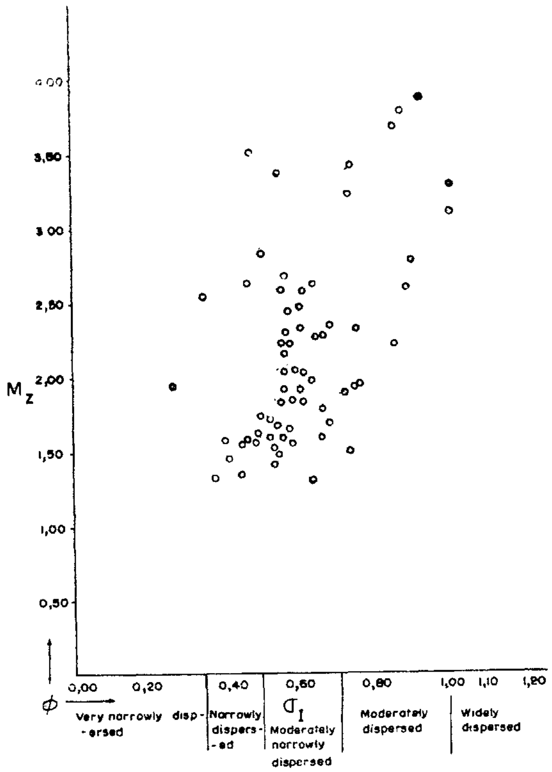


FIG. 6. A scatter plot of inclusive graphic mean size *vs.* graphic standard deviation.

either mesokurtic or platykurtic. The significance of kurtosis is not clear in the present case.

Inclusive graphic mean size varies from 1.25 phi to 3.85 phi indicating a variation in texture from very coarse to very fine. The sorting of the sediments is rather moderate with standard deviation of 0.15 phi to 0.4 phi. The study of the profile (Fig. 8) shows that median diameters generally vary from 0.1 to 0.4 mm, and median diameter increases with depth. The finer sediments occurring within 30 meters from the top are not so well sorted as those occurring further down in the sequence as evident from the profile. The vertical change in sorting and median diameters suggests varying energy conditions of the transporting medium.

MINERALOGICAL COMPOSITION OF THE SEDIMENTS

Except for the description of heavy mineral suites of Quaternary sediments obtained from a single borehole drilled near the city of Calcutta lying about 250 km to the south, no detailed work seems to have been done on the mineralogical aspect of the Quaternary sediments of the Lower Ganga valley of West Bengal (Coulson 1940). So the mineralogical data emanating from this study will have much importance for correlation of similar sediments occurring elsewhere.

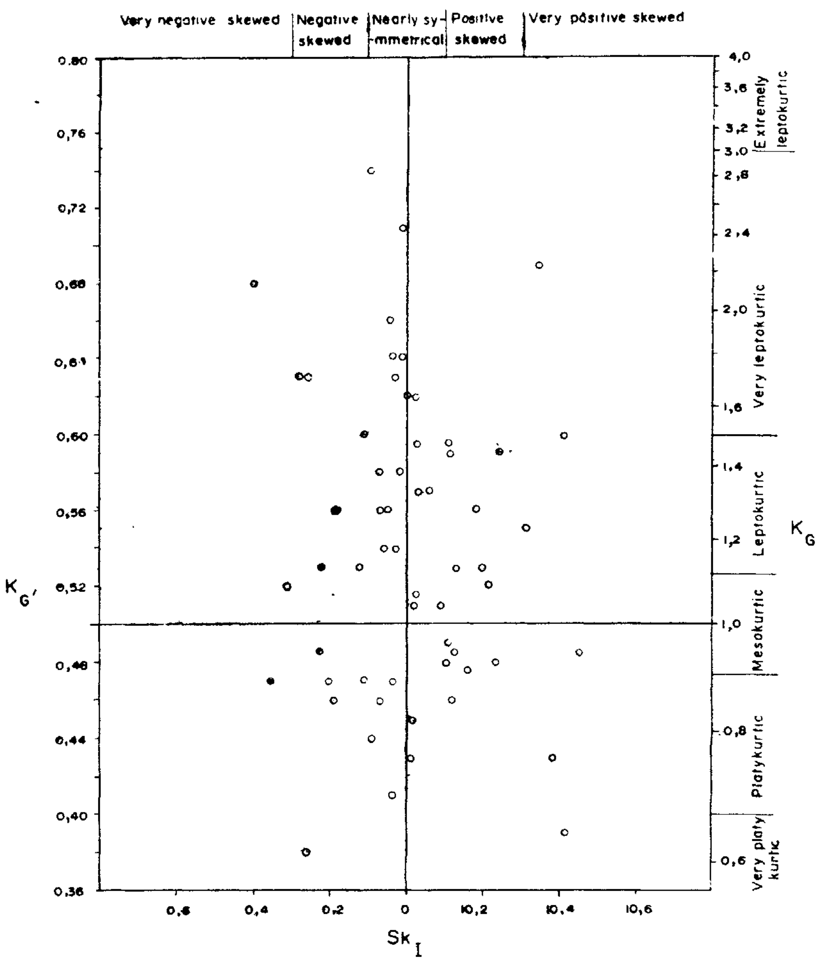


FIG. 7. A scatter plot of graphic kurtosis against inclusive graphic skewness.

Laboratory Procedure—The samples for heavy mineral separation were treated as per the methods of Mueller, (1967, pp. 41–42). Five grammes of the pretreated material from the 0.125–0.062 mm grade, was centrifuged in a bromoform liquid having a specific gravity of 2.83. About 100 samples selected from 15 boreholes were treated for separation of the heavies. After separation, both the heavy and light crops were collected. The light fractions were studied qualitatively only to identify the minerals present. The heavy minerals were studied under microscope and their frequencies were determined by counting. To depict the vertical dispersion of heavy minerals one profile is constructed for a representative borehole (Fig. 8). The heavy mineral assemblages are also represented by histograms and pie diagrams (Fig. 9) to reveal the pattern of their regional distribution.

Heavy Mineral Suites—The minerals present in heavies separated by bromoform consist of garnet, tourmaline, hornblende, zircon, kyanite, staurolite, rutile

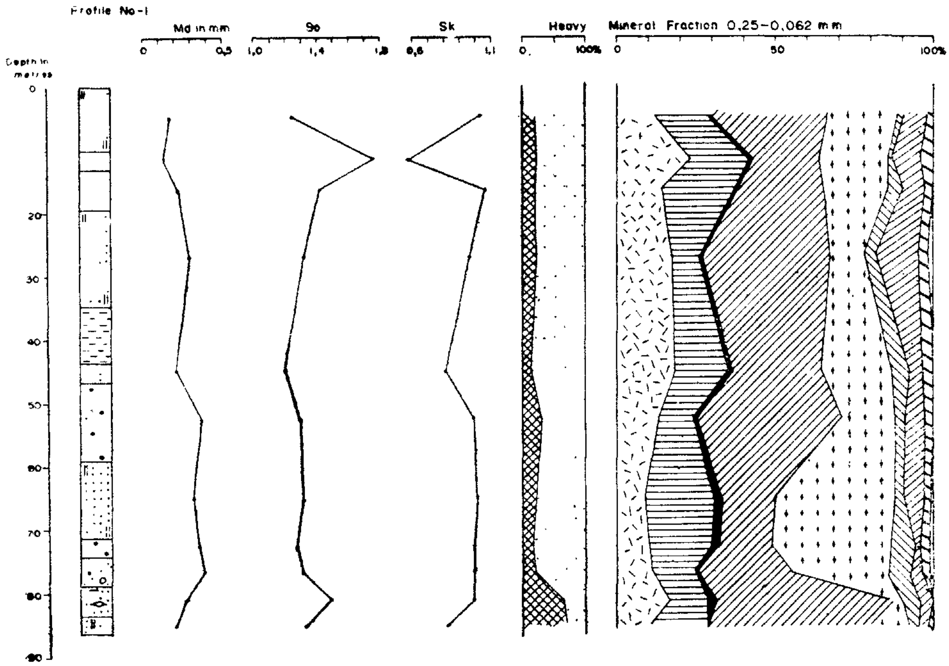


FIG. 8. A profile of borehole No. 1 showing the distribution of grain size parameters and heavy minerals.

and sillimanite in order of abundance. In some of the slides a few grains of anatase, apatite, epidote and augite have been observed. Opaque minerals consisting of magnetite, ilmenite, leucoxene and haematite are present in quantities generally variable from 10 to 30 per cent (Fig. 8). The characteristics of the non-opaque heavy minerals are described below:

Zircon—The mineral occurs generally in subangular to rounded grains, A few grains with good crystalline outline and zonal structure are also noted. Most of the grains contain inclusions oriented parallel to the *c*-axis. A few grains of brownish variety also occur.

Tourmaline—This mineral is present either in tabular or rounded form. Most of the grains are sharp-edged, indicating thereby the freshness of the mineral. Green and bluish-green varieties are very common. Brown variety has also been observed. Tourmaline is the most abundant stable mineral in the samples.

Rutile—It is generally yellowish brown in colour. A few grains with reddish brown colour have also been observed.

Garnet—This is the most dominant heavy mineral in all the samples studied. Grains are either colourless or pale pinkish with sharp edges. Inclusions are very common.

Amphibole—It is a dominant mineral occurring in angular to subrounded grains; shows a high degree of pleochroism. Some grains show alteration also.

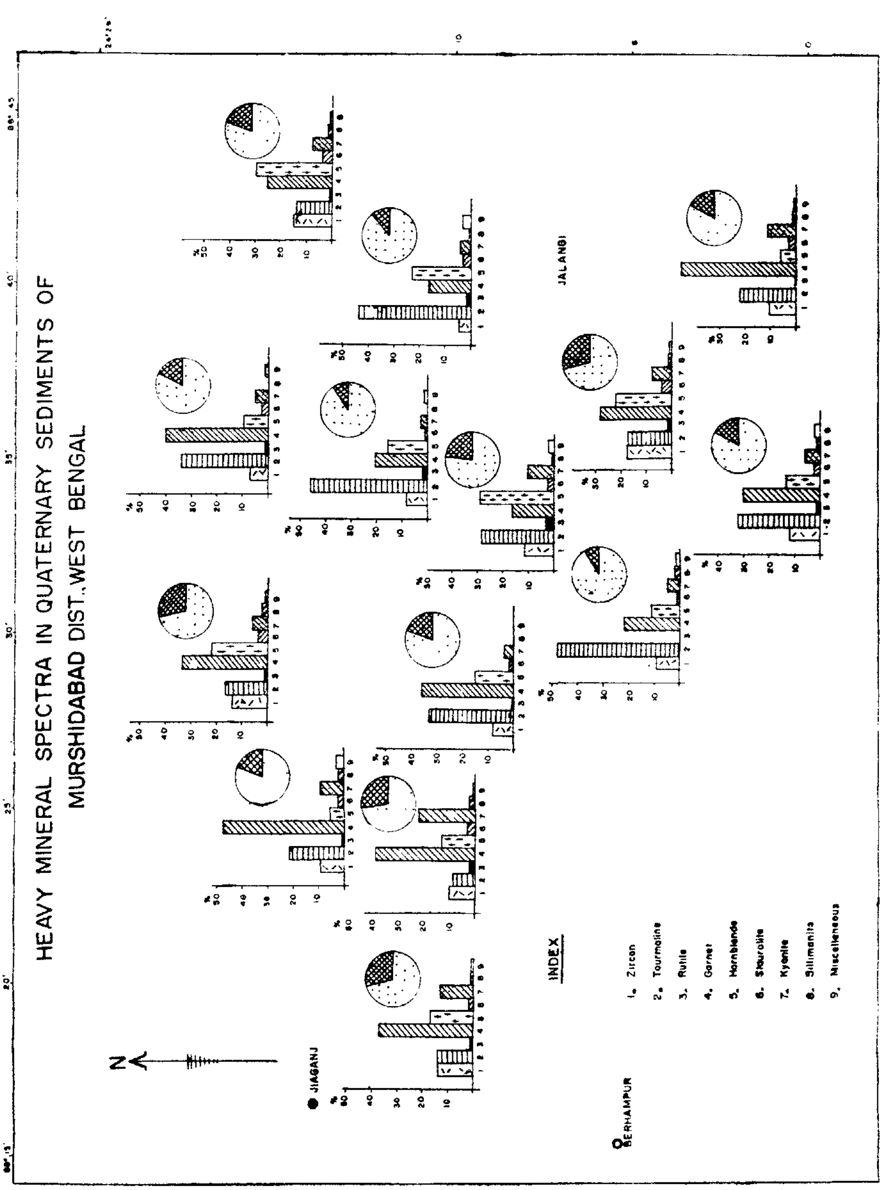


FIG. 9. A map showing the regional distribution of heavy minerals in Murshidabad area.

Staurolite—This mineral is present in small quantities in all the samples studied; shows pleochroism in tones of straw yellow. Inclusions of quartz are quite common.

Kyanite—It occurs as typically bladed form characterised by prominent cleavages. Some are short and other elongated.

Sillimanite—The mineral is not very common in the sediments and occurs as fibrous mass or slender prisms showing parallel extinction.

Heavy Mineral Dispersions and their Significance

The minerals present in the heavy mineral assemblage can be divided into two groups, namely (*i*) the stable group consisting of zircon, tourmaline and rutile and (*ii*) the metamorphic suite represented by garnet, kyanite, sillimanite and staurolite. Among the stable minerals although tourmaline is the most dominant, its frequency is rather variable from borehole to borehole (Fig. 9). In three boreholes Nos. 6, 10 & 11 lying in the east central part of the area the concentration of tourmaline is maximum being 44 to 48 per cent, while in the borehole No. 3 its percentage is as low as 9. In the rest of the boreholes concentration of tourmaline varies from 14 to 34 per cent. Zircon is present to the extent of 10 to 12 per cent on an average. Rutile is rather scarce; it never exceeds 3 per cent in concentration. The average combined concentration of the three stable minerals works out at 32 per cent.

Among the metamorphic suite garnet is predominant occurring to the extent of 30 to 40 per cent on an average. The highest percentage of 47 is recorded in the samples from the borehole No. 2. Kyanite is present in appreciable quantity; its frequency varies from 2 per cent in borehole No. 10 to 12 per cent in borehole No. 3. Frequency of staurolite is restricted to 2 to 3 per cent, while sillimanite is as low as 1 to 2 per cent in concentration and appears to be absent in the sediments from the boreholes Nos. 6, 10 and 13. Hornblende is variable from 6 to 24 per cent in frequency. The predominance of the metamorphic suites of minerals indicates that the sediments have been derived from high grade metamorphic rocks. Staurolite, kyanite, sillimanite, garnet and hornblende are unstable heavy minerals and are liable to weathering and other diagenetic changes during transport. The stable minerals like zircon, tourmaline and rutile on the other hand are not sensitive to weathering and diagenesis and can stand the rigour of long distant transport. So they are not very good indicators of transport hazards of sediments. The unstable minerals staurolite, kyanite, sillimanite and garnet present in the sediments are fresh and angular thereby suggesting that the sediments have not been transported from a distant source.

The preponderance of the metamorphic suite of minerals, kyanite and sillimanite particularly, indicates that the source rocks of the Quaternary sediments might be the high grade Archaean metamorphic rocks containing sillimanite and kyanite. Such kyanite and sillimanite bearing-rocks are known to occur in the Darjeeling Himalayan region lying about 500 to 600 km to the north of the study area. The drainage channels flowing through the area must have connections with those of the North Bengal receiving sediments from the Himalayan region and were responsible for the deposition of the Quaternary sediments.

The study of the profile (Fig. 8) shows that there is no major change or fluctuation in the distribution of the heavy minerals. The heavy minerals are qualitatively more or less uniformly distributed in the vertical sequence, although there may be minor variation in their frequency. No key or marker minerals could be identified as diagnostic of any particular lithological horizon. As such no lithological unit could be separated and classified on the basis of heavy minerals assemblage. The distribution of opaque minerals is also uniform vertically, except that in the bottom part of the profile (Fig. 8) the concentration of opaque minerals is as high as 70 per cent.

Hayman, quoted by Coulson (1940), described a "1302-foot" borehole drilled near Calcutta. The assemblage consists of ilmenite, hornblende, garnet, common epidote, kyanite, sillimanite, tourmaline and staurolite. This assemblage bears a marked similarity with the heavy mineral suites in the sediments from the Murshidabad area except the rarity of epidote. According to Hayman, this rich and exceedingly varied assemblage is suggestive of a recent origin for the sediments underlying the Calcutta area. Based on the evidence of heavy minerals the age of the Murshidabad sediments may also be considered to be Late Quaternary or Recent.

CONCLUSIONS

A sequence of sediments underlying the Quaternary plain of Murshidabad district, West Bengal is considered to be of Late Quaternary age from geomorphic criteria and are designated Bhagirathi formation to differentiate them from the Pleistocene sediments occurring to the west of the study area.

Log-probability plots of the sediments are characterised by three straight line segments representing well-developed suspension, saltation and surface creep or bed-load populations. The bed-load population is more in the samples from the coarse substratum of the geological sequence. The shape of the log-probability curves of the sediments suggests a fluvial origin. The C-M pattern diagram also indicates features suggesting depositional processes under fluviatile conditions.

The sediments are characterised by a rich and varied assemblage of heavy minerals consisting of garnet, tourmaline, hornblende, zircon, kyanite, staurolite, rutile, and sillimanite which also suggests a Recent or Late Quaternary age for the Bhagirathi formation.

The data presented in this paper will form a basis for future integrated study of the Quaternary sediments of the lower Ganga valley.

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