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SEDIMENTOLOGY OF THE QUATERNARY ALLUVIAL DEPOSITS IN AND AROUND DACCA, EAST PAKISTAN

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Abstract. Petrographic and mineralogical studies of the Modhupur Clay of Pleistocene age and the alluvium of the Recent have been carried out. The thick deposits of Modhupur Clay gradually grade from sandy-clay to clayey-sand downward. Statistical analysis of grain-size parameters clearly brings out this change with depth. The alluvium of the Recent is more closely related to the upper part of the Modhupur Clay in its petrogr aphic properties.

The Modhupur Clay and the alluvium differ in their heavy mineral contents, but igneous and metamorphic rocks together with preexisting sedimentary rocks as sources for the two are indicated. The sediments of both the Modhupur Clay and the alluvium are suggested largely to be the product of more than one cycle of erosion. Shape analysis of quartz grains from the two sediments indicates that present day erosion of Modhupur Clay has provided considerable amount of sediments to the alluvium of the area.

Geological evidence and petrographic characteristics of the sediments indicate a shallow-water continental environment of deposition possibly lacustrine or protected bay for the Modhupur Clay which gradually changed to flood plain condition. The alluvium of the Recent is a flood plain deposit.

East Pakistan occupies the major part of the Bengal basin. Except the hilly areas in the northeast and southeast of East Pakistan where Tertiary sedimentary rocks are exposed, the entire region is covered by Quaternary alluvium. The Quaternary alluvium has two distinct entities: one is the so called 'older alluvium' of Pleistocene age[1] and the other is the alluvium deposited by a network of river system during the Recent. The 'older alluvium' has been named as Modhupur Clay by the Geological Survey of Pakistan[2] and henceforth it will be referred to as such.

Besides several smaller outcrops, the Modhupur Clay occupies two major physiographically elevated units—the Barind and the Modhupur Tract (Fig. 1). The Barind covers an area of 2500 sq miles and lies between the Ganges and the Brahmaputra to the northwest of East Pakistan. The Modhupur Tract occupies an area of 1600 sq miles between Meghna and the Brahmaputra rivers extending from Dacca in the south to Jamalpur in the Mymensingh district in the north. The north-south extent of the Tract is about 70 miles while it stretches for about 35 miles along east–west.[3] Its present elevated position rising to about 100 ft above the surrounding alluvial flat is considered to be due to enechelon faulting[4],

Except for a preliminary study in the mineralogy and chemistry of the Pleistocene alluvium by Ahmad[5] and reconnaisance work of geomorphological nature by Morgan and McIntyre,[4] no geological investigation is known to have been carried out.

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Material and Methods

Outcrop and Lithology. The southern part of the Modhupur Tract, covering an area of 98 sq miles which includes the city of Dacca and its suburbs, has been mapped (Fig. 1). The aerial distribution of Modhupur Clay and its boundaries with the alluvium have been shown. The field mapping was supplemented and confirmed by the study of aerial photographs. Particularly the bird-foot pattern erosion boundary of the Modhupur Clay was plotted by photogeological interpretation.

The Modhupur Clay in its upper part consists of brown massive sandy-clay which is plastic when wet but becomes stiff and hard when dry. Mottling is a marked feature displayed on freshly excavated surface but on continued exposure sediments become dark brown obviously due to thorough oxidation of iron into ferric state. Limonitic concretions of about 1–5 mm size are found in abundance. Patches of carbonized remains of plants have been observed. With depth, the colour becomes less intense and varies from yellow to brownish yellow. The proportion of sand increases with depth so that the Modhupur Clay in its lower part becomes clayey-sand which is soft

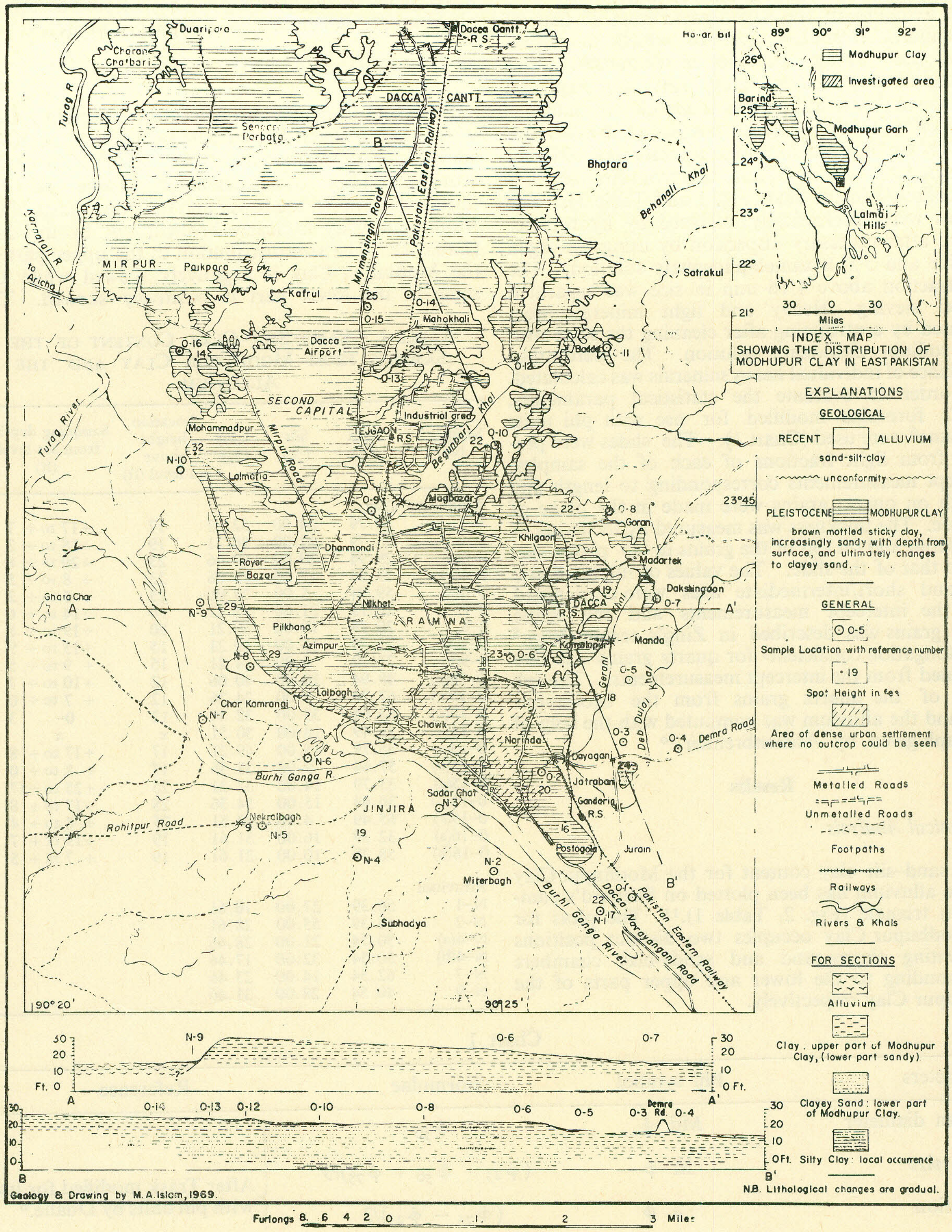

Fig. 1. Geological map of Dacca city and surrounding region and geological sections along the lines AA′ and BB′.

and rather friable. Mica becomes more abundant in the lower part of the Modhupur Clay.

The alluvium in the investigated area is that of Brahmaputra (Jamuna) river of which the Burhi Ganga and Turag are the distributaries. The alluvium is composed of grey, soft silty-clay and clay showing lamination with abundance of mica.

Method of Study. Twenty samples of the Modhupur Clay from eleven locations representing different depths and six samples of alluvium from five localities were collected in the field (Fig. 1 and Table 1). The samples were mechanically analyzed by hydrometer method after necessary dispersion by using hydrogen peroxide and 5% hexametaphosphate solution. The sand fraction above 1/16 mm in size was separated by wet sieving. Heavy and light minerals were separated by centrifuging after cleaning the sand with 10% sodium dithionate solution. The percentage abundance of individual heavy minerals was calculated.

In order to evaluate the statistical parameters, Trask's formulae modified for use with phi units by Duane[6] were used (Chart 1). The slides were prepared from light fractions of each of the samples. Intercept measurements corresponding to length and breadth on quartz grains were made in the plane of the slide. The thickness was measured by focussing at the bottom and on top of the grains in the plane vertical to that of the slide. The values of intermediate/long and short/intermediate axes were com puted from the intercept measurements and the shape of the grains was described in Zing's terminology.[8] The elongation coefficient[9] for quartz grains was also computed from the intercept measurements. The sph ericity of the quartz grains from the Modhupur Clay and the alluvium was computed with the help of the graph given by Aschenbrenner.[10]

Results

Mechanical Analysis

The sand–silt–clay content for the Modhupur Clay and the alluvium has been plotted on Shepard's composition triangle (Fig. 2, Table 1).[11] The plots for the Modhupur Clay occupies two distinct positions representing clayey-sand and sandy-clay chambers corresponding to the lower and upper parts of the Modhupur Clay respectively.

The grain-size envelops drawn for the upper and lower parts of the Modhupur Clay as well as for the alluvium are shown in Figs. 3(a), 3(b) and 3(c).

Statistical Measures

Statistical measures are helpful in comparing sediments and sedimentary environments and, therefore, statistical parameters for the size distribution of the sediments have been evaluated (Table 2). The difference between the lower and the upper parts of the Modhupur Clay is clearly brought out by the data (Table 2). The size distribution in the upper part of the Modhupur Clay is negatively skewed while the same in the lower part is positively skewed. The

TABLE 1. SAND–SILT–CLAY CONTENT OF THE SAMPLES FROM MODHUPUR CLAY AND THE ALLUVIUM.

Sample No.	Sand (%)	Silt (%)	Clay (%)	Location height above sea level (ft)	Sampling depth from sea level (ft)
Modhupur Clay					
0–1	23.79	24.00	52.21	17	+17 to + 7
0–4	21.79	22.00	56.21	19	+18 to + 3
0–6(a)	29.94	20.00	50.06	23	+20 to + 8
0–6(b)	33.94	17.00	49.06	23	+ 8 to + 5
0–6(c)	59.94	5.00	35.06	23	+ 5 to + 2
0–7	26.79	21.00	52.21	14	+14 to + 6
0–8	30.79	19.00	50.21	20	+19 to + 8
0–9(a)	25.79	15.00	59.21	15	+15 to + 9
0–9(b)	71.79	4.00	24.21	15	+ 9 to + 5
0–10(a)	49.94	10.00	40.06	12	+10 to + 7
0–10(b)	67.74	8.00	24.26	12	+ 7 to + 0
0–10(c)	32.64	35.00	32.36	12	0– 3
0–11	31.49	18.00	50.51	x	x
0–13(a)	35.79	15.00	49.21	17	+17 to + 8
0–13(b)	57.64	9.00	33.36	17	+ 8 to + 0
0–15(a)	33.79	14.00	52.21	25	+25 to +17
0–15(b)	30.64	15.00	54.36	25	+17 to + 8
0–15(c)	65.49	4.00	30.51	25	+ 8 to + 4
0–16(a)	32.39	16.00	51.61	19	+19 tk + 7
0–16(b)	58.39	10.00	31.61	19	+ 7 tk + 5
Alluvium					
N–1	56.39	27.00	16.61		
N–2	46.39	55.00	28.61		
N–4(a)	50.54	21.00	28.46		
N–4(b)	50.54	32.00	17.46		
N–7	62.54	14.00	23.46		
N–9	40.54	28.00	31.46		

Chart 1

Parameters	Phi symbol	Formulae	Reference
Median diameter	Md ϕ	ϕ_{50}	After Trask modified for use with phi units by Duane.[6]
Mean size	M ϕ	$(\phi_{25} + \phi_{50} + \phi_{75})/3$	
Deviation	σ ϕ	$(\phi_{75} - \phi_{25})/2$	
Skewness	Sk ϕ	$\phi_{25} + \phi_{75} - 2\,\phi_{50}$	
Graphic kurtosis	Kg ϕ	$(\phi_{95} - \phi_{5})/2.44(\phi_{75} - \phi_{25})$	After Friedman[7]

TABLE 2. GRAIN-SIZE PARAMETERS OF THE UPPER AND LOWER PARTS OF THE MODHUPUR CLAY AND THE ALLUVIUM.

Sample No.	Median dia (φ)	Mean size (φ)	Deviation φ	Skewness φ	Graphic Kurtosis φ
Upper part of Modhupur Clay					
0–1	5.35	5.32	0.32	–0.05	1.32
0–4	5.40	5.36	0.27	–0.05	1.12
0–6(a)	5.25	5.23	0.42	–0.05	1.69
0–6(b)	5.70	5.22	0.42	–1.45	0.83
0–7	5.30	5.28	0.72	–0.15	1.54
0–8	4.55	4.53	0.32	–0.05	1.20
0–9(a)	5.35	5.33	0.32	–0.05	1.45
0–11	5.30	5.26	0.40	–0.10	1.82
0–13(a)	5.25	5.18	0.45	–0.20	1.68
0–15(a)	5.25	5.23	0.42	–0.05	1.67
0–15(b)	5.30	5.26	0.40	–0.10	1.64
0–16(a)	5.30	5.23	0.40	–0.20	1.30
Lower part of Modhupur Clay					
0–6(c)	3.00	3.76	1.55	2.30	0.52
0–9(b)	3.90	4.20	0.95	0.90	0.84
0–10(a)	5.00	4.45	1.62	–1.65	0.52
0–10(b)	2.70	3.33	1.95	1.90	0.47
0–10(c)	5.25	5.25	0.35	0	1.14
0–13(b)	3.60	4.00	1.37	1.25	0.56
0–15(c)	3.10	3.72	1.45	1.88	0.54
0–16(b)	4.80	4.85	0.77	0.15	0.70
Alluvium					
N–1	4.85	4.83	0.57	0.05	0.80
N–2	5.35	5.22	0.55	–0.40	0.90
N–4(a)	5.00	4.98	0.59	–0.05	0.90
N–4(b)	5.00	4.93	0.55	–4.20	0.93
N–7	4.35	4.53	0.87	–0.55	0.80
N–9	5.20	5.15	0.47	–0.15	1.18

size distribution for alluvium is similar to that of the upper part of Modhupur Clay and is negatively skewed. According to Friedman's classification[7] of phi-deviation corresponding to Trask's sorting values, the results of the present study indicate that the upper part of the Modhupur Clay is well sorted while the lower part is only moderately sorted. The alluvium is also well sorted with moderately sorted levees.

The grain-size parameters, as given in Table 2, are known to bear significant relationship with each other and are at times helpful in distinguishing environments of sedimentation.[6,12,13,14] To show the interrelation between grain-size parameters of the sediments studies, scatter plots have been drawn for (i) skewness versus mean size (Fig. 4), (ii) median diameter versus deviation (Fig. 5) and (iii) mean size versus kurtosis (Fig. 6). Two significant and interesting results are obtained from these scatter plots (a) the upper and the lower parts of the Modhupur Clay can be separated by a clear line of demarcation and (b) the alluvium is more related to the upper part of the Modhupur Clay.

Mineralogy

The sand fraction of the Modhupur Clay and the alluvium were cleaned as described earlier and sieved into different size fractions. Light and heavy minerals separated from each of the fractions were examined and relative abundance of individual mineral was determined by grain counting.

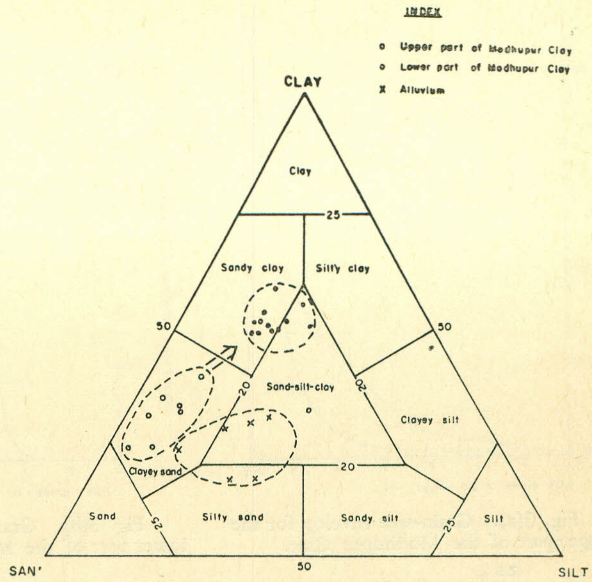

Fig. 2. Triangle diagram showing the mechanical composition of the Modhupur Clay and the alluvium.

Light Minerals. In the sand fraction of the Modhupur Clay quartz is the most abundant light mineral followed by mica and feldspar. The average quartz content is estimated to be about 85%, most of which lie within size grade of $< \frac{1}{2}$ mm. The micas are chiefly biotite and muscovite with a few flakes of lepidolite. The mica content varies from 5% to 15%. Biotite is much more abundant than muscovite. The feldspars comprise of members of both alkali feldspars and plagioclase and are found in trace amount in $\frac{1}{2}$ to $\frac{1}{4}$ mm size grade to over 5% in $\frac{1}{8}$ to $\frac{1}{16}$ mm size grade. Among the feldspars, plagioclase and orthoclase, occuring nearly in equal proportion, predominate.

In the sand separated from the alluvium common light minerals are micas, quartz and feldspars. Among the micas, biotite is more abundant than muscovite and together they account for the bulk of light fraction in all size grades. Quartz is generally restricted to $\frac{1}{8}$ to $\frac{1}{16}$ mm size grade and becomes negligible in coarser size fractions. The feldspars are also found concentrated in the above size grade and become extremely sparse in size grades above $\frac{1}{8}$ mm. An average of 5% has been estimated for the feldspars in the size grade $\frac{1}{8}$ to $\frac{1}{16}$ mm.

Heavy Minerals. The heavy mineral assemblage of the Modhupur Clay is listed below:

More common minerals	*Less common minerals*
Kyanite	Andalusite
Sillimanite	Allanite
Staurolite	Topaz
Garnet	Tremolite
Zircon	Rutile
Tourmaline	Pyrite
Epidote	
Hornblende	
Dark minerals.	

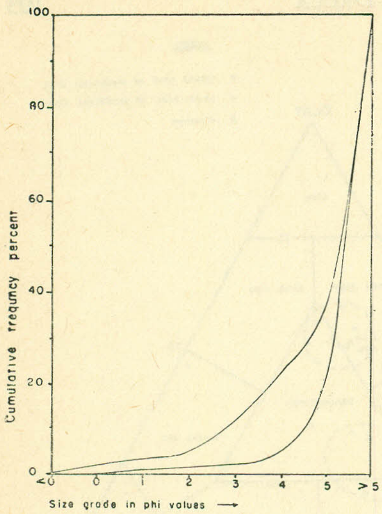

Fig. 3(a). Grain-size envelop for the upper part of the Modhupur Clay.

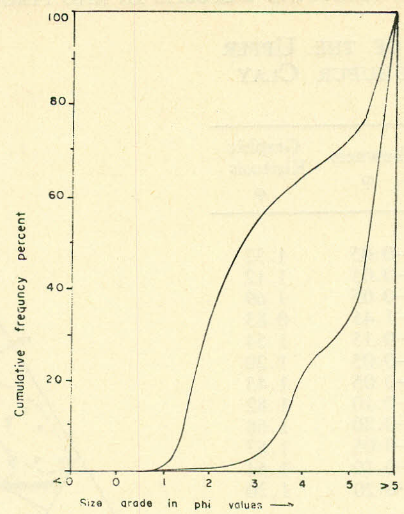

Fig. 3(b). Grain-size envelop for the lower part of the Modhupur Clay.

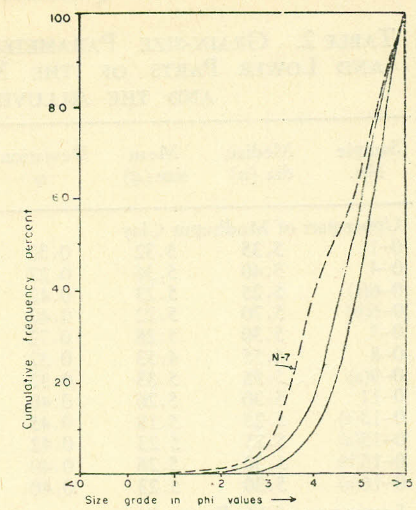

Fig. 3(c). Grain-size envelop for the alluvium.

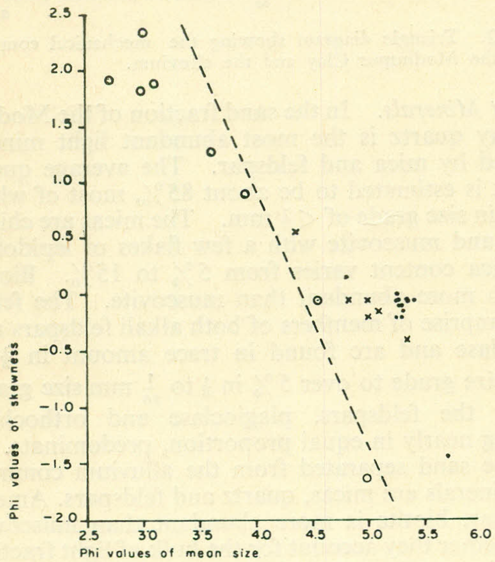

Fig. 4. Scatter plots for skewness versus mean size (symbols: ● upper part of the Modhupur Clay; O lower part of the Modhupur Clay; × alluvium).

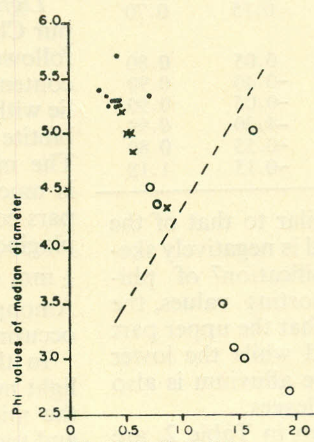

Fig. 5. Scatter plots of median diameter versus deviation (symbols: ● upper part of the Modhupur Clay; O lower part of the Modhupur Clay; x alluvium).

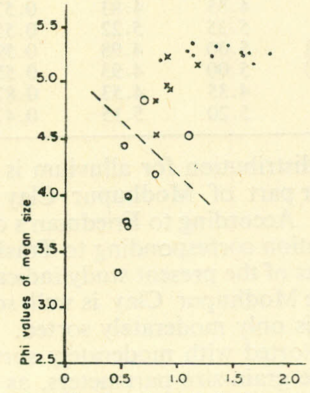

Fig. 6. Scatter plots of mean size versus graphic kurtosis (symbols: ● upper part of the Modhupur Clay; O lower part of the Modhupur Clay; x alluvium).

The heavy minerals show greater concentration in finer size grade ranging from $\frac{1}{4}$ to $\frac{1}{16}$ mm. No heavy mineral is present in coarser than $\frac{1}{2}$ mm size fraction.

The heavy mineral assemblage of the alluvium presents a contrasting picture. Here the dominant heavy minerals are hornblende and tremolite constituting from 81% to 93% of the total heavy minerals. Other minerals of common occurrence are garnet, zircon and ore minerals. Kyanite, sillimanite, topaz, tourmaline and actinolite are less frequent while rutile and epidote are rare.

The relative abundance of more common heavy minerals in the different size grades of the sand fractions of Modhupur Clay and the alluvium is shown in Fig. 7.

Textural Studies

Textural studies like shape factor, elongation coefficient and sphericity of sand grains have been analysed. For the study of these properties, relevant measurements have been made on the quartz grains of the sand fractions derived from the Modhupur Clay and the alluvium.

The shape factors of the quartz grains from the Modhupur Clay and the alluvium have been plotted in Figs. 8 and 9 respectively. In both the cases the quartz grains are found to be spherical in shape with only a few rods and discs.

The elongation coefficient of quartz grains from the Modhupur Clay and the alluvium is shown by frequency diagrams in Figs. 10 and 11 respectively. The coefficient of elongation of quartz grains from the Modhupur Clay is generally low with a small number of values going as high as 2.5 and that of the quartz grains from the alluvium ranges from 1 to 2.

The sphericity of the quartz grains from the Modhupur Clay (Fig. 12) mostly ranges from 0.87 to 0.96 with a number of lower values while the same from the alluvium (Fig. 13) varies from 0.89 to 0.96.

The textural properties studied indicate that the quartz grains from both the Modhupur Clay and the alluvium are spherical in shape. The histograms for sphericity and coefficient of elongation for the two sediments when compared suggest that the quartz grains from the Modhupur Clay have achieved relatively more spherical shape as compared to those from the alluvium. However, the quartz grains from both the sediments show marked angularity by presence of sharp edges and corners under microscope. The histograms for coefficient of elongation (Fig. 10) and sphericity (Fig. 12) in case of the quartz grains from the Modhupur Clay indicate only one dominant principal mode whereas similar diagrams (Figs. 11 and 13) for the quartz grains from the alluvium reveals more than one principal mode. The presence of more than one principal mode for sphericity and coefficient of elongation for quartz grains from the alluvium is considered to be due to contamination of the alluvium by sediments of the Modhupur Clay. It is suggested that the present day erosion of the Modhupur Clay has provided considerable amount of sediments to the alluvium of the area.

Sedimentation

The Bengal basin (Fig. 14), of which East Pakistan occupies a major portion, forms a part of the Indo-Gangetic trough which originated concomittently with the rise of the Himalyas to its north and attained its full development during the middle Miocene. Indian platform to the southwest and the Shillong Plateau to the immediate north have existed as stable blocks. Before the commencement of post-Miocene sedimentation northwest-southeast trending hill ranges now forming the Chittagong Hill Tracts and adjoining region had developed to the east and southeast of the basin. This is because Plio-Pleistocene sediments are known to overlie earlier rocks unconformably in the area.[15] Having located the basin and its surrounding there remains the problem of provenance and sedimentation.

The material of the 'older alluvium' (Modhupur Clay) is known to have been derived from the north and deposited during the Pleistocene epoch.[1] The

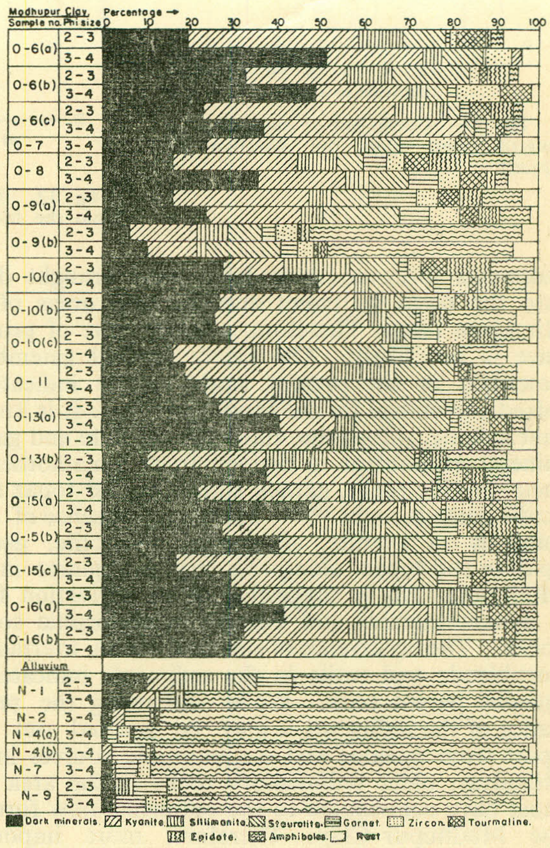

Fig. 7. Percentage distribution of major heavy minerals in the Modhupur Clay and the alluvium.

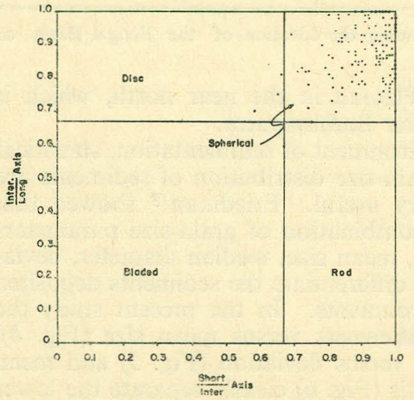

Fig. 8. Shape of quartz grains from the Modhupur Clay (150 grains).

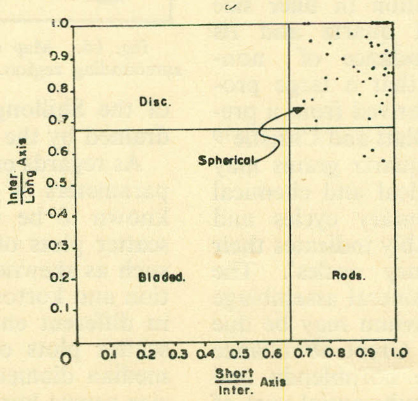

Fig. 9. Shape of quartz grains from the alluvium (50 grains)

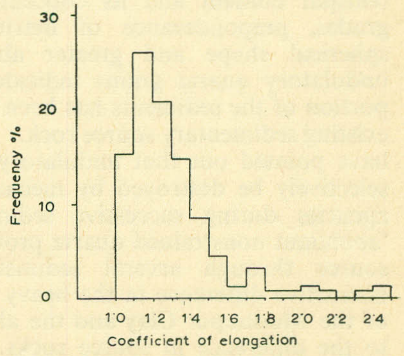

Fig. 10. Coefficient of elongation of quartz grains from the Modhupur Clay (150 grains)

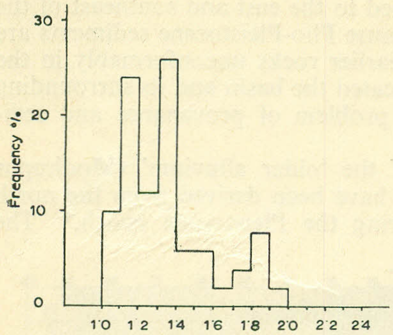

Fig. 11. Coefficient of elongation of quartz grains from the alluvium (50 grains).

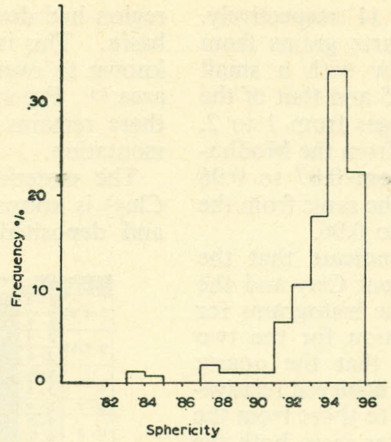

Fig. 12. Sphericity of quartz grains from the Modhupur Clay (150 grains).

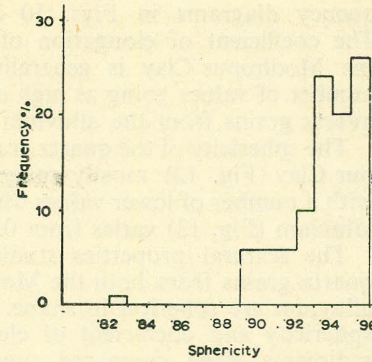

Fig. 13. Sphericity of quartz grains from the alluvium (50 grains)

sediments however, must have been brought down into the basin by rivers draining vast areas of the Himalyan range. Therefore, a single suite of provenance is not likely. The heavy mineral assemblage described in the present study clearly indicates a mixed percentage for the Modhupur Clay. It is known that kyanite, sillimanite, staurolite, epidote and garnet mineral assemblage is derived from dynamothermal metamorphic rocks, garnet, staurolite and topaz from acidic igneous rocks.[16,17] Therefore, presence of such minerals as kyanite, sillimanite, staurolite, garnet, epidote and topaz alongwith strained quartz in the Modhupur Clay is suggestive of its derivation from a dynamothermal and contact metamorphic source rocks. The occurrence of euhedral zircon, tourmaline, hornblende and rutile in the sediments indicates an igneous parent rock. While discussing the provenance of the sediments it may be pointed out that apart from igneous and metamorphic sources in the Himalyas, older sedimentary rocks in the area also must have contributed to the sediments now forming the Modhupur Clay. Therefore, more important here is the number of cycle of sedimentation and, of course, it is extremely difficult to recognise.[18] However near absence of polycrystalline quartz grains, low feldspar content and its concentration in finer size grades, preponderance of detrital quartz and its spherical shape and greater abundance of non-undulatory quartz grains indicate that a large proportion of the sediments has been derived from a pre-existing sedimentary source rock. Blatt and Christie[19] have pointed out that undulatory quartz grains may selectively be destroyed by mechanical and chemical agencies during successive sedimentary cycles and 'abundant nonstrained quartz probably indicates their source through several sedimentary cycles'. The distinctive difference in the heavy mineral assemblage of the Modhupur Clay and the alluvium may be due to the difference in source rocks. Great abundance of less stable heavy minerals like hornblende and tremolite, may also indicate that a substantial part of sediments forming the alluvium, is being derived directly from the igneous and metamorphic complex

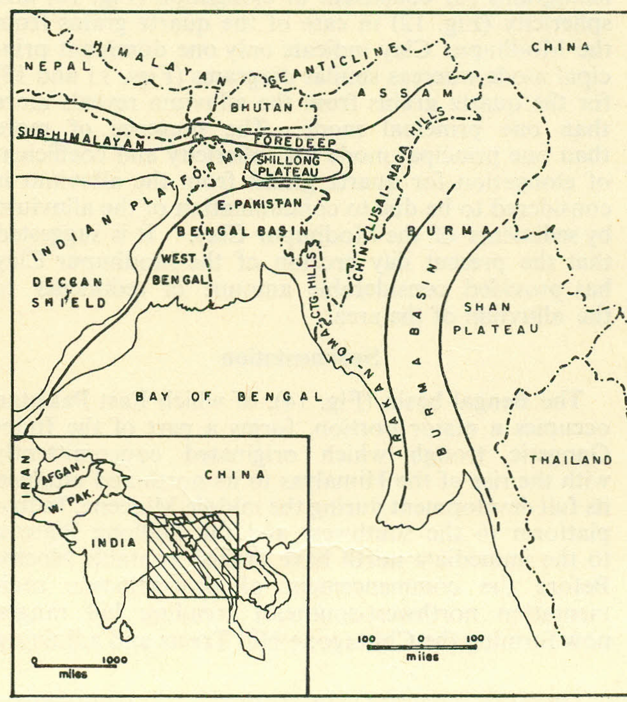

Fig. 14. Map showing the location of the Bengal Basin and surrounding region.

of the Shillong Plateau in the near north, which is drained by the river Brahmaputra.

As regards environment of sedimentation, statistical parameters of grain-size distribution of sediments are known to be very useful. Friedman[13] showed that scatter plots of combination of grain-size parameters such as skewness, mean size, median diameter, deviation and kurtosis differentiate the sediments deposited in different environments. In the present study the scatter plots of skewness versus mean size (Fig. 4), median diameter versus deviation (Fig. 5) and mean size versus kurtosis (Fig. 6) clearly separate the lower part from the upper part of the Modhupur Clay suggesting that they were deposited under two different environments. Field observations, however, suggest a gradation of properties and it is likely that the condition of deposition gradually changed from one environment to the other. Scatter plots for the alluvium group alongwith those for the upper part of the Modhupur Clay. This can be taken as suggestive of the similarity in condition of deposition of the two.

Mason and Folk,[20] Friedman[13] and Duane[6] have suggested that skewness is environment sensitive and that sediments of beach and tidal inlets show negative skewness while those from sheltered lagoons and dunes exhibit positive skewness. Negative skewness is known to be prevalent in sediments such as those of beaches, tidal inlets and littoral zones which have been subjected to constant winnowing action of water. Sediments deposited in areas of low energy level such as sheltered lagoons are characterized by positive skewness. In the present study the positive skewness of the lower part of the Modhupur Clay suggests that these were deposited in an environment where energy level was low perhaps similar to a protected bay/lagoon or lacustrine. It is interesting to note that the lower part of the Modhupur Clay occupies nearly similar position on composition triangle as the sediments of bay environment studied by Shepard and Moore.[21]

As the sedimentary basin filled up, the environment of deposition gradually changed to one of comparatively higher energy such as fluviatile or flood plain where winnowing action of the fluid media became effective as evidenced by the negative skewness of the sediments of the upper part of the Modhupur Clay. The alluvium of known flood plain environment shows negative skewness.

The base of the Modhupur Clay is not exposed. The records of the bore holes drilled by East Pakistan Water and Power Development Authority[22] in the Modhupur Clay (upto 350 ft.) indicate that sand content increases with depth so that in its lower part Modhupur Clay is largely an alternation of light coloured medium and fine sand often containing pebbles and granules of quartzite. Neither during the present investigation nor in any of the bore holes so far drilled by E.P. WAPDA, presence of any fossil but for some partially decomposed wood has been found.

On the basis of the above discussion, it is suggested that the deposition of the Modhupur Clay started in a lacustrine or a protected bay environment having no marine connections. With rapid accumulation of sediments the environment gradually changed to flood plain condition in which upper part of the Modhupur Clay was deposited. The close association of the grain-size parameters of the alluvium of known flood plain environment with those of the upper part of the Modhuopur Clay further lends support to the above conclusion.

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