

CLAY MINERALS IN QUATERNARY SEDIMENTS OF BANGLADESH: IMPLICATIONS IN ENGINEERING GEOLOGY

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With 5 figures and 3 tables

Abstract:

X-ray diffraction analyses and IR-spectroscopy were used to study clay minerals of some Quaternary sediments of Bangladesh. Diffraction patterns show that kaolinite, illite and chlorite are major constituents of the Recent deposits. IR-spectroscopy studies show halloysite to be present in these sediments. Pleistocene Madhupur clay contains halloysite and illite as major constituents, and vermiculite as minor constituent. The presence of halloysite is confirmed from its characteristic absorption band at 3550–3500 cm^{-1} range, and another one at $\sim 1640 \text{ cm}^{-1}$. Values of different engineering properties of the Quaternary sediments are within the range of engineering properties of kaolinite and illite, the major clay mineral groups in these sediments. The analyses show that Recent sediments are almost non-plastic with low swelling potential due to the presence of kaolinite, illite and chlorite. Expandable clay minerals like degraded illite and vermiculite cause higher plasticity and higher swelling potential in Madhupur clay.

Zusammenfassung:

Zur Bearbeitung von Tonproben aus dem Quartär Bangladeshs wurden Röntgendiffraktometrie und IR-Spektroskopie angewendet. Die Diffraktogramme zeigen Kaolinit, Illit und Chlorit als Hauptbestandteile der rezenten Ablagerungen. Mit IR-Spektroskopie kann der Nachweis von Halloysit in diesen Sedimenten erbracht werden. Pleistozäner Madhupur-Ton enthält Halloysit und Illit als Haupt- und Vermiculit als Nebenbestandteil. Das Auftreten von Halloysit ist durch seine charakteristischen Absorptionsbanden im Bereich von 3550–3500 cm^{-1} und einer anderen bei $\sim 1640 \text{ cm}^{-1}$ bestätigt. Die ingenieurgeologischen Eigenschaften der quartären Sedimente liegen im Bereich der typischen Werte von Kaolinit und Illit, welche in diesen Sedimenten die vorherrschenden Tonmineralgruppen sind. Die Analysen zeigen deutlich, daß die rezenten Sedimente sich kaum plastisch verhalten und durch das Auftreten von Kaolinit, Illit und Chlorit ein niedriges Quellungspotential aufweisen. Das Vorhandensein von quellbaren Tonmineralen wie degradiertes Illit und Vermiculit bedingt die höhere Plastizität und das größere Expansionspotential des Madhupur-Tones.

Introduction

Clays play an important role in controlling physical and engineering properties of soils. Plasticity, activity, swelling and shear strength largely depend on the clay minerals present in the soil. It is necessary to study the mineralogical aspects of different geological formations of foundation soil for projects like dams, highways, tunnels, etc. The detailed study of clay minerals help engineers and engineering geologists for effective design and construction of various types of engineering projects. The magnitude of expansion is largely controlled by the physico-chemical properties of constituent clay minerals. Of all the clay minerals, montmorillonite saturated with sodium as exchange ion has the greatest

potential for expansion. Apart from smectites other minerals with expanding lattices include vermiculite, swelling chlorite, halloysite and some interstratified mixed layer minerals (GILLOT, 1968).

The study of clay minerals in Quaternary sediments is of paramount importance, as 85% of the total land of Bangladesh are covered by these types of sediments. The present paper discusses the type and mode of occurrences of the clay minerals in Quaternary sediments. The influence of clay minerals on the engineering properties is also discussed. The work is mainly based on X-ray diffraction analyses and infrared studies. The infrared spectra are used to confirm the suspected presence of halloysite in either its hydrated (10 Å) or 'meta' (7 Å) form.

Materials

The study area is situated at the deeper part of the Bengal Basin. The area comprises the south-western portion of the Madhupur Tract (Dhaka terrace after ALAM, 1988) and the northwestern extremity of Dhaka depression. The land surface has uplifted about 5–15 m above sea level due to neotectonic movements. As a result, the streams have deeply incised without lateral spreading. The terrace has low dome to table shaped landform separated by shallow depressions. The terrace remains above the present flood level. It is surrounded by low-lying recent flood plains. The area is bounded by the Bansi flood plain in the west, Dhaleswari flood plain in the south and south-west, and Turag flood plain in the east. Broad depressions are common in the flood plains. Pleistocene terrace sediments are light yellowish grey, yellowish brown to deep red, and greyish white weathered silty clay to sandy clay. These are mottled, plastic, with low compressibility, high strength and low moisture content. Ferruginous and manganese concretions are abundant and calcareous nodules are occasionally present in Madhupur clay. The average thickness of Madhupur clay is 10 m. The flood plain is a poorly drained, flat featureless area of little or no relief, which is inundated by annual flood. Flood plain deposits are clayey silt to sandy silt varying from 1 to 15 m in thickness. They are characteristically grey to dark grey, non-plastic to slightly plastic, loosely compacted, contain high moisture content and have a substantial amount of organic matter. Dark grey to black organic clay associated with silty clay is also common. The gully type depressions present in the terrace are characterized by light to dark grey clayey silt with yellowish brown fine sand and black organic clay. After recession of flood, in some depressions in the low-lying areas stagnant waters led to a prevailing swampy environment. The upper parts of the depressions are covered by fine-grained flood sediments. Organic clay and peat are very common depression deposits. Organic clay is light to dark, soft, sticky, plastic and contains high moisture in natural condition

but becomes hard after drying. It consists of decomposed organic matter, clay minerals and a subordinate quantity of silty material.

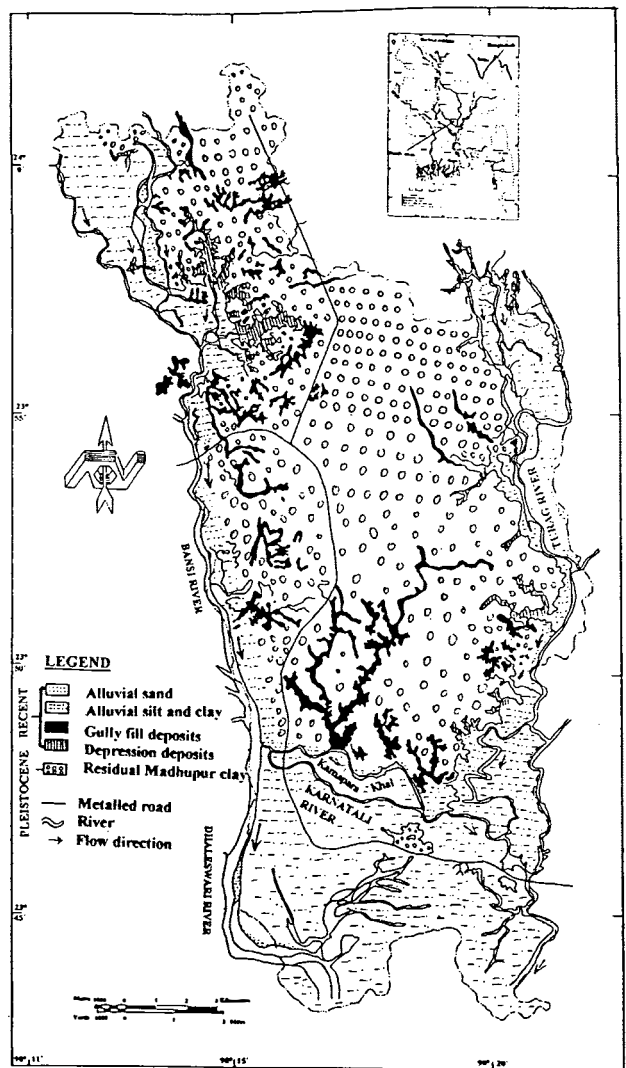


Fig. 1: Generalized geological map of the investigated area.

Experimental techniques

XRD: The $< 2\mu$ fraction was prepared for XRD analysis as an oriented mount. This was done by sedimenting a suspension under a vacuum on a ceramic tile (KINTER & DIAMOND, 1956). After the sedimentation of clay, the ceramic tile was air-dried. The X-ray diffraction pattern was obtained by using a Philips X-ray diffractometer

with $\text{CuK}\alpha$ radiation and the following sample conditions: 1) air dried 2) treated with ethylene glycol 3) heated to 400°C for 45 minutes, 4) heated to 550°C for 1 hour. Samples were scanned from approximately $2^\circ 2\theta$ to $30^\circ 2\theta$.

IRS: In addition to XRD, the samples were characterized by infrared spectroscopy. 2–3 mg of dried and powdered sample ($< 2 \mu\text{m}$) was dispersed in about 150 mg KBr. This was homogenized by stirring gently for 1–2 minutes without exerting any pressure that could disorder the clay minerals. The mixture was placed in a pellet die, uniformed at the top surface and evacuated for 3 minutes. Then it was pressed under vacuum over 12 mm circular sample area. The resulting pellet was uniformly transparent to the eye.

The infrared spectra were recorded in absorbance by a Matson Galaxy series 3000 Fourier-transform infrared (FTIR) spectrometer, which was optimized for the spectral range of $4000\text{--}400 \text{ cm}^{-1}$.

X-ray powder diffraction results

Kaolin minerals

In XRD profile kaolinite is identified by its 7 \AA (001) and 3.5 \AA (002) basal reflections. The (001) basal reflection of the Recent deposits ranged at $7.05\text{--}7.26 \text{ \AA}$ range. In some samples, peaks are sharp and symmetrical and in others, they are broad and weak. This fact suggests the variability in the crystalline order of kaolinite. On glycolation, the peaks show no apparent change in 7 \AA reflection. After heating to 550°C , the reflections are not longer visible. The presence of both kaolinite and chlorite in the Recent sediments made the identification process more complex. This is due to the similar d-spacing of the kaolinite and chlorite at 7 \AA and 3.5 \AA . The presence of coupling at 7.15 \AA and 3.5 \AA is the indication of the presence of both kaolinite and chlorite. Resolving both reflections, it is observed that kaolinite reflects (001) at 7.15 \AA and chlorite (002) at 7.08 \AA (BISCAY, 1964). The re-

flection at 3.5 \AA is considered to be the (002) reflection of kaolinite as all the chlorite basal planes other than (001) were destroyed at this temperature (C. Zen, 1959). Both the 7 \AA and 3.5 \AA reflections disappear when the sample is heated to 550°C for 1 hour. This fact supports the presence of kaolinite in the Recent sediments.

The (001) basal reflections show broad bands ranging between 7.23 \AA and 7.47 \AA . in the Madhupur clay. The broad diffuse bands and basal reflections at $7.2\text{--}7.5 \text{ \AA}$ range indicate high degree of crystalline disorder (Brindley, 1972). The peaks remain unaffected after ethylene glycol treatment.

Illite

Illite is a common clay mineral present in all samples. It is identified on the basis of following characteristic series of reflections. Illite shows (001), (002) and (003) basal reflections of X-ray powder diffraction at 10 \AA , 5 \AA and 3.5 \AA respectively. The intensities of the (001) and (003) reflections are greater than the intensities of (002) reflections. The intensity of the (003) reflection is the strongest and symmetrical.

WEAVER (1989) believed that most minerals referred to as illite contains some expandable layers. In the studied samples, the presence of approximately 5% expandable layers has been detected by ethylene glycol treatment, that makes the 10 \AA peak slightly wider and decreases the 001/003 peak height ratio (WEAVER, 1989). Most of the samples show a slight change in peak ratios suggesting the possibility of presence of negligible amount of expanded layers.

Chlorite

Chlorite minerals in clay grade materials are recognized principally by the sequence of basal (001) reflections on $14.0\text{--}14.3 \text{ \AA}$ range, depending on the species. Chlorite in which less than 30% of the octahedral positions are occupied by Fe-ions have medium-strong to strong intensities

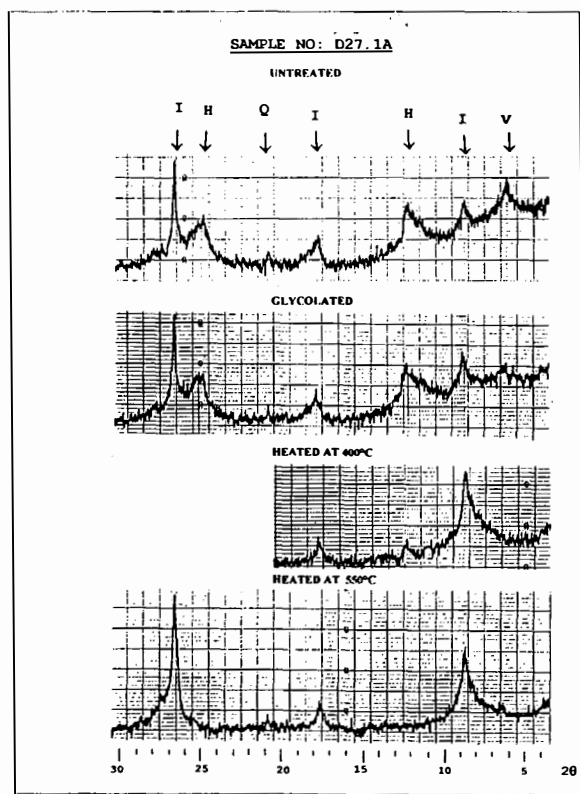
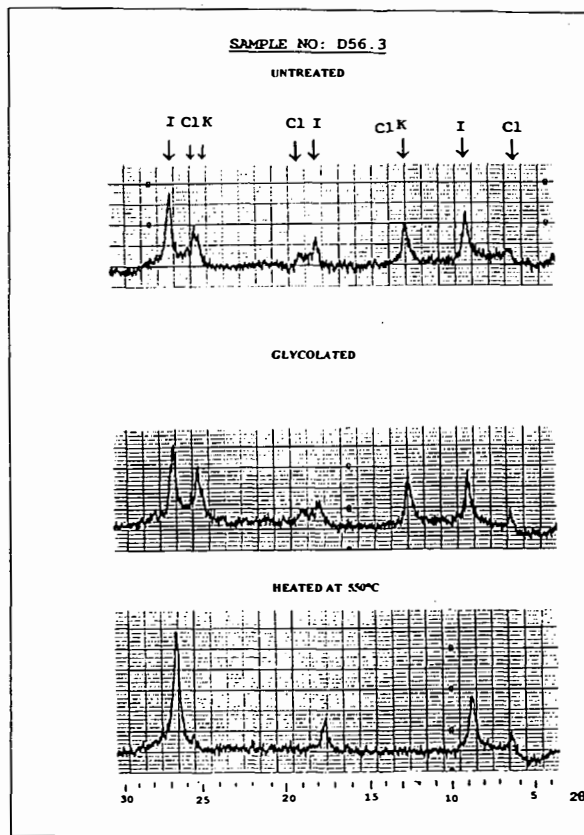
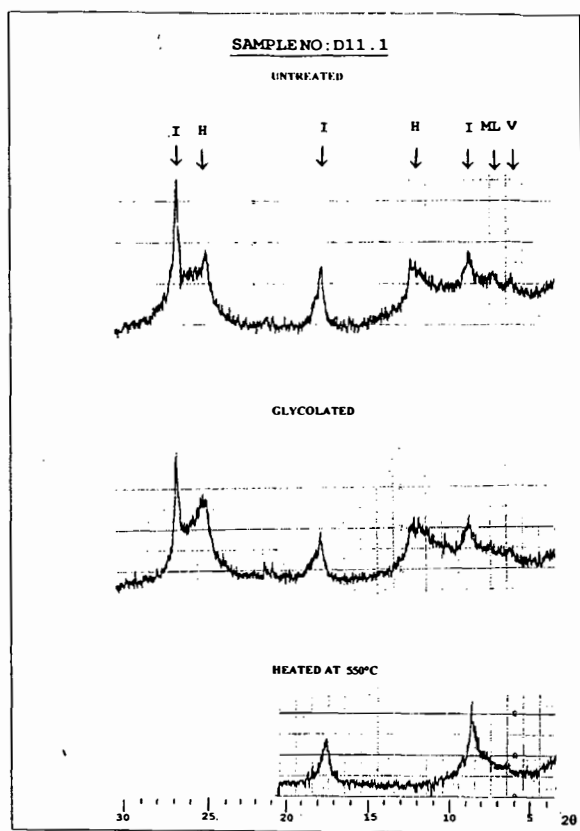
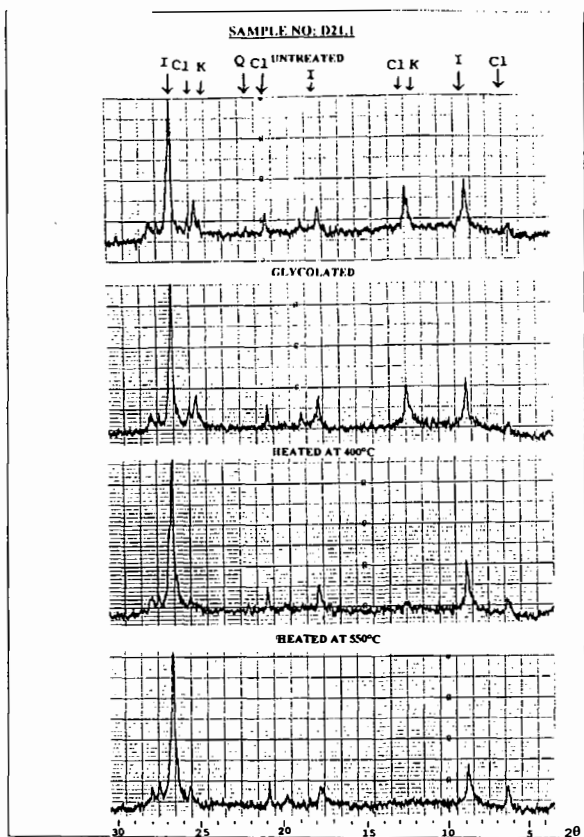


Fig. 2: XRD profile of <math>< 2 \mu</math> clay fraction of Recent sediments.

Fig. 3: XRD profile of Madhupur clay deposits.

for five orders of basal reflections. Chlorite-rich in iron gives relatively weak (001), (003), and (005) reflections, and strong (002) and (004) reflections (BRINDLEY, 1961).

Chlorite is present in Recent flood plain sediments. It shows weak (001) reflections at 14 Å. The (001) spacing of kaolinite at 7.15 Å is close to the (002) spacing of chlorite so that second order chlorite reflection tends to overlap the first order kaolinite reflection. This is true for the strong reflections from both minerals at about 7.1 Å and 3.55 Å. Heating the sample at 550°C for 1 hour, the first order reflection of chlorite becomes stronger and shifts slightly. At this temperature, the higher order reflections of chlorite disappear. The presence of weak (001) and (003) reflections might indicate either the presence of an iron chlorite or simply a trace of magnesia chlorite (BRINDLEY, 1961). The presence of magnesia chlorite could be discarded since (002) and (004) reflections change with the disappearance of (003) reflection (heating at 400°C).

Vermiculite

Vermiculite is present in Madhupur clay samples as minor constituent (Fig. 3). It shows basal reflection in the 14.2–14.4 Å range. The strong

reflection at 14.4 Å (Sample no: 27.1 Å) indicates the presence of Mg vermiculite (WALKER, 1972). Chlorite and montmorillonite have also 14 Å basal spacing. The dehydration behavior of vermiculite distinguishes it from chlorite. Heating the sample to 400°C and 550°C, the 14 Å reflection of chlorite remains close to this value (WALKER, 1972). The 14 Å vermiculite peak shifts to 10 Å, which is revealed from the stronger 10 Å reflection. It is distinguished from montmorillonite by failure of the Mg-lattice to expand beyond about 14.5 Å on treatment with glycerol, whereas, all Mg-montmorillonites expand to about 17.8 Å (WALKER, 1972).

Mixed-layer clays

It is difficult to properly evaluate the types of mixed-layer clays from X-ray diffractogram patterns. X-ray diffractions of Madhupur clay show reflections between 10 Å and 14 Å, which may be (10–14_v), (10–14_c) types of clays (Sample no: D11.1). The mixed-layer clays present in the Madhupur clay are probably the results of transformation of illite and chlorite. These mixed layers formed by leaching of K or Mg(OH)₂ from illite or chlorite layers, which is common during weathering.

Assignments and Wave number (cm ⁻¹) range	Kauri halloysite complexes									
	7Å	10 Å	KH ₂ PO ₄	KCl	KBr	KI	KOOCCH ₃	NH ₄ F	NH ₄ Cl	
OH stretch	3700-3690	√	√	√	√	√	√	√	√	√
	3640-3620	√	√	√	√	√	√	√	√	√
OH...H	3614-3606	–	–	√	√	√	√	–	–	√
H ₂ O interlayer	3570-3520	–	√	√	√	√	√	√	√	√
H ₂ O voids	3470-3105	–	√	√	√	√	√	√	√	√
Fermi resonance band	3180-3105	–	–	√	–	–	√	–	–	√

√ denotes presence of band; – denotes absence of band.

Table 1: Infrared absorption bands in halloysites (after CARR et al., 1978).

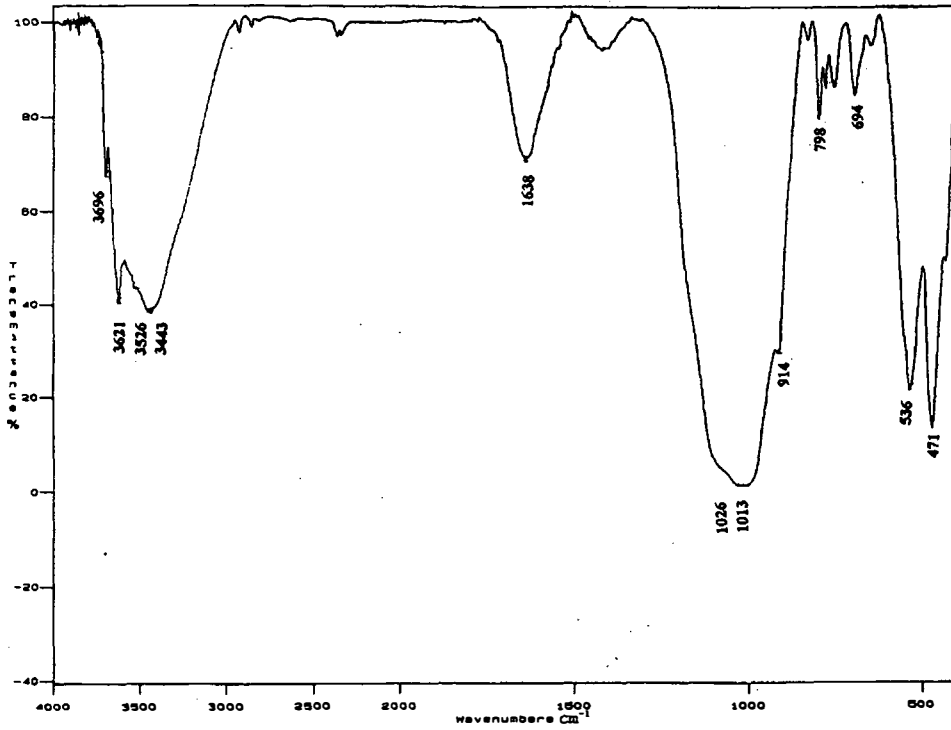


Fig. 4: Infrared absorption spectra of Recent sediments.

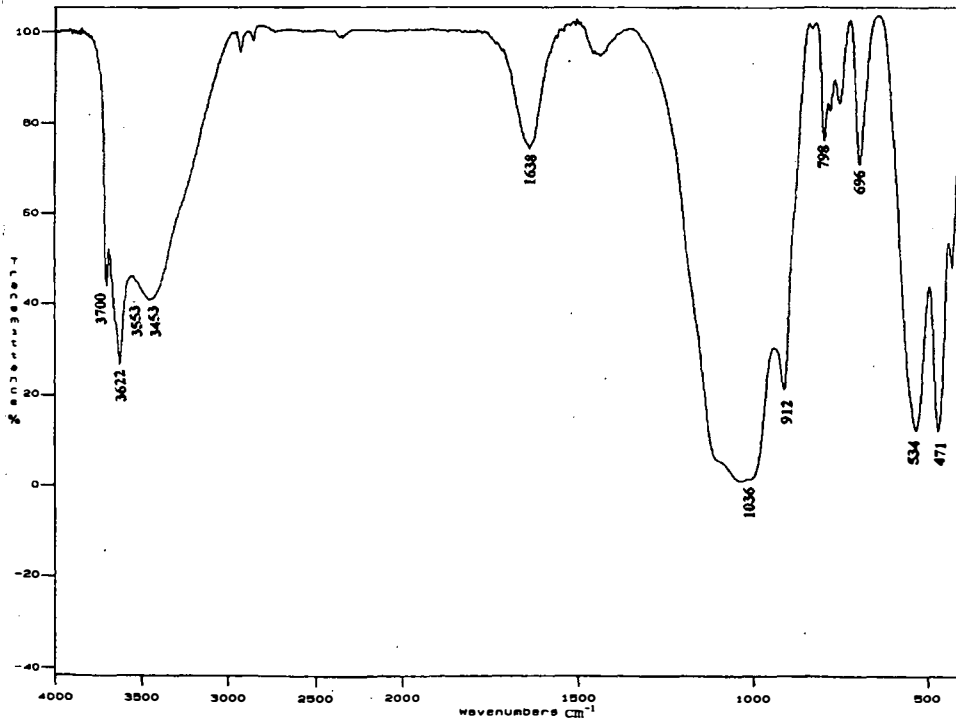


Fig. 5: Infrared spectra of Pleistocene deposits.

Infrared spectra

Halloysite

In Madhupur clay the outer stretching band at 3695 cm^{-1} is weaker than the inner surface hydroxyl band at 3622 cm^{-1} . The characteristic band of halloysite is present at 3553 cm^{-1} (KODAMA & OINUMA, 1963; YARIV & SHOVAL, 1976; MENDELOVICI & SAGARZAZU, 1985; LOMBARDI et al., 1987). This band possibly arises from surface OH, that is hydrogen-bonded to interlayer water molecules (KODAMA & OINUMA, 1963). The position of this band depends on the alkali halide used and the method of preparation of the disk (YARIV & SHOVAL, 1976). This band is followed by another absorption at 1640 cm^{-1} , which is a split in the water deformation band (TARASEVICH & GRIBINA, 1972). There are two types of water in halloysite (10 \AA), one consisting of isolated water molecules bonded to the trigonal bonds of the tetragonal sheet (hole water) and the other being more mobile interlayer water (associated water) (TARASEVICH & GRIBINA, 1972). Heated or unheated kaolinite never displays absorption in the range $3550\text{--}3500\text{ cm}^{-1}$ (MENDELOVICI & SAGARZAZU, 1985). A strong band at 3443 cm^{-1} is probably a second population of diagonal hole water (COSTANZO et al., 1984). A well-resolved Si-O frequency band with a large shoulder is present at 1034 cm^{-1} . This position generally increases with decreasing particle size and is related to the wave length of the radiation of the absorption maximum (FARMER & RUSSELL, 1966; LOMBARDI et al., 1987).

The IR spectra of the Recent sediments are quite similar to the absorption frequencies of the Madhupur Clay. The OH stretching band absorbs at 3695 and 3620 cm^{-1} . The former band is weaker than the later. The characteristic band of halloysite absorbs at a relatively lower frequency of 3626 cm^{-1} . The width and the intensity of this band are identical to the band in the Madhupur clay. The Si-O stretching band in the $1100\text{--}1000\text{ cm}^{-1}$ region exhibits a broad band with a doublet.

Illite

OINUMA & HAYASHI (1965) reported that 1M illites give a broad band 820 cm^{-1} , whereas 2M illites are characterized by a well-resolved doublet at $820\text{--}800\text{ cm}^{-1}$. An absorption band at 799 cm^{-1} is present in both the Recent and Madhupur clay samples. Quartz has also absorption band at 800 cm^{-1} . It is known from XRD analysis that quartz is nearly absent in clay fraction. Therefore, the band at $\sim 800\text{ cm}^{-1}$ is due to the presence of illite. Moreover, in the $550\text{--}400\text{ cm}^{-1}$ range, the frequency of the Si-O-M^{vi} band at $\sim 535\text{ cm}^{-1}$ points to illite. The sharp OH bending band at $\sim 915\text{ cm}^{-1}$ and bending mode of Si-O at 470 cm^{-1} confirms the di-octahedral character of illite (ELSASS & OLIVIER, 1978).

Discussion and conclusions

From X-ray diffraction studies comparisons have been made between the Recent flood plain sediments and Pleistocene Madhupur clay. Recent flood plain sediments composed of illite, kaolinite and chlorite. Illite and chlorite are identified by their characteristic reflections. In some samples kaolinite shows (001) reflection at 7.15 \AA . Apart from this, kaolinite also shows (001) reflections at 7.2 \AA . There are traces of quartz and feldspar in the Recent sediments. It is revealed from the peak irregularities that the illites present in the Madhupur clay are degraded. Kaolinite type minerals in the Madhupur clay samples show basal reflections in the $7.2\text{--}7.4\text{ \AA}$ region. Vermiculite and mixed layer clays are present as minor constituents. Traces of quartz and feldspar are present in both types of sediments.

IR spectra of both Recent flood plain and Madhupur clay sediments show absorption bands at $3550\text{--}3500\text{ cm}^{-1}$. The interlayer water of halloysite shows a band in the $3500\text{--}3550\text{ cm}^{-1}$ spectral region, whereas kaolinite never displays absorption spectra in this range. The distinctive behavior of halloysite (bands at $3500\text{--}3550\text{ cm}^{-1}$)

Mineral	Liquid limit (W _L)	Plastic limit (W _p)	Plasticity index (I _p)	Compression index (C _c)	Activity (A _c)
Montmorillonite	140-710	54-98	67-656	1.0-2.6	0.5-7.0
Illite	79-120	45-60	33-67	0.5-1.1	0.23-0.58
Kaolinite	38-59	27-37	11-23	0.19-0.28	0.01-0.41
Halloysite	56	94	38		

Table 2: Range of engineering properties of some common clay minerals (after CORNELL, 1951).

Sample	Liquid limit (W _L)	Plastic limit (W _p)	Plasticity index (I _p)	Compression index (C _c)
Recent alluvium	27-49	12-29	9-21	0.14-0.22
Madhupur clay	32-49	16-31	15-35	0.15-0.33

Table 3: Range of engineering properties of studied Quaternary sediments.

followed by a band at $\sim 1640 \text{ cm}^{-1}$ particular differentiate it from kaolinite (MENDELOVICI & SAGARZAZU, 1985). This observation suggests the presence of halloysite in both types of sediments.

The plasticity and swelling potential of kaolinite is the lowest among the clay minerals. kaolinite can be transformed to halloysite and vice-versa due to weathering (GILLOT, 1968). The plasticity of kaolinite increases with increasing crystalline disorder. Halloysite shows higher plasticity than that of kaolinite as it holds inter-layer water (GRIM, 1953). Halloysite can cause unusual engineering properties such as low compaction density, high optimum water content and frost susceptibility.

Illites present in the Pleistocene deposits are more degraded than those of Recent sediments, which is evident from their peaks. Intensive weathering of mica or illite resulted in replacement of interlayer K^+ by hydrated ions and lead to the formation of degraded illite (JACKSON, 1959). Degraded illite has a deficiency of inter-layer potassium ions and the structures tend to

expand in the presence of water in a similar manner as montmorillonite. The plasticity and swelling potential of illite is higher than kaolinite and lower than montmorillonite.

Chlorite present in the Recent sediment is of detrital inheritance. Chlorite is quite easily weathered under moderate conditions. Initially the hydroxide sheet is stripped from chlorite and a vermiculite and mixed-layer chlorite-vermiculite is formed (WEAVER & POLLARD, 1973). The plasticity of chlorite has values similar to those of kaolinite and varies considerably depending on the perfection of crystals (GRIM, 1953). Chlorite is absent in the Madhupur clay because it is less resistant in weathering process.

Vermiculite present in the Pleistocene deposits is a weathering product of chlorite. Mica or illite can also be transformed to vermiculite.

The secondary minerals present in Madhupur clay appear to be a function of the weathering process. The sequence of the type of secondary minerals produced, either by the varying degrees of intensity or by the time of exposure to weathering processes, has been found to be as follows: pri-

mary minerals secondary aluminosilicate clay minerals free oxides. Chemical hydromorphic weathering conditions over a long period of time favored the formation of sesquioxides of iron and aluminum. The sesquioxides are absorbed on the surface of the clay minerals in Madhupur clay soils. This absorption originates from the interaction of positively charged sesquioxides and the negatively charged clay particles (GIDIGASU, 1976).

It is revealed from the studied Quaternary sediments that the engineering properties (Table 3) are within the range of kaolinite and illite (Table 2), which are the major clay mineral groups present in these sediments.

The presence of non-expanding kaolinite, illite, and chlorite leads to almost non-plastic behavior and low swelling potential of the Recent sediments. Whereas, degraded illite and halloysite as major constituents, and traces of vermiculite and mixed layer clays cause high plasticity and swelling potential of the Madhupur clay.

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