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On the formation of cracking clay soils (Vertisols) in West Bengal

S.K. RAY*, T. BHATTACHARYYA, P. CHANDRAN, A.K. SAHOO[1], D. SARKAR[1], S.L. DURGE, P. RAJA, U.K. MAURYA AND D.K. PAL

Division of Soil Resource Studies, National Bureau of Soil Survey and Land Use Planning (ICAR), Amravati Road, Nagpur 440 010.
** Corresponding author email-skraysrs@yahoo.com*
[1] Regional Centre, National Bureau of Soil Survey and Land Use Planning (ICAR), Salt Lake, Sector-II, DK-Block, Kolkata 700 091.

Abstract : *During various soil survey programmes of West Bengal in the past soils of extensive areas with shrink-swell characteristics were classified as "Vertic" intergrades at the subgroup level of classification. The occurrence of Vertisols was identified in 2004 during a GEFSOC project programme in Chunchura of Hooghly district of West Bengal and such soils are described in this paper. The Chunchura soils have fulfilled all the necessary requirements viz. wide cracks, clay content (>30%), COLE (>0.06) and slickensides to classify them to Vertisols. Other properties including micromorphological and mineralogical properties are similar to Vertisols occurring in Deccan Trap basaltic areas. The soil clays of Chunchura are dominated by low-charge dioctahedral smectites similar to that obtained for Vertisol clays of the Deccan Trap area. Analysis of geomorphic and tectonic history of this part of the Bengal Basin indicates that the huge amount of smectitic parent material in the old fluvial/deltaic plains including the Damodar deltaic plain existing in the Vertisols area of Chunchura, were brought down as alluvium from the weathering Rajmahal Trap Basalt by the then east flowing rivers before they were shifted to the south in the late Holocene period.*

Vertisols are shrink-swell soils which require huge amount of smectite clay mineral for their formation (Franzmeier and Ross, 1968; Pal and Deshpande, 1987; Bhattacharyya *et al.*, 1997). In India, the source of this clay mineral is available in the alluvium of the weathering Deccan Trap basalt (Pal and Deshpande, 1987) or from parent material rich in bases. Thus, in India, Vertisols mostly occur in the Peninsular region. In addition, Vertisols occur in the Krishna and Godavari deltaic regions in Andhra Pradesh (Ray *et al.*, 1997) and in some alluvial flood plain areas of Tamil Nadu (Kalbande *et al.*, 1992; Pal *et al.*, 2006). Review of soil research in the Bengal basin indicates an extensive area with soils having considerable shrink-swell-activity (Shankaranarayana, 1982; Singh *et al.*, 1998). Vertical cracks were observed in the old fluvial and deltaic plains of the Bengal Basin which were more common and deeper in the Ajay-

Bhagirathi plain. During soil resource survey and mapping programme of West Bengal at 1:250,000 scale, extensive areas were classified as "vertic" intergrades at the subgroup level of classification (NBSS&LUP, 1983; Digar *et al.,* 1984; Halder *et al.*, 1992; Sarkar *et al.*, 2001; Nayak *et al.*, 2001). In the year 2004, during the GEFSOC project programme (Milne *et* al., 2006), we revisited some benchmark (BM) shrink-swell soils of Chunchura (IGP) and confirmed that these soils actually qualify for Vertisols (Soil Survey Staff, 2003). Although Ghosh and Datta (1974) and Ghosh and Kapoor (1982) reported the presence of about 30-60% smectite in clay fractions of some soils of West Bengal, it is however, difficult to reconcile that the soils of the Indo-Gangetic Plains (IGP) with dominantly micaceous minerals and light textured alluvium could form Vertisols which require huge amount of smectites for their formation.

In view of the above enigmatic situation, the present study was attempted to establish the parental legacy of Vertisols observed in Chunchura area of West Bengal in relation to the geomorphological and neotectonic history of the Bengal Basin in general, and the study area in particular.

Materials and Methods

Study area and soils

The study area is located in and around the research farm of Rice Research Station, Government of West Bengal at Chunchura in Hooghly district of West Bengal (Fig. 1). The soils of this area exhibit considerable shrink-swell activity and most of these soils were grouped earlier under non-vertic or vertic intergrades (NBSS&LUP, 1983; Digar *et al.*, 1984; Sarkar *et al.*, 2001). The a[illegible] has a humid sub-tropical climate with a mean annual rainfall of about 1600 mm and mean annual temperature of about 26°C. During our re-examination of these soils in 2004 we observed that these soils exhibit highly comparable shrink-swell properties as observed in Vertisols in Deccan basalt areas of central and western India. The soils under study was classified as Typic Endoaquerts (Soil Survey Staff, 2003).

Geomorphic and tectonic history

Broadly, the area lies in the Bengal Sedimentary Basin of the IGP. Within the basin, there are three major tectonic units *viz.* 1) tectonic shelf in the western part, 2) the Barind Tract Horst in the north and 3) the Ganga fluvio-deltaic plain (GFDP) in the eastern part (Singh *et al.*, 1998).

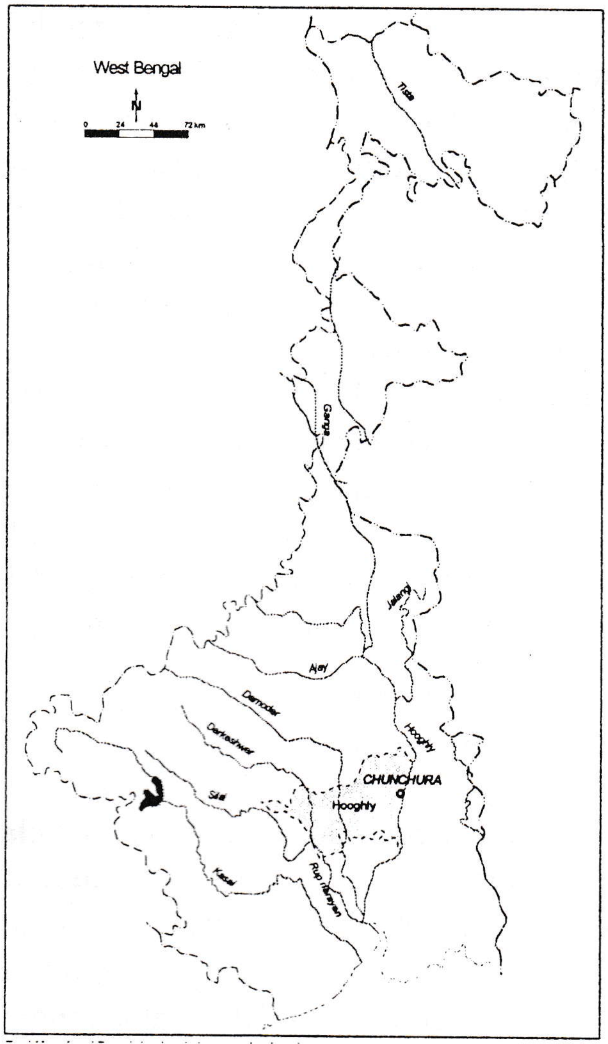


Fig. 1. Map of West Bengal showing study area and various rivers

The tectonic shelf and the Barind Tract Horst are separated by the Ganga-Padma fault while the Damodar fault separates the tectonic shelf and the GFDP Graben. The Medinipur-Farakka fault within the tectonic shelf separates the upland with red soils in the west from Bhagirathi-Ajay plain and Ajay-Silai plain in the east.

The study area which is dominated by shrink-swell soils belongs to the Damodar Deltaic Plain (DDP) which lies between Damodar river in the west and Hooghly river in the east. In the false colour composite (FCC), this plain is characterised by light gray colour with very common red mottles, fine texture and high drainage density and paleochannels marked by light red colour (Singh *et al.*, 1998). The plain width decreases southwards and exhibit the two styles of slope patterns, i.e. from west to east in the northern part and northwest to southeast in the southern part. This plain extends up to 70 km and 40 km in the north-south and east-west directions, respectively.

Methods

The site for soil profile in the Chunchura Rice Research Farm was selected after thorough examination of the cracks and their pattern and geomorphic position of the area. The morphological properties were described following the methods of the Soil Survey Manual (Soil Survey Division Staff, 1995). Soil samples were collected and processed for laboratory analysis. Undisturbed soil blocks (8 cm long, 6 cm wide and 5 cm thick) were collected from soil horizons, and thin sections were prepared (Jongerius and Heintzberger, 1975). They were described according to the nomenclature of Bullock *et al.* (1985).

The international pipette method was followed for the determination of particle-size distribution. Sand (2000-50 mm), silt (50-2 mm) and clay (<2 and <0.2 mm) fractions were separated from the samples after removing carbonates, organic mater and oxides of Fe and Al and then dispersing the soils according to the size segregation procedure of Jackson (1979). The bulk density was determined by a field-moist method using core sampler (diameter 5 cm and volume 100 cm^3) (Klute, 1986). The coefficient of linear extensibility (COLE) was determined following the method of Schafer and Singer (1976). The pH, EC, organic carbon, $CaCO_3$ equivalent, cation exchange capacity (CEC) and exchangeable N and K were determined by standard methods on the <2 mm fractions (Richards, 1954). Exchangeable Ca and Mg were determined following the 1N NaCl solution extraction method (Piper, 1966). The silt and clay fractions were analysed mineralogically by XRD of oriented samples saturated with either Ca or K using a Philips diffractometer with Ni-filtered CuKa at a scanning speed of 2^o2q/min and the minerals were identified using the method of Jackson (1979).

Results

The soil of the study area is very deep (unless perched water table at about 110 cm depth) with 25 cm wide cracks upto a depth of 13 cm and less than 1 cm wide cracks upto 20 cm (limitation in depth is due to moisture content of the profile). The colour of the soils vary from dark gray to very dark grayish brown with mottles throughout the profile. The soils have subangular blocky and angular blocky structures in the surface and subsurface horizons, respectively with slickensides in the subsurface horizons. There are few calcareous nodules of very fine to fine size mainly concentrated in the sub-surface horizons and few Fe/Mn concretions of fine size concentrated in the lower part of subsurface horizons.

The Chunchura soil has very less amount of sand, and are clayey in texture with clay content of 40-56% and fine clay constitutes nearly 56-65% of the total clay fractions (Table 1). The bulk density values are typical of Vertisols (Pal *et* al., 2006) and follow an irregular trend with depth. The soil has a COLE value ranging from 0.15 to 0.2. These properties are in contrast to soils developed in micaceous and loamy textured alluvial material of the IGP but are highly comparable to Vertisols of the Deccan basalt areas (Pal *et al*., 2006).

The pH values indicate the neutral to moderately alkaline nature of soils, ranging from 7.3 to 8.3. The soils are non-saline as EC values are very low. Organic carbon is high at the surface due

Table 1. *Physical and chemical properties of soils*

Table 1a. *Physical properties*

Depth (cm)	Horizon	B.D. Mg m^{-3}	COLE	Particle-size distribution (%)			Fine clay (%)	Fine clay/ total clay (%)
				Sand	Silt	Clay		
0-18	Ap	1.45	0.16	1.2	47.5	51.3	29.6	58
18-41	Bw	1.59	0.19	0.5	48.2	51.3	30.3	59
41-62	Bss1	1.50	0.19	0.2	48.8	50.9	30.9	61
62-91	Bss2	1.48	0.19	0.2	51.7	48.1	27.1	56
91-111	Bss/Bw	1.51	0.15	0.5	60.3	39.2	24.1	61
111-125	Ground water	-	0.20	0.2	48.8	51.0	32.7	64
125-160+	Ground water	-	0.20	0.2	44.0	55.7	36.0	65

Table 1b. *Chemical properties of soils*

Depth (cm)	pH water (1:2)	EC (1:2) dS m^{-1}	O.C (%)	$CaCO_3$. equivalent (%)	Extractable bases				B.S. (%)	Soil CEC	Clay CEC
					Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}			
					←cmol(p+) kg^{-1}→					←cmol(p+) kg^{-1}→	
0-18	7.3	0.16	1.42	1.5	18.8	12.1	0.5	0.5	97	33.0	65
18-41	8.2	0.20	0.54	2.2	14.7	18.7	0.7	0.5	100	34.8	68
41-62	8.1	0.25	0.53	2.8	18.3	17.8	0.7	0.5	110	33.9	67
62-91	8.2	0.21	0.53	3.1	18.3	18.7	0.7	0.5	107	35.7	74
91-111	8.3	0.18	0.40	4.0	18.1	10.3	0.6	0.5	94	31.3	80
111-125	8.1	0.27	0.46	2.8	24.2	9.0	0.6	0.6	92	37.4	73
125-160+	8.0	0.29	0.47	2.1	24.6	8.6	0.6	0.6	93	36.5	66

to cultivation of paddy (Sahrawat *et al.*, 2005). $CaCO_3$ equivalent varies from 1.5 to 4.0%. The exchange complex is dominated by Ca^{2+} and Mg^{2+} ions and CEC ranges from 31.3 to 36.5 cmol(p+)kg^{-1}. Thus, the morphological, physical and chemical properties of Chunchura soils are identical to Vertisols reported elsewhere in the Deccan basalt areas (Pal *et al.*, 2006).

The silt fractions (50-2 mm) of soils contained dominant amount of mica, quartz, followed by kaolin, hydroxy-interlayered vermiculite (HIV) and feldspar. The total clay fractions of soils contained dominantly smectite followed by HIV, mica and kaolin. The fine clay fractions are dominantly smectitic and smectite expands to ~18 A° with glycerol vapour, indicating the smectite to be dominantly montmorillonitic (Harward *et al.*, 1986). The ubiquitous presence of mica in the silt and clay fractions may suggest it to be the parent mineral for the formation of montmorillonite. Mica consists of both di- and trioctahedral type as evidenced from the more than unity ratio of 001/002 reflections of mica in the silt and clay fractions (Figs. 2a,b). In presence of trioctahedral mica, dioctahedral mica is unlikely to weather to dioctahedral smectite in the present soil environment (Pal, *et al.*, 2003).

The Greene-Kelly test indicated the presence of both beidellite (nontronite) and montmorillonitic nature of smectite. This smectite is characterised by low charge as evidenced by the expansion of 14 A° area on glycolation of the K-saturated and heated (300°C) samples (Fig. 2). The fine clay smectites of Vertisols of the Deccan basalt area showed the identical type and nature of smectite (Pal and Deshpande, 1987). Thus the smectitic clay mineral in the clay fractions of this Vertisol appear to be inherited from the alluvial parent material and are highly comparable to those of the Deccan basalt areas.

Micromorphology of the Chunchura soils showed parallel/poro/reticulate-striated plasmic fabric (Fig. 3) with strong plasma separation comparable to those observed in Vertisols of Deccan Trap region (Pal *et al.*, 2006). Granostriated fabric are also occasionally observed in these soils.

Discussion

The properties described above suggest that Chunchura soils belong to Vertisols and are thus classified as Typic Endoaquerts. It is known that the alluvium deposited by the river Hooghly (or Bhagirathi) (Fig. 1) in the study area is from the Himalayan source and is dominantly micaceous in nature (Sarkar and Chatterjee, 1964). Thus, it is unlikely

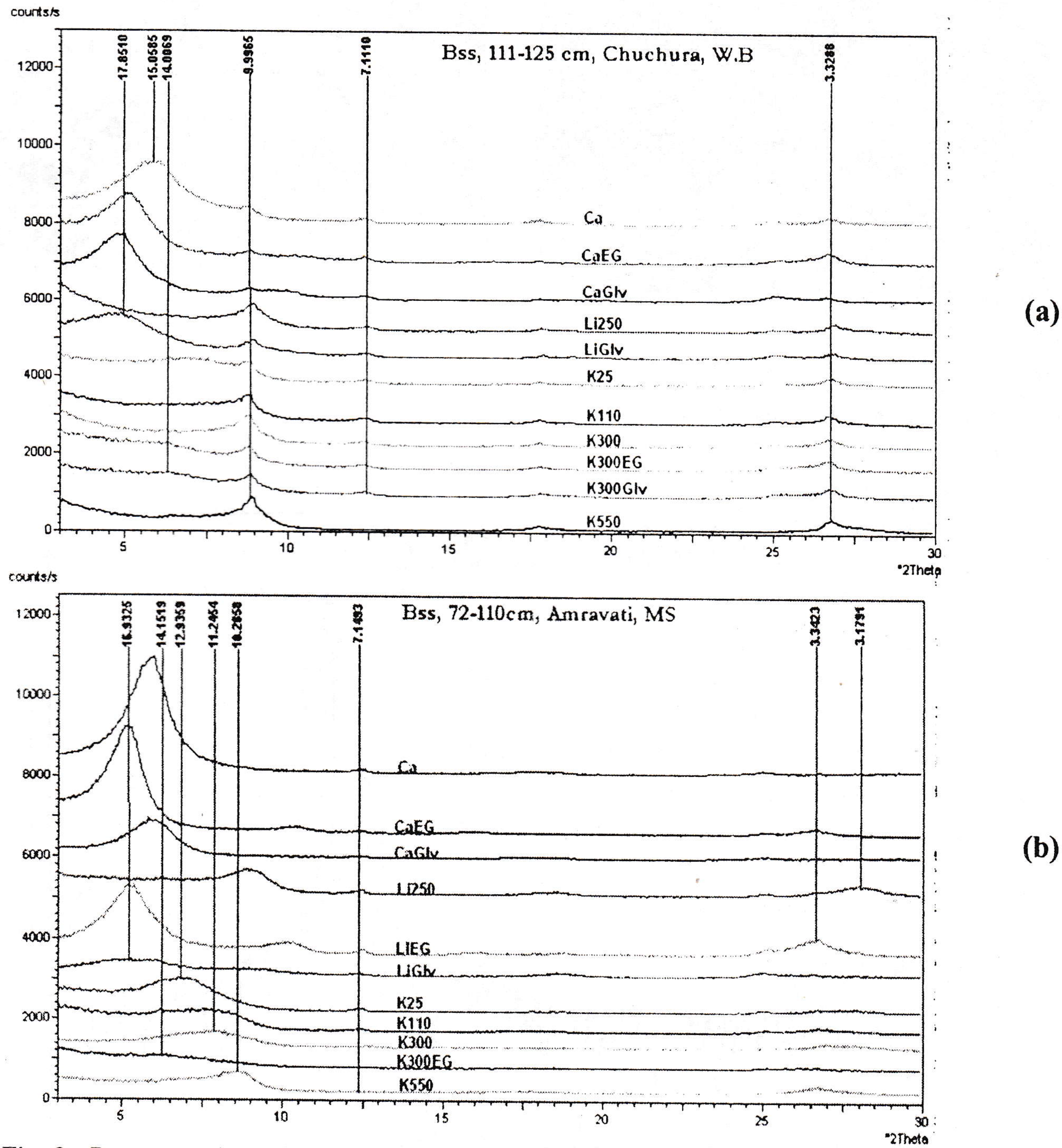
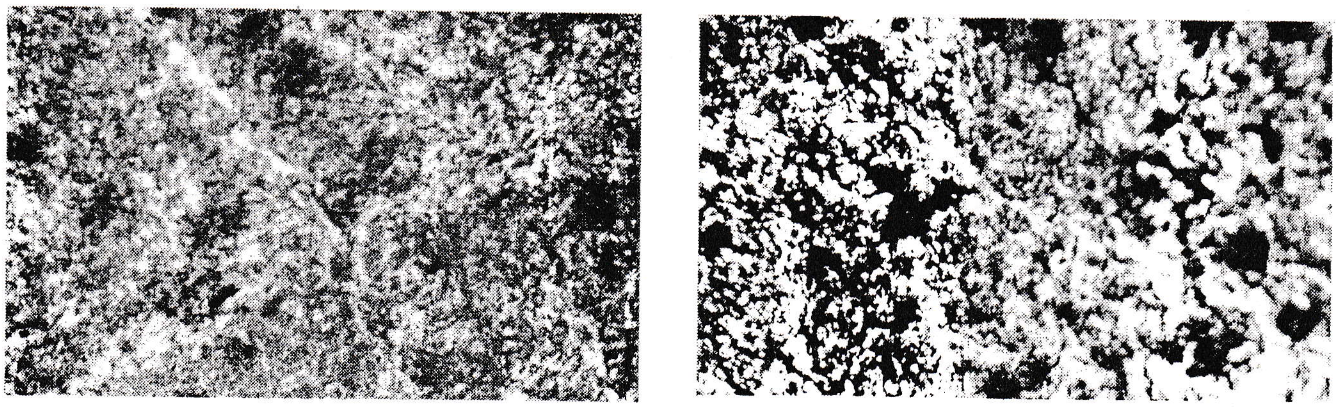


Fig. 2. Representative X-ray diffractrograms under various treatments of fine clays of soils of (a) Chunchura, (b) Deccan Trap area (Amravati): Ca = Ca saturated, CaEG = Ca-saturated and glycolated, CaGlv = Ca-saturated with glycerol vapour, Li250 = Li-saturated and heated at 250°C, LiEG = Li-saturated and glycolated, LiGlv = Li-saturated with glycerol vapour, K25/110/300/550 = K-saturated and heated to 25°, 110°, 300°, 550°C, K300EG = K-saturated, heated at 300°C and glycolated



(a) (b)

Fig.3. Representative microphotograph of plasmic fabric of Chunchura soil in cross polarized light (a) reticulate-striated and (b) parallel-striated fabric

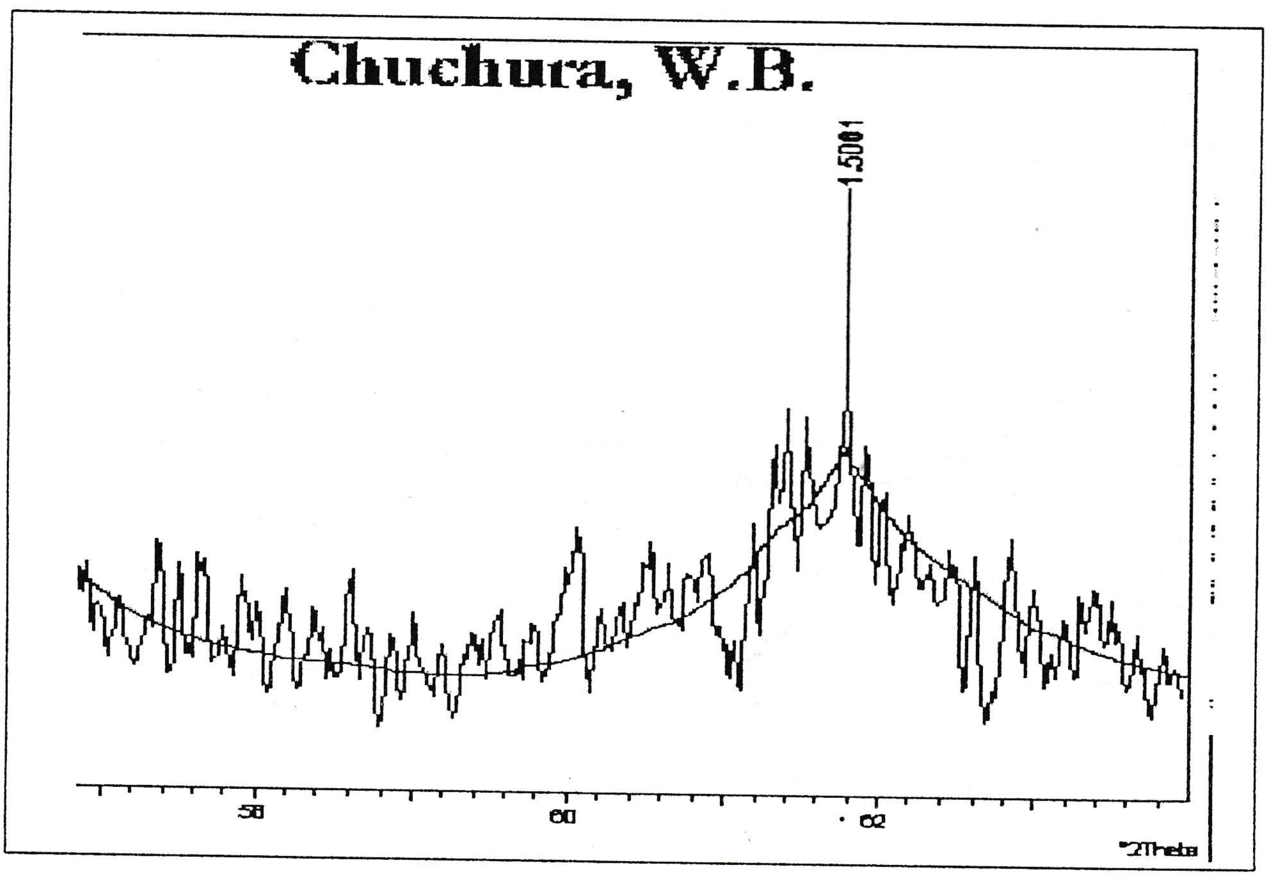


Fig. 4. The 060 reflection of fine clay smectites of Chunchura Vertisols showing their di-octahedral nature

that mica during the post-depositional period of the late Holocene period would produce such huge amount of smectite required for formation of the Vertisols. Mineralogical analysis showed that the Chunchura soils have smectites which are of low-charge similar to Vertisols of the Deccan Trap areas (Ray *et al.*, 2003). Moreover, the 060 reflections of fine clays of Chunchura soil (Fig. 4) at 1.500 A° indicated dioctahedral nature of the smectites that are ubiquitous in Vertisols of the Deccan Trap areas (Pal and Deshpande, 1987). Vertisols of the Deccan basalt area are formed in its alluvium brought down in the valleys and microdepressions in an earlier wetter climate (Pal and Deshpande, 1987; Bhattacharyya *et al.*, 1993; Pal *et al.*, 2006). Therefore, the Vertisols formed in Chunchura may also have been developed in the alluvium of the basalt in an earlier humid climate. This contention has been supported through the following discussion.

Detail geomorphological analysis of the lower IGP by Singh *et al.* (1998) showed that the landforms in the study area are related to basin tectonics. The Old Fluvial/ Deltaic Plain includes the Bhagirathi-Ajay Plain and the Ajay-Silai Plain which trend along the northwest-southeast direction. Most of the rivers originate in the western highlands and flows down the gentle slopes. However, towards the southern part of Ajay-Silai Plain, the Dwarkeshwar, Silai and Kasai rivers show an angular drainage pattern and the floodplains of most of the rivers are incised (Singh *et al.*, 1998). Moreover, some rivers are currently flowing along the southern margins of their floodplains. The Old Fluvial/Deltaic Plain also includes the Damodar Deltaic Plain which lies between the Damodar river in the west and the Hooghly river in the east. Our study area is represented by this plain. The Damodar river like other rivers stated above was flowing in the easterly direction to meet the Bhagirathi during the middle of the 18th century (Deshmukh, 1973) had since shifted its mouth 120 km to the south. Thus the plain is characterised by a network of paleo-channels with associated natural levees and swamps forming a dichotonic pattern (Howard, 1967). These paleo-channels fan out from the point where the rivers turn south from its easterly coarse, suggesting that the deltaic plain of the study area was constructed by the Damodar river some time in the past. It is interesting to note that these rivers flow from the west to the east draining the Rajmahal Trap area. The Rajmahal Traps consists of 2000 feet of bedded basalts or dolerites, with about 100 feet of interstratified sedimentary beds (inter-trappean beds) of siliceous and carbonaceous clays and sandstones (Wadia, 1989). The basalt is amygdaloidal filled with chalcedonic varieties of silica, calcite, zeolites or other secondary minerals. The rivers flowing in the vicinity of Rajmahal Trap are perennial in nature and huge amount of smectites were formed presumably due to higher rainfall in that area. Therefore, in view of the geomorphic history and the similar nature of smectites between Vertisols of Chunchura and Deccan Basalt area, it is most likely that the Vertisols of Chunchura in Hooghly district of West Bengal have been developed in the smectite-rich alluvium that has been carried from the Rajmahal Traps by the rivers once flowed towards the east.

Conclusion

The Vertisols of Chunchura area in the old fluvial/deltaic plain including the Damodar deltaic plain of West Bengal are developed in the smectite rich alluvium of the weathering Deccan basalt of the Rajmahal Trap of Bihar, brought down by the then east flowing rivers in the past, before they were shifted to the south during the middle of the 18th Century. The study thus highlights the importance of geomorphic and tectonic history in pedological study.

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