Journal of the Indian Society of Soil Science, Vol. 58, No. 1, pp 70-75 (2010)

Mineralogical Framework of Alluvial Soils Developed on the Aravalli Sediments

R.P. Sharma*[1], M.S. Rathore, R.S. Singh[2] and F.M. Qureshi
Department of Soil Science and Agricultural Chemistry, Rajasthan College of Agriculture,
Maharana Pratap University of Agriculture and Technology, Udaipur, 303 329, Rajasthan

The study area consists of the alluvial plains of Kothari River, a tributary of Banas and situated in Eastern Rajasthan Uplands. The area is surrounded by Aravalli hills. Sand constituted the major part of the soils of Kothari river plains. Quartz was the dominant mineral followed by feldspars and mica in all the plains. There was a mixed mineralogical makeup of clay fraction. Mixed mineralogy of alluvial plains revealed that the soils of the area were formed by mafic and felsic igneous rocks under moderate precipitation with higher base status. Higher cation content or base saturation with low rainfall (<1000 mm) favour the formation of smectites. Decreasing order of minerals (estimated semi-quantitatively) in the soils of alluvial plains could be depicted as: Illite/mica > smectite > kaolinite > feldspars > quartz > vermiculite = chlorite. Smectite content was highest in the soils of lower plains and least in upper rolling plains while illite/mica was highest in the soils of middle sloping plains. The ratio of 001 and 002 basal reflections of mica was more than unity, suggesting the presence of both biotite and muscovite mica minerals. Other minerals were found randomly distributed without any specific pattern. Youthful nature of the soils of upper rolling plains was indicated due to the presence of talc in their clay fraction. Mineralogy of silt size fraction was very similar to clay mineral framework except the higher content of quartz and feldspars and an equivalent reduction in 2:1 or 1:1 minerals. Smectite, mica, kaolinite, quartz, feldspars with trace amount of chlorite and vermiculite were found in silt size fraction.

Key words: Alluvial soils, Aravalli system, mineralogy, and soil forming processes

www.IndianJournals.com
Members Copy, Not for Commercial Sale
Downloaded From IP - 117.211.88.74 on dated 30-Aug-2013

Aravalli system covering a wide area in the Bhilwara district is seen in the form of belts and comprises quartzites, conglomerates, shales, slates, phyllites and composite gneisses. The geology of the study area is quite complex. The study area is almost underlined by Pre-Cambrean rocks, which consist of Bundelkhand gneiss, banded gneissic complex, Aravalli system, composite gneisses, Delhi system and Vindhayans. Alluvium-derived soils exhibit characteristics of both sediment transport and deposition and soil formation. Soil formation and sedimentation overlap, and sites protected from erosion and undergoing slight vertical accretion develop distinct horizons. For these reasons, soil profiles should be viewed in relation to sedimentary environments. It is very difficult to understand the variability and deposition process in rivers. Alluvial soils may be acid or calcareous, sandy or pebbly, clay rich or loamy and slightly or highly weathered. Floodplain geometry is governed by the flow characteristics of the river and the nature and amount of material available for transport and deposition. These factors are partly determined by the rocks, relief, and climate of the drainage basin. The alluvial soils in India are mainly concentrated in Indo-Gangetic plains. In India, distinction can be made between the arid zone floodplains of Punjab, Sind and Rajasthan, the intermediate conditions of U.P. and west monsoonal alluvium of the Ganges-Brahmaputra flood plains. In the arid zone, alkaline and saline soils with concrete are common, and savannah areas possess neutral to weakly alkaline soils, some times with calcium carbonate concretions. In area of high rainfall numerous moderately acid glayed alluvial soils occur (Gerrard 1987).

---

*Corresponding author (Email: rpsharma64@yahoo.com)

[1] Division of Crop Production, Indian Institute of Vegetable Research, P. B. No. 1, P. O. Jakhini (Shahanshahpur), Varanasi, 221 305, Uttar Pradesh

[2] NBSS&LUP, Regional Centre, Bohara Ganesh ji Road, University Campus, Udaipur, Rajasthan

Alluvial soils of Indo-Gangetic plains with 15-20% clay and larger portion of the silt are most productive as these soils contain enough of clay to provide an adequate surface for interaction with water and nutrients, to have a friable structure beneficial for tillage and root growth (Pal 2003). It is well known that without knowing the mineralogical framework of alluvial soils, formidable land use plan for the area is not possible. In view of necessity of adequate information the present study on alluvial soils of eastern Rajasthan upland was planned.

Materials and Methods

In the present investigation, an alluvial plain of Kothari river of Bhilwara district surrounded by Aravalli hills was selected, having three rainfall zones *viz.*, Upper rolling plains: Moderately sloping hills with a mean annual rainfall <600 mm (P1 to P4), Middle sloping plains: Gentle to very gently sloping plain with a mean annual rainfall 600-700 mm (P5 to P8) and Lower plains: Very gentle sloping plain with a mean annual rainfall 700-800 mm (P9 to P12). The area situated between 25°01′ and 25°58′ N latitude and 74°01′ and 75°28′ E longitude. Twelve pedons were selected for the study.

All these three groups of profiles were situated approximately 50 km apart to each other from higher (upper rolling plains) to lower elevation (lower plains). Four profiles within a group were selected for study and these were situated at a distance of 250 m and 500 m left and right side across the direction of river flow channel. Air-dried soil samples were gently crushed with a wooden roller and passed through 2 mm sieve and analyzed for general soil properties following the standard procedures (Jackson 1973).

The known amount of air-dried soil was treated with 1*N* sodium acetate buffer solution (pH 5.0) to destroy $CaCO_3$. After oxidizing organic matter with 30% H_2O_2, the samples were given citrate-bicarbonate-dithionite (CBD) treatment for the removal of free iron oxides. Silt (50-2 µm) and total clay (<2 µm) fractions were separated after dispersion according to the size segregation procedure of Jackson (1979). The silt (50-2 µm) and clay (<2 µm) fractions of surface and sub-surface layer of representative pedons were analyzed for qualitative mineralogy by X-ray diffraction techniques. Forty milligrams of silt and clay fractions were taken and saturated with Ca/K. Parallel orientated aggregate specimens of silt and clay samples for selected horizons of twelve pedons were prepared on a glass slide (4.5´2.5 cm) taking 1 mL suspension in each case. Slides were dried at a room temperature and then subjected to X-ray diffraction analysis (Jackson 1979).

Results and Discussion

Generalized Physicochemical Characteristics

Soil colour varied from gray (10YR 5/1) to very dark brown (10YR 2/2). The soils of upper rolling plains were relatively shallower (120 cm) than middle slopping plains (126 cm) and lower plains (140 cm). Sequence of soil horizon development was A-B-C in all the pedons except the soils of P6 and P10 where only A-C horizons were present. Soils of the area were sandy loam to loamy sand. Sand constituted the dominants fraction (37-92%) in the soils of all the three plains. Among the plains, sand fraction was relatively higher (76.9%) while silt (15.5%) and clay (7.6%) fractions were lower in the soils of upper rolling plains. The soils of lower plains contained higher amounts of silt (21.9%) and clay (13.1%) and lower amount of sand (65%). The soils of middle slopping plains were moderate in sand, silt and clay fractions. An increasing trend of silt and clay fractions down the depth was also noted in all three plains but it was more prominent in the soils of lower plains due to the process of eluviation and illuviation of soil materials. Value of pH and electrical conductivity was relatively lower (pH 7.29 and EC 0.17 dS m^{-1}) in the soils of upper rolling plains and higher (pH 8.10 and EC 0.60 dS m^{-1}) in the soils of lower plain but maximum (pH 8.49) mean pH values were recorded in the soils of middle sloping plains due to secondary accumulation of calcium carbonate. The level of EC was found within the safe limit and has no adverse effect on crop growth and production in Kothari river plains. Coefficient of variation was low (<15%) in case of pH while it was high (>35%) for EC in soils of all the three plains.

Mineralogical Composition of Sand Fractions

Sand constituted the major part of the soil of Kothari river plains. Quartz was found to be the dominant mineral followed by feldspars and mica in all the plains of the river; the XRD- pattern of sand fractions (Fig. 1) in soils of *Baniyon Ka Kheda* (P1) of upper sloping plains (P1-P4) showed a dominant peak of quartz at 3.36 Å in <100-mesh size fraction but it shifted at 3.30 Å in >100-mesh size fraction. It was also noted that <100-mesh size fraction of sand showed a peak at 4.26 Å but it disappeared in case of >100-mesh size fraction. In case of feldspars a dominant peak (3.17 Å) was noted in >100-mesh size sand fraction but it was relatively less dominant in <100-mesh size fractions. Inference could be made

www.IndianJournals.com
Members Copy, Not for Commercial Sale
Downloaded From IP - 117.211.88.74 on dated 30-Aug-2013

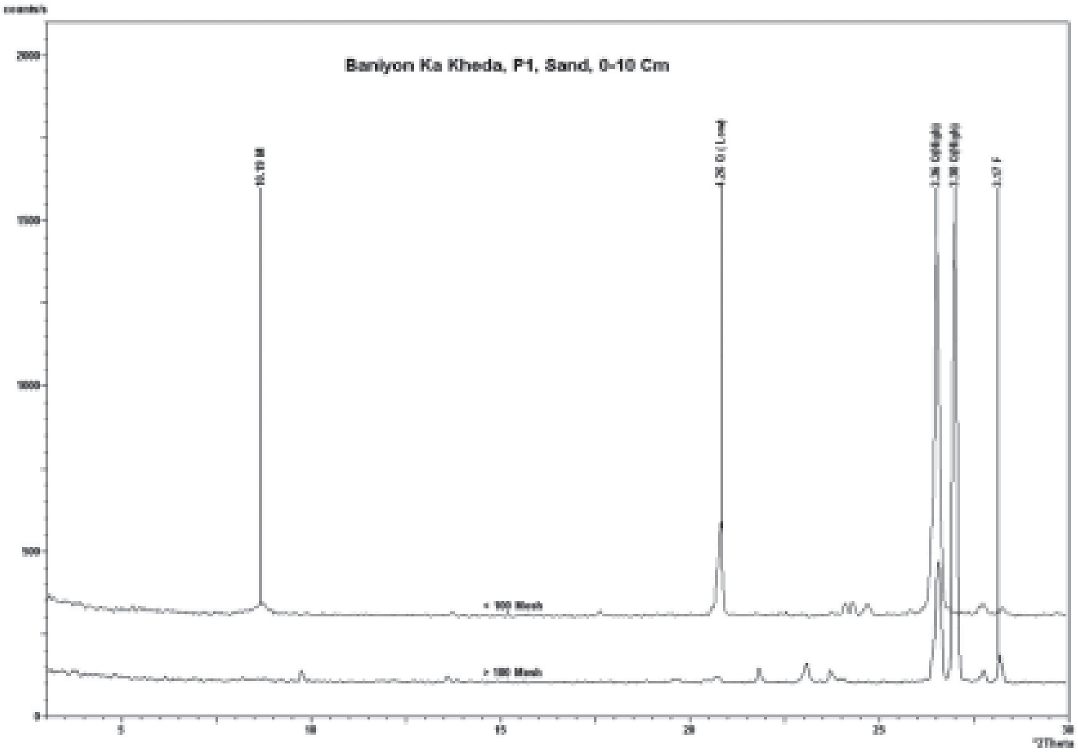

Fig. 1. Representative XRD patterns of 50-2000 µm sand fraction of the Ap horizon of Baniyon Ka Khera, soils of upper rolling plain (value of d-spacing is in Angstroms)

www.IndianJournals.com
Members Copy, Not for Commercial Sale
Downloaded From IP - 117.211.88.74 on dated 30-Aug-2013

on the basis of above information that feldspars were present more in coarser fraction while these were less in case of fine sand. Fine sand also contained a strong peak at 10 Å, which indicated that mica was dominant followed by quartz. Somewhat similar pattern of sand mineralogy was observed throughout the plains of the river. Chattopadhyay *et al.* (2003) while studying the sand mineralogy of extreme hot arid eco-region soils of Rajasthan also reported similar results.

Mineralogical Compositions of Silt Fraction

Smectite, mica, kaolinite, quartz, feldspars with trace amount of chlorite and vermiculite were noted in silt size fraction (Table 1). Mineralogy of silt size fraction was similar to that of clay size except for the higher content of quartz and feldspars and an equivalent reduction in 2:1 or 1:1 minerals. Mica dominated over the smectite and was followed by kaolinite. Talc was not detected in the silt fraction. A characteristic peak at 8.42 Å of amphiboles was noted in soils of upper rolling plains (P1-P4) and in soils of Sarano Ka Kheda (P6) of middle sloping plains. Amphiboles were absent in the silt fraction of lower plains (P9-P12). The XRD diffractogram of representative silt sample is presented in figure 2.

Mineralogical Compositions of Clay Fraction

Quantitative estimation of minerals (Table 2) present in clay size fractions by XRD analysis is difficult to perform with comparable precision simultaneously for all mineral components. Any attempt in this regard has always yielded semi-quantitative estimates (Gjems 1967). It represents the relative proportion of different minerals in clay fractions. The XRD diffractograms of representative clay sample is presented in figure 2**.**

Smectites: Smectite content ranged from 14 to 33, 16 to 33 and 36 to 44% with a mean values of 22, 24 and 39% in upper rolling plains (P1-P4), middle sloping plains (P5-P8) and lower plains (P9-P12), respectively. The smectite content recorded an increasing trend from upper rolling plains towards the lower plains. The smectite content appears to increase with the depth of pedons in upper rolling plains (P1-P4) and lower plains (P9-P12) but a reverse trend was observed in case of middle sloping plains (P5-P8). Similar trend was also reported in the alluvial soils of the Nile by Hamdi (1954). Alterations in the clay minerals in soil profile due to climate, topography and time affect the swell-shrink characteristics in alluvial soils. Several causes, such as the selective translocation of the swelling minerals in the subsurface horizons, selective weathering of illite/mica from

www.IndianJournals.com
Members Copy, Not for Commercial Sale
Downloaded From IP - 117.211.88.74 on dated 30-Aug-2013

Table 1. Mineralogical composition: Semi-quantitative mineralogical estimation of silt fraction

Profile		Smectite	Mica	Talc	Kaolinite	Quartz	Feldspar	Chlorite	Vermiculite
		←				(%)			→
Upper rolling plains with a mean annual rainfall <600 mm									
Baniyon Ka Khera	P1/1	9	47	tr	19	5	13	5	tr
	P1/3	21	31	tr	21	5	8	tr	14
Dulkhera	P4/1	15	34	tr	13	6	21	tr	11
	P4/3	30	19	tr	7	11	19	12	tr
Middle sloping plains with a mean annual rainfall 600-700 mm									
Sarano Ka Kheda	P6/1	18	25	nil	24	9	18	5	tr
	P6/4	20	20	nil	15	15	21	8	nil
Hamirgarh	P8/1	25	32	nil	14	8	11	tr	6
	P8/4	26	29	nil	13	tr	8	6	15
Lower plains with a mean annual rainfall 700-800 mm									
Akola	P9/1	17	25	nil	12	18	23	tr	tr
	P9/4	18	23	nil	11	11	23	5	9
Akola	P11/1	33	20	nil	21	tr	12	nil	10
	P11/3	34	17	nil	19	tr	10	9	7

tr: less than 5 per cent

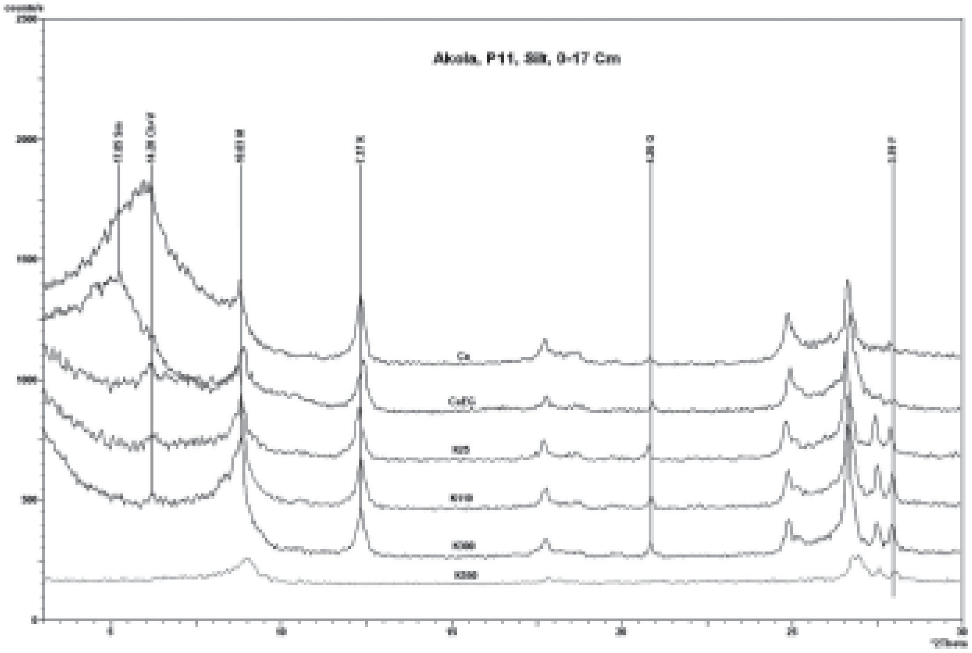

Fig. 2. Representative XRD patterns of 2-50 µm silt fraction of the Ap horizon of Akola, soils of lower plain: Ca = Ca-saturated, K-25/110/ 300/550 = K saturation and room temperature (25°C), K-saturation and heated to 110 °C, 300 °C and 550 °C; Sm = smectite, Ch = chlorite, V= vermiculite, M = mica, K= kaolin, Q = quartz, F = feldspar, Am = amphibole (value of d-spacing is in Angstroms)

silt to clay fraction and the selective destruction of the swelling minerals in the surface horizons (Razzaq and Hebillon 1979) might be the reasons of mineral alteration in soil depth. In the alluvial soils of river plains having semi-arid climate, smectite might be a weathering product of biotite mica through a 10 to 14 Å mixed layer phase (Pal and Despande 1987). A supply of cations *viz.*, iron, magnesium, calcium and sodium, excess of dissolved silica, and an alkaline environment all favour the production of smectites.

Illite/Mica: Illite or mica content varied from 27 to 43, 35 to 48 and 17 to 35% with a mean content of 33, 42 and 25% in upper rolling plains (P1-P4), middle sloping plains (P5-P8) and lower plains (P9-P12), respectively. Highest mica content was observed in middle sloping plains due to weathering of mica deposits in clay size particles. The ratio of 001 and 002 basal reflections of mica was more than unity, suggesting the presence of both biotite and muscovite mica minerals (Pal 2003).

Table 2. Mineralogical composition: Semi-quantitative mineralogical estimation of total clay fraction

Profile		Smectite	Mica	Talc	Kaolinite	Quartz	Feldspar	Chlorite	Vermiculite
		←				(%)			→
Upper rolling plains with a mean annual rainfall <600 mm									
Baniyon Ka Khera	P1/1	14	32	10	20	tr	11	6	tr
	P1/3	15	43	5	11	tr	8	tr	12
Dulkhera	P4/1	25	27	tr	18	5	6	11	tr
	P4/3	33	30	6	11	5	6	5	tr
Middle sloping plains with a mean annual rainfall 600-700 mm									
Sarano Ka Kheda	P6/1	16	47	tr	20	8	nil	5	tr
	P6/4	20	37	tr	15	6	7	8	6
Hamirgarh	P8/1	26	48	tr	10	tr	7	tr	tr
	P8/4	33	35	tr	7	5	5	tr	13
Lower plain with a mean annual rainfall 700-800 mm									
Akola	P9/1	44	24	nil	13	5	6	6	tr
	P9/4	36	35	nil	13	6	nil	tr	7
Akola	P11/1	36	17	nil	22	7	7	tr	8
	P11/3	39	23	nil	20	5	nil	tr	9

tr: less than 5 per cent

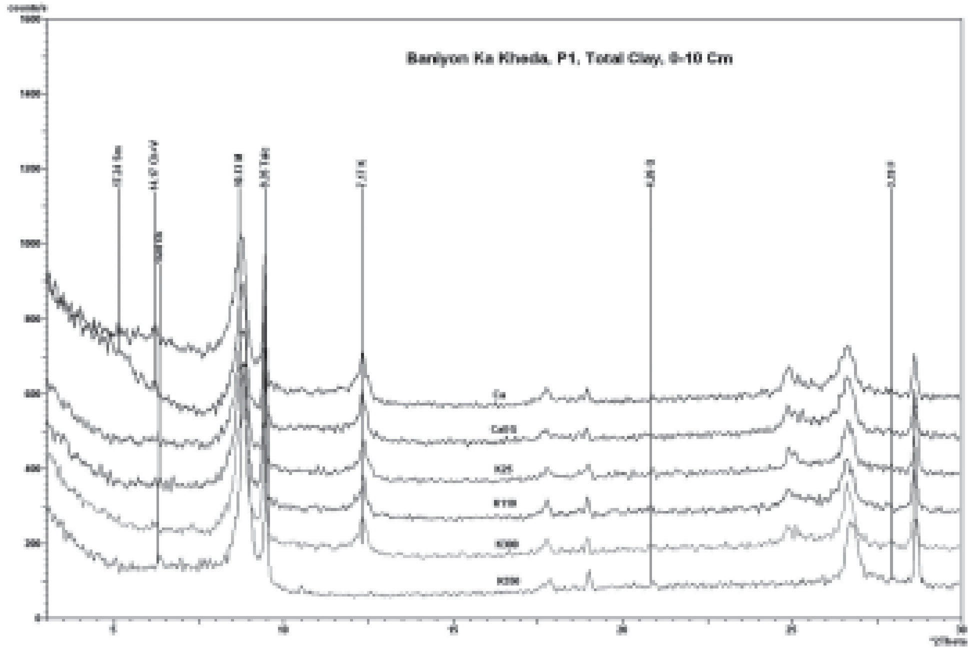

Fig. 3. Representative XRD patterns of <2 μm clay fraction of the Ap horizon of Baniyon Ka Kheda, soils of upper rolling plain: Ca = Ca-saturated, K-25/110/ 300/550 = K saturation and room temperature (25 °C), K-saturation and heated to 110 °C, 300 °C and 550 °C; Sm = smectite, Ch = chlorite, V= vermiculite, M = mica, K= kaolin, Q = quartz, F = feldspar (value of d-spacing is in Angstroms)

Kaolinite: X-ray differaction analysis of clay indicates the presence of kaolinite in all three plains. Semi-quantification showed that the Kaolinite content varied from 11 to 20, 7 to 20 and 13 to 22% in upper rolling plains (P1-P4), middle sloping plains (P5-P8) and lower plains (P9-P12), respectively. Further kaolinite content reduced with the depth of pedons in all the plains except in soils of Akola (P9) where it remained constant throughout the profile.

Vermiculite and Chlorite: Vermiculite and chlorite were also present from traces (<5%) to 10% in the soils of all the plains. The vermiculite was partially chloritised and showed wide variation among pedons (traces to 10%).

Talc: Trioctahedral mineral talc was noted in the clay fraction of upper rolling plains in the range of traces to 10%. Trace amount of talc was also observed in middle sloping plains (P5-P8) but was not observed in soils of lower plains (P9-P12).

www.IndianJournals.com
Members Copy, Not for Commercial Sale
Downloaded From IP - 117.211.88.74 on dated 30-Aug-2013

Quartz and Feldspars: Both the minerals (quartz and feldspars) varied from traces to 10% in alluvium of Kothari river. However feldspars were absent in surface soils of Sarano Ka Kheda (P6) and sub-surface soils of Akola (P9, P11).

Genesis of Minerals

Granite, gneissic complex, phyllites, quartzites, biotitic schists and chlorite para-schists were common rocks exposed on the hills and beneath the soils of upper, middle and lower plains. The presence of micaceous chlorites and mica in the clays of soils of alluvial plains revealed that these have been derived from rocks in the study area. Presence of smectites and vermiculites in the soils of middle sloping and lower plains indicated that mica might be weathering to give rise to smectite and vermiculite. The soils of lower plain received the outflows from the upper rolling and/or middle sloping plains. The analysis of data on chemical composition of soil indicates that the soil system was rich in silica and received continuous siliceous solution from the hills. These coupled with alkaline reaction might have led to the neoformation of smectites. The hypothesis further has strong footing on the presence of smectite with 16-17 Å basal spacing on ethylene glycol salvation of Ca-saturated samples. The purist form of smectites could not be attainable due to the transformation of biotite under the present set of weathering, having restricted drainage conditions, which do not encourage the leaching of liberated potassium and magnesium out of the system. The presence of these in the weathering environment may lead to the repotassication of weathered biotitic mica. Thus the present level of interpretation indicates that smectite group of minerals were formed *in situ* or during transporting of alluvium from higher topographical positions. Presence of these minerals were not able to give rise to the cracking phenomenon because of lower content of clay in the soils of all plains. The formation of vermiculites in the soils of middle sloping and lower plains may be ascribed to the trapping of Mg, released on weathering of chlorites or talc in the interlattice space of smectites. Besides these minerals, kaolinites, chlorites, talc, amphiboles, feldspars and quartz are inherited directly from the parent material. In general, the mineral composition of the soils would have been identical, if topography had not varied.

It was noted that both the silt and clay fractions contained the similar kind of clay minerals except that the quartz and feldspars were more in the silt fractions. The combination of minerals had a close similarity throughout the profile of the soils belonging either to Entisols or Inceptisols.

Conclusions

None of the clay minerals was found to be dominating in either silt or clay fractions. Both the fractions showed the presence of mixture of minerals namely mica, smectite, kaolinite and vermiculite. The presence of smectite and vermiculite amidst ubiquitous presence of mica indicates that mica might have weathered to give rise to smectite and vermiculite. In view of incipient development of soils in the study area and also the similar kind of minerals throughout the profiles it is suggested that the minerals present were not formed during the post-deposition period of the soil formation. They appear to be inherited from the parent materials. The transformation of mica might have occurred at the source area of alluvium or during their transportation by water.

References

Chattopadhyay, T., Sahoo, A.K. Shyampura, R.L. and Singh, R.S. (2003) Studies on the sand mineralogy of extreme hot arid eco-region soils of Rajasthan. *Indian Agriculturist* **47**, 241-246.

Gerrard, John (1987) *Alluvial Soils*. A Hutchinson Ross Publication, Van Nostrand Reinhold Company, New York, pp. 1-17.

Gjems, O. (1967) Studies on clay mineral formation on soil profiles in Scandinavia. *Nor. Medd. Sogfkorsoksves* **21**, 303-415.

Hamdi, H. (1954) Mineralogical study the alluvial suspended matter of the Nile, *Clay Mineral Bulletin* **12,** 209-219.

Jackson, M.L. (1973) *Soil Chemical Analysis.* Prentice Hall of India Private Ltd., New Delhi.

Jackson. M.L. (1979) *Soil Chemical Analysis. An Advance Course.* 2nd Edition. University of Wisconsin Madison, USA.

Pal, D.K. (2003) Significance of clays, clay and other minerals in the formation and management of Indian soils, *Journal of the Indian Society of Soil Science* **51**, 338-364.

Pal, D.K. and Despande, S.B. (1987) Parent material, mineralogy and genesis of two benchmark soils of Kashmir valley. *Journal of the Indian Society of Soil Science* **35**, 690-698.

Razzaq, A. and Herbillon, A.J. (1979) Clay mineralogical trend in alluvium-derived soils of Pakistan. *Pedologie* **29**, 5-23.

Received December 2007; Accepted November 2009

www.IndianJournals.com
Members Copy, Not for Commercial Sale
Downloaded From IP - 117.211.88.74 on dated 30-Aug-2013