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Mineralogy of soils of major geomorphic units of north-eastern Haryana, India

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Abstract: The study was carried to determine the mineralogy of soils of different geomorphic units for providing the more detailed information needed to improve agricultural production in north-eastern part of Haryana. The soils of the study area were slightly acidic to strongly alkaline in reaction (6-9.4). The cation exchange capacity and electrical conductivity varied from 3.10-26.80 cmol (+) kg^{-1} and 0.16-1.20 dSm^{-1}, respectively. In general, the soils were siliceous in nature with SiO_2 ranging from 68.60 to 87.90 percent. The soil samples from surface and subsurface diagnostic horizons were studied through X-ray diffraction. In fine sand, quartz was the dominant mineral followed by feldspars, muscovite, hornblende, tourmaline, zircon, biotite, iron ores and sphene. In silt fraction, quartz was the dominant mineral followed by mica, feldspars, chlorite, kaolinite, interstratified and traces of smectite and vermiculite. Semi-quantitative estimation of clay fraction indicated that illite was the single dominant mineral in the clay fraction of these pedons, however, its quantity was less in alluvial plains (28-30 %) compared to Shiwalik hills (36-49 %). Next to illite, a high amount of smectite (14-20 %) and vermiculite (11-17 %) were observed in clays of alluvial plains of Ghaggar (recent and old) whereas in Shiwalik hills (top and valley) these minerals were detected in small amount (6-11 %). Fairly good amount of kaolinite (10-17 %) and small amount of chlorite (4-11 %) were uniformly distributed in soil clays irrespective of geomorphic units showing their detrital origin. Medium intensity broad peaks in higher range diffractograms (14-24 A˚) indicated the presence of regular and irregular interstratified minerals in old alluvial plains of Ghaggar.

Keywords: Geomorphic unit, X-ray diffraction, Mineralogy, Diffractograms, Interstratified minerals

INTRODUCTION

A geomorphic surface or unit is defined as the part of the land surface with definite geographic boundaries formed by one or more agencies in a given period of time (Daniels *et al.*, 1970; Buol *et al.*, 2011). Four major geomorphic units have been recognized in north-eastern Haryana. Shiwalik hills are primarily represented by Upper Shiwaliks extending from Kalesar in the southeast to northwest of Kalka. However, Middle Shiwaliks are present but in patches. Shiwaliks are also exposed on the northeastern border of Punjab in continuation in a linear lithotectonic belt. Immediately south of the low structural cum denudational hills of the Shiwalik, lies the zone of piedmont deposits. Within this geomorphic unit, two distinct generations of piedmont deposits are evident, an older piedmont zone which has later been cut and partly eroded by a younger piedmont deposit. This piedmont zone mainly comprises of alluvial coalescing fans and fan cut terrace deposits. This older alluvial tract occupies a position between the hills in the northeast and the aeolian zone to the southwest. There is a conspicuous variation in the geomorphological set up to the north and south of the Ghaggar river. The southern tract shows the prevalence of dunal features and is differentiated by sand ridges upto 15 m high and 5 km long. However, northern tract exhibits low relief, stabilized dunes, marginal dunes occurring periodically in patches. The low-lying areas in the immediate vicinity of the major rivers viz. the Yamuna, the Sutlej, the Beas and the Ravi characterized by typical features of recent flood plain have been classified as flood plain. This distinguishable geomorphic unit, due to frequent inundation during high flash floods and owing to its low-lying nature, has no optimum land use pattern or planning. This is in fact the younger alluvium and is put under seasonal cultivation when free from floods (Chopra, 1990).

Topography plays a prominent role in determining the variation of soil properties, since such variations are on account of the orientation of hill slope on which the soil is formed. Moreover, the steep slopes, in general, promote rapid loss of soil by erosion as a result of low infiltration leading to excessive runoff (Brady and Weil, 2007). It not only conditions the microclimate but also influences soil properties by affecting multitude of soil forming processes. Understanding soil genesis needs elucidation of the chemical, mineralogical and physical composition of the soil because these properties determine the utility of the soils for sustainable agricultural production. Amidst the ultimate products of weathering, clay minerals and mineral colloids

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of various characteristics are influencing numerous soil properties in various ways (Churchman, 2010a). Clay minerals are hydrated aluminum silicates with very fine particle size, usually < 2μm (Moore and Reynolds, 1989). The permutations of minerals are largely related with nature and constitution of parent material and degree of weathering (Abbaslou *et al*., 2013). Owing to the rationales of primary mineral stability, alteration and neoformation of minerals, it is apparent that all soils develop from parent rocks and their elemental constitution begins to rely more on weathering environs rather on composition of parent materials. Therefore, associations of clay minerals in soils are regarded as indices of degree of soil development (McBride, 1994). Churchman (2010b) reported that, in general, minerals formed by neogenesis from solutions in the soil appear in smaller particles showing more disorder compared to other processes, for instance, hydrothermally or from deposits of oceanic or lacustrine origin. Since, little research has been carried out to compare the mineralogical composition of soils under different landscapes, therefore, clay mineralogy and the properties of the soils with different topography and vegetation were analysed. The aim of this work was to determine the relationship between geomorphic units and the mineralogy of the soil.

MATERIALS AND METHODS

The study area is situated between 76° 31' to 77° 35' E longitudes and 30° 03' to 30° 57' N latitudes covering districts of Panchkula, Ambala, Yamuna Nagar and Kurukshetra in Haryana. Most of the area is covered by quaternary deposits except hilly area. The general topography is undulating in the northern part and flat in the southern part. Geomorphologically, the area comprises of hilly terrain, piedmont plain and alluvial plain. Two major rivers flow through this area, Ghaggar and Yamuna. The climate is subtropical, semiarid, continental monsoonal with prolonged hot summer with mean annual precipitation of 578−1486 mm. The

Table 1. General characteristics of geomorphic units of north-eastern Haryana.

Pedon	Physiography	Drainage	Erosion	Land use
1	Shiwalik hill (Top)	Excessively drained	Very severe	Forest
2	Shiwalik hill (Top)	Runoff	Very severe	Forest (wasteland)
3	Shiwalik hill (Slope)	Runoff	Very severe	Forest
4	Shiwalik hill (Slope)	Runoff	Very severe	Forest
5	Shiwalik hill (Valley)	Excessively drained	Very severe	Forest
6	Shiwalik hill (Valley)	Well drained	Severe	Cultivation
7	Shiwalik hill (Valley)-gently undulating	Moderately well drained	Moderate	Cultivation
8	Shiwalik hill (Valley)	Imperfectly drained	Moderate	Forest
9	Shiwalik hill (Valley)	Imperfectly drained	Severe	Grasses, wasteland
10	Piedmont plain (Upper)	Well drained	Severe	Forest
11	Piedmont plain (Upper) - gently undulating	Moderate	Severe	Fallow and wheat
12	Piedmont plain (Upper) - gently to very gently undulating	Moderate	Moderate	Fallow and wheat
13	Piedmont plain (Lower) – very gently undulating	Well drained	Moderate	Cultivation
14	Piedmont plain (Lower) – nearly level	Well drained	Absent	Cultivation
15	Active floodplain (Ghaggar)	Well drained	Slight	Cultivation
16	Recent flood plain (Ghaggar)	Well drained	Absent	Cultivation
17	Recent flood plain (Yamuna)	Moderately well drained	Slightly to moderate	Cultivation
18	Old alluvial plain (Ghaggar)	Well drained	Absent	Cultivation
19	Old alluvial plain (Markhanda)	Poorly drained	Absent	Cultivation
20	Old alluvial plain (Yamuna)	Imperfectly drained	Absent	Cultivation
21	Low lying plain	Imperfect	Absent	Forest
22	Low lying plain	Imperfectly drained	Absent	Cultivation

Table 2. Semi-quantitative estimation of clay minerals in clay fraction (<2μ) of soils.

Geomorphic unit	Pedon	Horizon	Depth (cm)	I	V	S	K	C	Q	F	Inter.
Shiwalik hill (Top)	2	A1	0-37	48	6	10	13	11	<5	-	10
Shiwalik hill (Top)	2	2C	152-242	49	6	12	12	9	5	-	7
Shiwalik hill (Valley)	5	A1	0-23	43	12	9	12	10	5	-	9
Shiwalik hill (Valley)	5	C	53-106	36	11	17	13	8	8	<5	5
Shiwalik hill (Valley)	9	Ap	0-6	43	15	6	15	7	5	-	9
Shiwalik hill (Valley)	9	C	31-48	46	13	7	14	8	6	-	6
Active Flood Plain (Ghaggar)	15	Ap	0-26	28	17	20	10	5	5	-	15
Active Flood Plain (Ghaggar)	15	2C	86-120	31	12	16	15	4	6	-	16
Active Flood Plain (Ghaggar)	18	Ap	0-17	34	13	15	17	5	6	-	10
Active Flood Plain (Ghaggar)	18	B2	20-50	39	11	14	15	7	5	-	9

I=Illite, K= Kaolinite, C= Chlorite, S= Smectite, V=Vermiculite, Q= Quartz, F= Feldspar, Inter= Interstratified

Table 3. Physico-chemical composition of the soils of north-eastern Haryana.

Pedon No. and Horizon	Depth (cm)	pH (1:2)	EC (dSm^{-1})	Texture	CEC cmol $(p^+)\ kg^{-1}$	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5	MnO	LOI
						(%)									
Shiwalik hills (Top)															
Pedon 1	**Typic Udorthent**														
A1	0-18	6.40	0.53	Silt loam	9.70	81.60	5.02	3.86	1.17	0.74	0.75	0.68	0.090	0.059	2.77
C1	18-41	6.70	0.36	Sandy loam	6.45	84.40	4.44	3.91	1.20	0.52	0.82	0.62	0.080	0.049	1.65
C2	41-90	6.60	0.36	Loamy sand	3.95	87.90	2.95	2.85	1.16	0.46	0.78	0.56	0.080	0.029	1.05
Pedon 2	**Typic Udorthent**														
A1	0-37	8.51	0.53	Sandy clay loam	11.10	72.80	10.60	3.96	1.20	0.36	0.86	0.62	0.13	0.042	2.82
C1	37-152	9.05	0.77	Sandy clay loam	15.24	74.60	7.80	4.24	1.24	0.24	0.63	1.26	0.05	0.079	2.24
2C2	152-242	9.05	1.12	Sandy clay loam	13.96	72.20	12.60	4.30	1.10	0.42	0.67	1.03	0.03	0.036	2.62
Shiwalik hills (Slope)															
Pedon 3	**Typic Udorthent**														
A1	0-41	8.45	0.37	Clay loam	14.49	78.60	10.60	4.30	1.16	0.36	0.63	1.00	0.160	0.088	2.56
AC	41-70	8.25	0.44	Loam	9.61	78.20	8.70	4.16	1.18	0.24	0.86	1.15	0.080	0.038	2.87
C1	70-90	8.55	0.35	Sandy clay loam	14.71	79.80	8.70	4.26	1.08	0.46	0.78	1.03	0.060	0.046	2.63
C2	90-127	8.50	0.34	Sandy clay loam	13.43	82.60	6.20	4.15	0.96	0.20	0.54	0.80	0.060	0.052	2.09
Pedon 4	**Typic Udorthent**														
A1	0-13	7.85	0.85	Loam	15.20	78.80	8.40	4.21	0.90	0.40	0.30	1.15	0.07	0.043	1.96
C1	13-48	8.15	1.70	Clay loam	26.80	82.60	6.60	4.23	0.85	0.30	0.75	1.58	0.06	0.086	1.62
C2	48-86	8.20	1.00	Clay loam	22.80	84.20	6.80	4.30	0.68	0.40	0.63	1.60	0.03	0.058	1.42
Shiwalik hills (Valley)															
Pedon 5	**Typic Udipsamments**														
A1	0-23	8.4	0.39	Sand	7.83	85.60	3.90	3.89	1.02	0.50	0.71	0.53	0.07	0.067	1.82
AC	23-53	8.65	0.31	Sand	6.70	87.60	3.70	3.68	1.10	0.30	0.78	0.62	0.06	0.055	1.74
C	53-106	8.65	0.29	Sand	6.70	82.40	4.20	3.83	0.96	0.30	0.95	0.56	0.08	0.034	1.96
2C	106-190	8.70	0.28	Sandy loam	9.20	84.90	4.20	4.00	0.84	0.40	0.82	0.90	0.06	0.026	1.68
Pedon 6	**Typic Udorthents**														
Ap	0-20	8.20	0.35	Loamy sand	12.20	82.60	5.60	3.94	1.61	0.68	0.71	0.75	0.12	0.034	1.68
B1	20-50	8.50	0.31	Sandy loam	11.70	79.60	6.60	3.94	1.23	0.50	0.51	1.00	0.06	0.037	2.08
B2	50-70	8.55	0.25	Sandy loam	8.90	84.20	5.20	3.84	1.14	0.30	0.48	0.87	0.05	0.033	1.83
C	70-100	8.35	0.35	Sandy loam	10.20	82.20	4.90	4.04	0.95	0.26	0.67	1.07	0.06	0.045	1.72
Pedon 7	**Typic Eutrudept**														
Ap	0-17	6.80	0.49	Sandy clay loam	12.19	78.80	10.20	4.13	1.10	0.68	0.63	1.0	0.05	0.053	1.92
B	17-95	7.15	0.16	Clay loam	15.90	79.60	10.70	4.35	1.24	0.35	0.75	1.0	0.03	0.080	1.76
BC	95-160	7.30	0.20	Clay loam	16.20	82.40	9.80	4.31	1.13	0.42	0.63	1.0	0.02	0.079	1.58
Pedon 8	**Aquic Udipsamments**														
Ap	0-6	6.0	1.03	Sand	5.34	83.80	4.46	4.22	1.36	0.85	0.51	1.19	0.16	0.047	1.83
AC	6-31	6.55	0.60	Sand	7.17	84.80	4.96	4.21	1.23	0.64	0.63	1.03	0.08	0.046	1.62
C	31-48	7.20	0.43	Loamy sand	6.61	85.60	4.76	4.16	1.08	0.52	0.60	1.00	0.05	0.040	1.58
Pedon 9	**Fluventic Udorthents**														
A1	0-10	6.85	0.67	Sandy clay loam	14.83	76.60	10.40	4.19	1.27	0.75	0.48	1.23	0.13	0.051	2.42
AC	10-31	6.50	0.21	Sandy clay loam	8.29	78.90	10.10	4.20	1.38	0.62	0.63	1.07	0.08	0.042	2.32
C1	31-66	6.45	0.28	Sandy loam	11.15	82.60	7.60	4.20	1.05	0.50	0.42	0.96	0.05	0.059	2.08
C2	66-88	6.45	0.22	Sandy loam	6.64	84.20	7.40	4.20	0.96	0.50	0.51	1.10	0.03	0.052	1.96
R	88+	Hard rock													

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Piedmont plains (Upper)															
Pedon 10	**Typic Eutrudept**														
Ap	0-35	7.35	0.25	Loamy sand	9.05	84.40	3.20	2.95	1.04	0.60	1.11	1.30	0.080	0.055	1.63
B	35-110	6.80	0.21	Sandy loam	8.92	83.20	2.20	3.00	0.90	0.50	0.90	1.26	0.060	0.057	1.82
BC	110-241	7.00	0.21	Sandy loam	12.71	83.70	3.40	2.98	1.10	0.65	1.00	1.23	0.070	0.039	2.06
Pedon 11	**Typic Udipsamments**														
Ap	0-29	6.50	0.26	Sand	3.90	84.20	6.42	2.36	1.20	0.60	0.71	1.19	0.096	0.038	1.57
C1	29-57	6.70	0.18	Sand	3.10	85.60	5.60	0.49	1.34	0.86	0.63	1.46	0.082	0.050	1.68
C2	57-89	6.80	0.15	Sand	3.80	82.60	6.91	0.89	1.17	0.42	0.75	1.15	0.092	0.054	1.32
Pedon 12	**Lithic Udorthents**														
Ap	0-15	7.00	0.21	Sandy loam	5.21	79.60	5.66	3.80	2.34	1.12	1.87	0.62	0.052	0.046	1.69
AC	15-38	7.00	0.22	Loamy sand	7.92	82.40	4.26	4.00	1.62	0.95	0.60	0.71	0.042	0.096	1.46
C	38-63	7.05	0.24	Sandy loam	7.84	84.60	4.08	4.15	1.00	0.58	0.80	0.78	0.017	0.124	1.24
R	63+	Stone layer													
Piedmont plains (Lower)															
Pedon 13	**Udic Ustorthent**														
Ap	0-24	7.00	0.27	Sandy clay loam	7.50	80.40	2.66	0.92	2.30	0.76	0.78	1.61	0.075	0.063	1.20
C1	24-63	7.20	0.20	Sandy loam	7.30	82.60	3.66	1.27	2.10	0.52	0.78	1.42	0.067	0.058	1.64
C2	63-91	7.40	0.13	Loamy sand	5.50	79.80	4.26	1.94	2.24	0.85	0.73	1.58	0.023	0.051	1.92
C3	91-152	7.45	0.13	Loamy sand	5.00	84.60	3.98	3.95	1.68	0.34	0.67	1.38	0.041	0.047	1.87
Pedon 14	**Udic Haplustepts**														
Ap	0-16	8.20	0.89	Loamy sand	11.00	74.90	10.30	2.75	1.05	1.35	0.90	0.70	0.14	0.055	2.05
B1	16-29	7.60	0.75	Sandy loam	11.02	68.70	14.90	4.30	1.23	2.85	0.80	0.78	0.11	0.067	2.10
B21	29-40	7.40	0.50	Sandy loam	5.90	73.70	11.80	4.05	1.23	2.01	0.80	0.60	0.16	0.090	2.99
B22	40-110	7.40	0.50	Loam	5.91	75.90	10.50	3.11	1.45	1.40	0.85	0.52	0.11	0.065	2.99
B23	110-155	7.50	0.30	Loam	5.95	75.00	8.30	3.90	1.39	1.20	0.63	0.50	0.09	0.064	1.08
Flood plains															
Pedon 15	**Typic Ustorthents**														
Ap	0-26	8.05	0.94	Sandy clay loam	15.00	80.61	6.70	4.19	1.60	1.20	1.17	1.62	0.160	0.075	2.12
C1	26-54	8.90	0.59	Sandy loam	12.00	81.20	5.78	4.15	1.30	1.10	1.06	1.46	0.124	0.060	1.92
C2	54-86	8.85	0.52	Sandy loam	10.90	82.20	5.60	4.03	1.27	0.98	0.57	1.15	0.112	0.045	1.98
2C1	86-112	8.90	0.47	Sandy loam	10.20	78.60	5.62	4.02	1.24	1.11	0.75	1.19	0.091	0.041	1.52
2C2	112-190	8.10	0.46	Sandy loam	13.10	77.90	6.66	4.04	1.14	1.30	0.75	1.15	0.130	0.002	2.42
3C	19-240	8.80	0.44	Loamy sand	9.30	82.70	5.84	3.98	1.10	0.95	0.75	1.00	0.063	0.001	1.45
Pedon 16	**Typic Ustorthents**														
Ap	0-26	7.40	1.10	Sandy loam	10.31	82.60	3.99	3.87	3.20	1.20	0.36	1.38	0.12	0.004	1.58
C	26-58	8.15	0.56	Loamy sand	8.43	84.40	4.68	4.24	2.60	0.50	0.30	0.65	0.09	0.006	0.89
IIC2	58-192	8.35	0.50	Loamy sand	9.48	82.60	4.24	3.87	2.50	1.20	0.54	0.84	0.08	0.004	1.23
IIIC	192-220	8.20	0.41	Sand	6.35	84.80	3.87	3.80	2.14	1.00	0.67	0.78	0.07	0.002	0.75
Pedon 17	**Typic Ustorthents**														
Ap	0-16	7.30	0.75	Sandy loam	12.60	85.00	5.40	2.30	1.42	1.01	0.59	0.45	0.053	0.034	1.45
C	16-45	7.50	0.58	Sandy loam	11.50	81.00	6.90	2.35	1.35	0.96	0.63	0.37	0.035	0.025	1.45
2C	45-65	7.80	0.26	Sand	6.65	80.90	7.80	2.40	1.49	1.20	0.65	0.34	0.091	0.037	1.40
2C2	65-127	8.00	0.26	Sand	4.57	84.00	7.50	4.04	1.65	1.23	0.63	0.36	0.071	0.045	1.45
2C3	127-165	8.00	0.30	Sand	6.95	79.10	5.80	3.92	1.69	1.52	0.57	0.33	0.073	0.030	1.42

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Old alluvial plains														
Pedon 18	**Fluventic Haplustepts**													
Ap	0-17	8.30	0.71	Sandy loam	12.27	76.20	8.74	4.13	1.68	1.18	0.71	1.66	0.125	0.007	2.13
AB	17-28	8.60	0.44	Sandy clay loam	11.20	68.90	10.42	4.22	2.14	1.32	0.63	1.62	0.116	0.003	3.05
B21	28-50	8.80	0.39	Sandy clay loam	15.30	68.90	10.57	4.29	2.25	1.71	0.67	1.58	0.116	0.002	2.98
B22	50-82	9.20	0.40	Sandy clay loam	16.40	70.20	10.02	4.28	1.72	1.10	0.63	1.46	0.100	0.003	2.75
B23	82-121	9.20	0.55	Sandy clay loam	13.00	74.60	8.51	4.32	1.10	0.92	0.67	1.66	0.092	0.004	2.17
BC	121-134	9.30	0.29	Sandy loam	12.75	76.60	7.62	4.55	1.00	0.82	0.60	3.80	0.090	0.005	2.05
C	134-165	9.40	0.31	Sandy loam	12.30	82.60	5.82	3.87	1.00	0.80	0.48	0.87	0.120	0.006	1.28
2C	165-210	9.15	0.38	Sandy clay loam	16.23	84.50	4.72	4.17	1.20	0.85	0.51	1.34	0.140	0.005	1.12
Pedon 19	**Typic Haplustept**														
Ap	0-21	8.10	0.50	Sandy loam	6.20	82.60	4.09	3.91	1.21	0.40	0.75	1.07	0.05	0.003	1.12
B1	21-61	8.30	0.24	Sandy clay loam	9.10	80.60	4.62	4.11	1.41	0.50	0.78	1.26	0.05	0.001	1.32
B2	61-110	8.30	0.20	Sandy clay loam	12.07	80.90	4.66	3.96	1.36	0.42	0.60	0.90	0.03	0.008	1.42
BC	110-176	8.15	0.16	Sandy loam	6.90	82.80	4.86	4.05	0.96	0.37	0.71	1.15	0.06	0.002	1.24
Pedon 20	**Aquic Haplustept**														
Ap	0-21	7.10	0.38	Sandy loam	9.82	82.60	6.12	3.96	2.00	0.50	0.75	1.46	0.160	0.041	1.23
AB	21-41	8.00	0.29	Sandy loam	8.85	79.90	5.96	4.06	1.82	0.50	0.75	1.38	1.120	0.047	1.46
B21	41-72	8.30	0.24	Sandy clay loam	13.10	72.60	5.18	4.08	1.65	0.40	0.51	1.38	0.085	0.064	2.61
B22	72-164	8.30	0.26	Clay loam	17.00	70.60	6.26	3.98	2.54	0.86	0.63	1.20	0.075	0.064	2.96
Low lying old alluvial plains															
Pedon 21	**Aquic Ustorthent**														
Ap1	0-12	8.20	0.75	Clay loam	14.00	68.60	10.40	4.33	1.30	0.75	0.90	1.87	0.061	0.060	2.73
Ap2	12-20	8.30	0.61	Clay loam	16.40	69.70	11.40	4.35	1.24	0.75	0.90	1.87	0.092	0.064	2.65
C1	20-35	8.65	0.53	Sandy clay loam	11.42	72.20	8.60	4.29	1.20	0.60	0.90	2.00	0.052	0.057	2.42
C2	35-51	8.90	0.44	Sandy clay loam	9.92	73.80	9.60	4.18	1.00	0.50	1.00	1.79	0.050	0.048	2.42
2C1	51-124	8.80	0.49	Sandy clay loam	11.50	74.60	9.60	4.20	0.90	0.50	0.75	1.79	0.080	0.067	2.29
2C2	124-150	9.10	0.55	Sandy loam	11.40	78.80	10.10	4.31	1.20	0.50	0.86	1.79	0.050	0.062	2.17
Pedon 22	**Aquic Ustorthent**														
Ap	0-18	8.50	0.76	Sandy clay loam	11.62	72.50	10.20	4.21	1.64	0.80	0.70	1.50	0.062	0.045	2.10
AC	18-33	8.60	0.60	Sandy clay loam	10.50	72.80	10.20	4.23	1.72	0.78	0.90	1.50	0.062	0.045	2.10
2C	33-53	8.45	0.58	Sandy loam	9.72	74.20	9.80	4.21	1.53	0.31	0.86	1.70	0.051	0.041	1.93
3C1	53-80	8.75	0.51	Sandy clay loam	10.10	76.60	8.90	4.29	1.20	0.62	0.86	1.52	0.042	0.058	1.86
3C2	80-102	9.10	0.33	Sandy clay loam	9.80	72.40	10.20	4.23	1.60	0.64	0.82	1.60	0.030	0.061	2.10
3C3	102-180	9.20	0.23	Sandy clay loam	9.80	78.60	9.80	4.25	1.32	0.73	0.90	1.58	0.017	0.056	1.73
4C	180-250	9.10	0.31	Sandy loam	9.30	78.40	9.80	4.22	1.17	0.43	0.86	1.54	0.017	0.063	1.69

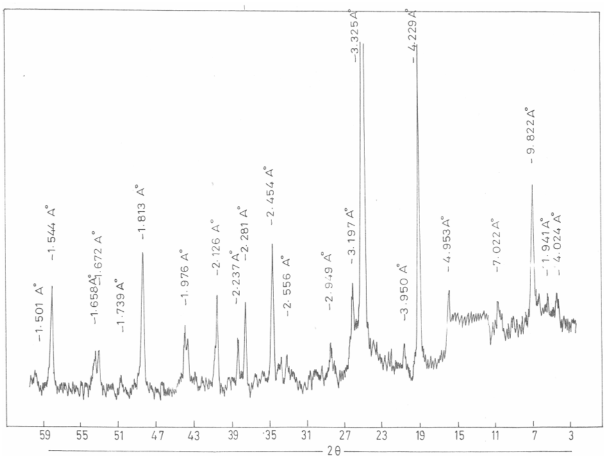

Fig. 1. *X-ray diffractograms of silt fraction (2μ) of pedon 2 Shiwalik Hill Top (Ap: 0-37).*

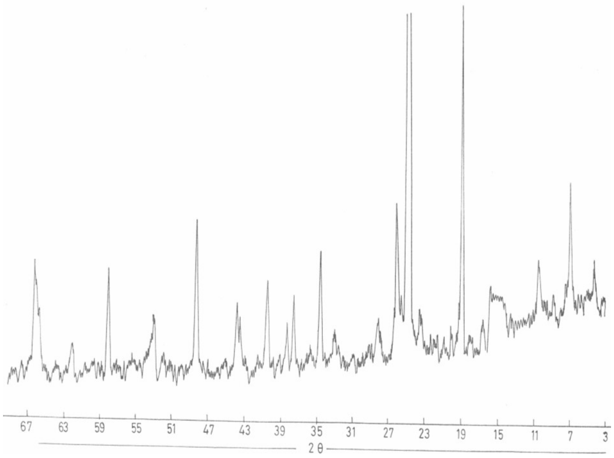

Fig. 2. *X-ray diffractograms of silt fraction (2μ) of pedon 8 Shiwalik Hill Valley (Ap: 0-17).*

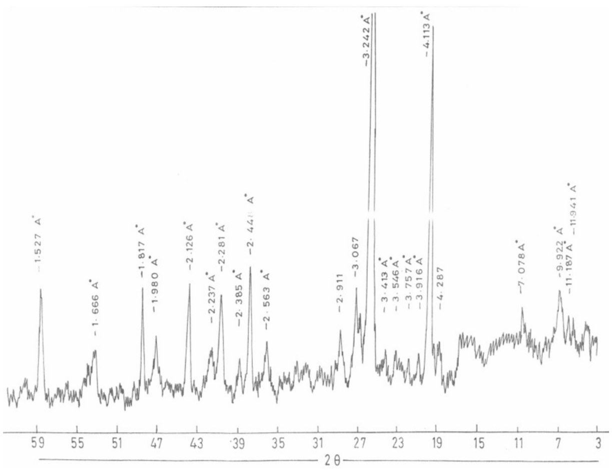

Fig. 3. *X-ray diffractograms of silt fraction (2μ) of pedon 15 Active Flood Plain (Ghaggar) (Ap: 0-26).*

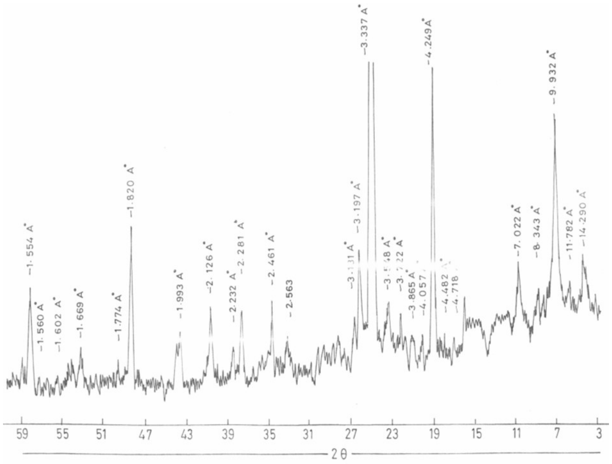

Fig. 4. *X-ray diffractograms of silt fraction (2μ) of pedon 18 Old Alluvial Plain (Ghaggar) (Ap: 0-17).*

maximum rainfall occurs during monsoon i.e., July to September. The soil moisture regime is ustic and udic and soil temperature regime is hyperthermic. The soil of Shiwalik hill (top and valley) and recent flood plains of Ghaggar were Typic Udorthents/ Udipsamments and soils of old alluvial plains of Ghaggar were Typic Haplustepts (Soil Survey Staff, 2006). Topographic maps of India (1:50,000) were used to identify sites for profile excavation and soil augering. On the basis of geomorphic-soil relationship established in the area, 22 representative pedons were exposed and studied in the field. These pedons also form a toposequence, a transect covering from Shiwalik hills to lower alluvial plains. The 22 profiles were selected during an inventory of the characteristics and variability of the different soil types. The soils chosen were assumed to be representative of the area. Sampling of each pedon was done by pedological horizon; 2-3kg of soil was collected per horizon. A total of 120 samples were collected, air-dried, ground using wooden pestle and mortar and passed through a 2mm sieve. Soil samples were analysed for pH, electrical conductivity (EC_e) cation exchange capacity (CEC) and texture using standard procedures (Soil Conservation Service, 1972). Based on physico-chemical characteristics, 10 soil samples representing different soil horizons were selected for detailed mineralogical analysis. The mineralogical composition of soils was determined by X-ray diffraction analysis (XRD). The XRD analysis was conducted on the clay fraction isolated from soils that were pre-treated with H_2O_2. For removal of soil organic matter 10g of 2mm air dried sample was weighed into a 1000ml beaker and treated with 30 % H_2O_2 until effervescence ceases followed by heating to about 90°C to remove excess H_2O_2. The sample was washed with distilled water before transferring into a 250ml centrifuge tube. The soil was dispersed by Na_2CO_3 and the clay fraction was isolated by sedimentation. The following treated slides were scanned: Mg-saturated, Mg-saturated and glycerol solvated, K-saturated, K-saturated and heated, HCl treated Mg-saturated and HCl treated and then Mg saturated-glycerol solvated clays were prepared as oriented specimen and mounted on glass slides, analysed on

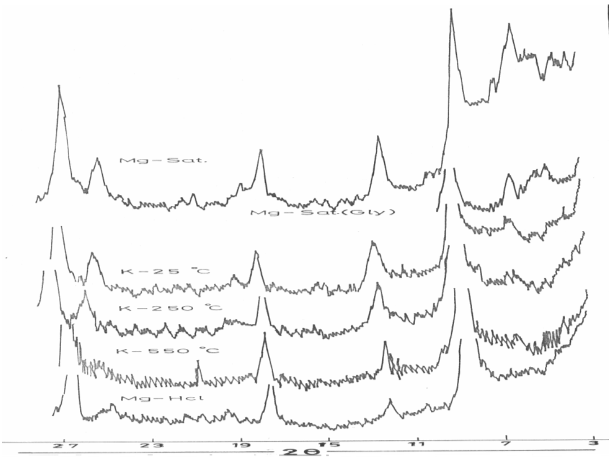

Fig. 5. *X-ray diffractograms of clay fraction (2μ) of pedon 2 of Shiwalik hills Top (A_1: 0-37).*

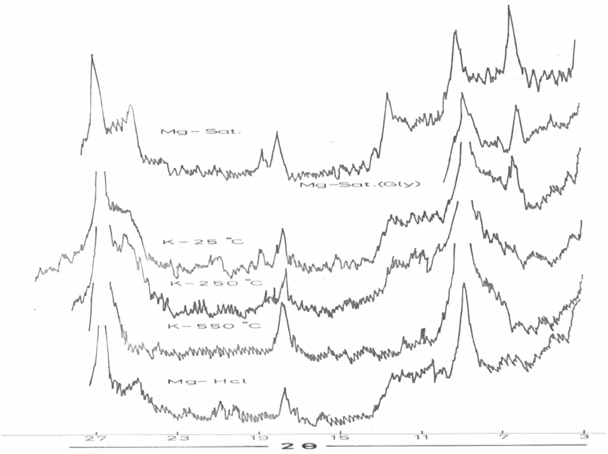

Fig. 6. *X-ray diffractograms of clay fraction (2μ) of pedon 2 of Shiwalik hills Top (II_c: 152-200).*

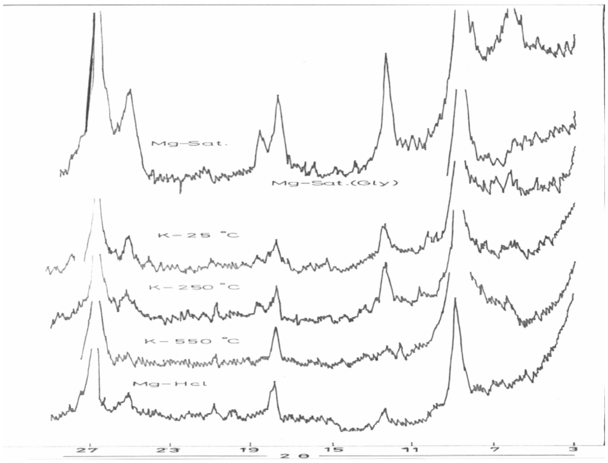

Fig. 7. *X-ray diffractograms of clay fraction (2μ) of pedon 5 of Shiwalik hills valley (A_1: 0-23).*

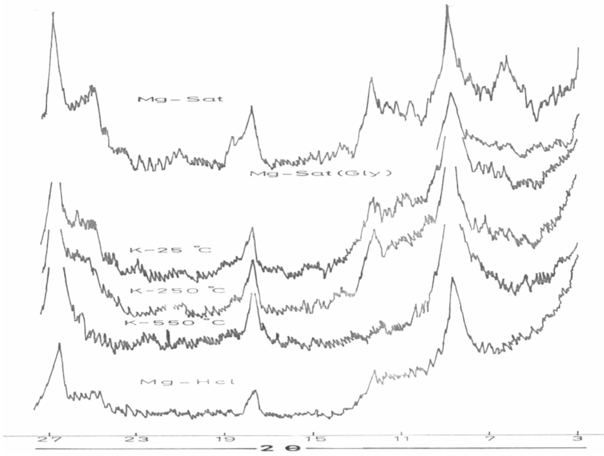

Fig. 8. *X-ray diffractograms of clay fraction (2μ) of pedon 5 of Shiwalik hills valley (C: 53-106).*

Philips PW 1390 X-ray diffractometer using Ni-filtered CuKα-radiation target and operated at 30KV and 20mA. Semi-quantitative estimates were prepared on the basis of relative peak area ratio after necessary correction for background (Gjems, 1967; Ghosh and Dutta, 1974; Karanthansis and Hajek, 1982). The total oxide concentrations in the soil samples were obtained by X-ray fluorescence spectrometry using glass beads method.

RESULTS AND DISCUSSION

The general site characteristics of the soils developed on four major geomorphic units of north-eastern Haryana viz., Shiwalik hills, piedmont plains, flood plains and old alluvial plains are given in Table 1. The soils had various parent materials and the land forms were flaty to gently undulating. The horizonation of different profiles is shown in table 3. The land use, by and large, included chir pines, bamboo, shisham, mulberry etc (forests) and wheat, mustard, barley, paddy etc.

Physico-chemical properties: The texture of different geomorphic units is shown in Table 2. In each location, soils mostly had quite different textures. At some locations individual soil profiles had very different textures relative to other profiles at that location. Some profiles showed a systematically increasing clay percentage with depth (pedon 7) that could be attributed to pedogenesis (illuviation) but could also reflect the presence of sedimentary layers deposited under a regime where transport conditions become more energetic over time (Wongpokhom *et al*. 2008).

The results reveal that the soils in terms of chemical reaction varied from slightly acidic to strongly alkaline. There was a substantial variation in pH in different locations. According to pH classes, described by Soil Survey Staff (2006), the soils of pedon 1 (Shiwalik hills-top), pedons 7, 8 and 9 (valleys), pedons 10, 11 and 12 (upper piedmont plains) were slightly acidic to neutral (6-7.35) in reaction which may be due to high rainfall and more vegetation in the area. The soils of pedon 3 and 4 (Shiwalik hill-slope), pedons 5 and 6 (valleys), pedon 14 (lower piedmont plains), pedons 16 and 17 (flood plains) and pedon 20 (old alluvial plain) were moderately alkaline (7.8 to

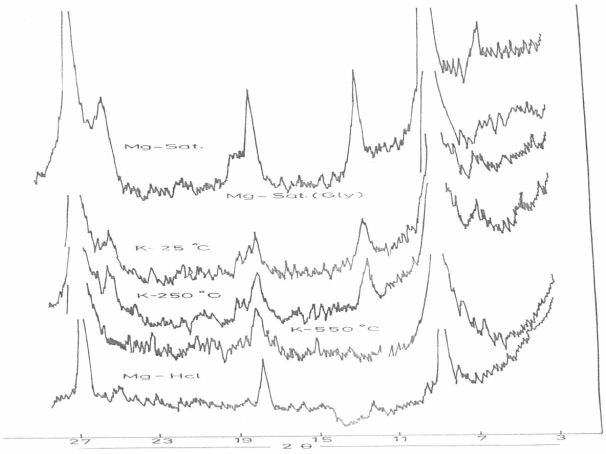

Fig. 9. *X-ray diffractograms of clay fraction (2μ) of pedon 8 of Shiwalik hills valley (Ap: 0-6).*

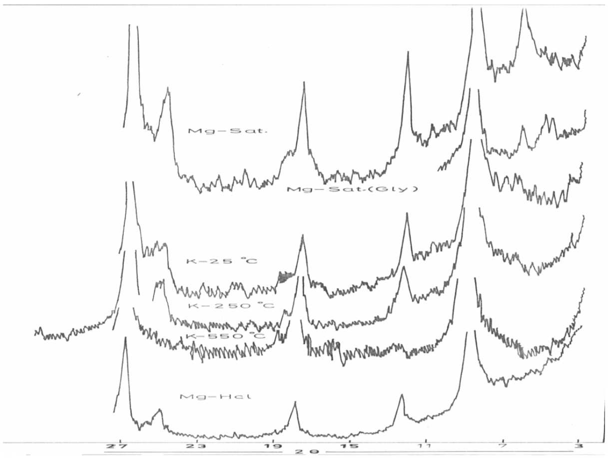

Fig. 10. *X-ray diffractograms of clay fraction (2μ) of pedon 8 of Shiwalik hills valley (C: 31-48).*

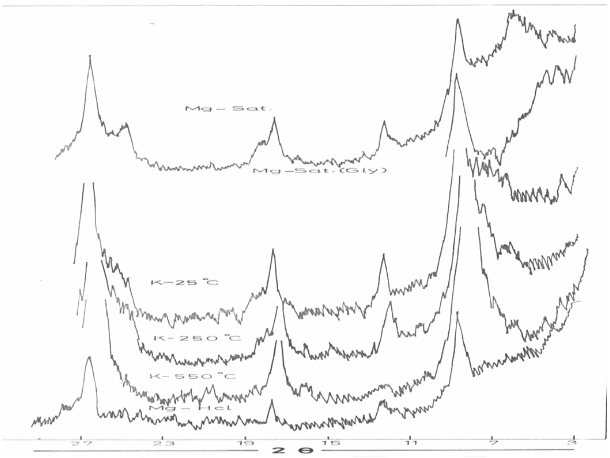

Fig. 11. *X-ray diffractograms of clay fraction (2μ) of pedon 15 Active Flood Plain (Ghaggar) (Ap: 0-26).*

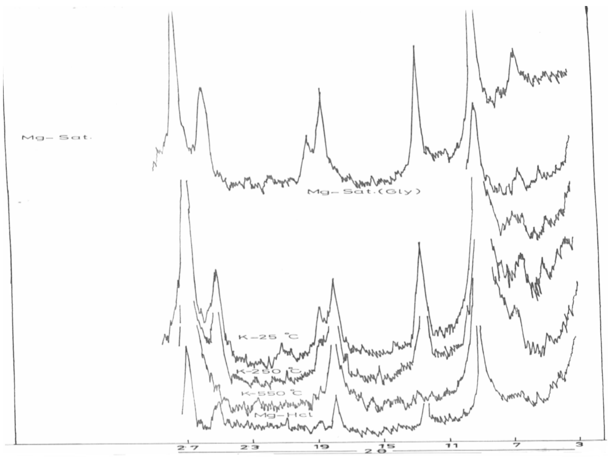

Fig. 12. *X-ray diffractograms of clay fraction (2μ) of pedon 15 Active Flood Plain (Ghaggar) (II_{C1}: 86-112).*

8.3) in reaction whereas pedons 2, 15, 18, 19, 21 and 22 were strongly alkaline (8.3 to 9.4) in reaction. There was an increase in pH with depth in all pedons except 9 and 14 which might be attributed to the loss of bases from the surface. The increase in pH in deeper horizons was also reported by Kaistha and Gupta (1993) in the soils of the north-west Himalayan region. The cation exchange capacity was found to be less (3.10 to 12.02 cmol (p^+) kg^{-1}) in pedons 1 and 8 (Shiwalik hills), pedons 10, 11, 12, 13 and 14 (piedmont plains) compared to pedons 2, 3 and 4 (Shiwalik hills), pedons 5, 6 and 7 (valleys), pedons 15 and 17 (flood plains) and pedons 18, 19, 20, 21 and 22 of old alluvial plains having (9.61 to 17 cmol (p^+) kg^{-1}). The low cation exchange capacity of these soils is due to dominance of illite and other low charge minerals and low organic matter content (Sharma *et al*., 2011). Lower horizons of pedon 4 had highest cation exchange capacity (22.20 to 26.80 cmol (p^+) kg^{-1}). The higher CEC in pedons 3, 4, 7, 15, 18 and 21 may be related to variation in content and nature of organic carbon and inorganic colloids (Sireesha and Naidu, 2015). Sawhney *et al*. (1996) evinced that the wide variation in CEC among different landscapes of Shiwalik hills of Punjab may be assigned to difference in clay content and stratified and young nature of materials. Sharma *et al.* (1997) reported that substantially wide variation of CEC (2.8-32.8 cmol (p^+) kg^{-1}) in Inceptisols of north-west India.

The electrical conductivity (EC) of saturation extract revealed that soils of all geomorphic units were non-saline in nature (0.16 to 1.20 dSm^{-1}). The EC of flood plains (pedons 15, 16, 17), old alluvial plains (pedons 18, 19, 20) and low lying alluvial plains (pedon 21, 22) was found to decrease with depth. The soils of Shiwalik hills (top and slope; pedons 1, 2, 3,4) valleys (pedons 5, 6, 7, 8, 9) and piedmont plains (pedons 10, 11, 12, 13, 14) showed more electrical conductivity in subsurface horizons which might be due to high and erratic rainfall.

The chemical composition of soils observed to have been influenced not only by parent material but also to extent by pedo-environment including microclimate and geomorphology. In general, the soils were siliceous in nature with SiO_2 ranging from 68.60 to 87.90 percent. The soils of Shiwalik hills (top and slope) and

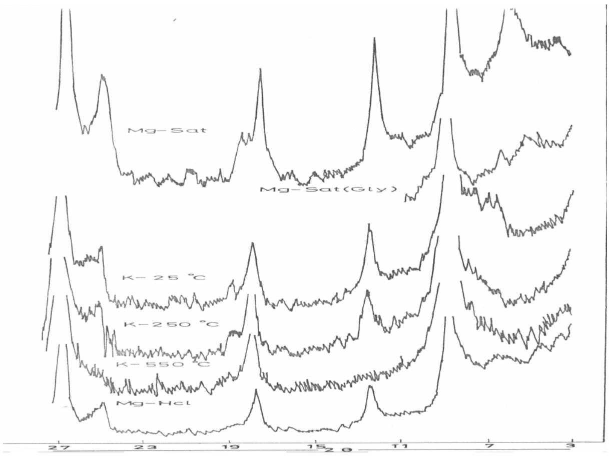

Fig. 13. *X-ray diffractograms of clay fraction (2μ) of pedon 18 Old Alluvial Plain (Ghaggar) (Ap: 0-17).*

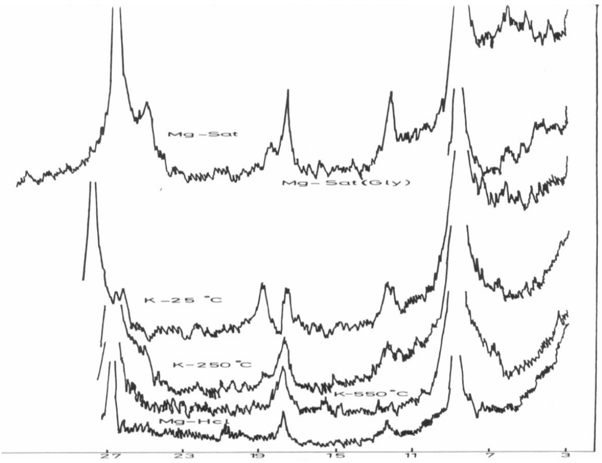

Fig. 14. *X-ray diffractograms of clay fraction (2μ) of pedon 18 Old Alluvial Plain (Ghaggar) (AB: 20-50).*

valleys were having more SiO_2 (72.2 to 87.9 %) than old alluvial plains and low lying alluvial plains (68.8 to 78.8 %). This may be due to higher amount of quartz in parent material (Ahuja, 1981; Khan *et al*., 1997). Sireesha and Naidu (2015) reported that the values of SiO_2 and Al_2O_3 reflect the presence of appreciable amount of 2:1 type of clay minerals. Walia and Rao (1997) reported that SiO_2 varied from 59.7-76.8 % which may be attributed to the nature and source of alluvium in Trans-Yamuna plains. In pedons 1, 3, 7, 8 and 9 of Shiwalik hills, SiO_2 increased with depth or exhibited no particular pattern which may be attributed to sediment deposition. The SiO_2 in the horizons of flood plains (pedons 15, 17) and low lying alluvial plains (pedon 21) exhibited the decreasing pattern with depth which may be ascribed to deposition of finer alluvium in lower horizons. Aluminium and iron were important constituents of soils at all locations. The amount of Al_2O_3 and Fe_2O_3 varied from 2.2 to 14.7 percent and 0.49 to 4.55 percent, respectively and showed that the amount of Al_2O_3 increased with depth indicating the weathering of aluminosilicates and ferromagnesium minerals at the surface and then by leaching the B-horizons were enriched. Walia and Rao (1997) reported that increase in Fe_2O_3 content with depth suggests more iron bearing minerals in subsurface horizons. Yadav (1999) ascertained that Al_2O_3 and Fe_2O_3 varied from 4.8-18.1 and 1.35-8.49 %, respectively in major landforms of Haryana. The amount of CaO and MgO varied from 0.68 to 3.83 and 0.31 to 1.71 percent, respectively. The irregular distribution of CaO and MgO showed the lithological discontinuity (pedons 2, 5, 8, 17, 18, 20, 22). The presence of CaO and MgO infer the occurrence of minerals rich in calcium and magnesium (Sireesha and Naidu, 2015). Sodium oxide (Na_2O) and K_2O were present in low amount, i.e, 0.26 to 1.87 and 0.50 to 3.80 percent, respectively. The presence of Na_2O and K_2O showed the weathering of sodium and potassium in feldspar minerals. Raina *et al* (2006) reported that K_2O in all pedons indicates the presence of K bearing clay minerals i.e. micas and feldspars (Khan *et al*., 1997). The vertical distribution pattern of the above oxides within the profiles showed variation which indicated that pedochemical weathering processes were not intense enough to bring about any change in the distribution pattern of the silicate minerals containing these elements.

Mineralogical properties

Fine sand: The kind of the fine sand minerals and their order of abundance are presented in table 1. The mineralogical properties of fine sand fraction revealed that quartz was dominant mineral followed by orthoclase-feldspars, muscovite, hornblende, tourmaline, zircon, biotite, iron ores and sphene. Heavy minerals were found more in subsurface horizons compared to light minerals in these areas. Mineralogical composition on Shiwalik hills, piedmont plains showed the advanced stage of weathering compared to flood plains and old alluvial plains. Ahuja *et al*. (1984) ascertained that the distribution of minerals and low degree of pedogenic development was mainly due to the influence of preservation of sediment sequences with less time and lower intensity of weathering in Ghaggar river basin of Haryana and Punjab. Gupta *et al*. (2009) described that quartz, feldspar and muscovite-mica were the main minerals in the light sand fraction and opaque type of minerals like zircon, tourmaline, augite, hornblende and biotite in heavy fractions of sand.

Silt mineralogy: The silt mineralogy was almost similar to clay mineralogy with additional amount of feldspars. However, the distribution pattern of minerals in silt was reverse to that of clay. Quartz was the dominant mineral followed by mica except active flood plain (Ghaggar) where feldspar was the second most dominant mineral. On the contrary, mica content was relatively higher in silt fraction because it tends to concentrate in the finer fraction during the course of weathering (Sharma *et al*., 2011). Moreover, in silt fraction, feldspars were represented by both K- and Na -feldspars (albite). The relatively lower amount of feldspars in silt fraction compared to sand fraction may be due to the fact that the former has undergone more intense weathering due to increased fineness of the particles compared with later (Brindley and Brown, 1980; Sidhu, 1982; Sharma *et al*., 2011). Besides, small amounts of chlorite, kaolinite, interstratified and traces of smectite and vermiculite were observed. Although abundance of quartz was highest in silt fraction, its content was comparatively lower in sand fraction. Likewise, earlier investigations reported decrease in quartz content with reduction with particle size (Sidhu and Gilkes, 1977; Jassal *et al*., 2000). The diffractograms of silt fraction of pedons 2, 8, 15 and 18 are presented in figures 1, 2, 3 and 4, respectively.

Clay mineralogy: The semi-quantitative evaluation of the clay fraction is shown in table1 revealed that illite was the single dominant clay mineral in all the soils under study which may be ascribed to the dominance of micaceous rocks in the parent material (Sharma *et al*., 2011). However, its quantity was less in the old alluvial plain (Ghaggar) 28.39 % compared to Shiwalik hills (36-49 %). The strong and sharp maxima at 10 A˚ with its submultiple at 5 and 3.33 A˚ in potassium as well as magnesium saturated clays which remained unaffected on glycolation (Mg clay) and heating upto 550 □ (K clay) confirmed its presence. The strong and sharp XRD peaks indicate that illite standard was highly crystalline. The 10˚A reflections were slightly asymmetrical towards low 2θ angles particularly in clays of Ghaggar flood plain soils. This might be due to the replacement of interlayer potassium by hydrated cations leading to transformation into smectite and vermiculite group of minerals (Shanwal and Ghosh, 1987; Dutta, 2000).

Next to illite, a high amount of smectite (14-20 %) and vermiculite (11-17 %) were observed in clays of Ghaggar flood plain. However, these minerals were also detected in Shiwalik hills but in small amount (6-17 %). Shifting of 14˚ A peaks to ≈ 18 A˚ on glycolation of Mg-clay and reduction of 14˚ A peak in K clay on heating confirmed the presence of smectite and vermiculite, respectively. The presence of smectite in the soil could be attributed to alkaline soil pH condition and high exchangeable Ca and Mg that allows the neoformation of smectite in the soil (Duchaufour, 1998; Navarrete *et al*., 2011). Fairly good amount of kaolinite (10-17 %) and small amount (4-11 %) chlorite were uniformly distributed in soil clays irrespective of geomorphic units showing their detrital origin (Shanwal and Ghosh, 1987). Their presence was confirmed by disappearance of 7.2˚ A and persistence of 14˚ A peaks in K-clays on heating upto 550 □ . Since the soils are relatively young, kaolinite seems of pedogenic origin rather than inherited from parent materials. The possible sources of pedogenic kaolinite are the weathering of vermiculite, chlorite and smectite (Navarrete *et al*., 2011).

Medium intensity broad peaks in higher range of diffractograms (14-24˚ A) indicated the presence of regular and irregular interstratified minerals. The fairly good amount of interstratified minerals (9-15 %) in old alluvial plain (Ghaggar) supported the above mentioned hypothesis of potassium removal and illite weathering. A small amount of quartz was also observed in all the clay samples. However, feldspar was almost absent except negligible amount (<5 %) in one sample of Shiwalik valley clays. Therefore, mineralogical composition of clay is a function of weathering reaction during the process of soil development controlled by pedogenic features. By and large, the distribution of clay minerals is expected to bear close relation with climate and parent material. The diffractograms of clay fraction of pedons 2, 5, 8, 15 and 18 are presented in figures 5, 6; 7, 8; 9, 10; 11, 12 and 13 and 14, respectively.

Conclusion

The soils have mixed mineralogy showing presence of quartz, mica and feldspars in sand and silt fractions and illite, smectite, vermiculite, kaolinite, chlorite and interstratified minerals in clay fraction. A fairly good amount of interstratified minerals in old alluvial plain supported the hypothesis of potassium removal and illite weathering. Study of mineralogy of such important soils helped us in understanding the potential nutrient reserves in the soil, degree of weathering and knowledge about soil development. The distribution of clay minerals in soils is expected to bear a close relationship with climate and zonal distribution. Since soil minerals primarily control the physical and chemical properties of soils particularly those minerals present in clay fraction, therefore, the study of mineralogy is imperative for understanding the nature of soils. The characteristics of the soils showed the considerable heterogeneity in profile, pH, electrical conductivity and soil mineralogy irrespective of geomorphic units.

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