Relation of Parent Material and Environment to the Clay Minerals of Some Indian Soils of Arid Tropical Zone

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The object of the investigation is to find out the relation, that may exist between the occurrence of a particular clay mineral formed under a specific climatic influence, and the weatherable rock-forming minerals of the coarser separates of the soil. Not much work on this aspect with Indian soils has been done. DAS et al. [6] for the first time and DAS [7] latter examined the mineralogical composition of a number of Indian soils under different climatic conditions of occurrences and valuable informations were obtained regarding the ionic environment of the weathering zones and the secondary minerals in clay fractions. Investigation undertaken here pays particular attention to the rock-derived minerals in sand and silt in order to understand the specific role the weatherable minerals in them may play in creating and maintaining the ionic environment through liberation of alkali and alkaline earth cations, leading to the formation of different species of clay minerals in the soil under different set of weathering conditions.

The present paper deals with the soil occurring on arid tropical regions, namely alluvium-derived desert, alluvial and black soil from Churu, Ludhiana and Annegeri, respectively. Soils of humid and perhumid tropics have been included in latter studies. However, for convenience, climatic zone (HOSKING [13]), geography (Table 1.), profile characteristics (Table 2.), geology and also the sand mineralogy and deduction of nature and composition of parent material (Results Part I). therefrom, have been dealt in this paper taking all the soils together.

Material and method

From each experimental soil profiles, samples from three dephts, irrespective of horizon, are taken.

Geology

Churu: Within a radius of 60 miles the area is alluvium-pleistocene and Recent (ROY [24]). To the south-east about 50 miles from Churu around Singhana and Khetri are rocks belonging to Delhi system (mainly sandstones, quartzitic, shale partly or completely metamorphosed). In the same direction around Jhun Jhnu, there are small exposures of Malani rhyolites (HERON [12]).

Ludhiana: Ludhiana is situated near the Himalayan foothill on the Indus alluvium. This alluvium is formed concomitantly with the elevation

Table 1

Geography and climatic data (Chatterjee [4]) of the soils

Sample point	Sample location			Soil group	Climatic zone	Meyer's N.S.Quotient	Annual value	
	Latitude	Longitude	Height above m. s. l. ft.				No. of rainy days	Normal rainfall in inches
Churu, Rajasthan	28°15′—28° 20′ N	74° 55′—75° E	—	Alluvium-derived desert	Arid desert	20—25	14	11,79
Ludhiana, Punjab	30° 56′ N	75° 52′ E	812	Indus alluvium	Arid	40—50	29	24,73
Annegeri, Dharwar, Mysore	15° 48′ N	75° 18′ E	2069	Medium black	Semiarid	100—125	54	27,63
Manchkund, Koraput, Orissa *Padwa*, Koraput, Orissa	18° 32′ 35″— —18° 42′ 47″ N 18° 23′ 15″— —18° 23′ 20″ N	82° 33′ 40″— 82° 33′ 45″ E 82° 40′ 30″— —82° 40′ 50″ E	—	Red ferruginous	Semihumid to humid	250	85,3	60,48
Pasighat, Siang, N. E. F. A.	28° 4′ N	95° 21′ E	—	Dihang flat alluvium	Humid to perhumid	1000	134	143,82
Cherrapunji, K. and J. Hills, Assam.	25° 15′ N	91° 44′ E	4309	Highly weathered old alluvium	Highly perhumid	4000	136	425,2

Table 2

Characteristic soil feature data (air dry basis)

Sampling sites and depth, inches	105° moisture %	$CaCO_3$ %	Organic matter %	Mechanical composition in %				C/N ratio	pH (H_2O)
				clay	silt	fine sand	coarse sand		
Churu									
0—5	1,43	0,17	0,19	10,10	3,70	75,73	8,68	4,4	7,7
21—49	0,80	0,04	0,16	11,80	4,75	75,27	7,18	3,5	8,1
Ludhiana									
0—6	0,88	0,09	0,22	11,70	10,70	37,35	39,07	4,4	8,0
12—24	2,40	0,04	0,23	22,55	14,55	31,39	28,83	3,2	7,5
48—72	0,93	10,19	0,08	8,35	8,00	21,63	50,82	1,7	7,9
Annegeri									
0—6	10,82	Nil	0,42	57,65	15,05	7,65	8,41	6,3	7,6
12—24	11,63	Nil	0,47	56,65	14,85	8,61	7,74	9,5	7,9
48—72	10,67	6,13	0,31	55,45	14,30	8,65	4,48	10,2	8,8
Manchkund									
0—6	2,97	Nil	1,89	37,80	27,00	16,70	13,38	9,8	6,4
6—24	3,21	Nil	1,15	44,50	27,45	13,83	9,87	7,0	6,0
24—48	4,47	Nil	0,46	58,30	19,70	11,22	5,86	4,0	5,6
Padwa									
0—6	2,49	Nil	1,41	42,90	14,60	18,80	19,79	8,4	6,0
12—48	3,85	Nil	0,77	62,80	10,85	3,94	17,79	8,3	5,2
Pasighat									
0—7	2,75	Nil	1,75	26,05	42,74	22,61	4,09	7,5	6,2
7—29	2,92	Nil	0,70	24,20	41,75	26,48	3,95	4,5	5,9
29—50	2,70	Nil	0,72	26,90	37,50	27,79	4,39	6,3	5,9
50+	5,54	Nil	0,66	28,25	28,85	32,77	3,93	6,8	5,8
Cerrapunji									
0—6	9,53	Nil	2,84	31,35	23,95	26,38	5,95	9,3	4,4
12—24	4,35	Nil	0,34	35,88	27,23	19,97	12,24	3,1	4,8
48—72	4,71	Nil	0,35	38,15	25,55	20,67	10,57	4,1	4,6

and gradual weathering of the Himalayas, the geological formation of which ranges from Archaean to Tertiary (Siwalik) with a great variety of rock types (KRISHNAN [17]).

Annegeri: Archaean rocks (gneisses and schists) constitute the formation of the area (KRISHNAN [17]). The main rock types are:

a) *Dharwar schists and gneisses.* It is the ancient sediment now highly metamorphosed to schists and intruded repeatedly by granites and granitic gneisses.

b) *Peninsular gneisses.* It is the mixture of different types of granitic rocks with inclusions of hornblendic rocks. The rocks are metamorphosed (gneissic) and entered into the Dharwar schists as intrusives.

Manchkund and Padwa: The ancient country rock is mainly ferruginous-schists (KRISHNAN [17]) containing much haematite and limonite and bands of garnet-magnetite rocks. The country rocks are intervened in monotonous repetition by alternating bands of a host of well-developed Archaean rocks of

Eastern Ghats. The principal groups are garnet-sillimanite-schists and gneisses (Khondalite series), Charnockites series, calc-gneisses and gneissose-granites.

Pasighat: The Dihang river, which flows from north to south across the Abor hills and descends to the alluvial plain near Pasighat, has built up the alluvial deposit around Pasighat. The river on its southward journey across the hills towards Pasighat traverses the following geological formation (COGGINBROWN [5]), namely:

1. Abor volcanic rocks — composed of basalt (augite, magnetite, calcic felspar)
2. Gondwana rocks — composed of quartzite, shales (quartz, felspar, mica), sandstones.
3. Metamorphic rocks — composed of slates, micaceous phyllite, dolomitic rocks, quartzite, mica-schist.
4. Pleistocene and Siwalik rocks.

Cherrapunji: In Cherra plateau, the rock immediately underneath the soil is Sylhet limestone of Tertiary (Eocone). Immediately underneath the limestone is Cherra sandstones of Tertiary. Beneath the Sylhet limestones and Cherra sandstone there are some sediments of sandstones limestones and a lava flow (basalt, Sylhet trap). The succession of rocks with Sylhet limestone at the top and basalt at the bottom are underlain by Archaean core rocks (GHOSH [9]) represented by hornblende biotite-gneisses, quartz-biotite-sillimanite rocks, mica-schists (with garnet), chlorite-schists and hornblende-schists.

Samples for X-ray and D.T.A.

Clay fractions ($<2\ \mu$) obtained by the international method were freed of organic matter and converted into H-clay by treatment with N/20 HCl.

Coarse silt ($20-50\ \mu$) separated from sand by wet-sieving and repeated decantation (JACKSON [14]) were cleansed of free oxides following the procedure laid down by AGUILERA and JACKSON [2].

The entire clay ($<2\ \mu$ size) and coarse silt were subjected to X-ray using nickel filtered Cu K_α radiation and Phillip's large Debye–Scherrer powder camera.

Differential thermal diagrams of organic matter free clay in the H-form were obtained with the help of a manually operated D.T.A. apparatus.

Surface area

Total and external surfaces of clay fractions free of "free oxides" were determined following the procedure recommended by DYAL and HENDRICKS [8].

Y-value of soil clays was calculated according the formula given by MARTIN and RUSSEL [20].

Cation exchange capacity of soil and soil clay was determined by the ammonium acetate method and distillation as given by PEECH et al. [23]. The exchangeable Ca and Mg were determined by versenate titration, Na and K determined photometrically.

Determinations of other chemical constituents of soils and of soil clays were done in their usual and conventional ways.

Fine Sand (50—100 μ)

The separation of heavy (>2,9) and light (<2,9) fractions was done by the bromoformtribromomethane method of KRUMBEIN and PETTIJOHN [18]. Standard petrographic procedure as outlined by WINCHELL [28] were followed.

Results — Part I

Petrographic study

Detailed mineralogical composition of the heavy and light fractions is illustrated in Table 3 and 4, respectively. The summarised account of provenance (MILNER [21]) is presented in Table 5.

Deduction of the nature and composition of parent material: A qualitative estimation as to tne above is done from the study of provenance and supplemented with local geological information. In alluvial soil where any definite geological information is lacking, the probable nature and composition of the source rock (which supplied the alluvial material) is deduced by comparing the rock types as assessed from the provenance with those of the rock outcrop nearby.

Churu: The study of mineral association in table 5 brings out that the alluvial parent material of this soil consists of components derived mainly from acid igneous rock and a rock related to metamorphosed mafics (amphibolite type).

The rock fragments (Table 4) identified are mainly of fine grained quartzitic and some are of volcanic rocks. The former comprises one of the important rock types of Delhi system (refer geol. description) and the latter may be looked upon as being derived from rhyolite (volcanic granite); the small exposure of Malani rhyolite a few miles south-east of this place might be the source. This furthermore suggests that the extensive alluvium around Churu is partly supplied by the materials transported from the rock outcrops nearby. The dominance of angular minerals in both the fractions also indicates that the material is transported only through a short distance.

Ludhiana: Table 5 shows that the parent material of this alluvial soil consists dominantly of materials derived from granitic and metamorphic rocks (mainly mica-schists and some basic metamorphic rocks). Since the sample point lies within the extensive alluvium area (refer geol.), the parent material is expected to be of transported origin, which is here corroborated by the presence of a varied assemblage of rock types as indicated in the provenance.

Frequent well developed crystal outline of zircon and tourmaline also suggests that the parent material has not been transported through long distance. Apparently, the source areas of the parent materials lay in the sub-Himalayan region north of the locality.

Annegeri: Inherited heavy minerals and their association indicate the occurrence of a mixed assemblage of metamorphic rocks with granites in the underlying parent material of this soil. This is in accordance with the rock types of the area (cf. geol. description). Study therefore confirms that the parent materials of the soil are of residual origin.

Manchkund and Padwa: Provenance study discloses that the parent material of these soils is a material predominantly derived from acid igneous

Table 3

Mineral composition of heavy fractions (frequency of mineral in percent)

Sampling sites and depth, inches	Opaques	Tourmaline	Epidotes	Zircon	Garnet	Amphibole gr	Biotite	Chlorites	Rutile	Kyanite	Hydro-mica	Sillimanite
Churu												
0—5	21,5	28,5	17,3	13,6	9,8	7,0	1,4	0,9	—	tr.	—	—
21—49	17,2	27,8	9,7	17,6	12,5	9,9	3,7	0,9	—	tr.	—	—
Ludhiana												
0—6	12,2	23,4	8,2	3,0	8,6	1,7	39,1	2,3	—	1,5	—	—
48—72	11,4	18,2	6,4	7,5	3,6	6,1	45,4	0,7	—	0,7	—	—
Annegeri*												
0—6	++++	—	+++	+	—	—	tr.	—	—	—	—	—
48—72	++++	tr.	++++	+	—	+	—	—	+	—	—	—
Manchkund												
0—6	77,4	—	—	16,3	0,7	0,7	—	—	1,0	0,3	3,7	—
24—48	82,9	—	0,3	14,6	—	0,8	—	—	0,8	0,5	—	—
Padwa												
0—6	91,4	0,4	—	4,3	0,4	—	—	0,4	1,5	—	1,1	—
12—48	84,7	0,3	—	4,4	2,5	0,3	—	—	5,0	—	1,9	—
Pasighat												
0—7	35,2	6,4	20,8	11,9	5,0	12,9	—	5,9	—	2,0	—	—
50+	36,0	1,6	20,0	15,6	4,0	7,2	1,2	13,2	—	1,2	—	—
Cherrapunji												
0—6	50,8	8,7	0,5	22,2	1,6	3,2	1,6	9,7	—	—	—	1,1
48—72	61,8	3,4	2,1	20,1	2,1	8,2	—	2,1	0,3	—	—	—

* Quantitative estimation was not possible as the volume of grains obtained was too small for modal analysis.
+ relative abundance,
tr. = trace

Remarks

Churu: 1. Tourmaline predominant. 2. Opaques mainly ilmenite few magnetite, rarely limonite. 3. Amphiboles essentially hornblendic.

Ludhiana: 1. Biotite predominant. 2. Amongst opaques, magnetite abundant, some ilmenite. 3. Amphiboles mainly represented by hornblende.

Annegeri: 1. Opaques mostly magnetite 2. Epidotes dominant amongst non-opaques. 3. Amphiboles chiefly hornblendic.

Manchkund & Padwa: 1. Limonite predominant in opaques-constituting 22,6—30,2% of the total heavy suite in (0—6) and (24—48″) samples of Manchkund and 30,6—37,7% in (0—6) and (12—48″) layers of Padwa. Other opaques being magnetite, ilmenite and haematite. 2. Zircon predominant in non-opaques. 3. Amphiboles mainly tremolitic.

Pasighat: 1. Epidotes predominant in non-opaques. 2. Opaques chiefly ilmenite and magnetite. 3. Amphiboles mostly hornblendic (0—7″) and actinolite with tremolite and hornblende in (50+″) layer.

Cherrapunji: 1. Opaques mainly ilmenite, some limonite. 2. Zircon predominant amongst non-opaques 3. Amphiboles chiefly tremolitic.

Table 4

Mineral composition of light fractions (Frequency of mineral in percent)

Sampling sites and depth in inches	Quartz	Felspars				Muscovite	Rock fragments	Composition
		Plagioclase	Variety and alteration*	K-felspar	Variety and alteration*			
Churu								
0— 5	62.4	23,9	mainly oligoclase with some albite, former moderately altered, latter fresh	4.8	microcline-perthite, slightly altered	—	8,9	fine grained quartzitic and volcanic
21—49	57,5	19.2	mostly andesine to labradorite, slightly altered	7,7	var. same; fresh	1,1	14,5	
Ludhiana								
0— 6	50.8	14,7	Moderately altered, no exact member could be identified	12,3	microcline slightly perthitic, alteration very slight	18.3	3,9	fine grained schistose rock with micaceous mineral; quartzitic
48—72	50.8	18,3	mostly oligoclase to andesine; fresh, slight to moderately altered	7.3	do	19.1	—	
Annegeri								
0— 6	81.4	9.2	mainly oligoclase, andesine being next in abundance; slightly altered	6.7	microcline-perthite, fresh	2,7	—	
48—72	83.0	5.7	var. same; highly altered geochemically	8.7	do	2.7	—	
Manchkund								
0— 6	42.1	5.5	acidic (mostly oligoclase), slightly to moderately altered	33.8	microcline-perthite, slight alteration	17.4	1.3	
24—48	50.0	4.9	mainly intermediate Ab_{50}—An_{5}; fairly fresh	26,6	var. same; fairly fresh	13,6	4.9	
Padwa								
0—6	68.2	4.2	basic (towards anorthite), altered	15,3	microcline-perthite, slight alteration	11.1	1,2	
12—48	59.8	7.5	var. same; slightly altered to fresh	15.0	var. same; fresh	11.0	6.7	
Pasighat								
0—7	72.6	12.7	chiefly oligoclase with alteration	5.5	microcline-perthite, moderately altered	1.4	6,9	fine grained schistose; quartz-felspar; traces of chert
50+	59.5	16.8	var. same; fresh, some slightly to moderately altered	11.9	var. same; fresh & slightly altered	4,0	7,9	
Cherrapunji								
0— 6	62.7	5.3	heavily altered, no species could be determined	—		18.8	13.3	fine grained micaceous schists; shale
48—72	59.1	8.1	mostly oligoclase-andesine, slightly to fairly altered	0,9	microcline, moderately altered	23.2	8.7	

* observation based on increased pitting, number of cracks and degree of clouding-up of grains.

rock and some mixed metamorphic components. The latter are mainly of mica-schists with some tremolite-schist in Manchkund and is of calc-gneiss type in case of Padwa.

There is a strikingly large amount of opaques specially rich in limonite (Table 3) in both the soils. They originate in sands obviously by inheritance from the ferruginous-schistose country rocks (refer geology) underlying the soils and this parent rock-soil genetic relation clearly establishes the pedogenic role of this family of rock in the formation of these soils.

Acid igneous rock, the presence of which is indicated (Table 5), might represent Charnockites which constitutes one of the rock types around the region. In view of the absence of pyroxene and hypersthene or enstatite which characterise the mineraological constituents of Charnockites (WADIA [27]), it may be said that this group of easily weatherable mineral have fully weathered or have, possibly, been altered to limonitic iron ores (MOHR and van BAREN [22]). In a similar way, calc-gneiss as indicated (Table 5) represents the calc-gneiss occurring around the region (Geol. description). Disappearance of pyroxene, hypersthene and augite which usually associates calc-gneiss (KRISHNAN [17]) has likewise taken place under the existing humid weathering condition. The rock types deduced from the provenance are thus in close agreement with those actually occurring around the region, establishing that the soils are of sedentary formation.

Pasighat: One of the rock types around Pasighat alluvial plains, as the geology of the area points out, is a metamorphic rock composing mainly of dolomitic materials and mica-schists. Calc-schist (dolomitic limestone metamorphosed) and mica-schist as deduced from the mineral association thus bears out and confirms the occurrence of the above metamorphic components in the parent material composition of the soil. Quartz-felspar rock fragments (Table 4) may similarly be attributed to their possible derivation from Gondwana system (refer geol.) composing of sandstones, quartzites etc. The study thus gives a clue that the alluvial material on which Pasighat soil has developed, has been fed with materials from metamorphosed (calc-schists) and other varied assemblage of rock types exposed in the close vicinity.

Cherrapunji: Cherrapunji is situtated on the Shillong plateau, the core of which is represented by rocks of the Archaeans underlaid by Cretaceous-Tertiary sediments (Geol. record). All the rock types as deduced from study of accessory mineral assemblage (Table 5) may thus be looked upon as being representatives of the Archaean system. Weathered comminuted schistose rock fragments (Table 4) gives a direct clue as to the occurrence of metamorphic schists of the Archaeans in the parent rock composition and they furthermore indicates the pedogenic contribution of this family of rock in the formation of the soil. Fine grained shale particles may, on the other hand, be looked upon as being derived from the Cretaceous and Tertiary system. Rock types as shown by the provenance are thus in close agreement with those of the underlying solid geology revealing that the soil has developed in situ from the rocks, chiefly acid igneous and basic metamorphics (like hornblende-, and chlorite-schists) of the Archaeans.

Though inherited from the basic metamorphic components of parent material, survival of chlorites and amphiboles in good amounts in Cherrapunji sand (also in Pasighat) against perhumid weathering conditions with accompanying acid soil reaction, is interesting. In the event of adherence of chlorites

Table 5

Provence Study

Sampling sites	Association	Probable source rock
Churu	tourmaline, zircon, muscovite epidote, amphiboles, biotite, chlorite, garnet, kyanite, plagioclase	acid igneous (dominant) metamorphic (amphibolite)
Ludhiana	euhedral tourmaline, zircon, muscovite biotite, garnet, kyanite, schistose rock fragments epidote, chlorite, amphiboles, opaques	granitic rock (dominant) mica-schist* basic metamorphic
Annegeri	zircon, muscovite, tourmaline, opaques epidote, biotite, amphiboles	acid igneous basic metamorphic
Manchkund	high abundance of muscovite, K-felspars, intermediate plagioclase in felsic and zircon amidst accessories rutile, garnet, kyanite tremolite with kyanite	dominance of acid igneous rock mainly mica-schist** minor tremolite-schist
Padwa	muscovite, K-felspars, zircon, tourmaline Ca-end plagioclase, high amount of garnet, rutile	acid igneous (dominant) mixed metamorphic, mainly calc-gneiss
Pasighat	zircon, tourmaline, K-felspars, muscovite epidote, amphiboles, chlorite, biotite garnet, kyanite, biotite	acid igneous calc-schist** (dominant) mica-schist (minor)
herrapunji	zircon (large amount), tourmaline, biotite, high abundance of muscovite garnet, sillimanite, rutile chlorite, epidote, amphiboles	dominant occurrence of acid granite garnet-sillimanite-schist basic metamorphic

* mixed metamorphic of which mica-schist is conspicuous ** mixed metamorphic

it may be said that weathering of the original ferromagnesium chlorites or the incomplete reconstitution of them through diagenesis has yielded this chlorite which therefore may be looked upon as secondary (pedogenic) and thus having a more weathering stability (Jackson et al. [15]).

Uniformity in mineral composition in different layers goes to show that all the profiles under study are homogenous, being derived from materials of the same composition and origin.

Part II

Base-exchange behaviour of soils

Table 6 indicates that CEC values are low in Churu and Ludhiana. In the former soil more than 57 percent of the total exchangeable cation is Ca^{2+}, followed by Mg^{2+}. In Ludhiana, K^{+} and Mg^{2+} are the dominant

Table 6

Base-exchange properties of the whole soils (oven dry basis)

Sampling sites and depth in inches	Percent adsorbed cations					Base Saturation at pH 7,0 (percent)	C E C at pH 7,0
	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	H^{+}		
Churu							
0—5	57,70	31,73	4,18	6,39	0	100	7,2
21—49	82,71	20,20	1,68	6,61	0	100	8,9
Ludhiana							
0—6	26,89	20,67	45,30	7,14	0	100	6,2
12—24	38,26	17,28	33,19	11,26	0	100	4,8
48—72	44,33	20,97	23,81	10,89	0	100	5,0
Annegeri							
0—6	63,36	31,56	1,08	3,99	0	100	68,7
12—24	63,19	30,87	1,18	4,67	0	100	70,1
48—72	37,60	45,27	1,01	16,11	0	100	56,7

exchangeable cations. High base saturation with K^{+} and Mg^{2+} in the above two soils (Ludhiana and Churu, respectively) indicates that within the soil material, primary weatherable minerals of K- and Mg-bearing types occur as dominant constituents in equilibrium with secondary minerals in the clay complex. Such an equilibrium is indicative of clay mica and 2 : 1 expanding or chloritic minerals in Ludhiana and Churu soil clays, respectively.

In the semi arid soil from Annegeri, the c.e.c. is high. Since the organic matter content (Table 2) of the soil is low, the high capacity may be due to the presence of clay mineral of 2 : 1 expanding type. This is supported by the presence of high exchangeable Mg^{2+} and Ca^{2+}, particularly Mg^{2+}.

CEC, specific surface and Y-value of soil clays

Results are shown in Table 7. The fairly high exchange capacities together with the Y-value of the order of 20,9 (being the upper limit of illitic mineral — Martin and Russel [20]) and fairly high internal surface areas indicate the existence of highly degraded illite or, an expanding lattice type clay mineral in Churu clay.

In Ludhiana, Y-value of 16,4 with internal surfaces of 117,3 to 144,4 sq.m./gm. are an indication of the presence of illite like clay minerals, probably of the degraded type. The exchange capacity also points to the same.

CEC of Annegeri soil clays is high and suggests 2 : 1 type expanding clay mineral like montmorillonite. The existence of highly expanding layer lattice is also indicated by the large total surface area and confirmed by equally high internal surface. High Y-value in the tune of 41,2 is also suggestive of the dominance of expanding type secondary mineral in this soil (Martin and Russel [20]).

Chemical properties of soil clays

Results are presented in Table 8. Fairly high silica content and SiO_2/Al_2O_3 molar ratio of 3 or so, suggest 2 : 1 type clay mineral in Churu clay. High K_2O suggests the occurrence of a dominantly illitic mineral. In addition, fairly high MgO content (c. 2,23 per cent) reveals some magnesium bearing layer silicate mineral. A similar argument holds forth in case of Ludhian clay. High silica and molar SiO_2/Al_2O_3 ratio are definite indications of 2 : 1 layer lattice mineral in Annegeri clays. The paucity of K_2O in this clay indicates an apparent absence of illite. In view of fairly good amount of MgO and CaO and seemingly high content of SiO_2, inference leads to montmorillonitic clay mineral in this soil clays.

Mineralogy of soil clays — X-ray study

Diffraction pattern of Churu sample shows a diffuse reflection at about 10 Å tailing towards long intensity line indicating the presence of degraded illite. This is further confirmed by heating the sample on to 600°C whereby

Table 7

Ethylene glycol retention, C E C and Y-value of soil clays

Sampling sites and depth in inches	Total surface	External surface	Internal surface	C E C meq/100 gm.	Y-value (surface layer)
	sq. m/gm				
Churu					
0—5	246,6	43,2	203,4	51,0	20,9
21—49	308,1	117,7	190,4	58,3	
Ludhiana					
0—6	162,3	45,0	117,3	44,1	
12—24	175,9	45,8	130,1	60,4	16,4
48—72	177,0	32,6	144,4	52,7	
Annegeri					
0—6	576,1	51,3	524,8	102,9	
12—24	409,3	44,0	365,3	124,2	41,2
48—72	379,2	52,1	327,1	107,5	

the diffuse pattern becomes somewhat defined at 9,8 Å. In addition to illite, X-ray diagram reveals the presence of a small amount of kaolinite corresponding to its (001) basal spacing at 7 Å and other subsequent basal reflections. The presence of kaolinite is confirmed by heat treatment. Besides these lines, the diagram shows a 14,02 Å line which remains stable on glyceration as well as heat treatment. This is due to presence of chlorite. Treatment with 10% HCl confirms chlorite.

In Ludhiana clays, the 10 Å spacing is highly diffuse and on heating, the spacing becomes sharp at 9,98 Å indicating the presence of degraded illite. Besides this, other fairly well defined spacings of illite are also to be noted, viz., 4,44 Å, 3,33 Å, 2,57 Å and 1,50 Å (060). Sample also shows the presence of a small amount of kaolinite (001 at 7,07 Å) which is confirmed on heating to 600°C. Diffraction diagram further shows a diffuse pattern in the 2 θ region corresponding to 14,4 Å, spreading upto 9,9 Å, with some weakly defined line at 14,4 Å. Stability of the latter towards heat and glycerol treatment suggests the presence of chlorite in this clay. Chlorite in Ludhiana soil was also noted by KANWAR [16].

The dominant mineral in Annegeri clays is montmorillonite — the presence of which is clearly indicated by a well defined 14,06 Å spacing which closes to 9,54 Å on heating, and on glyceration shifts towards longer spacing with a reflection at 17 Å (MACEWAN [19]). Presence of a little quantity of illite is also indicated by having 3,33, 2,57 and 1,50 Å lines and a (001) diffuse reflection in the region of 9,9 Å. A very low intensity 7 Å line and its elimination on heating indicates a small amount of kaolinite too in this clay.

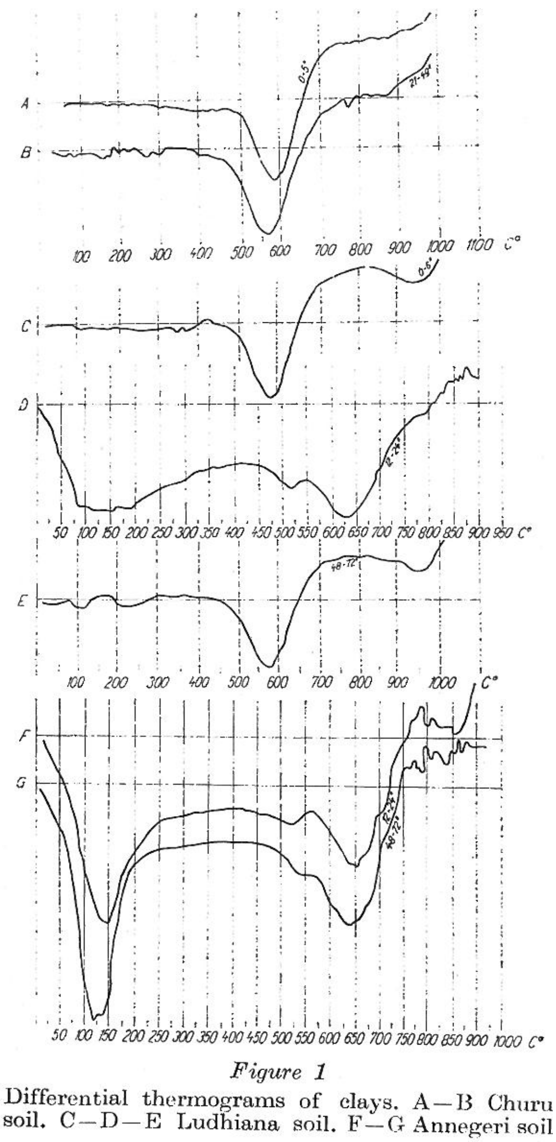

Figure 1

Differential thermograms of clays. A—B Churu soil. C—D—E Ludhiana soil. F—G Annegeri soil

Differential thermal analysis

D.T.A. curve of Churu clay (Fig. 1) is almost flat upto 350°C showing little or no loss of water at low temperature. This is followed by a small endothermic reaction and finally a sharp endothermic peak at 573°C (Curve A) and 555°—567°C (Curve B). These characters indicate kaolinite. The shifting of the main endotherm which is usually at 610—620°C in well crystallised kaolinite (GRIM [11]) towards lower temperature, in this case, however may be due to the presence of other mineral like illite (ADHIKARI [1]).

In Ludhiana differential thermal diagram (cf. Curve D, Fig. 1) indicates gradual but substantial water loss attended with a base line drift from the beginning upto a temperature about 800°C where the dehydration is considered to be complete. This shows the first dehydration peak in the vicinity of 95°C continuing uniformly upto 200°C, the second one in the region of 525°C and the third in the proximity of 600—650°C but there is no high

Table 8

Elemental analyses of soil clays (oven dry basis)

Sampling sites and depth in inches	SiO_2	Al_2O_3	Total Fe_2O_3	TiO_2	CaO	MgO	K_2O	Ignition loss	SiO_2/Al_2O_3 molar ratio
	%								
Churu									
0—5	45,45	23,39	10,77	0,44	0,82	1,19	6,50	10,96	3,3
20—49	43,58	24,11	9,07	0,45	0,86	2,23	6,62	13,13	3,1
Ludhiana									
0—6	40,89	27,22	12,27	0,40	0,84	1,07	8,09	9,96	2,5
12—24	42,44	33,60	4,43	0,86	0,96	2,21	5,65	9,85	2,1
48—72	43,50	26,57	12,55	0,69	0,76	0,90	5,80	9,23	2,8
Annegeri									
0—6	51,87	24,48	11,94	0,68	1,48	1,38	0,81	10,15	3,6
12—24	53,23	15,50	12,96	0,72	0,92	1,00	0,85	13,02	5,9
48—72	55,27	16,17	11,67	0,91	0,80	1,81	0,65	12,72	5,8

temperature reaction. These features are the characteristic dehydroxylation reaction (ADHIKARI [1]) and discloses the presence of illite together with some kaolinite in it. The broad endothermic dehydration reaction at low temperature may possibly denote the degraded state of illite present.

The curves (Fig. 1) of Annegeri soil clays show considerable water loss at low temperature between 100—150°C with sharp endothermic peaks at 145 and 117,5°C (doublet) for the 12—24″ and 48—72″ samples, respectively. This endotherm with a sharp base line drift indicates sorbed water in the large interplanar spaces of expanding layer silicate. This suggests montmorillonite. The second sharp endothermic peaks at 650—655°C (Curve F) and at 637,5°C (Curve G) corresponding to main dehydroxylation reaction may also be due to montmorillonite. The presence of the latter is further supported by a third small endothermic peak at about 860°C (due to loss of the last hydroxyls) followed by an exothermic reaction in the region of about 900°C (GREENE-KELLY [10]). A weak peak between 500 and 550°C may account for a small amount of kaolinite.

Summarising the results — Churu and Ludhiana clay are predominantly illitic containing small amounts of kaolinite and chlorite, whereas Annegeri clay contains essentially monomineralic montmorillonite clay with a minor amount of kaolinite and illite.

Mineralogy of coarse silt

X-ray study of Churu sample shows that quartz constitutes the major mineral in this fraction; besides it contains mica and some felspars.

The presence of the former is indicated by the (001) spacing at 10,72 Å. In view of the long spacing, the mica present appears to be a hydrated one.

Quartz is the principal mineral in Ludhiana coarse silt. Besides, felspars are present in appreciable quantities. The presence of mica is also detected by X-ray analysis. The spacing of 10,93 Å, longer than the usual (001) spacing value, indicates that mica is hydrated.

X-ray data of Annegeri silts reveals quartz to be the most dominant. A very little quantity of felspar is found to be present. There is present also a small amount of secondary mica, indicated by (001) reflection being at 10,879 Å.

Discussions

Churu. Churu soil has developed on tropical alluvium of Plesitocene and Recent under a desert arid weathering condition. The alluvium parent material consists dominantly of materials derived from acid igneous and some metamorphic rocks (amphibolitic).

Amongst the weatherable aluminosilicates, amphiboles (mostly hornblende) occur in appreciable amount together with small amount of biotite and traces of chlorite, in the heavy crop of fine sand. In the felsic fraction, quartz is dominant and muscovite is scarc or absent. Plagioclase which is markedly abundant, is constituted mostly of andesine to labradorite, and is in a state of alteration. Compared to these soda-calcic felspars, fine sand contains only a small amount of K-felspar, very slightly altered. Occurrence of a minor amount of felspar in silt fraction when compared with its abundance in the fine sand (present mostly as plagioclase), signifies that the silt fraction is chemically more reactive than the sand size fraction and affords evidence for plagioclase weathering in this soil.

Calcium and magnesium occurring as dominant exchangeable ions owe their derivation to the weatherable minerals of calcium bearing plagioclase and amphiboles. Arid weathering condition having minimum leaching effectiveness, ensures retention in the weathering zone, of Ca and Mg yielded by the decomposition of those minerals. The ions thus liberated and mobilised, have appeared in the exchange complex creating thereby an ionic environment of alkaline earth cations.

Though primary micas through reduction in particle size, is the usual precursor of illite, in parent material without primary micas (c. volcanic granite) as one studied here, illite may be synthesized during soil developmental processes in the same manner as other secondary minerals (BARSHAD [3].) The same may be the process of formation of illite in Churu clay. The latter seems, therefore, to be associated more with the weathering of basic plagioclases, abudantly present in soil. Chlorite, the other mineral in clay, is presumably, ascribed to amphiboles in fine sand. The alkaline earths soil environment appears to promote both illite and chlorite formation as well as their stabilisation.

Ludhiana. This soil has been formed on the Indus alluvium of Recent geological formation under arid climate. The alluvium parent material is composed of a varied type of rocks, of which the prominent ones are acid igneous and metamophic rocks like mica-schist and some basic metamorphics.

Alkaline pH, percent base saturation and richness of Ca^{2+}, Mg^{2+} and K^{+} ions in exchange sites and abundance of weatherable biotite mica in sand, disclose that the soil is in early stage of weathering. Considerable presence of easily decomposible plagioclase (X-ray study supplemented with calcium analysis) in coarse silt also lends support to the fact that the soil as a whole is not much chemically active.

Among the minerals in fine sand, the striking feature is the occurrence of micas — both biotite and muscovite, in large quantities. In the heavy detritals, accompanying minerals (besides biotite) belonging to weatherable aluminosilicate group, include amphiboles and chlorites. Amongst felspars, plagioclase, intermediate ($Ab_{50}An_{50}$) with moderate alteration, occurs in fairly high amount and K-felspar (microcline) in appreciable quantity.

It appears that much of the illitic fraction of Ludhiana clay is derived from the micas of parent material. Potassium rich ionic environment (evaluated from high saturation of exchangeable K^+) which resulted from the decomposition of primary micas, specially biotite appears to favour the formation and stabilisation of this illite. Chlorite in soil clay fraction, on the other hand, appears to be associated with biotite and amphiboles. The latter minerals weather fairly rapidly and may be presumed to build up on their breakdown, an environment of Mg-ions (as measured from its high content in the exchange complex) in the soil weathering zone. And it is this magnesium which might have promoted the formation of chlorite in clay fraction.

Kaolin occurring as a minor mineral seems to be associated with the felspars in sand. Minor occurrence is due to the incipient weathering condition that might restrict the decomposition of felspars.

Annegeri. The soil has developed in situ from the underlying parent roksc of the Archaean. The latter is mainly composed of a mixed assemblage of metamorphic rocks adequately rich in alkaline earth (mainly magnesium) bearing and iron bearing mafics, in a highly metamorphosed state.

Distinctly alkaline reaction, accumulation of $CaCO_3$ and high saturation of calcium and magnesium in the exchange complex indicate that leaching process inside the soil is not pronounced.

Fine sand is poor in muscovite. K-felspar occurs in small amount and are fairly fresh. Soda-lime felspar on the other hand is fairly common. They are mostly oligoclase to andesine, grains marked with slight alteration. They, however, appear to have been geochemically altered (saussuritisation; TYRELL [26]). This gives further evidence for a high degree of metamorphism of the parent rock as noted from the geological information. Epidote predominating in the accessory mineral crop of fine sand may be looked upon as an altered product of the ferromagnesium minerals and felspars (WINCHELL [28]) as resulted from such hydrothermal metamorphism. This further contributes supplemental evidence of the presence of a large ferromagnesium mineral suite in the original parent rock. Present paucity of these group of mafics in fine sand, shows that they being prone to easy weathering, have been spent up n the formation of the soil, yielding a weathering product initially rich in iron and alkaline earth cations. It appears that the semi arid climate with insufficient leaching has ensured that the liberated bases are retained in the weathering system, thus raising the percentage adsorption of Ca & Mg in soil exchange complex and pH initially above 7. The calcium and magnesium anic environment thus liberated and mobilised, has promoted the formation indstabilisation of montmorillonite, the predominant clay mineral in Annegeri black soil.

Absence of any appreciable quantity of muscovite probably explains the paucity of illite in this clay. A low content of exchangeable K^+ at the same time discloses that this soil in its weathering zone did not have an adequate potash environment which is an important precondition for clay-mica formation.

The investigation furthermore goes to show that though trap basalts is the typical parentage to mostly all Indian black soils, they may also form on other parent material as one studied here, the prerequisites being the richness of alkaline earths and Fe-bearing weatherable rock-forming minerals and assurance of mobilisation of their weathering products in the soil system. The same was noted also by TAMHANE and NAMJOSHI [25].

Summary

Genesis of clay minerals through the approach of ionic environment of weathering zone is studied taking three Indian soils belonging to arid tropical climate. Assessment of their parentage, content and alteration of minerals in coarser soil fractions are studied in relation to their role of yielding and maintaining the ionic environment as finally governed by the weathering condition prevailing in the soils. The study showed that ferromagnesium silicates like biotite, amphiboles and chlorites in fine sand are associated with Mg-bearing secondary minerals in clay, when the weathering intensity is low or moderate. When illite is dominant fine sand contains high K-bearing minerals, particularly muscovite (Ludhiana). When both the alkali and alkaline earths constitute the parent rock composition, under above similar condition of weathering, Mg-bearing clay mineral and illite are the constituent minerals in clay (Ludhiana). It also follows from the study that the ion species constituting the integrating parts of the mineral lattice, i.e. K^+ in illite, Ca^{2+} and Mg^{2+} in montmorillonite and Mg^{2+} in chlorite stabilises these minerals if present largely as exchangeable ions.

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