

GENESIS OF ALKALI SOILS AT DIFFERENT GEOMORPHIC LOCATIONS IN HARYANA

by

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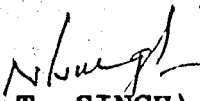
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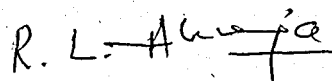
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CERTIFICATE - I

This is to certify that this dissertation entitled, 'Genesis of alkali soils at different geomorphic locations in Haryana', submitted for the degree of Ph.D. in the subject of Soil Science to Ch. Charan Singh Haryana Agricultural University, Hisar is a bonafied research work carried out by Shri Raj Kumar Gupta under our joint supervision and that no part of this has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.


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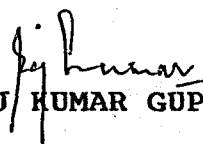
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CHAPTER 1

INTRODUCTION

Technical and social developments throw light on new problems day after day. Some of them are crucial for the future of mankind and reveal new aspects of problems that have been known for a long time. A fair proportion of such problems is closely related to predictions and prognosis for the next millennium and influences the production and availability of food and other commodities for the ever growing population of the world. There is an abundance of prognosis of different scales and kinds, but at the same time there is a shortage of reliable analyses of the predictable prospects facing, for instance, fertile soils, sustainable agricultural production, and the carrying capacity of the surface layers of the earth in the face of pollution and destruction by chemical, physical and biological agents.

One of the hazards, that threaten not only soil fertility but also purity of water, plant, animal and human life, is the high salinity of soils and waters. Salinity influences the environment mainly through soil material and buffering capacity of soil plays a dominant role in diminishing or abolishing its effects (Szabolcs, 1989).

Salt affected soils occur under different environmental conditions and have diverse morphological, physical, chemical and biological properties, but one common feature - the dominating influence of electrolytes on the soil forming processes, joins them into one family.

Salt affected soils really constitute a global problem as they occur practically every where on the globe covering about 10 per cent of the total surface of dry land Szabolcs (1989). Salt affected soils range from small spots to large areas and no continent is free from this problem. No climatic zone

is free from salt affected soils, though their appearance is focused either in deserts and semi deserts or in bottom lands and river valleys only. Although their causes may be different yet they all lead to one end i.e. throwing these soils out of production.

Based on FAN-UNESCO Soil Map of the World, the extent of salt affected soils (excluding Europe) has been estimated by Massoud (1974) at 901.4 m ha. Of these about 62 per cent soils are alkali in nature. For Europe, total salt affected area was reported to be 50.8 m ha (Szabolcs, 1989).

In the Indian sub continent a total of about 7 m ha of soils are salt affected (Bhumbla, 1977; Abrol and Bhumbla, 1977) and 2.8 m ha are affected with soil alkalinity problem. Of these, a major chunk of 2.5 m ha of alkali soils are present in the Indo-Gangetic plains of northern India, covering the states of Haryana, Punjab and Uttar Pradesh (Abrol and Bhumbla, 1971). With the application of sophisticated equipment and use of remote sensing technique, salt affected soils have been identified in many more areas where they were unknown before. Recently, Szabolcs (1989) reported 23.8 m ha of total salt affected soils in India. This area has been further split into 20.2 and 3.6 m ha as saline and alkali soils, respectively. Enormous differences in the total reported area of these soils points to large gaps in the knowledge acquired and the ground truth. In addition all these reports consider only the surface layer and thus in no way include lands that are saline/alkaline below the plough layer.

Taking into account the U.N. projections (Salas, 1981) which indicated that world population may touch 6.2 billion by 2000 A.D. and a projected 50 per cent increase in demand for food in the next 20 years; special significance is attached to the agricultural exploitation of the fertile and potentially

productive alkali soils. The situation becomes even more demanding where man to land ratio is increasing every day.

In India it has long been taken for granted that alkali and saline soils occur under arid and semi arid conditions and the inter-relation of soil salinity and environmental conditions has often been considered with respect to climate (Bhargava et al. 1980; Bhargava and Bhattacharjee, 1982). Although aridity does promote accumulation of salts in soils and water, yet accumulation of electrolytes in a soil is never the less a complex process which can not be interpreted as a simple consequence of climatic effects (Szabolcs, 1989).

Modern landscape geochemistry, represents a holistic approach to mass and energy flows which lead to the formation of salt affected soils. According to this approach (besides the influence of the climate) the geochemical and bio-geochemical processes determining the mass flow that affects soil formation should also be studied.

In India lot of work has been done on the genesis of alkali soils. Most of the workers have suggested their origin to the release of sodium by weathering of alumino-silicates and subsequent carbonation resulting in the formation of sodium carbonate (Bhargava and Bhattacharjee, 1982). In fact this mechanism has been borrowed from the Kovda (1964), who proposed it for the formation of alkali soils of Russia in basaltic and volcanic parent materials.

Owing to the near absence of these basaltic parent material in the catchment, of these soils, their different morphological characteristics as admitted by Bhargava and Bhattacharjee (1982) in their concluding remarks and dominant illitic mineralogy; the exact mechanism of formation of alkali soils of India is still obscure. Besides all the reasons quoted for the formation of alkali soils their exist a problem of all together different kind in the state

of Haryana which so far has escaped the attention of workers. The problem is associated directly with the nature of geological formations spanning from Pleistocene to as old as Precambrian era.

Accordingly, the present investigation, to understand the genesis of alkali soil, in north India, particularly the Haryana state was undertaken with the following objectives:

1. To study the geomorphology and alkali soils relationship in Haryana using remote sensing data.
2. To study the genesis of alkali soils through morphological, physical, chemical and mineralogical analyses.
3. To compare the weathering of alumino-silicate minerals in alkali, reclaimed alkali and normal soils.
4. To highlight the classification problems of these soils and redefine soil taxa for accommodating these soils in the Soil Taxonomy.

CHAPTER 2

REVIEW OF LITERATURE

- 2.1 History of the study area
 - 2.11 Himalayan geology
 - 2.12 The Siwalik deposits
 - 2.13 The Salt Range
 - 2.14 Shifting of river courses
 - 2.2 Salt affected soils
 - 2.21 General grouping
 - 2.22 Global distribution
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 - 2.74 Kaolinite
- 2.8 Taxonomy of salt affected soils

2.1 History of the study area

2.1.1 Himalayan geology: The quaternary period has seen the final upliftment of the Himalayas. Time and again its present site was flooded by sea which girdled the earth. It separated a great northern continent of which Asiatic part is known as Angaraland from a southern continent known as Gondwanaland. Though the Himalaya rose out of the Tethys sea during Eocene epoch some 65 million years ago the sea basin was accumulating sediments that are now found as rocks in the Himalaya dating from the Cambrian period about half a billion years ago. These Cambrian rocks constitute the bulk of the Central Himalayan zone. These gigantic masses of sediments that had been accumulating upon the gradually sinking floor of the Tethys disturbed the gravimetric equilibrium of crust towards the end of Eocene when a series of mountain building movements resulted in the uplift of (mostly Eocene nummulitic limestone) the Himalayas (Pascoe, 1965; Dey, 1968; Wadia, 1979).

Though the Himalayan mountain chain is young many of its rivers—the Indus, Satluj, Bhagirathi, Alakananda with other tributaries of the Ganges system and the Brahmaputra are older than it. These rivers during the process of mountain formation by the folding and uplift of bed rocks, kept very much to their old channels so that erosion of the valley kept pace with the elevation of the mountains. The rivers have therefore developed deep transverse gorges that are characteristic feature of the Himalayas. During and after uplifts rivers not only dissected, deepened and widened their valleys by the infusion of new vigour through increased gradients, but also left past of their previously laid down deposits as bench line terraces at higher levels along their channels. The Indo-Gangetic plain which lies at the foot of Himalaya marks the side of a basin 2-3 thousand metre deep resulted from the compression exerted on the peninsular margin against the advancing crustal waves from north during the uplift of the Himalaya. The basin has been filled up with river alluvium derived from the rising Himalaya as well as the plateau on the south (Dey, 1968).

2.12 The Siwalik deposits: Molasses like Siwalik deposition did not follow until the main Himalayan orogeny reached the southern areas and strong erosion began. The Siwalik basin was a narrow depression paralleling the Himalayan chain bordering the northern peninsular shield from which a considerable amount of detritus was still received. Some of the sediments were distributed along rivers running parallel to incipient Himalayan ranges (Indobrahm). It was not until the upper Pliocene and earlier Pleistocene that main orogenic Himalayan phase produced the Siwalik conglomerates and local fans. During the culminating phase and over thrusting of Siwaliks; fluvio-glacial deposition produced boulders much larger than those of Siwalik conglomerates (Gansser, 1964).

2.13 Salt Range: Salt Range is a range of hills and low mountains between the valleys of the Indus and the Jhelum rivers in the northern region of Punjab in Pakistan. It derives its name from extensive deposits of rock salt (sodium chloride) that forms one of the richest salt fields in the world. This range is approximately 300 km long, 8.3 km wide and about 700 m high (Encycl. Britani., 1975).

Structurally, the salt range is a highly upheaved block of north-western part of Indian shield. At the time of upheaval of the Salt Range beginning in mid Tertiary period (26 m yr ago) the ancient river system was dismembered. Sedimentary mantle of Salt Range is represented by thick deposits of late Pre-cambrian, Paleozoic and Mesozoic (i.e. more than 65 m to 570 m yr ago). Pre-cambrian deposits are represent by the widely known salt bearing strata, which is more than 500m thick. In the lower part these contain marl, gypsum and slaty shale. In the central part are located the main strata of salt. Upper part of strata includes magnesium rich limestone, gypsum and bituminous argillites. Pre-cambrian layer in topped by obliquely laminated sand stone and is about 210 m thick (The Encycl. Britani., 1975).

The rock salt deposit of Pre-cambrian Shali formation in the Mandi district of Himachal Pradesh in Himalaya region is the only known rock salt occurrence in India. It is pink coloured, hard, compact and is closely associated with a marly lithocomplex. Salt was deposited in Shali epicontinental sea shelf marginal to a stable land complex. It has suffered intense tectonic complications (Gansser, 1964). The salt bed is correlated with saline series of salt range in Pakistan (Srikantia and Sharma, 1972). Besides this many hot water springs and brine seepages are present in the Mandi, Sirmur, Solan and Shimla districts of Himachal Pradesh.

2.14 Shifting of river courses: Great changes have taken place in the topography of north western India with in comparatively recent geological times. So much so that in Rann, which was gulf of sea until much after Alexander's invasion, submergence and complimentary uplift took place as late as 1819 A.D. (Seth, 1963). The Indus river itself has only two fixed points in its course through the plains and has been changing its course frequently (Wadia, 1926).

The streams making for Rajasthan across the low watershed converged towards a large dry watercourse (Ghaggar) which runs parallel to Satluj and was fed by its waters. In its lower reaches (Hakra river), it was probably fed by the Indus in the 8th century A.D. (Encycl. Britani., 1951). The Beas did not join the Indus either but probably followed a distinct course to the Indus (Medlicott and Blanford, 1879). It now joins the Satluj due to westering of the latter. The confluence of the two also probably shifted 150 miles up from near Behawalpur to above Ferozepur (Chaturvedi, 1952).

The most remarkable case is that of the Saraswati which was a considerable river known to Vedic Aryans and followed its old course in the sixth century B.C. Extensive studies by geographers,, suggest that even Satluj could have been one of the tributaries of Sarasvati there by lending a perennial water

source to the mighty Sarasvati in the Himalayas (Bhardwaj, 1987). The latest view suggests that the present bed of Soan which now drains into Yamuna is the erstwhile bed of Drsadvati which originated in the Sirmur district of Himachal Pradesh and flowed parallel to Yamuna upto Karnal and there after straight south until it was obstructed by Aravallis where it turned west and finally joined the Sarasvati at Sirsa (Kar and Ghose, 1984). With the tectonic thrusts and upheavals that followed, headwaters of Sarasvati-Drsadvati system were cut off leading to the receding of the rivers.

Thus the Sarasvati had disappeared in the early centuries of the Christian era, the Satluj was no longer independent of the Indus in early years of that era and by 1790 A.D. the Hakra was dead (Encycl. Britani, 1951). The westering of the Indus and the northering of Satluj have resulted in Indus basin being permanently separated from the Peninsula by vast desert spaces, which is justified by the presence of ancient river beds in it (Seth, 1963).

Similarly Chautang river which was flowing southwardly through Yamuna alluvial plain changed its course and took a westwardly turn near Jind in Haryana. Chautang abandoned its course mainly due to accretion of sediments brought by itself and soil salinity patches developed along the left bank. Shifting courses of Satluj and Chautang have been traced from landsat imagery by Manchanda (1984).

Earlier reports on the salt affected soils: One of the earliest report about the status of climate and soils of this area is from the travel diary accounts of Chinese travellers, Hiuen-Tsang and I-Tsing who visited during the middle of 7th century A.D. (Seth, 1963). He records in travel diary (translated by Beal, 1961) "In general the plains below the western mountains are dry and saline (Chapter 2), there are dense and shady forests and rice is cultivated near Jullunder (in Punjab)."

2.2 Salt affected soils

Salt affected soils occur in association with their normal counterparts but betray following differences (Szabolcs, 1980, 1989) which form their distinguishing features.

1. They have higher concentration of electrolytes than other soils.
2. Electrolytes dominate the soil farming process.
3. The fertility of the soil is adversely affected by high concentration of electrolytes through restricted availability of water and nutrients.

Salt build-up in soil may influence its behaviour for crop production in several ways through changes in the proportions of exchangeable cations, soil reaction, soil physical properties, and osmotic and specific ion toxicity effects.

2.21 General grouping of salt affected soils: General intent of grouping salt affected soils is to facilitate discussions on soil management and to group soil according to crop responses. These soils have been separated into two broad groups, saline soils and alkali soil (Abrol and Bhumbla, 1978; Bhumbla and Abrol, 1978; Szabolcs, 1989).

Saline soils: Soils often recognized by the presence of white encrustation, having pH_s less than 8.5, ESP or SAR less than 15 and preponderance of chlorides and sulphates of Na, Ca and Mg. EC_e is more than 4 dSm^{-1} at 25°C . However, soil salinization with neutral soluble salts of Na invariably result in soil solution $SAR > 15$. Such soils are termed saline-sodic (U.S. Salinity Laboratory Staff, 1954). Experimental evidences show that leaching of these saline sodic soils (containing neutral sodium salts and high SAR solutions) with good quality waters generally result in desalinization and simultaneous desodification accomplished through increased solubility of naturally present CaCO_3 and gypsum (Dieleman, 1963; Leffelaar and Sharma, 1977; Khosla et al.

1979; Jury et al. 1979). Such saline sodic soil essentially need to be grouped and managed like the saline soils (Gupta and Abrol, 1989).

Alkali soils: Soils with pH_s more than 8.5, ESP of 15 or more and pre-ponderance of carbonates and bicarbonates of sodium. The EC_e is limit less if originating from salts capable of alkali hydrolysis otherwise less than 4 dSm^{-1} at 25°C. Abrol et al. (1980) suggested pH_s 8.2 as a more realistic diagnostic criteria for distinguishing sodic from the non-sodic soil.

From management considerations Gupta and Abrol (1989) and Singh (1989) used the term alkali for soils that have high sodicity, high pH and soluble carbonate [$(Na/(Cl + SO_4) > 1.0)$] with variable quantities of soluble salts. Earlier, Bhargava et al. (1976) grouped soils with $pH > 8.5$, $ESP > 15$ and $EC_e > 4 dSm^{-1}$ at 25°C and preponderance of carbonates, bicarbonates of alkali as alkali soils under the consideration that these saline sodic (U.S. Salinity Lab. Staff, 1954) soils will turn sodic upon leaching with good quality water.

2.22 Global distribution: Salt affected soils occupy extensive areas and occur globally. However accurate data concerning salt affected lands of the world are rather scarce. Based on the FAO/UNESCO soil map of the world the extent of salt affected soils has been estimated by Massoud (1974) at 901.4 m ha (Table 2.1).

Thus, excluding Europe, 61.9 per cent of salt affected soils are alkali in nature. Szabolcs (1989) reported area of salt affected soils in Europe as 50.8 m ha.

Table 2.1 Global distribution of salt affected soils

Continent	Area in thousand hectares		
	Saline	Alkali	Total
North America	6,191	9,564	15,755
Mexico and Central America	1,965	-	1,965
South America	69,410	59,573	129,163
Africa	53,492	26,946	80,438
South Asia	83,312	1,798	85,110
North and Central Asia	91,621	120,065	211,686
South-east Asia	19,983	-	19,983
Australia	17,359	339,971	357,330
Total	343,333	558,097	901,430

Source: FAO/UNESCO, 1974 Soil Map of the World. 1:50000000 Vol.1.

Legend. UNESCO, Paris.

2.23 Distribution in India: Bhumbra (1977) and Abrol and Bhumbra (1977) estimated seven m ha of salt affected soils in India about 2.8 m ha are affected with soil sodicity (Mehta, 1983). Based on FAO/UNESCO Soil Map of the World, Szabolcs (1989) reported 23.8 m ha of total salt affected soils in India. This area has been further split into 20.2 m ha as saline and 3.6 m ha as alkali phases. Of these 2.5 m ha of alkali soils are present in the Indo-Gangetic plains of north-west India covering the states of Punjab, Haryana and Uttar Pradesh (Abrol and Bhumbra, 1971). By using remote sensing

techniques. Sharma (1989) estimated that a total of 217,139 ha area is salt affected in the Haryana. Out of this alkali soils occupy 84720 ha.

Most of this general grouping as well as extent of salt affected soils is based on the observation from the upper few centimetres only. Till now, the so called adjoining normal soils which are normal in upper horizons and alkali in lower horizons have neither been grouped nor accounted for in the total area.

2.24 Macro-morphology and other salient characteristics

Alkali soils occupying the micro-depressions in the Indo- Gangetic alluvial plain have been studied by several workers (Medlicott, 1963; Center 1880; Leather, 1914; Auden et al. 1942; Aggarwal and Mehrotra, 1953; Aggarwal and Yadav, 1954; Govindarajan and Murthy, 1969; Kanwar and Bhumbra, 1969, Sharma, 1979; Bhargava and Abrol, 1978, Sharma, 1989). The salient characteristics of typical alkali pedon as reported by Bhargava and Abrol (1978) are: (i) an ochric edipedon with hues of 2.5Y or 10 YR (ii) high value and chromas (iii) textural gradation from sandy loam to clay loam (iv) platy structure in surface few centimetres followed by subangular/angular blocky structure below (v) presence of Fe/Mn concretions in B horizons (vi) very low organic matter status decreasing gradually with depth (vii) preponderance of carbonates and bicarbonates of Na (viii) gradual decrease of EC_e , pH, ESP and SAR with depth (ix) low to very low infiltration rate (x) occasional presence of fluctuating good quality water table and (xi) calcic horizon usually occurring about one metre depth.

Singh (1989) compared the morphology of alkali soils of Indo-Gangetic region with those of Solonetz of Europe and USSR. The former are more deteriorated in surface horizons while the latter have good A horizon and natric B horizon. The above genetic difference is due to the difference in the mode

of their evolution. Alkali soils in Europe and USA have developed under the impact of ground water (Szabolcs, 1989), whereas in India the process of alkalization has taken place at surface as they are commonly met with good quality ground water. Thus the authors agree that these Indo-Gangetic alkali soils have developed in a different way. But the process is simply not clear.

2.25 Alkali soils occurrence and formation: Soil is a function of climate, vegetation, parent material, relief and time. Alkali soils generally occur in association with so called normal cultivated soils (Vinayak et al. 1981). As such the influence of climate, vegetation acting on same parent material over the same duration of time is eliminated.

There is general agreement in the reports (Aggarwal and Yadav, 1954; Abrol and Bhumbra, 1971; Bhumbra et al., 1973; Bhargava and Bhattacharjee, 1982; Mehta, 1983; Sharma, 1989; Szabolcs, 1989 and Acharya and Abrol, 1991) that these soils occur in 20-30 cm micro depressions only.

These concavities facilitating periodic accretion through accumulation of surface wash, serve as evaporating pans. Bhargava et al. (1980) reported that weathering of alumino-silicates and the dual factors of micro-relief and climate facilitating seasonal floodings and evaporation of accumulated run-off wash played a critical role in the formation of alkali soils.

Recently, Sharma (1989) reported that decisively alkali soils in Haryana occur on and above 230m contour to about 265m height above mean sea level. Earlier, Ahuja and Khanna (1983) have even reported the occurrence of alkali soils near Sirsa on the levees of Ghaggar river at a height of about 200m above mean sea level.

Recently, Grewal and Juneja (1991) reported the occurrence of high pH

soils in the hilly forested catchment of the Siwalik hills where there are no micro depressions and height above mean sea level is about 300 m. At the same time, Szabolcs (1989) reported that salt affected soils (alkaline) in mountainous regions of high and medium heights are more frequent than was previously realised.

Bhargava and Abrol (1978), Bhargava et al. (1980), Bhargava and Bhattacharjee (1982) reported the occurrence of alkali soils in an exclusive rainfall zone of 550 to 1000 mm in the entire Indo-Gangetic plains. These authors further reported that alkali soils mostly occur in the Ustic soil moisture regime in Punjab and Haryana.

However, the reports of Grewal and Juneja (1991) and Ahuja and Khanna (1983) regarding the occurrence of alkali soils in hilly areas having udic moisture regime with rainfall more than 1200 mm and uplands of Ghaggar basin with rainfall of 410 mm contradicts the generalizations mechanisms of Bhargava and Abrol (1978) and Bhargava et al. (1980) for the formation of these alkali soils.

2.26 Underground water table: A shallow under ground water table with seasonal fluctuations prevails below some of sodic soils (Leather, 1914; Bhumbra et al., 1973; Bhargava and Abrol, 1978). This water, having very low degree of mineralisation (Sharma et al., 1976; Manchanda, 1976) and being non-sodic, is extensively used for irrigation and has never been observed to be an active source of sodification. The observations of White comb (1971); Abrol et al. (1972) and Bhumbra (1977) further confirmed that nearness to a canal or presence of a shallow water table does not contribute to alkalization of soils.

2.3 Mechanisms of sodium carbonate formation:

Various theories have been discussed and disputed regarding the formation

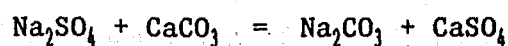
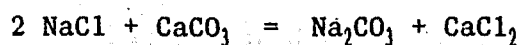
of sodium carbonate in the literature. Some important mechanisms relevant to present investigation are discussed.

2.31 Weathering of alumino-silicates and carbonation: Carbonation of weathering alumino-silicates yields solutions of bicarbonates and carbonates of Ca, Mg, Na and K in addition to colloidal form of Si and Al. Upon evaporation Ca and Mg carbonates get precipitated while NaHCO_3 gradually loses CO_2 to form Na_2CO_3 . The bicarbonates and carbonates of alkali migrate with subterranean and surface waters and accumulate in undrained areas under arid climate to form alkaline soils (Kovda, 1964). This school of thought has been widely advocated by Bhargava et al. (1980). It is based on their observation regarding the release of Na from soil minerals which they suggest are plagioclase feldspars. However, a critical examination of table 1 of Bhargava and Bhattacharjee (1982) indicated that sand B (non-sodic, with $\text{Na}_2\text{O} = 1.54\%$) releases 89 g kg^{-1} Na as compared to sand A (sodic, with $\text{Na}_2\text{O} = 1.74\%$) which releases 88 g kg^{-1} of Na. Thus a non-sodic sand even though having less total Na releases as much Na as a sodic sand and the evidences regarding the source of Na from which it is being released are lacking.

Recently, Gupta and Gupta (1989) reported that alkali soils of Mundlana near Panipat have more (10 per cent) of sodium feldspars as compared to saline soils (3.2 per cent) of that area. Authors, further observed that sodium feldspars are less stable in alkali environment (8.9 pH) as compared to saline soils (pH_s 7.3). Thus, the authors concluded that presence of high amount of Na feldspar having low stability in alkali soils acted as diffused source of Na. On the contrary, research based on thermo-dynamic principles on weathering of soil minerals by Garrel and Christ, (1965); Kittrick (1971); Rai and Lindsay (1975); Lindsay (1979); Rai and Kittrick (1989), strongly indicate that soil minerals including albite become more stable as pH increases.

Furthermore, Beek and Breemen (1973) reported that interstitial water of any soil with a pH between 8.5 and 10 at atmospheric $p\text{CO}_2$ must contain between 2.5×10^{-3} and 10^{-1} eq. alkalinity/litre. The authors find it difficult to imagine that such high alkalinities can be produced by CO_2 attack on minerals only; because most of the weathering processes in question come to an almost complete stand still at pH values above 8 to 8.5.

2.32 Reaction of neutral sodium salts with CaCO_3 : According to Hilgard (1906) sodium carbonate may be formed by the:

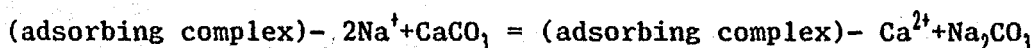
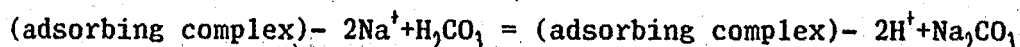


But this reaction presupposes the coming together of lime stone deposits with salts of Na and as such the reaction will proceed in the direction of least soluble component i.e. CaCO_3 .

However, Manchanda (1984) gives considerable weightage to this process for the formation of alkali soils in the Indo- Gangetic plains on the plea that:

- i) Himalayan zone is still not stable
- ii) Deposits of dolomite, calcareous shale, lime stone gypsum and rock salt are abundant in the Himalayas.
- iii) Some tectonic movement in catchment zone must have resulted in the release of different salts and their subsequent reaction with each other resulting in the formation of Na_2CO_3 and other salts.
- vi) These salts were brought down by the rivers and deposited in the geosyncline areas.

2.33 Exchange reactions: Gedroitz (1912), Kelley (1915) and Sigmond (1924) associated Na_2CO_3 formation to the sodium saturated soil complex and H_2CO_3 or CaCO_3



Many scientists agree that this scheme represents the basic process of Na_2CO_3 formation. But Gedroitz (1912) scheme of things play significant role in soils having highly dispersed material and high colloid content. Thus as far as soils of Indo-Gangetic plains are concerned where electrolyte concentration is high in light to medium textured soils, it can not be applied.

Other mechanisms of Na_2CO_3 formation, from microbiological reduction of Na_2SO_4 and from the decay of certain high Na containing plants are not of much relevance in the present context. 1987).

2.4 Transportation and geochemical separation of electrolytes:

Studies by Bhargava et al. (1980) on draino-climatic sequence in Haryana highlighted the process of geochemical separation of electrolytes leading to evolution of alkali and saline soils in two distinct zone. Authors have ascribed it to the geochemical process of ionic separation and deposition facilitated by differences in coefficient of energy (CE) and consequently by ionic mobilities under the influence of operating continental cycles. CE value for anions common in these soils viz. NO_3 , Cl, SO_4 and CO_3 and HCO_3 are 0.18, 0.23, 0.66 and 0.78, respectively; the one with lowest CE being the most mobile (Kovda, 1973).

Singh et al. (1980) reported that around a rainfall of about 750 mm, CO_3 and HCO_3 are the dominant anions followed by Cl and SO_4 ; around isohyets of 500-550 mm mixed anionic composition with SO_4 - Cl - CO_3 or SO_4 - CO_3 - Cl are common. Below 300 mm isohyete Cl and SO_4 dominate with only traces of CO_3 . Thus there are definite zones of salt migration and accumulation with rainfall and topography providing the basis for the formation of a particular class of salt

affected soils (Bhargava et al. 1980, Sandu et al. 1980). Interestingly, the influence of the composition of ground water is reflected in the nature of soluble salts in the corresponding soil. Earlier, Singh (1968) has arrived at a similar conclusions from a survey of soils and waters of Hisar district in Haryana.

2.5 Calcium carbonate nodules - genesis

A distinct, regular and thick zone of calcium carbonate accumulation mainly dolomite (Sharma and Bhargava, 1981) exists at about one metre below the surface in alkali soils. Smooth boundary of calcic horizon irregular shape of individual concretions and regularity of occurrence underneath vast areas highlights their pedogenic origin (Sehgal and Stoops, 1972; Sidhu et al., 1977; Bhargava et al., 1980). The calcic horizon are not impervious to plant roots and water as reported by Raychaudhuri and Govindarajan (1971) nor have they originated as a result of aeolian drift of calcareous particles from parts of Rajasthan as concluded by Dregne (1976).

The zone of calcic horizon possibly indicate the zone of shallow water table fluctuations, when water table recedes the soil solution concentrates and Ca, and Mg present in it are the first to precipitate irreversibly as carbonates. With every passing hydrological cycle the concretions continue to grow in size and occlude diverse kind of soil material (Kanwar and Sehgal, 1962).

All these reports indicate the pedogenic formation of calcium carbonate. However, there are many other reports which support the primary origin of calcium carbonate concretions. Sen (1953) compared the alkali soils of Karnal with that of adjoining normal soils and attributed the low calcium carbonate content of the later to greater leaching of calcium in these soils than the alkali soils where this process must have been restricted.

Manchanda (1978) and Ahuja (1981) reported the similarity of chemical composition of calcium carbonate nodules of the Yamuna river plain, Chautang river plain, Ghaggar river plain and inter-fluvial plains. These authors further reported the presence of these nodules in the levees and channels thereby confirming their primary origin (Manchanda et al., 1984 and Ahuja and Khanna, 1984). Dhir et al. (1982) reported the age of CaCO_3 nodules in the soils of Rajasthan between eleven to thirty thousand years while alluvial deposition based on river shifting studies is stated to be less than 10,000 years old (Bakilwal and Sharma, 1980).

2.6 Soil mineralogy

The vast alluvial tract between the mobile Himalayan mountain system and the stable Peninsular shield in the south is filled with material brought by the Himalayan as well as Southern rivers. Tectonic movements caused high lands on both sides of the 'trough' to attain steeper gradients. These aggravated the erosive power of the streams and that in turn produced more detritus which was transported and deposited. Mineralogy of coarse and fine fraction is reviewed in the subsequent paragraphs.

2.6.1 Coarse fraction mineralogy: The sand mineralogy of these alluvial soils show quartz, micas, chlorite and a few feldspars and heavy resistant minerals such as tourmaline, garnet, zircon, apatite, gypsum, calcite, barite and fresh potash feldspars of authigenic origin (Roonwal and Garlapuri, 1984). Quartz is the most abundant constituent. Muscovite-biotite and chlorite appears to be related to illite chlorite clays. Deficiency of ferro-magnesian minerals confirms the gneissic-granitic source material of these soils.

Pundeer et al. (1974) observed rounded garnet grains and quartz grains with growth structure and heavy mineral suit in the soils of Hoshiarpur district in Punjab. Authors concluded that parent material of these soils had been

derived from the reworked Siwalik formations. Pundeer et al. (1978) further reported quartz and muscovite as dominant light minerals and biotite, tourmaline, garnet, kyanite and sphene as the major heavy minerals in the Satluj plains. They suggested a dominant metamorphic and a subsidiary acid igneous terrain in the source area of these soils.

Sidhu and Sehgal (1978), while presenting the sediment mineralogy of the Indus basin reported the quartz to be dominant mineral with feldspars, micas, tourmaline, garnet, kyanite, sphene, chlorite, epidote, amphibole, zircon and opaques.

Sehgal et al. (1973), while working on the salt affected soils of Sangrur district (Pb.) reported that dominant mineral association was of hornblende-epidote and garnet with occasional presence of para metamorphic minerals, indicating the mixed origin of alluvial material.

Manchanda (1978) reported the predominance of quartz followed by muscovite and albite as light fraction minerals in the salt impregnated soils of Haryana. Higher percentage of calcite was reported in the saline soils. The heavy minerals were hornblende, chlorite and iron ores distributed in the profile with small amounts of biotite, tourmaline and zircon.

Ahuja et al. (1984) reported quartz followed by muscovite as the dominant mineral in light fraction along with albite, oligoclase, orthoclase and sericite. The heavy minerals were hornblende, iron ores, biotite, chlorite, tourmaline, zircon, epidote, apatite, garnet and sphene. Their occurrence is indicative of para metamorphic and sedimentary type of parent material of the soils of Ghaggar basin.

2.62 Fine fraction mineralogy: Most of the earlier work is mainly limited to the identification of dominant clay minerals in salt affected soils. Information on quantitative mineralogy particularly of the profile samples was generally lacking. One of the earliest report on the clay minerals of saline and alkali soils is from Kanwar (1961) who did not observe any material change in clay minerals except that salt affected soils have more illite and less chlorite. Sehgal and Connick (1971) reported that chlorite is not second largest mineral of these soils but it is intergrades of chloritised vermiculite and chloritised montmorillonite which are present in second largest amount next to illite.

Sidhu and Gilkes (1977) contradicted Sehgal (1971) observations and reported that in these young soils some chlorite is present in sand and silt fraction, which can give rise to clay sized chlorite by simple mechanical breakdown during transportation.

Kapoor (1980) reported the presence of analcime in sodic soils in addition to illite, chlorite and smectite. Further more, Kapoor et al. (1981) indicated that mixed layer minerals occur in second largest abundance. These are mostly intergrades of illite smectite and illite chlorite. Vinayak (1984) reported that illite and smectite are dominant in salt affected soils as compared to only illite soils.

Sharma (1989) reported illite, chlorite, vermiculite and smectite as the dominant minerals in these soils. Clay mineralogical suite of saline and alkali soils was similar except some small variations such as the absence of chlorite and vermiculite and presence of small quantity of kaolinite in saline soils.

Due to presence of high amounts of sodium alkali soils get highly dispersed and puddled on wetting and develop deep wide cracks and their surface

get peeled off as drying proceeds (Acharya and Abrol, 1991). However, it is difficult to visualize the cracking phenomenon in these soils due to mere presence of sodium as some swelling and shrinking type of clay has to be present.

Clay mineralogy of the soils affected with sodicity or salinity is similar to that of the main soil groups with which they are associated. In the alluvial tract these soils seem to contain higher proportions of mixed layer minerals and sodicity appears to favour the formation of three component mixed layer minerals (Ghosh and Kapoor, 1982).

2.7 . Genesis and transformation of clay minerals

Most of the mineralogical investigations have been exploratory, often confined to identification and semi- quantitative estimates of minerals. Nevertheless, there has been some attempts to explain the mineralogical composition of soil clays from known or established weathering sequences. Subsequent paragraphs present a brief review of these investigations.

2.7.1 Micas: The term 'illite' has been widely used in India to denote the non-expanding 1.0 nm layer silicates of soil clays of alluvium derived soils of Indo-Gangetic plain. Sidhu and Gilkes (1977) found both muscovite in coarse fraction and illite in clays of these soils to be of 2M, poly type, indicating that illite was derived from muscovite. The mechanism suggested were communitation and loss of part of the inter layer potassium during transportation, sedimentation and pedogenesis following deposition. Sehgal (1974) suggested the formation of trioctahedral illite from biotite.

The illite content of clays of some salt affected soil profiles was found to be decreasing down the profile (Kapoor et al., 1981). This was attributed to weathering of the illite of the surface soil clays to smectite which

preferentially get translocated downward, giving an increase of illite in the surface soil clay. This was only apparent because the illite content on soil basis increased with depth. Both dioctahedral and trioctahedral illites were found in soil clays, but only trioctahedral mineral weathered to smectite through chloritised intermediate. This report however, does not provided convincing evidence as regards the transformation of illite to smectite.

Presence of humic and fulvic acids in the soil solution plays a definite role in weathering of micas (Tan, 1978). Due to their chelating power these substances can effectively remove major constituent elements such as Fe, Al, Mg, K and Si from soil solution thus enhancing dissolution of the mineral. Schnitzer and Kodama (1976) also showed that fulvic acid can promote dissolution of micaceous minerals. The ease with which the micas were attacked and the amount of K released; decreased in the order of biotite > phlogopite > muscovite.

Fanning et al. (1989) reported that if the chemistry of leaching water favours K release, leaching promotes the transformation by carrying away the reaction products.

Swindale and Uehara (1966) and Juang and Uehara (1968) hypothesized mica synthesis in surface horizons of certain high rainfall soils of Hawaii. Their observation was based on the absence of mica in basaltic parent material, and increase in its content in < 2 μ m clay towards surface horizons. However, detailed studies by Dymond et al. (1974) of the soils studied by above workers in Hawaii pointed to the aeolian origin of mica.

Many workers have reported that interstratified or mixed layer illite/smectite in shales becomes progressively richer in illite layers and poorer in smectite layers with increasing depth of burial in sedimentary basins

and with increasing temperature (Burtner and Warner, 1986; Pollastro, 1985). The overall transformation process has been termed illitization. Potassium is preferred to Na during illitization (Ebert, 1980) because it has lower hydration energy and high selectivity by interlayer. Smectite interlayer collapses and illite forms by expulsion of Na and associated water.

Fanning (1989) covering the evidences of transformation of micas to expansible 2:1 minerals reported that mica content of clay fraction of soils developed from nearly uniform material often increases with depth, reflecting greater mica weathering at the soil surface. Kapoor et al. (1981) reported a downward decreasing clay illite content in alkali soils. However, their interpretation of more weathering of illite to smectite in surface layers and subsequent migration is not in consonance with the observations of Fanning (1989).

2.72 Expanding 2:1 layer silicates: The expanding minerals belonging to vermiculite and smectite groups are essentially weathering products of the micas. MacEwan (1948) was the first to report occurrence of vermiculite in soils. Sidhu and Gilkes (1977) observed that biotite weathered in alluvium derived soils of north-western India first to vermiculite by loss of interlayer potassium and charge reduction and later to kaolinite. The ready laboratory conversion of biotite to vermiculite by replacement of K with hydrated ions has been long known (Barshad, 1948). Kapoor et al. (1980) found the weathering of biotite to vermiculite in alkali soils through an intermediate mixed layer mineral stage.

Vermiculite may also be formed by replacement of brucite layers of magnesian chlorite by exchangeable cations in regions of high rainfall and leaching (Sehgal, 1974). The observation of Sidhu and Gilkes (1977) that a vermiculite like artifact may form from chlorite by oxidation of octahedral

ferrous iron during the laboratory pretreatment of soils with H_2O_2 should caution soil clay mineralogists.

The use of group name smectite, formerly montmorillonite, to denote the layer mineral that expands to 1.8nm with Mg saturation and glycerol solvation and collapses to 1.0nm on heating is fairly recent. The age old practice of rice cultivation, under submerged conditions, on soils developed on the Indo-Gangetic alluvium could have resulted in smectite formation nucleated by hydrous oxides of Fe on surface of layer silicates (Ghosh et al., 1976). Some saline-sodic soils of Indo-Gangetic plain are characterized by abundance of smectite in clay (Sehgal, 1974; Sidhu and Gilhes, 1977; Kapoor, 1981; Sharma, 1989). These smectites have been supposed to be formed by transformation of micas in the presence of high concentration of alkali and alkali earth cations. Minerals formed by this process are called transformation smectites (Robert, 1973).

Sharma (1981) found the smectites as the dominant clay mineral in various land forms of soils of N.E. Punjab. Abundance of this mineral in all the land forms indicate only limited pedogenesis. Author suggested that it was inherited from parent material itself in these recent alluvial soils.

Smectites become unstable whenever soil leaching becomes pronounced. Evidence is growing for the direct transformation of montmorillonite to kaolinite during intense weathering (Altschuler et al., 1963; Wilson and Cradwick, 1972; Morgan et al., 1979). Given enough time (3-4 yr) and suitably adjusted Si and Al levels the direct route occurs in the laboratory under room temperature and pressure. Smectite is unstable under improved soil drainage because of removal of bases and/or silica (Karthansis and Hajek, 1983. Drastic improvements in soil drainage can increase the weathering rates of smectite so much that even intermediately stable minerals are not formed (Combs et al.,

1982). These important observation may help to explain the drastic changes in physico-chemical characteristics of smectite containing alkali soils upon reclamation with chemical amendments or natural vegetation.

2.73 Chlorite and other interstratified minerals:

The presence of chlorite minerals in soils of India has been reported by many workers (Pundeer et al., 1978; Kapoor et al., 1981). It is possible that much of chlorite in soil is inherited from parent material. Vermiculite-chlorite intergrades were frequently found in soil clays of the Ganga plain (Raman and Deshpande, 1975) indicating the chloritisation of vermiculite.

The formation of chloritic material by interlayering of vermiculite derived from illite in some soils on alluvium was postulated by Sehgal (1974). Sidhu and Gilkes (1977), on the other hand considered clay mineral chlorite to be derived from primary chlorite by communitation. However, both random and regular interstratifications of illite and chlorite were identified in these soils (Kapoor et al. 1980a) indicating the weathering sequence: clay mica, interstratified mineral-vermiculite-smectite.

Kapoor et al. (1981) postulated a mechanism involving nucleation and silication to explain the formation of a three component interstratified mineral from biotite in the saline-sodic soils of Haryana and Uttar Pradesh.

2.74 Kaolinite: Presence of kaolinite is an indicator of a highly leached environment with good drainage. Presence of kaolinite in soil clays of semi-arid regions (Murali et al., 1978) is probably a legacy from an earlier humid climate or has been inherited from parent material (Sidhu and Gilhes, 1977). Though kaolinite may form from feldspars through an intermediate mica stage, it now appears that it is usually formed by neosynthesis from the

products of hydrolytic decomposition of feldspars and other primary minerals (Sarma and Sidhu, 1982).

2.8 Taxonomy of salt affected soils

Most of the salt affected soils of Indo-Gangetic plain in N.W. India do not find suitable places in the Soil Taxonomy of Soil Survey Staff (1975). A natric and salic horizons have been defined in the system to describe the conditions of sodicity and salinity. Natric horizon is, however, a subsurface diagnostic horizon which classifies well the typical Solonetz having a productive and fertile A horizon. Indian soils having sodicity in the surface horizon as well do not fit into the definition for natric horizon. There are certain other problems as well:

(i) Alkali soils of Indo-Gangetic alluvium plain lack a prismatic or columnar structure in the B horizon. To overcome this, Sehgal et al. (1975) proposed inclusion of subangular blocky structure within the realm of the natric horizon.

(ii) Alkali soils lacking illuvial characteristics in the B horizon qualify as Halaquepts instead of being classified as Natraqualf or Natrustalf.

(iii) The conditions of soil salinity or sodicity are difficult to depict at great group level in Entisols and Inceptisols. To solve this difficulty in classification of Entisols and Inceptisols with high pH and high ESP, Ahuja and Khanna (1983) proposed a Natric sub group with Ustifluvents and Ustochrepts.

At many places alkali soils are also associated with very high salt percentage in surface horizon. For such cases Sehgal (1975) and Srinivasan (1976) proposed a Salic subgroup with NatrustalFs. To classify Salorthids with lithological discontinuities, stratification and irregular organic carbon distribution Sehgal (1986) proposed a Fluventic subgroup with Salorthids.

Earlier Manchanda (1979) proposed Epihalic, Epinatric and Epi-halonatric subgroup to take care of salinity, alkalinity and salinity plus alkalinity problems on the surface horizon. Recently, Sharma (1989) has classified the salt affected soils of Haryana following the various proposals of Sehgal (1975) and Ahuja and Khanna (1983).

CHAPTER 3

MATERIALS AND METHODS

- 3.1 General description of area
 - 3.11 Location and extent
 - 3.12 Geology
 - 3.13 Geological formations contributing to alluvium
 - 3.14 Relief and drainage
 - 3.15 Climate
 - 3.16 Agriculture and land use
 - 3.17 Irrigation
- 3.2 Selection of pedon sites
 - 3.21 Preparation of geomorphology map
- 3.3 Macro-morphology study
- 3.4 Collection and processing of soil and water samples
- 3.5 Laboratory analysis
 - 3.51 Physical characteristics
 - 3.52 Chemical characteristics
 - 3.53 Elemental analysis
 - 3.54 Loss on ignition
 - 3.55 Mineralogical analysis
 - 3.56 Sand and silt mineralogy
 - 3.57 Thermodynamic stability of minerals

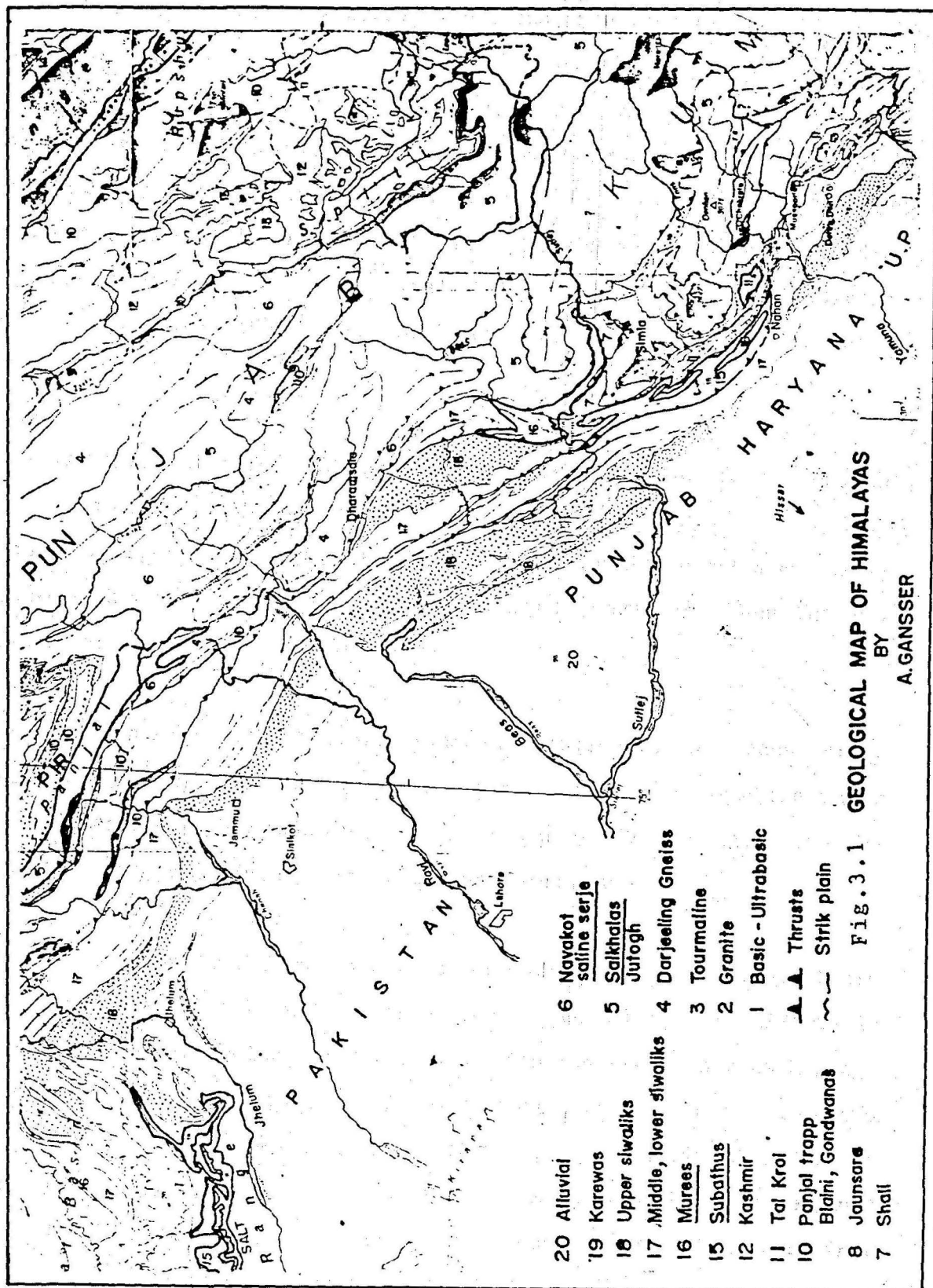
3.1 General description of area

3.11 Location and extent: Area under study falls in the Haryana state which lies between 27°39' to 30°55'N latitude and 74°29'8" to 76°36'5"E longitude

(Survey of India, (1:250,000) topo maps numbers 44 K, 44 O, 44 P, 45 M, 53 B, 53 C, 53 D, 53 F, 53 G, 53 M, 54 A and 54 E). The Haryana state constituting NW part of India is bounded by the states of Uttar Pradesh and union territory of Delhi in east, Himachal Pradesh in North, union territory of Chandigarh and Punjab in north-west, Rajasthan in south and west. Its total geographical area is 44,222 km². In general it slopes from north to south west excepting areas of Faridabad that slope south east and the areas close to Aravallis in the south where slopes are reversed.

3.12 Geology: Geologically this area lies in the divide between Satluj and Yamuna. According to Pascoe (1965) a huge sunken trough was formed as a result of tectonic changes and orogenic upheaval, between the Himalayas and Deccan Plateau which in its present form is filled up with unvarying monotony of pleistocene and sub-recent alluvial deposits of the rivers draining the Himalayas and sub-Himalaya. The exact depth of alluvium has not been ascertained but magnetic and seismic explorations show that it is variable from less than 1000 m to over 5000 m. Underlying the alluvium are unconsolidated Siwaliks and older tertiary sediments of the Himalaya piedmont and below these lie more consolidated older formations such as Gondwanas and Cretaceous. Alluvium basically comprises of the sediments washed off from the Himalayas in north as from well as the Gondwanalands on the south.

3.13 Geological formations contributing to alluvium: The geology of this area is rather complex, several geological series have been established in and around this area. At this point, it is necessary to look into some details of the geological history in order to comprehend their contribution to the alluvium carried by the draining river network. Major geological formations in the area (Fig. 3.1) traversed by the present and ancient rivers, responsible for the formation of the soils of Haryana, include the Subathus, Murrees, upper, middle and lower Siwaliks including Tal, Krol, Blaini, infra-Krol, Jutogh, Navakot,



Gondwanas, Panjal Traps, Shali and Jaunsar series. All these geological formations are of the sub and lower Himalayas and span from Pliocene to Pre-Cambrian.

The rocks of sub-Himalayan system relevant to present study can be sub-divided into two major series namely Siwaliks and Sirmur series. Siwalik series is further sub-divided into upper Siwalik (conglomerate stage), middle Siwalik (sand-rock stage) and lower Siwalik (sand stone stage). The Sirmur series has also been further sub-divided into Kasauli, Dagshai and Subathu series.

The Siwaliks are of sub-aerial fluviatile origin due to the forces of rain and river. Upper Siwalik consists of soft earths, clays and boulder conglomerates. Middle Siwaliks comprise of massive sand rocks, clays and shales. The lower Siwalik are identified by grey micaceous sand stone and the red shales. This is also known as Nahan stage.

In the Sirmur series the Kasauli series is represented by lacustrine, coarse soft grey or greenish sand stones, Dagshai series by brackish water lagoon, bright red and purple nodular clay overlain by firm sandstone and the Subathus by the gypseous shales with subordinate lenticular lime stone.

The beds of upper Siwalik conglomerate and middle Siwalik sand-rock are composed of soft sands of salt and pepper colour. The Nahan stage differs in its great induration with colour brownish and greenish brown to bluish grey. Although clays are found throughout the Siwalik system, but purple and red clays are a special character of the Nahan stage. Nahans, that consist of medium to fine-grained micaceous sandstones, siltstone and claystone and few shale bands have been further divided into upper and lower Nahans. Upper Nahans are finer grained sediments, siltstones and silty-shales with few red clay bands. Whereas

lower Nahans contain alternating thick beds of coarse grained sandstones and red clay.

The Eocene system comprises of the Ranikot (lowest), Laki (middle) and the Kirthar (upper) series. These also include the salt range and Kashmir formations. Salt Range is a continuous range of low, flat topped mountains raising abruptly out of the flat (erstwhile) Punjab plains. The range extends from longitude 74° to 71° E with approximately east-west strike. The name Salt-Range is aptly derived from the circumstances that its lower exposed rock contains large beds of pure halite. This is mainly the saline series which is mostly stiff clay, dark red colours, with abundant gypsum and salt and thin beds of dolomite (Gansser, 1964). The rock salt deposits of Pre-cambrian Shali formation exposed in a geological window near Mandi in Himachal Pradesh in Himalayan region have been correlated with the saline series of the Salt Range of Western Himalayas (Srikantia and Sharma, 1972). Much of the affluent from these area has been carried in Satluj since ages.

One of the Eocene formation includes the Subathu series of Sirmurs. Most important inliers of the Subathu type are exposed in the Murree hill zone at the hill station of Subathu (District Solan) and occur as a narrow rim bordering the out crop of Krol limestone. Murree hills (Nummulitic limestone and shale) represent Subathu stage, while Murree beds represent Dagshai and Kasauli stage. Whole of Sirmur series is a perfectly continuous and comfortable group of deposits gradually transitioning from the Subathus stage upto Dagshai stage and then into Kasauli stage. Subathu stage corresponds to Eocene deposit, while Kasauli to lower Miocene. Subathus of this area comprise of nummulitic limestone, olive-grey pyriteous or iron stone shale along with aluminous clays and dykes of ultra basic intrusions. These Eocene out crops of nummulitic limestone extends as a more or less continuous belt from Sindh and Suleman hills through Pir Panjal and with some intermission to Nainital. Subathu series is

the typically developed Eocene of outer Himalayas near Shimla. These rocks are red and grey, gypsiferous and calcareous shales with some inter-bedded sandstones and subordinate limestone including Nummulites.

The Miocene system is perhaps fully developed in India and is found in all the tertiary formations of the extra-peninsular India. Here the term-Sirmur series applies to the group ranging from Eocene to Miocene and is encountered in Shimla-Himalayas. The lower part of this group includes the Subathus whereas the upper part comprises of Dagshai and Kasauli of Sirmurs (Murree beds) belonging to lower Miocene period. The Murree out crop thins rapidly eastwards and finally merges to the typical Dagshai and Kasauli bands of Sirmur in Shimla area. It appears probable that unlike the Siwaliks, which are derived entirely from denudation of Himalayan granite and other rocks, the Murrees have originated from sediments whose source was the iron bearing Purana formation of the Peninsular highlands of south. In the Dagshai beds over lie the Subathus. Lower part of Dagshai is made up of brackish water or lagoon, bright red and purple nodular clay, whereas the upper Dagshai is a thickly stratified fine grained hard sandstone perfectly transitioning into overlying Kasauli group (Wadia, 1966).

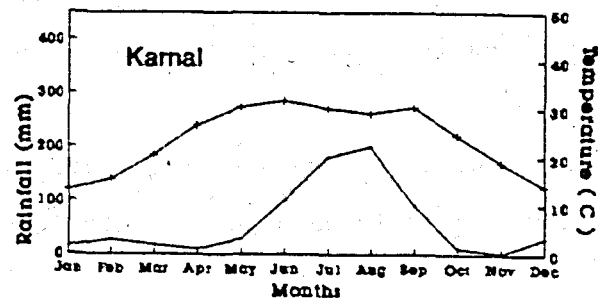
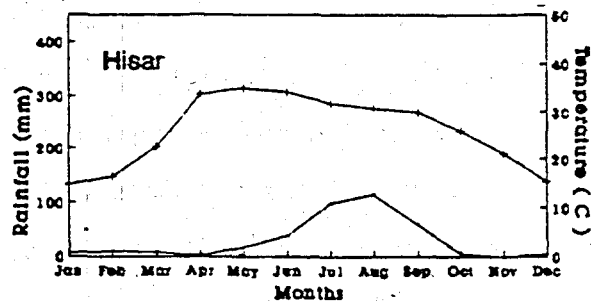
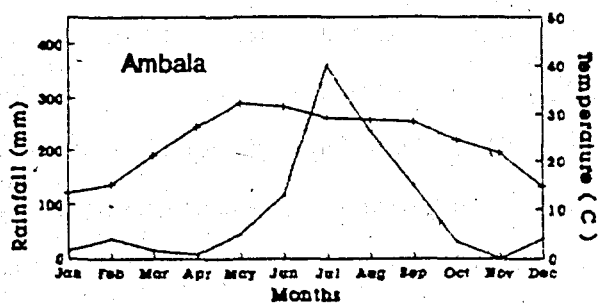
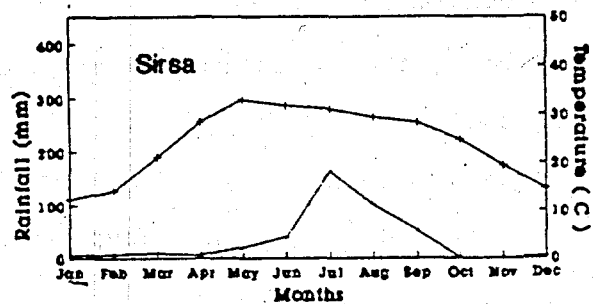
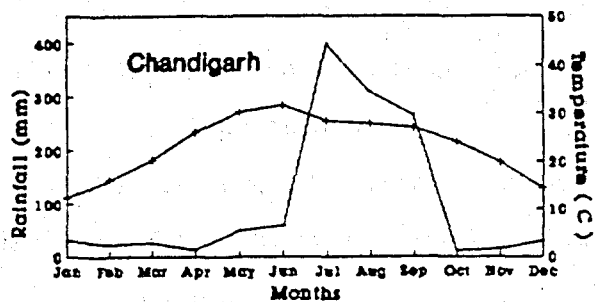
However, in the lower Miocene to Oligocene period there has been series of igneous outwards in many parts of extrapeninsular India, mainly intrusive or plutonic in nature. These events enriched the Siwaliks and Sirmurs with granite, syanite diorite and gabbro.

3.14 Relief and drainage: The general topography of the state varies from undulating in the upper reaches of north to flat in the central and southern parts. Physiographically, the area can be sub-divided into three distinct units: (i) The hilly terrain in the north-western part which varies in altitudes from 1000 m to 1150 m above mean sea level. (ii) The wavy plains : a system of

alluvial cones and intercones which overlap and coalesce together to form a wavy plain with rather a steep slope. Average altitude of this area is about 345 m above mean sea level. (iii) The alluvial plain below the wavy plain extends westwards covering greater part of Haryana state. The monotony of the plains is broken by the occurrence of sand dunes and isolated patches of Aravallis hills in the south and western parts.

The state of Haryana is mainly drained by Ghaggar, Tangri, Markanda, Sarasvati, Soan and Yamuna river network. The Yamuna flows along the eastern boundary of the state. In the ancient past entire state of Haryana was included under boundaries of the Kurukshetra (not to be confused with present Kurukshetra district) marked on the east by the Drsadvati and on the west by the mighty Sarasvati. There were several tributaries to these rivers and as such the Ghaggar, Sarasvati, Drsadvati system may thus be considered the effective network of Haryana. The Ghaggar river along with its tributaries has been shifting laterally, leaving many relict channels, bars, interlocked levees and basins. The area in between Ghaggar and old relict course of Chautang is relatively a raised upland plain. It is indiscretely covered with aeolian deposits. The lowest elevation of ground levels in the state are on an axis approximately running through Jhajjar, Bhiwani, Hisar and Sirsa where elevation vary from 200 m to 220 m. South of this depression axis the ground levels rise towards Rajasthan.

3.15 Climate: The area experiences a sub-tropical continental semi-dry monsoon type of climate with prolonged hot periods from March to October. Average annual rainfall as shown in Table Appendix - i varies from 360 mm in Hisar, 410 mm in Sirsa, 711 mm in Karnal, 1037 mm in Ambala to 1226 mm in Chandigarh. Nearly 70 per cent of the rainfall (Fig. 3.2) is received from south-west monsoon during the months of July, August and September in the districts of



— Rainfall —+— Temperature

Fig.3.2 Temperature and rainfall

Karnal, Hisar and Sirsa. Winter rains contribute significantly in the areas around Chandigarh and Ambala.

The mean monthly temperature (Fig. 3.2) is more than 20°C in eight months and less than 15°C in two to three months (Appendix - i). January and February are the coldest months. Steep rise in temperature commences in April and reaches its maximum in June. The mean annual temperature is much higher than 22°C and the difference between mean summer and mean winter temperature is much higher than 5°C. Thus the soils of these areas qualify for hyperthermic temperature regime.

3.16 Agriculture and landuse: Due to the availability and suitability of sub-soil water supplemented by large network of canals for irrigation, agriculture forms the backbone of the economy. With improved technology in the field of agriculture, including release of high yielding varieties, use of balanced fertilizers, adoption of reclamation technology and increasing mechanization, cropping intensity is continuously increasing. Paddy-wheat crop rotation is dominant in northern parts of the state. Cotton, bajra, sugarcane, maize, sunflower, gram and oilseeds are other important crops of the area.

Extensive cultivation in the area has led to large scale destruction of natural flora. The natural vegetation is mainly of the following species.

Grasses and weeds: Sarkanda (Saccharum munja), AK (Calotropis procera), Barn grass (Sorghum halepense), Dub (Cynodon dactylon), Dharan (Cenchrus spp.), Pohli (Carthamus oxycantha), Tandla (Digefera arvensis), Noonkhai (Kochia prostrata), Sporobolous marginatus, Desmostachya bipinnata, Saueda maritima, Leptochloa fusca, Dicanthium annulatum, Atriplex.

Bushes and trees: Khair dela (Caparis decidua), Malah (Ziziphus nummularia),

Shisham (Dalbergia sisoo), Kikar (Acacia nilotica), Neem (Azadirchata indica), Ber (Zizyphus jujuba), Jand (Prosopis specigera), Jal (Salvadora oleoides), Dhak (Butea monosperma), Safeda (Eucalyptus tereticornis sp.).

3.17 Irrigation: The Haryana state has an old history of being served by Western Yamuna Canal, modernized system of which is about a century old. It utilises the run of river discharge in Yamuna. It gives rise to Sirsa branch which crosses to Narwana sub division of Jind district.

Bhakra canal system became operative about 30 years ago. It utilises stored water of River Satluj through the Bhakra Dam. Scarcity of canal water in Western Yamuna Canal has been some what ameliorated by switching Sirsa Branch system to Bhakra Branch and Barwala link.

Besides this a sizable area in the state is being irrigated through tubewells exploiting the underground water.

3.2 Selection of soil sampling sites

As the present investigation was entirely dependent upon correct site location, utmost attention was given to profile site selection. For undertaking field work following procedure was adopted.

3.21 Preparation of geomorphology map of Haryana state: At the first instance uncontrolled mosaic of the study area was prepared by using false colour composites (FCC) of band 2,3,4 of the IRS-IA satellite imageries in the scale of 1:250,000. IRS-IA images pertaining to path no. 29, 30 and 31 and row no. 46, 47 and 48 were used for this purpose.

Major landforms were identified and delineated on the satellite imageries by visual interpretation on the basis of elements of landuse, landscape,

drainage and image characteristics such as tone texture etc.) so as to give geomorphology map of the Haryana state. Based on the information from geomorphological map and topo maps twenty one soil profile sites were selected so as to represent a wide range of geomorphic positions, topography, drainage, rainfall, temperature, elevation, water table, different river basins and land uses (Fig. 4.1).

3.3 Macro-morphology study

Soil profiles were exposed in the field upto about 1.5 m depth. Horizons were demarcated in each profile on the basis of soil characteristics, such as colour, texture, structure, mottling, reaction and concretions etc. Morphological description for each profile was recorded according to FAO Guidelines for Soil Profile Description (1966).

3.4 Collection and processing of soil and water samples

Representative soil samples from each horizon of the profile and water samples of the nearest tubewell, hand pump or stream were collected for laboratory analysis. Soil samples were air dried, ground in a wooden pestle mortar and made to pass through 2 mm sieve for laboratory analysis. Coarse fragments such as CaCO_3 concretions, Fe-Mn concretions or rock fragments were weighed for calculating their percentage. For organic carbon and CaCO_3 determinations, soil samples were further passed through 0.5 mm sieve.

Water samples were filtered to separate out sediments if any and stored in polythene bottles.

3.5 Laboratory analysis

Following laboratory analysis were conducted:

3.51 Physical characteristics

Particle size analysis: Particle size fractionation was carried by using the procedure of Jackson (1975). Silt and clay fractions were further separated by repeated gravity sedimentation and decantation procedure of Jackson (1975). Soil texture was estimated with the help of USDA soil textural diagram.

Hydraulic conductivity: Hydraulic conductivity of disturbed soil samples was determined by adopting the method described by Richards (1954).

Moisture retention: Moisture retention at 1/3 and 15 atmosphere pressure were determined with the Richards pressure plate apparatus (Richards and Fireman, 1943).

Bulk density: Bulk density of the clods was calculated from their mass and volume. Volume was determined by immersing the wax coated clods in a specially designed apparatus for this purpose.

3.52 Chemical characteristics: pH, electrical conductivity (EC) of the soil samples was measured in 1:2 soil water suspension and organic carbon was estimated by using Walkley and Black's titration method (Walkley and Black, 1934). Calcium carbonate was determined by acid neutralization method of Williams (1949) using a calcimeter.

Soluble salts: Saturation paste was prepared according to the procedure outlined by the Rhoades (1982). Na^+ , K^+ were determined by using EEL flame photometer Ca^{++} , Mg^{++} were analysed on Atomic Absorption Spectro-photometer. CO_3 , HCO_3 , Cl and SO_4 ions were estimated as per the procedures outlined by the Jackson (1958). pH of soil paste and EC of saturation extract were also measured.

Exchangeable cations: Cations exchange capacity was determined by the procedure of Belyayeva (1967) as modified by Jackson (1975) for calcareous and sodic soils. This method involves removal of soluble salts with 80% methanol. Sum of the cations in this leachate is equal to cation exchange capacity.

Micronutrients: The plant available fraction of Zn, Cu, Mn and Fe was determined by extracting a portion of 10g soil with 20 ml of diethylene-triamine penta acetic acid (DTPA) extractant (0.005M DTPA + 0.01 CaCl_2 + 0.1M triethanol amine adjusted to pH 7.30) (Lindsay and Norvell, 1978). Determination of these four micronutrient cations was made from this extract with an Atomic Absorption Spectro-photometer (Pye Unicam Model SP 2900 AAS).

3.53 Elemental analysis: For this purpose the soil was digested with HF in a closed vessel as recommended by Jackson (1975) for elemental analysis. About 200 mg of sand, silt, clay or soil sample, after removal of carbonates with $\text{NaOAc}-\text{CH}_3\text{COOH}$ buffer of pH 5.0, organic matter with 30% H_2O_2 and free iron oxide coatings with $\text{Na}_2\text{S}_2\text{O}_4$ was washed five times with 1M $(\text{NH}_4)\text{CO}_3$ in a centrifuge tube to replace the hydrated inter layer cations and then once with 80% methanol. Contents of the centrifuge tube were evaporated to dryness at 110°C for 12 hours. 50 mg of the sample was weighted into a 250 ml wide mouth polypropylene bottle, followed by addition of 1 ml of freshly prepared aqua regia to decompose the carbonates and disperse the sample. Then 10 ml of 48% HF was added by a plastic pipette. Bottle was screw tightened immediately and kept for 8 hours. The samples in the polypropylene bottles were heated at 80°C in an oven for 30 minutes and cooled. 100 ml of saturated H_3BO_3 solution were added to the decomposed sample and bottle was capped immediately. This H_3BO_3 addition effects the dissolution of precipitated metal hexafluorates thereby completing decomposition of the silicates. Contents of the bottle were further diluted to 200 ml by weighing. Principal advantage of this technique is that

all elements including Si and Na can be determined from a single sample solution on an Atomic Absorption Spectro-photometer.

However, in the present investigation due to non compatibility of N_2O with the instrument, Si and Al were determined colorimetrically. Other elements: Na, K, Ca, Mg, Fe, Mn, Zn Cu were determined by directly feeding the solution on Atomic Absorption Spectrophotometer. All the standards contained 0.5% (vol./wt.) aqua regia, 5% (vol./wt.) HF and 50% (vol./wt.) H_3BO_3 .

Si and Al were determined by molybdosilicate yellow colour and aluminon-acetate buffer methods, respectively, as given by Jackson (1975).

3.54 Loss on ignition: A known amount of oven dry sand, silt clay or soil fraction after pretreatments for removal of carbonates, organic matter and free iron oxides was ignited in a platinum crucible at about $950^{\circ}C$ to a constant weight. Loss in weight between $110^{\circ}C$ and $950^{\circ}C$ has been reported as loss on ignition and mainly represents the various forms water associated with the minerals (Jackson, 1975).

3.55 Mineralogical analysis: Sand, silt and clay fractions were further prepared for mineralogical analysis on x-ray diffractometer as per procedures indicated by Jackson (1975). Clay samples used for x-ray diffraction analysis were saturated with Mg as well as K separately as per the ion saturation procedure of Jackson (1975). Finally, oriented aggregate specimens were prepared from these clay suspension by coating the Mg-saturated clays on one side of slide, where as the K-saturated suspensions were coated on both sides of slide to prevent bending of slide while heating. Slides were exposed to x-ray after the following treatment: (i) Mg-saturation (ii) Mg saturation and 1:10, Glycerol: ethanol solvation (iii) K saturation (iv) K saturation and heating. Additional clay samples were boiled in 4N HCl for 1/2 hr. After

thorough washing, clays were saturated with K and slides prepared in the same manner as above x-ray diffractograms obtained after scanning samples on the x-ray diffractometer using nickel filtered Cu-K- α radiation; were interpreted for various spacings recorded by different constituent minerals. Semi-quantitative estimates were prepared on the basis of relative peak area ratio after necessary corrections for back ground following the procedure recommended by Gjems (1976) and Ghosh and Datta (1972).

3.56 Sand and silt mineralogy: Sand and silt samples were ground separately in an agate mortar and pestle and random powder x-ray diffraction pattern were obtained by packing the sample in an aluminium sample holder. Since HCl treatment was not given to sand and silt fraction so absence of kaolinite could not be confirmed and thus expressed as chlorite + kaolinite.

3.57 Thermodynamic stability of minerals: Stability diagrams of primary and secondary alumino-silicates were prepared by employing the thermodynamic model for predicting the weathering and stability of minerals as given by Rai and Lindsay (1975) by employing Gibb's standard free energy of formation (ΔG^0).

CHAPTER 4

EXPERIMENTAL RESULTS

4.1 Geomorphology

4.2 Geomorphology and soils

4.3 Soil characteristics

(morphology, physico-chemical, characteristics, micronutrients, exchangeable cations, saturation extract analysis, elemental analysis of sand, silt, clay, soil, coarse fragments, soil taxonomy, thermo-dynamic stability of minerals, qualitative and semi-quantitative analysis of sand, silt and clay minerals)

4.31 Siwalik hills

4.32 Piedmont

4.33 Alluvial plain

4.4 Water quality

4.1 Geomorphology

Geomorphological analysis of the Haryana state was made by using informations on geology, topography and drainage pattern in conjunction with the elemental analysis and image characteristics of satellite imageries. Seven major landforms units in the state have been identified. These are (i) Siwalik hills (ii) piedmont plains (iii) active flood plain (iv) alluvial plains (v) fluvio-aeolian plains (vi) aeolian plains (vii) Aravallis and pediments. Location of pedon sites in various geomorphic units is depicted in figure 4.1.

4.2 Geomorphology and soils

Soil forming factors: Climate, vegetation, parent material, relief and time are responsible for the formation as well as differentiation of the soil profiles. Earlier work as reviewed in the previous chapter indicated geomorphology and local topography as the major factors for the development of alkalinity in the soil profile. Accordingly, two catenary sequences representing most of the geomorphological units were studied.

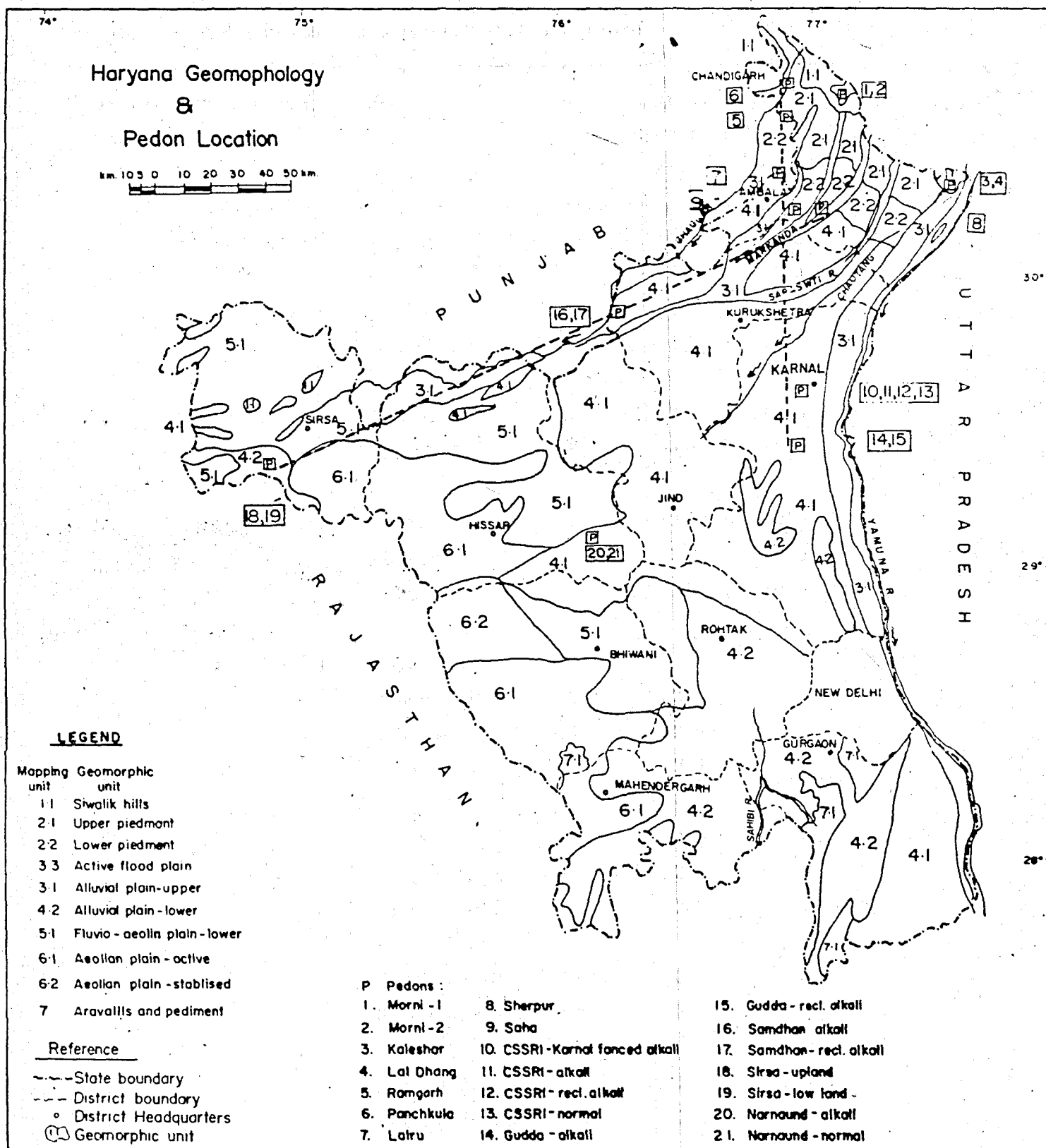


Fig.4.1 Geomorphology and pedon location map of Haryana

Table 4.1 Geomorphology and pedon reference table

Mapping Unit	Geomorphology	Pedon	No.	Approx. Elevation (m)	Approx. Rainfall (mm)
1.1	Siwalik Hill	Morni-1	1	1175	1200
		Morni-2	2	1150	1200
		Kaleshar	3	613	1250
		Lal Dhang	4	613	1250
2.1	Upper Piedmont	Ramgarh	5	380	1100
		Panchkula	6	480	1125
2.2	Lower Piedmont	Lalru	7	285	1050
		Sherpur	8	285	1050
		Saha	9	276	1050
4.1	Alluvial plain-upper	CSSRI, Karnal			
		-fenced alkali	10	245	711
		-alkali	11	245	711
		-recl.alkali (20 yr)	12	245	711
		-normal	13	245	711
		Gudda-alkali	14	237	711
		Gudda-recl. (10 yr)	15	237	711
		Samdhan-alkali	16	228	700
		Samdhan-recl. alkali(5 yr)	17	228	700
		Narnaund-alkali	18	228	360
		Narnaund-normal	19	219	360
4.2	Alluvial plain-lower	Sirsa-upland	20	198	410
		Sirsa-lowland	21	198	410

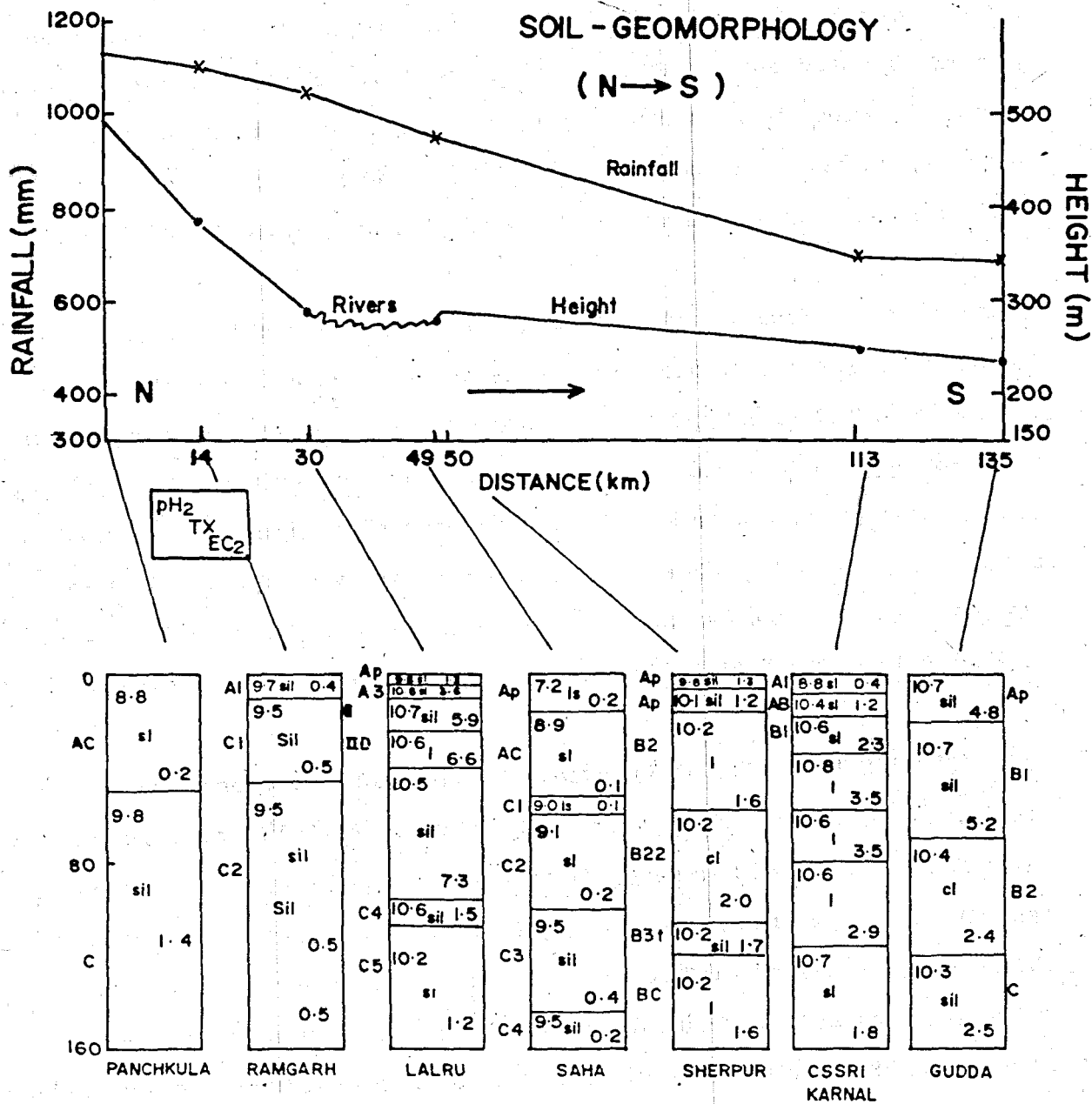


Fig.4.2 Soil geomorphology, North-South transect

4.21 North-south transect: This section starts in north ($76^{\circ}54'54''\text{E}$, $30^{\circ}44'47''\text{N}$) and extends in south ($76^{\circ}56'45''\text{E}$, $29^{\circ}30'8''\text{E}$), thus covering a distance of about 135 km (Fig. 4.2). It represents the areas of lower Siwalik hills, upper piedmont, lower piedmont and the upper alluvial plains. General direction of slope is from north to south; however at the base of piedmont there is sharp break in the degree of slope. This break point is also intersected by various rivers: Ghaggar, Tangri and Markanda. Elevation varies from 480 m to 237m. Average rainfall ranged from about 1100 mm to about 711 mm.

To study the effect of physiography-topography on the development of alkali soils only three soil characteristics were considered texture, pH_2 and EC_2 . Barring the surface horizon, irrespective of the variation in elevation or rainfall, soil texture was dominantly silt loam followed by loam and clay loam. There was not much difference in pH_2 . The pH of B horizon varied only from 8.8 to 10.7. Similarly EC_2 was generally below 4 dSm^{-1} except in the Lalru upland soils. Maximum EC_2 in case of Lalru uplands, situated at an elevation of 285 m and with a rainfall of about 1000 mm, was 5.8 dSm^{-1} ($\text{EC}_2 = 21.9 \text{ dSm}^{-1}$).

4.22 North-west transect: Starting in north ($77^{\circ}1'28''\text{E}$, $30^{\circ}21'16''\text{N}$) this section extends upto $74^{\circ}54'1''\text{E}$, $29^{\circ}26'11''\text{N}$ in west of Haryana state (Fig. 4.3). It represents the area of lower piedmont at the base of Siwalik hills and lower alluvial plain. General direction of slope is from north to west. At the base of piedmont, the slope is broken by the old track of Sarasvati river thereafter the change in slope is quite gentle. Elevation varied from 285m in north to 198 m in west. Average rainfall varied from 950 mm in north to only 325 mm in west.

Texture was dominantly silt loam followed by clay loam, loam and silty clay with the exception of upper parts of Saha profile having lithological discontinuity and the Samdhan alkali profile existing close to old river channel of the Sarasvati river. Here the pH_2 varied from 10.1 to 8.5. Interestingly,

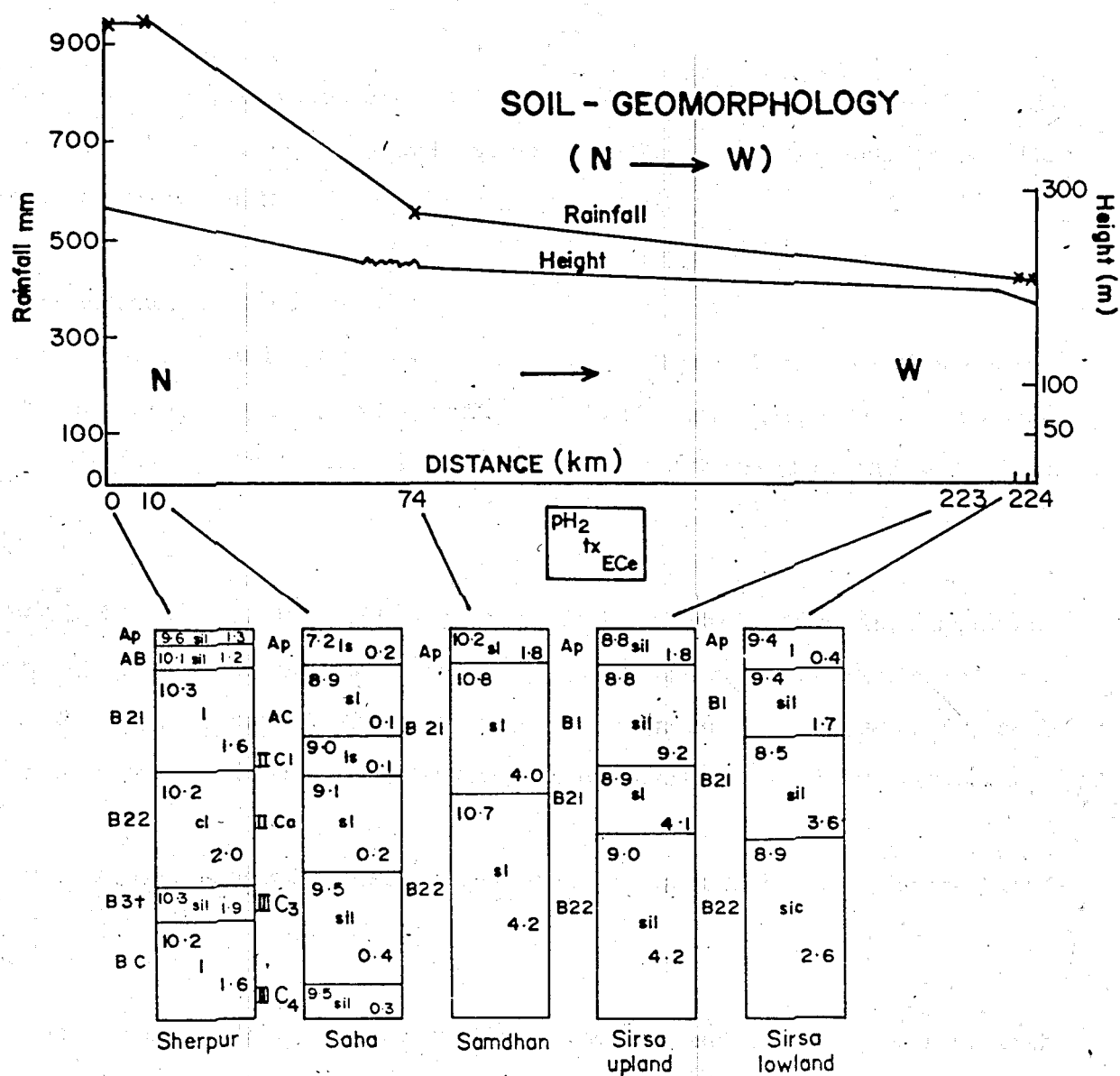


Fig.4.3 Soil geomorphology, North-West transect

the pedons located at higher elevation had relatively higher pH as compared to pedons at lower elevation in the west. The EC_e of all the pedons was generally less than 4 dSm^{-1} .

Thus, a general comparison of both the transects indicated that geomorphology, local topography and rainfall may not be responsible for the alkalinity of these soils.

4.3 Soil characteristics

Morphological and physico-chemical characteristics, thermodynamic stability of primary and secondary minerals and mineralogy of the typical pedons (table 4.1) representing different landform are discussed in subsequent pages.

4.31 Siwalik hills: Siwalik hills have been further sub-divided into upper and lower parts. These soils have udic moisture regime and hyperthermic temperature regime. These areas have 25-30 per cent slope and are excessively drained. Representative soils of upper and lower part of Siwaliks are discussed below.

4.311 Siwalik hills-upper: These areas are represented by the Morni-I and Morni-II pedons.

Morphology: These soils have dark reddish brown to reddish brown colour with hue varying from 5YR to 7YR and value and chroma ranging between 3 and 4. Texture varied from sandy loam to loam. Soils have (Table 4.1.1, 4.2.1) ochric epipedon. Structure of B horizon in both the soils is moderate, medium sub-angular blocky. Morni-I soils have thin patchy cutans and were calcareous in nature below 11 cm, Morni-II soils were relatively coarser in texture and were non-calcareous.

Physical characteristics: A perusal of table 4.1.2 and 4.2.2 indicates that Morni-I soils have higher amounts of clay, available water content and bulk density as compared to Morni-II soils. Hydraulic conductivity of the Morni-II soils was higher (1.11 to 1.68 cm hr^{-1}) than the Morni-I soils indicating better drainability of these soils. A decrease in available water content even with increase of clay content with depth in Morni-I pedon may be due to migration of fine clay and/or the effect increasing calcareousness of the profile. Presence of thin patchy cutans in the B horizon of these soils has been indicated under under macro-morphology.

Chemical characteristics: These soils (Table 4.1.2 and 4.2.2) have medium to high organic carbon(O.C.) There is general decrease in O.C. content with depth. Morni-I soils have as high as 1.27 per cent of O.C. in the surface horizon. pH_2 increased from 8.1 in surface horizon to 8.9 in lower depths in Morni-I soils. However, the same was around 7.6 in the non-calcareous soils of Morni-I. Increasing CaCO_3 content may be responsible for the increasing pH with depth in the Morni-I soils. EC_2 of all the soils was less than 0.4 dSm^{-1} .

Micro-nutrients: These soils have high amounts of DTPA extractable Fe, Mn and Cu, however, the contents of Zn were less than critical in the subsurface horizons (Table 4.1.2 and 4.2.2).

Exchangeable cations: Calcium appears as the dominant cation in these soils (Table 4.1.3 and 4.2.3). Exchangeable sodium varied from 0.6 to 0.8 cmol kg^{-1} with only exception of surface horizon of Morni-I having 1.5 cmol kg^{-1} of exchangeable sodium. Magnesium varied from 0.3 to $0.8 \text{ c mol kg}^{-1}$. Morni-I soils had relatively more exchangeable potassium. CEC and ESP of Morni-I varied from 11.29 to $13.05 \text{ c mol kg}^{-1}$ and 9 to 11 ranged between 6.64 to $7.72 \text{ c mol kg}^{-1}$ and 9 to 7 respectively with depth.

Saturation extract: This pHs of Morni-I (Table 4.1.4) and Morni-II (Table 4.2.4) varied from 8.0 to 8.3 and 7.4 to 7.6 respectively. EC_e of these soils was less than 0.76 dSm^{-1} . Calcium followed by magnesium and bicarbonate followed by chlorides were the dominant cations and anions, respectively. Carbonates were absent. Amounts of potassium and sulphate were very low. Water soluble sodium varied from 0.63 to 0.20 me/l. SAR of all the samples was negligible.

Elemental composition (per cent): Elemental composition of sand (2.0–0.05 mm), silt (0.05–0.002 mm) and clay fractions ($< 0.002 \text{ mm}$) of soil and whole soil after removal of carbonates, organic matter, free iron oxides, exchangeable and water soluble ions was analysed. Coarse fragments were analysed without any pre-treatment.

Sand: The SiO_2 and Al_2O_3 contents varied from 85.48 to 90.16 and 2.44 to 3.06, respectively (Table 4.1.5 and 4.2.5). Fe_2O_3 content increased with depth generally MgO varied from 0.58 to 2.0 and Na_2O varied from 0.99 to 1.24. K_2O ranged between 0.23 to 0.38. MnO content varied from 0.009 to 0.037 in different horizons. Loss on ignition ranged between 1.2 to 3.8.

Silt: The SiO_2 and Al_2O_3 of these soils varied between 70.37 to 75.13 and 11.48 to 15.26, respectively (Table 4.1.6 and 4.2.6). Fe_2O_3 ranged between 2.4 to 4.03. MgO and Na_2O varied between 1.09 to 3.17 and 1.11 to 1.46, respectively. K_2O content ranged between 1.09 to 1.93. P_2O_5 varied from traces to 0.082. MnO content ranged between 0.031 to 0.054. Loss on ignition varied from around 2.0 to 4.7.

Clay: The SiO_2 and Al_2O_3 content ranged between 50.1 to 52.8 and 22.18 to 24.38 respectively (Table 4.1.7 and 4.2.7). Fe_2O_3 content varied from 3.41 to 4.93. MgO and Na_2O varied from 2.14 to 4.79 and 0.15 to 0.17, respectively. K_2O content ranged between 1.8 to 1.9 in Morni-I and 1.5 to 1.7 in Morni-II soils.

MnO and ZnO content varied from 0.018 to 0.084 and 0.017 to 0.039, respectively. Loss on ignition in these soils ranged from 6.7 to 10.8.

A comparison of the elemental composition of the three fraction indicated that in general contents of SiO_2 , Na_2O decreased while the contents of Fe_2O_3 , MgO , K_2O , P_2O_5 , ZnO and MnO and loss on ignition increased with increase in the fineness of mineral fraction.

Soil: There was a general increase in Al_2O_3 , Fe_2O_3 , MgO and K_2O content with depth upto B horizon (Table 4.1.8 and 4.2.8). However, the reverse was observed in the SiO_2 and Na_2O content. Soils of Morni-II had more SiO_2 and less Al_2O_3 as compared to Morni-I soils. Loss on ignition in Morni-II soils was higher, varying from 4.4 to 6.4.

Coarse fragments: The coarse fragments in both soils varied a great deal:

Morni-1: The SiO_2 , Al_2O_3 , Fe_2O_3 , CaO upto 60 cm varied between 33.5 to 42.9, 1.2 to 2.2, 1.7 to 2.1 and 20.2 to 24.3, respectively (Table 4.1.9). The C horizon had higher amounts of SiO_2 , Fe_2O_3 , Al_2O_3 , Na_2O and K_2O but lesser amounts of CaO (8.74). Loss on ignition varied between 4.69 to 5.62. High amounts of CaO in these coarse fragments was due to their calcareous parent material.

Morni-2: Coarse fragments of these soils were non calcareous and had high amounts of SiO_2 ranging between 83-90 (Table 4.2.9). Al_2O_3 and Fe_2O_3 varied from 2.1 to 2.2 and 2.7 to 2.9, respectively. MgO content was lower and Na_2O was higher than the Morni-1 soils. K_2O content of these coarse fragments was closer to those of the C horizon of Morni-1. CaO content was very low. Loss on ignition varied from 2.4 to 2.9. A perusal of the foregoing results indicated that these hills have soils derived from calcareous parent material in the upper depths and these are under lain by soils derived from non-calcareous weathered sandstone materials.

Soil Taxonomy: Soils have been classified as per the guidelines of Soil Survey Staff (1975). Morni-1 soils have well developed cambic B horizon and are calcareous through out with a udic moisture regime. As such these have been classified as fine loamy, mixed hyperthermic, Typic Eutrochrept. Morni-2 soils are non calcareous and a developed cambic horizon. As such these have been classified as coarse loamy, skeletal, mixed, hyperthermic Typic Dystrochrept.

Stability of alumino-silicates: Equilibrium reactions between soil minerals and the ambient soil solution control the solubility/weatherability or stability of the alumino-silicates. Elementary thermodynamics has been used to find the stability of various primary and secondary alumino-silicates.

The soil solution activities of Al^{3+} and H_4SiO_4 maintained by various primary and secondary minerals at the pHs and at the activity level of various constituent cations are depicted in figure 4.4. In these diagrams the minerals that maintain the lowest Al^{3+} activity at a given H_4SiO_4 level are the most stable.

Morni-2 soils have good hydraulic conductivity and are excessively drained owing to their topographical position. Under such leaching environment these are likely to maintain a low level of H_4SiO_4 activity.

Thus, at pHs 8.0 and at activity levels of constituent cations in soil solution, under low level of H_4SiO_4 ($10^{-5}M$) activity, common alumino-silicates in A horizon of Morni-1 pedon change in stability in the increasing order as: vermiculite, albite, microcline, illite, montmorillonite, muscovite, kaolinite and chlorite.

Similarly, at pHs 8.2 and 8.3 and at constituent cations activity levels in soil solution under low level of H_4SiO_4 ($10^{-5}M$) activity, common

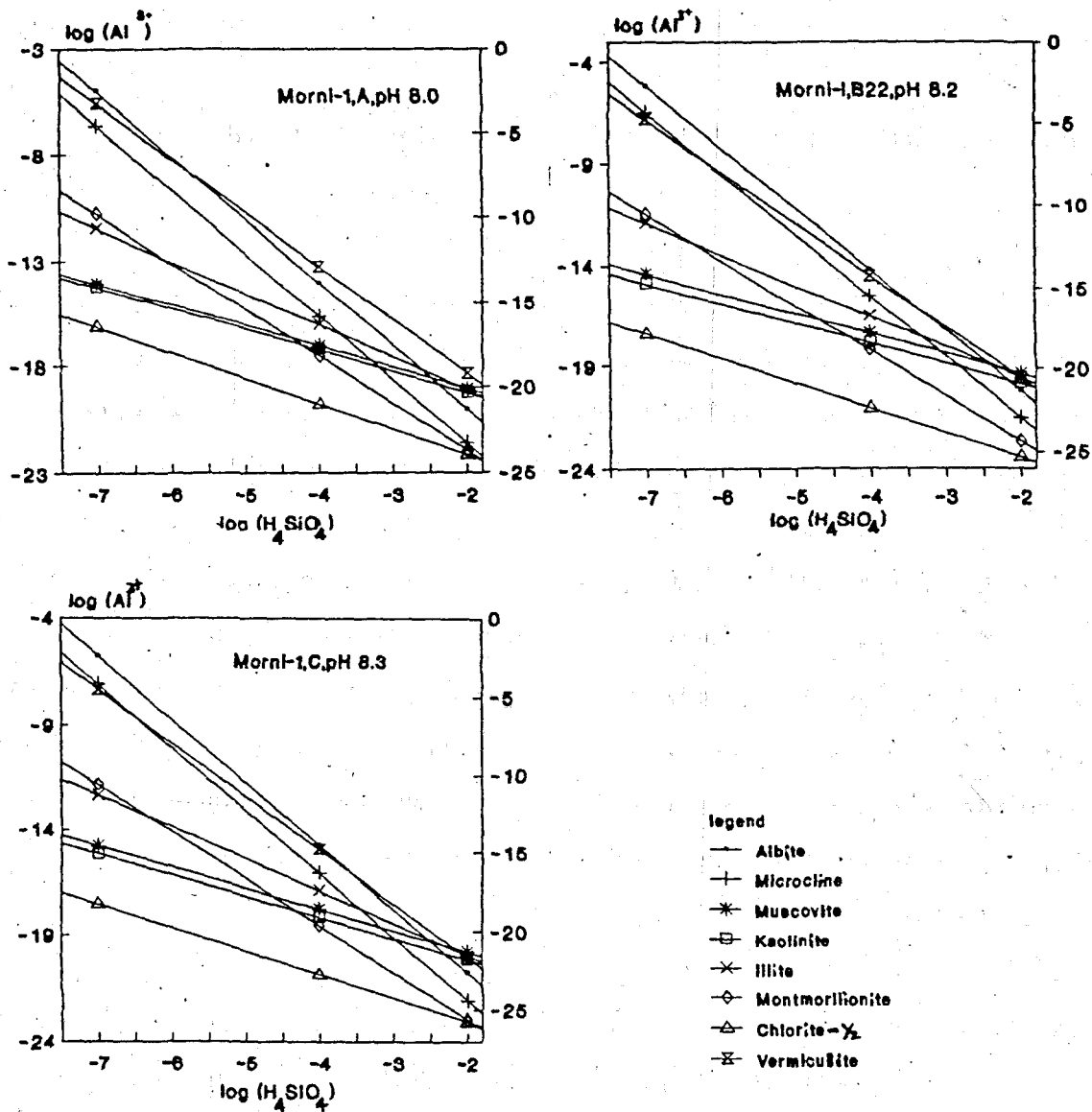


Fig. 4.4 Stability of aluminosilicates

alumino-silicates in B22 and C horizon of Morni-1 pedon can be arranged in order of increasing stability as: albite, vermiculite, microcline, illite montmorillonite, muscovite, kaolinite and chlorite.

Thus under these highly leaching environment albite and vermiculite are less stable.

Mineralogy: X-ray diffraction analysis of sand (2-0.05 mm), silt (0.05-0.002 mm) and clay (< 0.002 mm) fractions of the soils for selected horizons was carried out. X-ray diffraction patterns have been interpreted for qualitative and semi-quantitative information. Results obtained are presented below.

Sand: In the surface horizon of Morni-2 soils (Fig. 4.5, Table 4.1.10) the quartz (0.426 nm) was the dominant mineral followed by mica (1.0 nm), plagioclase feldspars (0.321 to 0.328 nm), chlorite (1.4 nm), orthoclase feldspars (0.312 to 0.323 nm), amphiboles (0.845 nm) and mixed layer minerals (1.21 nm). In the subsurface horizon calcite (0.303 nm) A) was the second most dominant mineral after quartz and other minerals were in the same order of preponderance.

Silt: Mineralogy of silt fraction (Fig.4.5, Table 4.1.10) was similar to the sand fraction excepting that chlorite and calcite were absent in surface horizon. Micaceous minerals and plagioclase feldspars increased and calcite decreased considerably. General order of mineral preponderance in subsurface horizon was quartz, mica, plagioclase feldspar, chlorite, calcite, mixed layer minerals and amphiboles.

Clay: X-ray diffractogram (Fig.4.6, 4.7, 4.8) of clay indicated a very strong and well defined peaks for illite (1.0, 0.498, 0.333 nm) accompanied by a strong 1.4 nm peak alongwith its higher orders at 0.472 nm and 0.354 nm in Mg-treated

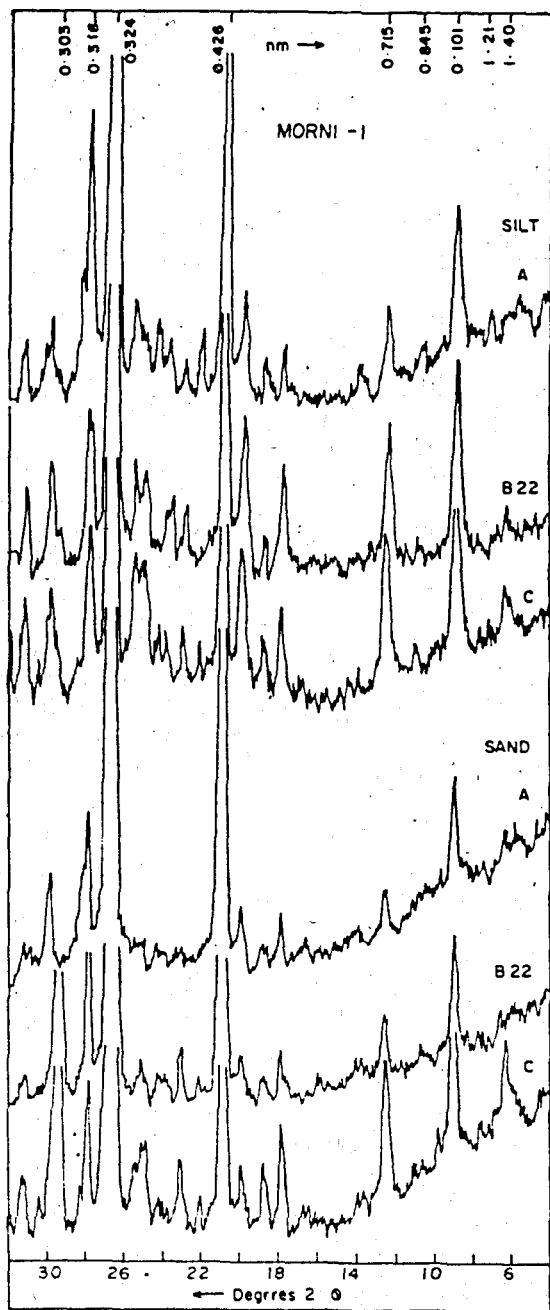


Fig. 4.5 XRD pattern of sand and silt minerals

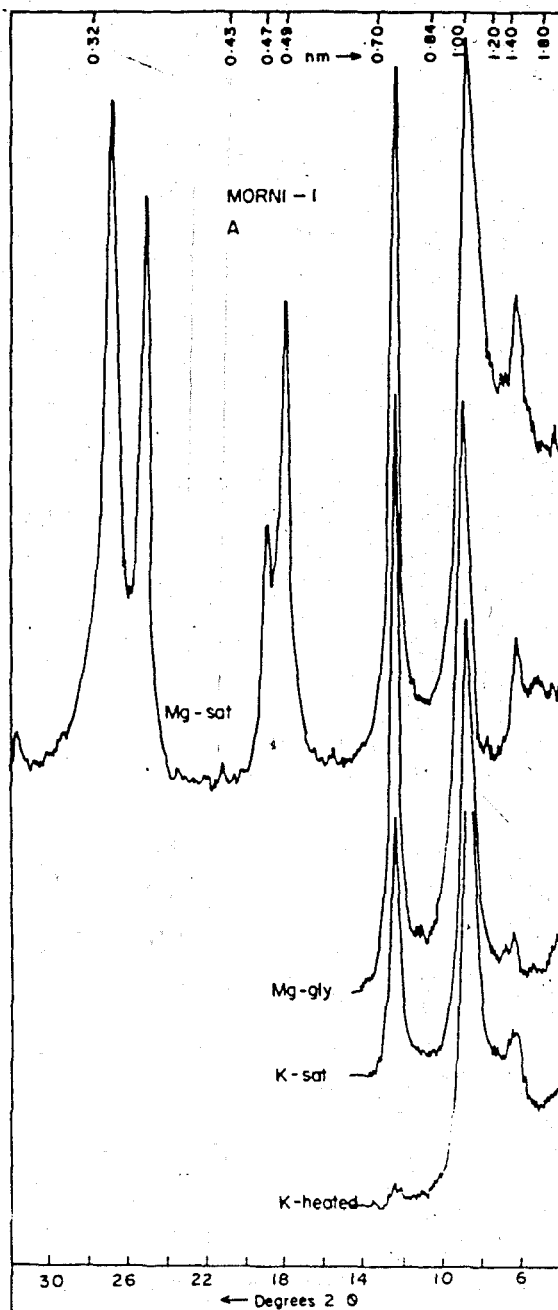


Fig. 4.6 XRD pattern of clay minerals

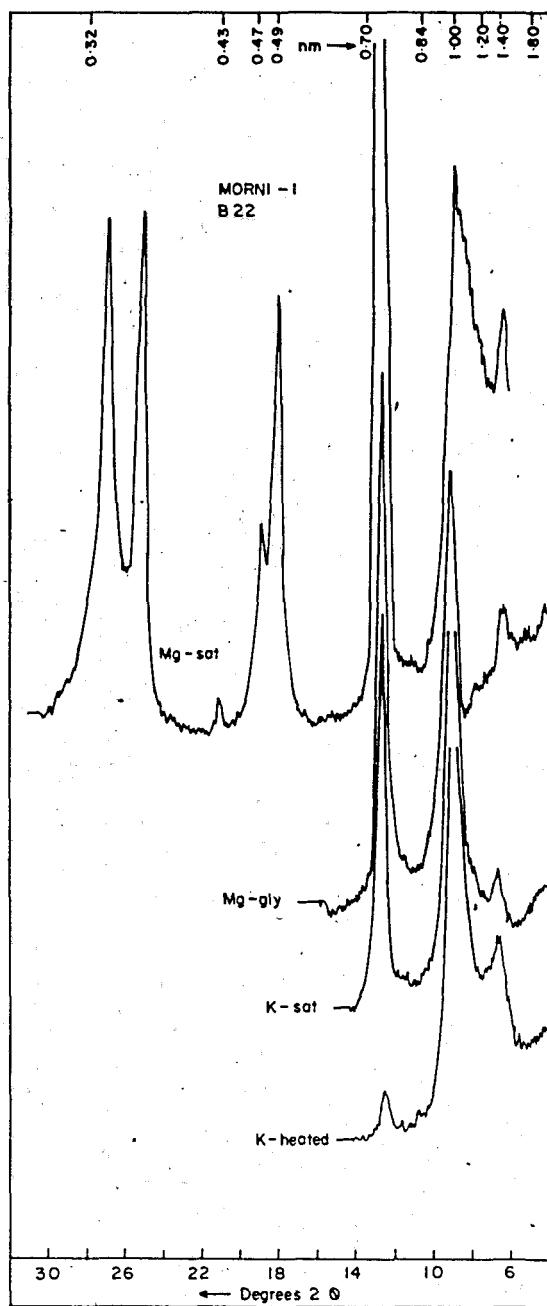


Fig. 4.7 XRD pattern of clay minerals

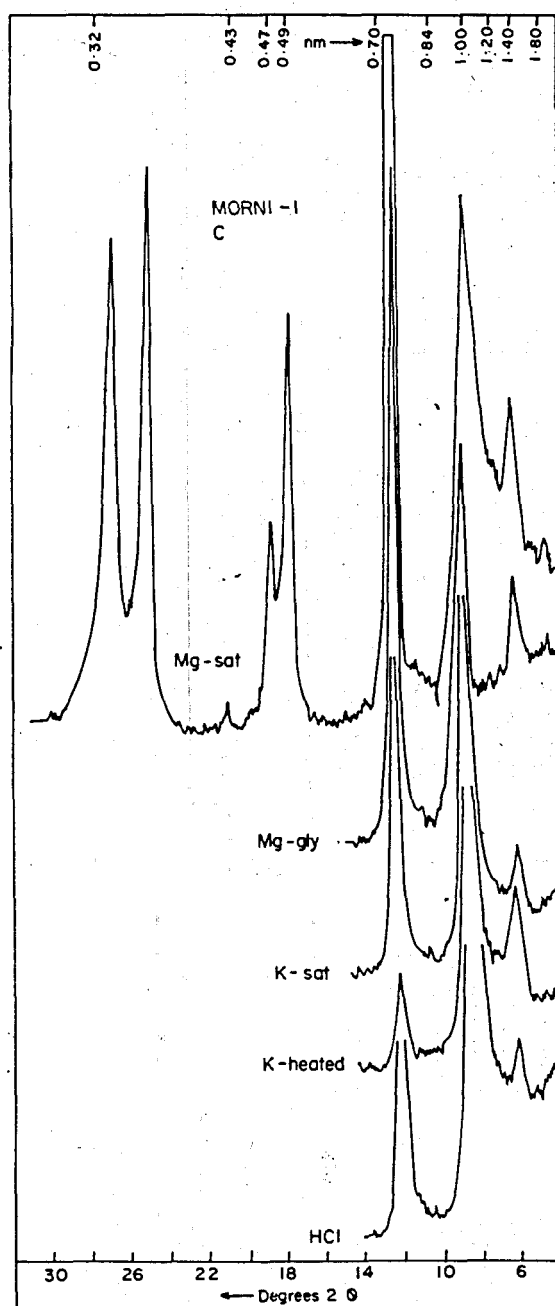


Fig. 4.8 XRD pattern of clay minerals

Pedon No. 1

MORNI - 1

Classification: Typic Eutrochrept, fine loamy, mixed, hyperthermic

Location: 77° 4' 10"E, 30° 42' 10"N, 5 km before village Morni

Physiography: Siwalik hills

Topography: Hill crest with 25 percent slope

Drainage: Excessively drained

Landuse: Scrubby forest, pines, cactus

Elevation = 1175 m

Rainfall: 1200 mm

Table 4.1.1 Morphology

Lab. No.	Depth (cm)	Horizon	Boundary	Colour (moist)	Texture (USDA)	Structure	Consistence (wet)	Cutans	Roots	Coarse fragments	Reaction
7	0-5	A	cw	7.5YR 4/4	1	1m, sbk	wss, wsp	-	m, vf-f	-	-
8	5-11	B1	bw	5YR 4/4	1	2m, sbk	wss, wsp	-	m, f	-	-
9	11-27	B21	aw	5YR 3/4	1	2m, sbk	wss, wsp	p, tn	c, f	conca, c	3
10	27-44	B22	gw	5YR 4/4	1	2m, abk	wss, wsp	p, tn	c, f	conca, c	4
11	44-60	BC	cw	5YR 4/4	1	2m, abk	wss, wsp	p, tn	c, f	conca, c	4
12	60-115+	C		5YR 4/4	1	2m, abk	wss, wsp	-	f, f	conca, c	4

Table 4.1.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)			Coarse fragments (%)	Water content (%)		
		Sand (2 - 0.05)	Silt (0.05 - 0.002)	Clay (< 0.002)		1/3 bar	15 bar	Available
-----% of < 2 mm-----								
7	0-5	44.8	36.3	18.9	-	24.0	7.7	16.3
8	5-11	35.7	40.4	23.9	36	26.0	7.6	18.4
9	11-27	40.4	35.4	24.2	21	20.6	7.5	13.1
10	27-44	26.8	47.3	25.9	27	18.2	6.2	12.0
11	44-60	34.2	47.3	18.5	41	18.1	5.4	12.7
12	60-115+	34.6	49.0	16.4	70	17.8	4.8	13.0

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)			
								Fe	Mn	Cu	Zn
7	0-5	1.27	0.0	8.1	0.38	1.65	0.366	11.8	6.5	0.30	0.60
8	5-11	0.52	0.8	8.4	0.22	1.71	0.255	5.4	4.7	0.50	0.40
9	11-27	0.39	2.8	8.6	0.20	1.73	0.225	3.0	5.4	0.38	0.26
10	27-44	0.24	6.9	8.8	0.17	1.72	0.200	2.2	5.1	0.30	0.34
11	44-60	0.15	10.2	8.9	0.16	1.71	0.245	2.2	3.7	0.30	0.30
12	60-115+	0.06	7.7	9.0	0.14	1.68	0.303	2.0	2.4	0.40	0.32

Table 4.1.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)				CEC	ESP
		Na	Mg	Ca	K		
						(c mol kg ⁻¹)	
7	0-5	1.5	0.8	10.4	0.37	13.1	11
8	5-11	0.8	0.5	10.4	0.18	11.9	7
9	11-27	0.8	0.5	11.0	0.12	12.4	6
10	27-44	0.6	0.5	11.6	0.14	12.8	5
11	44-60	0.6	0.3	11.1	0.15	12.2	5
12	60-115+	0.6	0.3	10.2	0.15	11.3	5

Table 4.1.4 Saturation extract analysis

Lab. No.	Depth (cm)	Saturation (%)	pH _s	EC _e dSm ⁻¹	Saturation extract analysis (me/l)							SAR	
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl		SO ₄
7	0-5	49.8	8.0	0.76	0.63	2.5	4.3	0.48	-	4.3	2.5	0.40	0.3
8	5-11	48.5	8.2	0.55	0.15	2.8	3.0	0.05	-	4.2	1.5	0.18	0.1
9	11-27	45.0	8.2	0.56	0.20	2.8	2.6	0.09	-	2.5	2.5	0.34	0.1
10	27-44	44.3	8.2	0.38	0.14	1.9	1.8	0.05	-	1.7	1.1	0.64	0.1
11	44-60	41.0	8.3	0.37	0.15	1.2	2.0	0.06	-	1.5	2.0	0.16	0.1
12	60-115+	43.7	8.3	0.39	0.20	1.3	2.3	0.08	-	1.5	1.7	0.20	0.1

Table 4.1.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
7	0-5	89.0	2.44	1.05	0.0	0.83	0.99	0.23	0.78	0.009	1.89
8	5-11	89.8	2.92	1.09	0.4	1.58	1.12	0.34	0.02	0.030	2.55
9	11-27	90.2	2.60	1.03	0.0	2.90	1.03	0.27	0.37	0.037	1.56
10	27-44	89.7	2.56	1.39	0.6	1.08	0.99	0.29	-	0.071	2.90
11	44-60	87.0	2.70	1.13	0.7	0.58	1.03	0.32	-	0.134	3.81
12	60-115	85.5	3.06	1.63	0.2	0.92	1.15	0.38	-	0.017	3.08

Table 4.1.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
	0-5	72.8	13.1	2.43	0.0	2.00	1.46	1.12	0.08	0.054	3.02
	5-11	72.6	13.8	2.42	0.0	2.17	1.11	1.09	0.05	0.044	2.58
	11-27	71.3	14.7	3.05	0.0	2.25	1.27	1.56	0.06	0.052	3.65
10	27-44	70.2	15.3	2.99	0.1	1.09	1.11	1.68	0.05	0.050	1.88
11	44-60	71.2	14.1	2.89	0.1	3.17	1.24	1.75	0.03	0.049	2.35
12	60-115	70.4	14.3	4.03	0.0	2.59	1.42	1.85	0.08	0.046	3.79

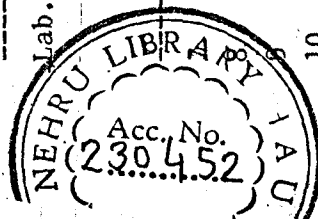


Table 4.1.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	
7	0-5	50.1	23.8	4.39	0.0	2.97	0.16	1.89	0.03 1.89
8	5-11	51.3	22.2	4.02	0.0	2.40	0.15	1.89	0.04 6.67
9	11-27	51.9	23.2	3.99	0.0	2.22	0.15	1.86	0.05 6.82
10	27-44	50.8	24.1	3.89	0.0	2.39	0.14	1.85	0.04 9.14
11	44-60	51.9	22.1	3.63	0.0	4.79	0.15	1.89	0.04 8.94
12	60-115	52.8	23.1	3.96	0.1	3.56	0.12	1.90	0.02 7.85

Table 4.1.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	
7	0-5	74.9	10.6	3.60	0.0	1.34	0.58	0.61	0.063 5.89
8	5-11	72.6	11.2	3.66	0.0	1.22	0.50	0.51	0.076 4.32
9	11-27	73.0	11.6	4.09	0.0	1.70	0.33	0.76	0.045 4.43
10	27-44	70.4	13.3	3.90	0.3	1.57	0.30	0.79	0.028 5.93
11	44-60	73.2	11.8	3.49	0.6	1.55	0.37	0.70	0.057 6.46
12	60-115+	73.6	11.6	3.80	0.8	1.95	0.42	0.72	0.070 6.41

Table 4.1.9 Elemental composition of lime concretions

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	MnO
8	5-11	42.9	1.2	1.99	20.6	2.02	0.22	2.46	0.16	0.226
9	11-27	42.4	1.4	2.06	20.2	1.10	0.16	0.46	0.06	0.163
10	27-44	33.5	2.1	1.70	24.3	1.72	0.16	0.41	0.13	0.173
11	44-60	39.3	2.1	2.10	22.6	1.09	0.18	0.46	0.11	0.129
12	60-115+	72.6	2.2	2.42	8.7	1.59	0.23	0.55	0.04	0.090

Table 4.1.10 Semi-quantitative estimates of sand and silt minerals

Lab.No.	Depth (cm)	Chlorite	Mixed layers	Mica	Amphibole	Chlorite + Kaolinite	Quartz	Orthoclases	Plagioclases	Calcite
Sand										
7	0-5	++	+	+++	++	++	+++++	++	+++	-
10	27-44	++	++	+++	+	++	+++++	++	++	++++
12	60-115+	+++	+	+++	++	+++	++++	++	++	++++
Silt										
7	0-5	-	++	+++	++	++	+++++	++	++++	-
10	27-44	++	++	+++	++	+++	+++++	++	+++	++
12	60-115+	++	++	+++	++	+++	+++++	++	+++	++

4.1.1.11 Semi-quantitative estimates of clay minerals

Lab. No.	Depth (cm)	Smectite	Chlorite	Vermiculite	Illite %	Mixed layer	Kaolinite	Quartz	Feldspar	Amphibole
7	0-5	3	8	4	73	6	4	1	1	-
10	27-44	2	7	4	72	9	3	1	1	1
12	60-115+	1	7	3	75	4	6	1	2	1

Pedon No. 2

MORNI - 2

Classification: Typic Dystrachrept, coarse loamy, mixed, hyperthermic

Location: 77° 4' 10"E, 30° 42' 10"N, 5.25 km before village Morni

Physiography: Siwalik hills

Topography: Hill crest with 30 percent slope

Drainage: Excessively drained

Landuse: Scrubby forest, pines, cactus

Elevation = 1150 m

Rainfall: 1200 mm

Table 4.2.1 Morphology

Lab. No.	Depth (cm)	Horizon	Boundary	Colour (moist)	Texture (USDA)	Structure	Consistence (wet)	Cutans	Roots	Coarse fragments	Reaction
13	0-10	A	gw	5YR 4/4	s1	2m,sbk	wso,wpo	-	c,f	-	-
14	10-29	B	aw	7.5YR 4/4	s1	2m,sbk	wss,wsp	-	c,f	f	-
15	29-100+	C		7.5YR 4/4	s1	-	-	-	-	weathered sandstone	-

Table 4.2.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)			Coarse fragments (%)	Water content (%)		
		Sand (2 - 0.05)	Silt (0.05 - 0.002)	Clay (< 0.002)		1/3 bar	15 bar	Available
13	0-10	77.7	13.8	8.5	11	14.1	3.8	10.3
14	10-29	74.1	16.0	9.9	12	14.0	4.1	9.9
15	29-100+	69.9	18.0	12.1	16	13.9	3.8	10.1

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)			
								Fe	Mn	Cu	Zn
13	0-10	0.69	0.0	7.6	0.15	1.57	1.669	7.8	11.8	0.40	0.34
14	10-29	0.19	0.0	7.7	0.26	1.57	1.076	3.6	13.8	0.44	0.10
15	29-100+	0.18	0.0	7.7	0.07	-	1.113	3.2	17.0	0.42	0.16

Table 4.2.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)				CEC (c mol kg ⁻¹)	ESP
		Na	Mg	Ca	K		
13	0-10	0.6	0.6	5.3	0.14	6.6	9
14	10-29	0.6	0.6	5.4	0.10	6.7	9
15	29-100+	0.6	0.7	6.3	0.10	7.7	7

Table 4.2.4 Saturation extract analysis

Lab. No.	Depth (cm)	Saturation (%)	pH _s	EC _e dSm ⁻¹	Saturation extract analysis (me/l)								SAR
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl	SO ₄	
13	0-10	36	7.4	0.52	0.36	2.5	2.5	0.11	-	3.9	1.5	0.14	0.22
14	10-29	38	7.6	0.46	0.30	2.4	1.8	0.08	-	2.8	1.0	0.58	0.20
15	29-100+	42	7.6	0.39	0.27	1.1	1.8	0.03	-	2.6	0.8	0.20	0.22

Table 4.2.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
13	0-10	90.2	2.55	0.90	0.0	1.00	1.11	0.23	0.00	0.019	1.30
14	10-29	89.2	2.64	1.06	0.0	1.00	1.15	0.24	0.00	0.014	1.20
15	29-100+	88.1	3.02	1.43	0.0	1.33	1.24	0.35	0.00	0.030	1.48

Table 4.2.6: Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
13	0-10	76.3	11.5	3.50	0.0	3.09	1.39	1.90	0.060	0.031	2.62
14	10-29	74.2	12.1	2.86	0.0	2.09	1.38	1.81	tr.	0.045	4.69
15	29-100+	75.1	12.3	3.28	0.0	2.67	1.14	1.93	tr.	0.054	3.80

Table 4.2.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)									Loss on ignition	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	ZnO	MnO	(%)
13	0-10	52.7	24.2	3.85	0.17	2.14	0.16	1.69	0.14	0.039	0.030	8.49
14	10-29	51.1	23.9	3.41	0.00	2.37	0.14	1.64	0.13	0.024	0.015	10.76
15	29-100+	52.2	24.4	4.93	0.11	2.15	0.16	1.46	0.19	0.034	0.084	7.82

Table 4.2.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	MnO
13	0-10	83.9	5.8	2.40	0.0	0.94	0.41	0.33	0.02	0.039
14	10-29	83.1	6.3	2.82	0.0	1.09	0.38	0.40	0.01	0.025
15	29-100+	82.0	6.0	3.38	0.0	0.82	0.34	0.52	0.01	0.068

Table 4.2.9 Elemental composition of coarse fragments

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O		P ₂ O ₅	MnO
13	0-10	90.2	2.1	2.99	1.08	0.75	0.27	0.50	0.08	0.136	2.40
14	10-29	89.8	2.1	2.80	0.00	1.05	0.26	0.56	0.03	0.115	2.63
15	29-100+	83.5	2.2	2.72	0.10	0.87	0.31	0.53	0.06	0.084	2.90

samples. 1.0 nm component seems to be slightly degraded specially in B22 horizon. A small part of 1.4 nm peak resolved to a maxima at 1.8 nm on glycerol solvation and was attributed to presence of smectite. An other part of 1.4 nm partially collapsed to 1.0 nm on K-saturation and heating the sample thereby confirming the presence of vermiculite. Vermiculite is basically dioctahedral type. Residual 1.4 nm that persisted even after K saturation and heating, was attributed to chlorite. XRD pattern showed the presence of mixed layer minerals registering peaks around 1.2 nm region. Mixed layer minerals seemed to be mostly mica-chlorite type as peak position was little affected by any treatment. In C horizon mixed layer minerals were mostly mica-chlorite and some mica-vermiculite type.

In addition to the above diffractogram also recorded sharp but small peaks at 0.84, 0.426 and 0.323 nm thus indicating the presence of amphiboles, quartz and feldspars. Semi- quantitative estimates calculated on the basis of corrected peak area values (Table 4.1.11) suggest the dominance of illite followed by chlorite, mixed layers, kaolinite, vermiculite and smectites. Illite content ranged between 72 to 75 per cent. Primary minerals associated in the clays contributed only minor proportions.

4.312 Siwalik hills-lower: These areas are represented by Kaleshar and Lal Dhang pedons. Detailed characteristics of these soils are discussed in the subsequent paragraphs.

Morphology: Kaleshar pedon had 10YR hues and value chroma were 5 and 3 to 4 respectively (Table 4.3.1). In case of Lal Dhang pedon the dominant hue was 5YR with value 4 and chroma 6 (Table 4.4.1). Texture of Lal Dhang soils was sandy loam to loam. Kaleshar soils were having lithological discontinuity and texture varied from silt loam to sand. There was no structure development.

Physical characteristics: A perusal of table 4.3.2 indicated that upper horizon of Kaleshar contained as high as 52 per cent of silt and the lower most horizon was having about 98 per cent sand. Hydraulic conductivity and available water of silty loam horizon was 0.548 cm hr^{-1} and 20.8 per cent.

On the other hand Lal Dhang pedon (Table 4.4.2) had 9 to 15 per cent clay and their bulk density varied from 1.57 to 1.69 Mg m^{-3} . The hydraulic conductivity ranged between 0.47 to 0.98 cm hr^{-1} . Available moisture ranged between 8.0 to 13.3 per cent.

Chemical characteristics: The pH_2 and EC_2 of Kaleshar pedon (Table 4.3.2) for silty loam and sandy horizon were 8.3 and 7.6 and 0.2 and 0.5 dSm^{-1} , respectively.

The pH_2 and EC_2 of Lal Dhang soil varied from 6.5 to 6.7 and 0.03 to 0.18 dSm^{-1} , respectively (table 4.4.2). Both these soils were non-calcareous and the content of organic carbon was very low.

Micro-nutrients: These soils have fairly good amounts of DTPA- extractable Fe, Mn and Cu but Zn was below the critical limit. However, the available micro-nutrients were in abundance in Lal Dhang pedon.

Exchangeable cations: Calcium followed by Mg was the dominant cation on the exchange complex. Exchangeable sodium varied between 0.2 to $0.6 \text{ c mol kg}^{-1}$. CEC of upper horizon of Kaleshar (Table 4.3.3) was $3.22 \text{ c mol kg}^{-1}$. In case of Lal Dhang (Table 4.4.3) CEC of upper and lower horizon was 6.04 and $10.27 \text{ cmol kg}^{-1}$, respectively. ESP was low in both the soils.

Saturation extract: The pH_s and EC_s upper and lower horizon of Kaleshar (Table 4.3.4) was 8.2 and 7.7 and 0.85 and 1.98 dSm^{-1} , respectively. Dominant cation

and anion were magnesium and chloride. Next dominant cation and anion were sodium and bicarbonate.

The pHs of Lal Dhang soils (Table 4.4.4) was in acidic range and EC_e very low. Dominant cation and anion pair in this case was also Mg and Cl, respectively.

Elemental composition (per cent)

Sand: The SiO_2 content was around 87 and Al_2O_3 varied from 3.2 to 4.6 in Kaleshar soils. Fe_2O_3 and MnO varied from 2.29 to 2.23 and 0.068 to 0.075, respectively. MgO varied from 1.08 to 1.67 Na_2O and K_2O ranged between 1.65 to 1.85 and 0.57 to 0.79, respectively. Loss on ignition varied from 1.10 to 1.46 per cent (Table 4.3.5).

In case of Lal Dhang soils SiO_2 and P_2O_5 contents were higher (Table 4.4.5) as compared to Kaleshar. However, the contents of all other elements were lower. Loss on ignition was also low and varied between 0.67 to 0.76 per cent.

Silt: The SiO_2 content in both the soils ranged between 72.26 to 73.86. Al_2O_3 content was higher in the Lal Dhang soils (Table 4.4.6). Fe_2O_3 content in both the soils varied from 2.50 to 2.89 excepting the lower horizon of Kaleshar soils (Table 4.3.6) which has high Fe_2O_3 content of 6.29. MgO, K_2O and Na_2O content was higher in Kaleshar as compared to the Lal Dhang. Loss on ignition in both the soils varied from 3.00 to 3.97 per cent.

Clay: The SiO_2 and Al_2O_3 content of Kaleshar soils (Table 4.3.7) ranged between 50.36 to 52.45 and 21.91 to 22.46, respectively. MgO and K_2O varied between 2.76 to 2.86 and 1.12 to 1.34, respectively. Lower horizon of these soils was having higher Na_2O content (0.34) as compared to 0.10 m upper horizons. Loss on ignition in these soils varied from 11.25 to 12.05 per cent.

Lal Dhang soils (Table 4.4.7) have relatively lower SiO_2 , Fe_2O_3 , Na_2O , MgO and P_2O_5 content. However, the Al_2O_3 and MnO content were higher than Kaleshar soils. Loss on ignition varied from 13.05 to 14.28 per cent.

Soil: The SiO_2 , Al_2O_3 , Fe_2O_3 and MgO content of upper silt loam horizon of Kaleshar pedon was 77.86, 9.26, 3.48 and 1.19, respectively (Table 4.3.8). The same were 86.53, 3.38, 2.66 and 0.33 for lower sand horizon. Na_2O and K_2O contents were higher in the upper horizon. Loss on ignition for upper and lower horizons was 4.37 and 0.81 per cent respectively.

The SiO_2 and Al_2O_3 content of Lal Dhang soils (Table 4.4.8) varied from 81.26 to 77.51 and 8.10 to 10.77, respectively. Fe_2O_3 and MgO ranged between 2.62 to 3.35 and 0.57 to 1.12, respectively. Na_2O , K_2O and P_2O_5 content of these soils were lower than that of Kaleshar pedon. Loss on ignition varied from 2.8 to 4.0 per cent.

A perusal of the elemental composition of various soil fraction indicated that both these soils have developed from entirely different parent material.

Soil Taxonomy: Following the guidelines of Soil Survey Staff (1975) and taking into account the absence of B horizon in these soils have been classified as mixed, hyperthermic, Typic Udorthents. Textural family of Kaleshar was silty over sandy, and that of Lal Dhang was coarse loamy.

Stability of alumino-silicates: In addition to elemental composition of minerals, ambient soil solution composition and pH controls the solubility of various alumino-silicates. Lal Dhang soils have high hydraulic conductivity and are excessively drained due to their topographical position. As such these soils are likely to maintain a very low level of H_4SiO_4 activity.

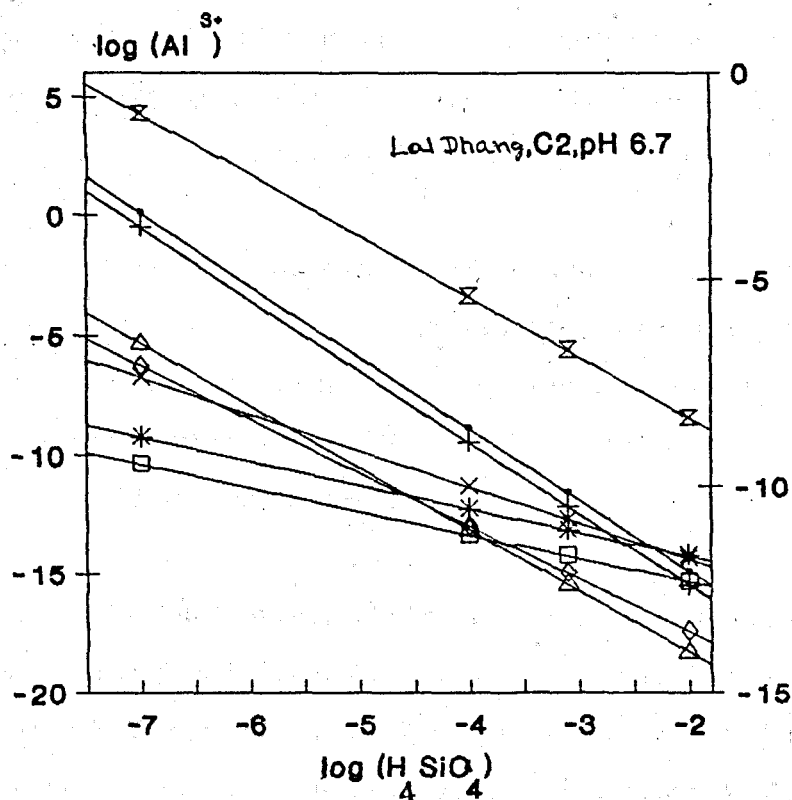
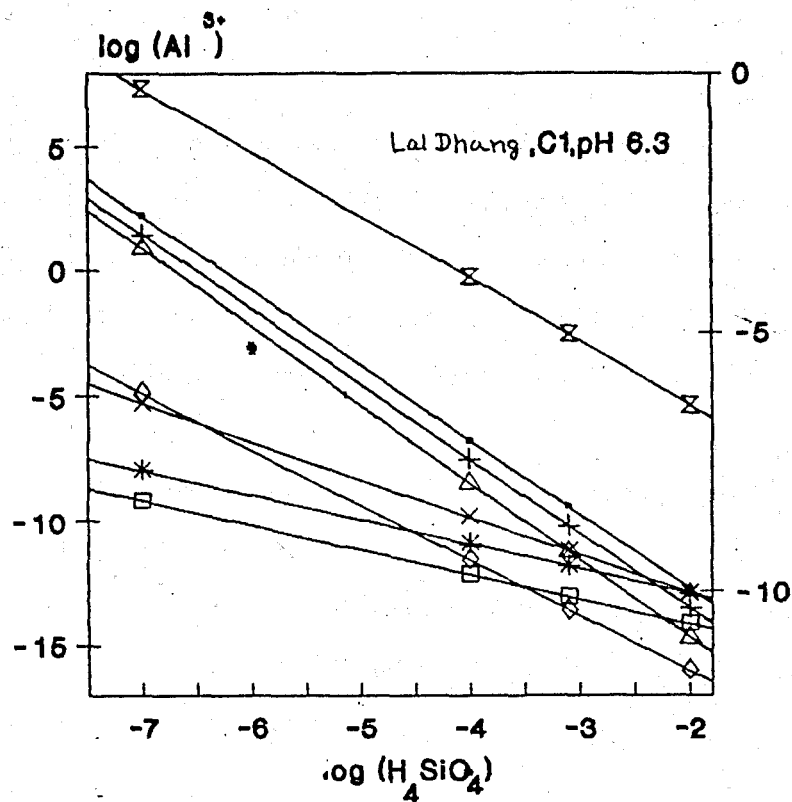


Fig. 4.9 Stability of aluminosilicates

Thus, at pHs 6.3 and 6.7 and at constituent cations activity level in soil solution, under low H_4SiO_4 activity (10^{-5} M), common alumino-silicates in C1 and C2 horizon of Lal Dhang (Fig. 4.9) soils can be arranged in order of increasing stability as: vermiculite, albite, microcline, chlorite, illite, montmorillonite, muscovite and kaolinite.

Therefore, muscovite and kaolinite are most stable under low pHs and high leaching environment.

Mineralogy: Qualitative and semi-quantitative information obtained from the XRD patterns of sand, silt and clay fractions of Lal Dhang soils is presented in the subsequent paragraphs.

Sand: The Quartz (0.426 nm) dominated among the minerals (Fig. 4.10, Table 4.4.9) in sand fraction. Its contents were higher than 70 per cent. Other minerals in the decreasing order of abundance were mica, kaolinite and feldspars and amphiboles. Chlorite and calcite were absent. Small amounts of goethite were also present in surface horizon of these soils.

Silt: Mineralogy of the silt fraction of these soils (Fig. 4.10, Table 4.4.9) was similar to that of sand fraction excepting that mica content increased considerably. Presence of mixed layer minerals and absence of amphiboles in both the horizons was also noticed in these soils. Chlorite (1.4 nm) and calcite (0.303 nm) were both absent.

Clay: The XRD pattern of these clays (Fig. 4.11, 4.12) indicated very strong and well defined peaks for illite accompanied by a strong (0.715 nm) peak along with its higher order at 0.358 nm in Mg treated samples. The 1.4 nm peak was virtually absent in these soils. Persistence of 0.715 nm peak even after 4N HCl treatment of clay confirmed the presence of kaolinite in these soils. Contents of illite and kaolinite (Table 4.4.10) varied from 39 to 40 and 34 to 36 per

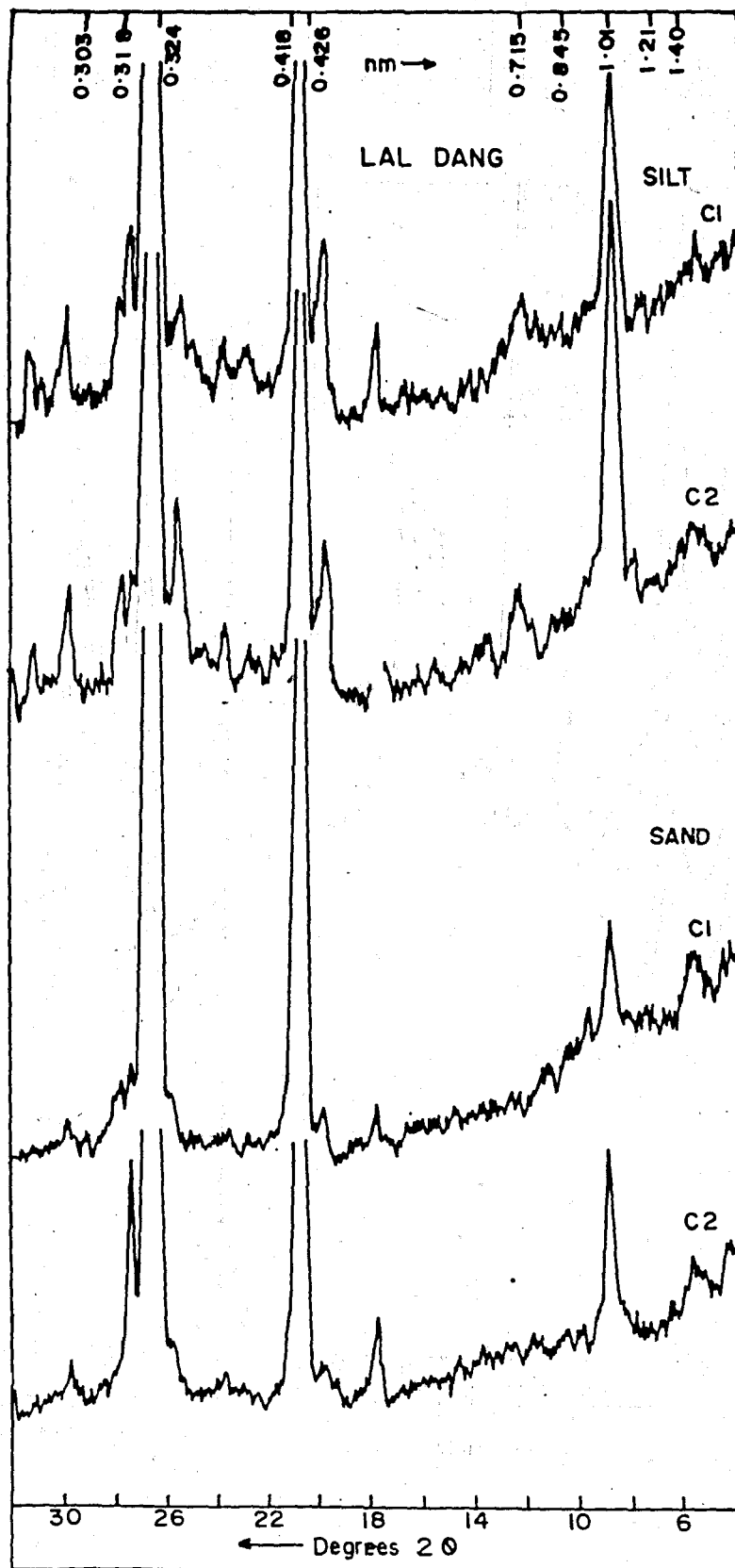


Fig. 4.10 XRD pattern of sand and silt minerals

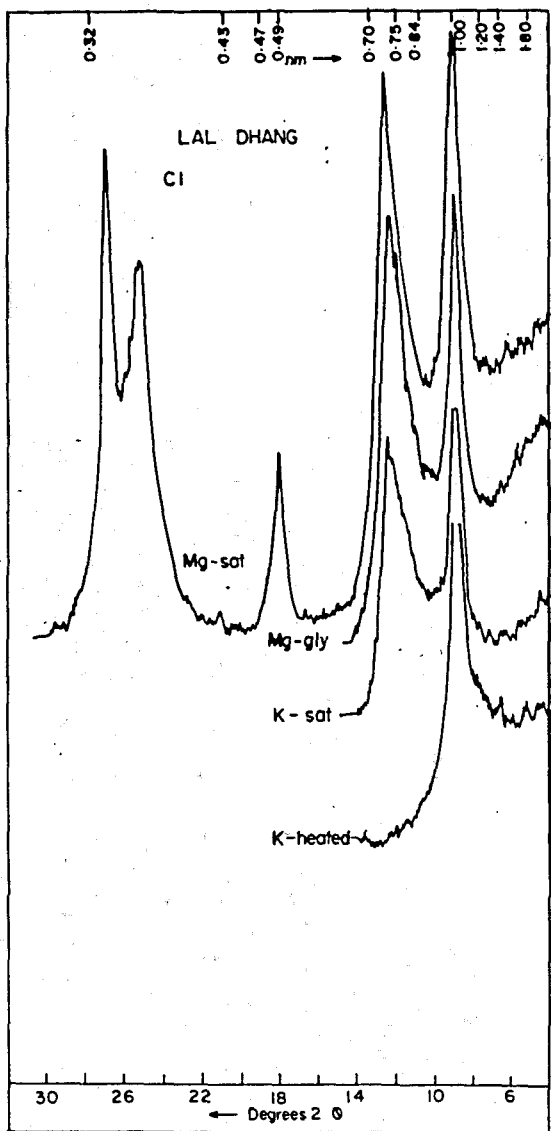


Fig. 4.11 XRD pattern of clay minerals

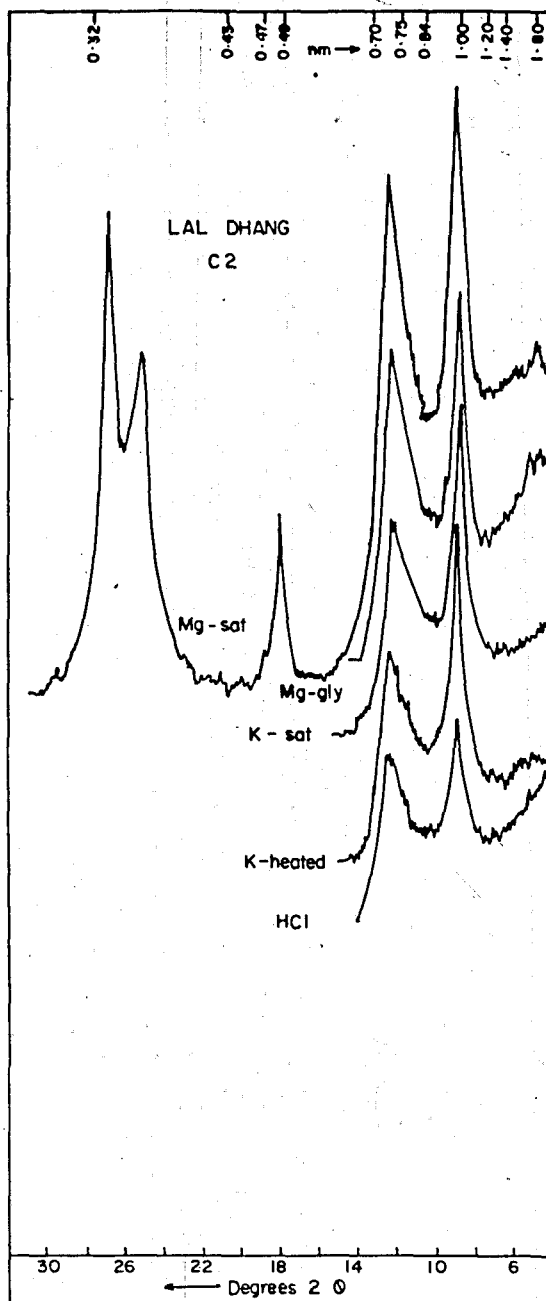


Fig. 4.12 XRD pattern of clay minerals

Pedon No. 3

KALESHAR

Classification: Typic Udorthent, silty over sandy, mixed, hyperthermic

Location: 77°33' 54"E, 30° 23' 27"N, 8 km ahead of Kaleshar forest, district Yamunanagar

Physiography: Siwalik hills on the bank of river Yamuna

Topography: Hill crest 35 per cent slope

Drainage: Excessively drained

Landuse: Scrubby forest, pines, cactus

Elevation : 613 m

Rainfall: 1250 mm

Table 4.3.1 Morphology

Lab. No.	Depth (cm)	Horizon	Boundary	Colour (moist)	Texture (USDA)	Structure	Consistence (wet)	Cutans	Roots	Coarse fragments	Reaction
34	0-500	C1	cs	10YR 5/4	sil	-	wss, wpo	-	-	-	-
35	500-510+	C2		10YR 5/3	s	-	wso, wpo	-	-	-	-

Table 4.3.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)			Coarse fragments (%)	Water content (%)		
		Sand	Silt	Clay		1/3 bar	15 bar	Available
		(2 - 0.05)	(0.05 - 0.002)	(< 0.002)				
-----% of < 2 mm -----								
34	0-500	43.1	52.1	4.8	-	29.9	9.1	20.8
35	500-510+	98.2	1.3	0.5	-	3.8	2.2	1.6

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity		DTPA extractable (mg kg ⁻¹)		
							cm hr ⁻¹		Fe	Mn	Cu Zn
34	0-500	0.05	0.0	8.4	0.23	1.49	0.549		5.4	1.5	0.36 0.20
35	500-510+	0.03	0.0	7.7	0.52	-	44.035		5.2	2.8	0.18 0.18

Table 4.3.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)					CEC	ESP
		Na	Mg	Ca	K	(c mol kg ⁻¹)		
34	0-500	0.3	1.0	2.1	0.09		3.2	10
35	500-510+	-	-	-	0.07		-	-

Table 4.3.4 Saturation extract analysis

Lab. No.	Depth (cm)	Saturation (%)	pH _s	EC _e dSm ⁻¹	Saturation extract analysis (me/l)							SAR	
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl		SO ₄
34	0-500	41.0	8.2	0.85	3.7	3.8	1.3	0.04	0.4	1.05	5.5	0.26	2.3
35	500-510+	28.2	7.7	1.98	7.4	6.3	2.3	0.03	-	2.10	15.0	0.14	0.7

Table 4.3.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)						Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	
34	0-500	87.4	3.2	2.29	0.0	1.67	1.65	0.79
35	500-510+	87.8	4.6	2.23	0.0	1.08	1.85	0.57
								0.068
								0.075
								1.46
								1.10

Table 4.3.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)						Loss on ignition(%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	
34	0-500	72.9	13.2	2.89	0.0	1.82	1.39	1.66
35	500-510+	73.9	10.1	6.29	0.0	2.44	2.32	2.07
								0.010
								0.046
								3.97
								-

Table 4.3.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	ZnO	MnO	
34	0-500	52.5	21.9	5.49	0.06	2.76	0.10	1.12	0.27	0.024	0.025	11.3
35	500-510+	50.4	22.5	9.28	0.92	2.86	0.34	1.34	0.42	0.049	0.017	12.1

Table 4.3.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	MnO
34	0-500	77.9	9.3	3.48	0.0	1.19	0.58	0.69	0.07	0.010
35	500-510+	86.5	3.4	2.66	0.0	0.33	0.89	0.48	0.11	0.080

Pedon No. 4

LAL DHANG

Classification: Typic Udorthent coarse loamy, mixed, hyperthermic

Location: 77°33' 7"E, 30° 22' 46"N, Lal Dhang in Kaleshar reserve forest, district Yamunanagar

Physiography: Siwalik hills

Topography: Vertical cliff, 30 per cent slope

Drainage: Excessively drained

Landuse: Forest, sal, teak

Elevation = 613 m

Rainfall: 1250 mm

Table 4.4.1 Morphology

Lab. No.	Depth (cm)	Horizon	Boundary	Colour (moist)	Texture (USDA)	Structure	Consistence (wet)	Cutans	Roots	Coarse fragments	Reaction
36	0-70	C1	gi	5YR 4/6	sl	-	wss, wpo	-	c, f	-	-
37	70-180	C2		5YR 4/6	1	-	wss, wpo	-	c, f	-	-

Table 4.4.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)			Coarse fragments (%)	Water content (%)		
		Sand (2 - 0.05)	Silt (0.05 - 0.002)	Clay (< 0.002)		1/3 bar	15 bar	Available
-----% of < 2 mm -----								
36	0-70	61.1	29.1	9.8	-	17.0	8.2	8.8
37	70-180	45.5	39.4	15.1	-	20.6	13.3	7.3

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)			
								Fe	Mn	Cu	Zn
36	0-70	0.04	0.0	6.5	0.03	1.69	0.968	6.0	14.3	0.46	0.86
37	70-180+	0.09	0.0	6.7	0.18	1.57	0.471	4.0	9.4	0.20	0.52

Table 4.4.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)					CEC (c mol kg ⁻¹)	ESP
		Na	Mg	Ca	K			
36	0-70	0.2	1.6	3.7	0.12		6.0	3.3
37	70-180+	0.6	2.0	7.5	0.02		9.3	6.0

Table 4.4.4 Saturation extract analysis

Lab. No.	Depth (cm)	Saturation%	pH _s	EC _e dSm ⁻¹	Saturation extract analysis (me/l)								SAR
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl	SO ₄	
36	0-70	35.0	6.3	0.12	0.20	4.3	1.0	0.02	-	1.1	4.0	0.16	0.12
37	70-180+	57.3	6.7	0.37	0.74	4.0	1.0	0.05	-	1.4	4.0	0.18	0.47

Table 4.4.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	
36	0-70	89.1	1.82	0.47	0.0	0.67	0.70	0.21	0.67
37	70-180+	90.2	1.83	0.75	0.0	0.67	0.70	0.22	0.76

Table 4.4.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	
36	0-70	72.3	16.3	2.66	0.0	1.20	1.08	1.64	3.62
37	70-180	73.7	16.5	2.50	0.0	1.12	0.90	1.45	3.00

Table 4.4.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)										Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	ZnO	MnO	
36	0-70	48.3	26.8	3.38	0.15	1.14	0.09	1.07	0.15	0.031	0.041	13.1
37	70-180+	49.5	27.1	3.65	0.20	1.12	0.09	1.05	0.17	0.030	0.004	14.3

Table 4.4.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	MnO
36	0-70	81.3	8.1	2.62	0.0	0.57	0.11	0.39	0.00	0.035
37	70-180+	77.5	10.7	3.35	0.0	1.12	0.00	0.49	0.02	0.045

Table 4.4.9 Semi quantitative estimates of sand and silt minerals

Lab.No.	Depth (cm)	Chlorite	Mica	Amphibole	Chlorite + Kaolinite	Quartz	Orthoclases	Plagioclases	Calcite	Goethite
Sand										
36	0-70	-	++	++	++	+++++	++	+	-	++
37	70-180+	-	+++	++	++	+++++	+++	-	-	-
Silt										
36	0-70	-	++	++++	++	+++++	+++	++	-	-
37	70-180+	-	++	++++	++	+++++	++	++	-	-

Table 4.4.10 Semi quantitative estimates of clay size minerals

Lab. No.	Depth (cm)	Smectite	Chlorite	Vermiculite	Illite	Mixed layer	Kaolinite	Halloysite	Quartz	Feldspar	Amphibole
%											
36	0-70	-	-	-	39	5	36	18	1	1	-
37	70-180+	-	-	-	40	6	34	17	1	2	-

cent respectively. A shoulder at 0.72 to 0.75 nm on the lower side of kaolinite indicated the presence of halloysite. Its persistence even after the HCl-treatment of clay confirmed the presence of Halloysite. Halloysite content in these soils varied between 17 to 18 per cent. XRD pattern showed that mica is well defined and does not seem to have changed much. In these clays 0.7 nm peak was asymmetrical towards lower side, probably due to the presence of Halloysite. This indicated that kaolinite is degrading 5.6 per cent mixed layer minerals were also present. Mixed layer minerals were irregular in nature and are of mica-chlorite type. Minerals were mostly diocta type. In general the order of abundance of clay minerals was: illite, kaolinite, halloysite and mixed layer minerals. Primary minerals associated with these clays contributed very little.

4.32 Piedmont: Land form of piedmont has been further sub-divided into upper and lower piedmont to study the effect of physiography and local topography, on the genesis of alkali soils. The Same is discussed below.

4.321 Upper piedmont: This geomorphic unit has been represented by soils of Ramgarh and Panchkula pedons. Elevation of these highly sloping undulating lands ranged between 380 and 480 m and rainfall ranged between 1100 and 1125 mm. Both these soils were excessively drained on the surface. Based on present geomorphology of this area it can be confidently concluded that these soils were never flooded by rivers atleast in the last few centuries. These soils have udic moisture regime and hyperthermic temperature regime.

Morphology: These soils (Table 4.5.1 and 4.6.1) have reddish brown to brown colours. A 7.5YR hue, value 4 to 6 and chroma 3 to 4 dominated in these soils. However, the colours of surface horizon of Ramgarh soils were more reddish and the lower most horizon had yellowish brown colours. Dominant texture was silt loam and wet consistency was sticky and plastic. Mostly these soils was calcareous in nature and lime concretions were invariably present.

Physical characteristics: These soils contained large amounts of silt ranging from 31.6 to 62.9 per cent and coarse fragments mostly lime concretions ranged between 10 to 36 per cent (Table 4.5.2 and 4.6.2). Undisturbed clod bulk density was mostly 1.67 Mg m^{-3} with the exception of topmost horizon of Panchkula pedon having a bulk density of 1.89 Mg m^{-3} due to large amount's of coarse fragments. Hydraulic conductivity ranged from almost nil to 0.123 cm/hr with the exception of upper horizon of Panchkula having 0.636 cm/hr of hydraulic conductivity. Available water content ranged between 9.3 to 16.2 per cent. Soils high in silt generally indicated a lower available moisture.

Chemical characteristics: pH_2 and EC_2 of these soils (Table 4.5.2 and 4.6.2) ranged between 8.8 to 9.8 and 0.20 to 1.36 dSm^{-1} respectively. O.C. content of surface horizon varied between 0.11 to 0.30 per cent. There was sharp decrease in O.C. content below the surface horizon. In the subsurface horizons it ranged between 0.05 to 0.09 per cent. CaCO_3 content varied between 0.05 to 9.20 per cent.

Micro-nutrients: DTPA extractable Fe, Mn, Cu were above the critical limit. However, available Zn content was far below the critical limit of 0.6 mg kg^{-1} .

Exchangeable cations: A perusal of data (Table 4.5.3 and 4.6.3) indicated that calcium followed by the sodium were the dominant cations on the exchange complex. CEC of Panchkula pedon varied between 9.3 to $12.2 \text{ cmol kg}^{-1}$. Lower horizons of these soils contained high sodium on exchange complex, thus their ESP was as high as 45 in this high rainfall area with udic moisture regime. Soils of Ramgarh cut had higher CEC, varying from 18.50 to $23.59 \text{ cmol kg}^{-1}$. Their ESP varied between 14 to 24.

Saturation extract: The pH_s and EC_s of these soils (Table 4.5.4 and 4.6.4) varied between 8.4 to 8.9 and 0.69 to 3.49 dSm^{-1} , respectively. Sodium followed

by magnesium dominated among the cations. Chlorides followed by bicarbonates dominated among the anions. Subsurface horizon of Panchkula soils contained as high as 26.7 me/l of Na and almost an equal amount of chlorides in the saturation extract—indicating NaCl to be the dominant salt in the soil solution. SAR of this horizon was 14. Saturation extract of Ramgarh (Table 4.5.4) soils also had 1.4 me/l of carbonates. Their SAR varied between 2.25 to 4.18.

Elemental composition (per cent):

Sand: The SiO_2 and Al_2O_3 content of sand fraction of these soils (Table 4.5.5, 4.6.5) varied between 85.22 to 90.47 and 2.53 to 3.42, respectively. Fe_2O_3 ranged from 1.33 to 2.03. CaO varied upto 0.81. MgO and Na_2O ranged between 1.17 to 2.50 and 1.01 to 1.24, respectively. K_2O content of both the soils were almost similar. MnO content of these soils varied from 0.030 to 0.107. Loss on ignition in these soils was almost uniform (1.25 to 1.77) excepting the C1 horizon of Ramgarh soils having a loss of 3.86 per cent.

Silt: A perusal of table 4.56 and 4.66 indicates that SiO_2 and Al_2O_3 contents of these soils are almost uniform. Fe_2O_3 and MnO content ranged between 2.6 to 4.06 and 0.030 to 0.102, respectively. MgO and Na_2O content varied between 1.75 to 2.97 and 0.96 to 1.58, respectively. Excepting the C1 horizon of Ramgarh pedon, K_2O content was also similar. Loss on ignition of silt fraction of these soils varied from 2.63 to 4.86 per cent.

Clay: The SiO_2 and Al_2O_3 content of these soils (Table 4.5.7 and 4.6.7) were almost uniform and varied between 49.85 to 53.14 and 22.89 to 24.16, respectively. Similarly, Fe_2O_3 and MnO ranged between 4.64 to 5.10 and 0.065 to 0.080, respectively. MgO content of these soils varied between 2.19 to 3.14 excepting the C1 horizon of Ramgarh having a high amount of 9.52. This horizon also contained higher amounts of P_2O_5 and K_2O . Na_2O content of clay fraction

varied from 0.10 to 0.16. Loss on ignition of these clay ranged between 7.94 to 10.91.

Soil: A perusal table 4.5.8 indicated that C1 horizon of Ramgarh pedon which was having 5YR colours had lower SiO_2 , K_2O and Na_2O and higher Al_2O_3 , Fe_2O_3 , MgO , P_2O_5 and MnO as compared to the underlying and overlying horizon. Loss on ignition was higher in this horizon.

In case of Panchkula pedon (Table 4.6.8) SiO_2 and Al_2O_3 ranged between 72.82 to 77.43 and 9.47 to 13.94, respectively. In general C horizon had higher amounts of Na_2O , K_2O , P_2O_5 , MnO , MgO and Fe_2O_3 as compared to the surface horizon. Loss on ignition in AC and C horizon was 5.75 and 4.48, respectively.

Coarse fragments: Both soils contained coarse fragments in the form lime concretions. In the Panchkula pedon, these were present in upper horizon whereas in Ramgarh pedon these were concentrated mainly in lower most horizons. SiO_2 , MgO , Na_2O , P_2O_5 and MnO_2 content of the concretions of Panchkula (Table 4.6.9) was higher and Al_2O_3 , CaO and K_2O content was lower than that of the Ramgarh pedon (Table 4.5.9) concretions. Loss on ignition of the Panchkula and Ramgarh concretions was 4.93 and 4.12 per cent, respectively.

Soil Taxonomy: Taking into account the macro-morphology, physical and chemical characteristics, these soils have been classified as fine loamy, mixed, hyperthermic family of Typic Udorthent. However, this classification as per Soil Taxonomy (1975) failed to indicate the alkali nature of these soils at any of its categories.

Stability of alumino-silicates: In addition to the elemental composition, solubility of alumino-silicates is controlled by the pH and cation composition of the ambient soil solution. Weathering of minerals release various ions into

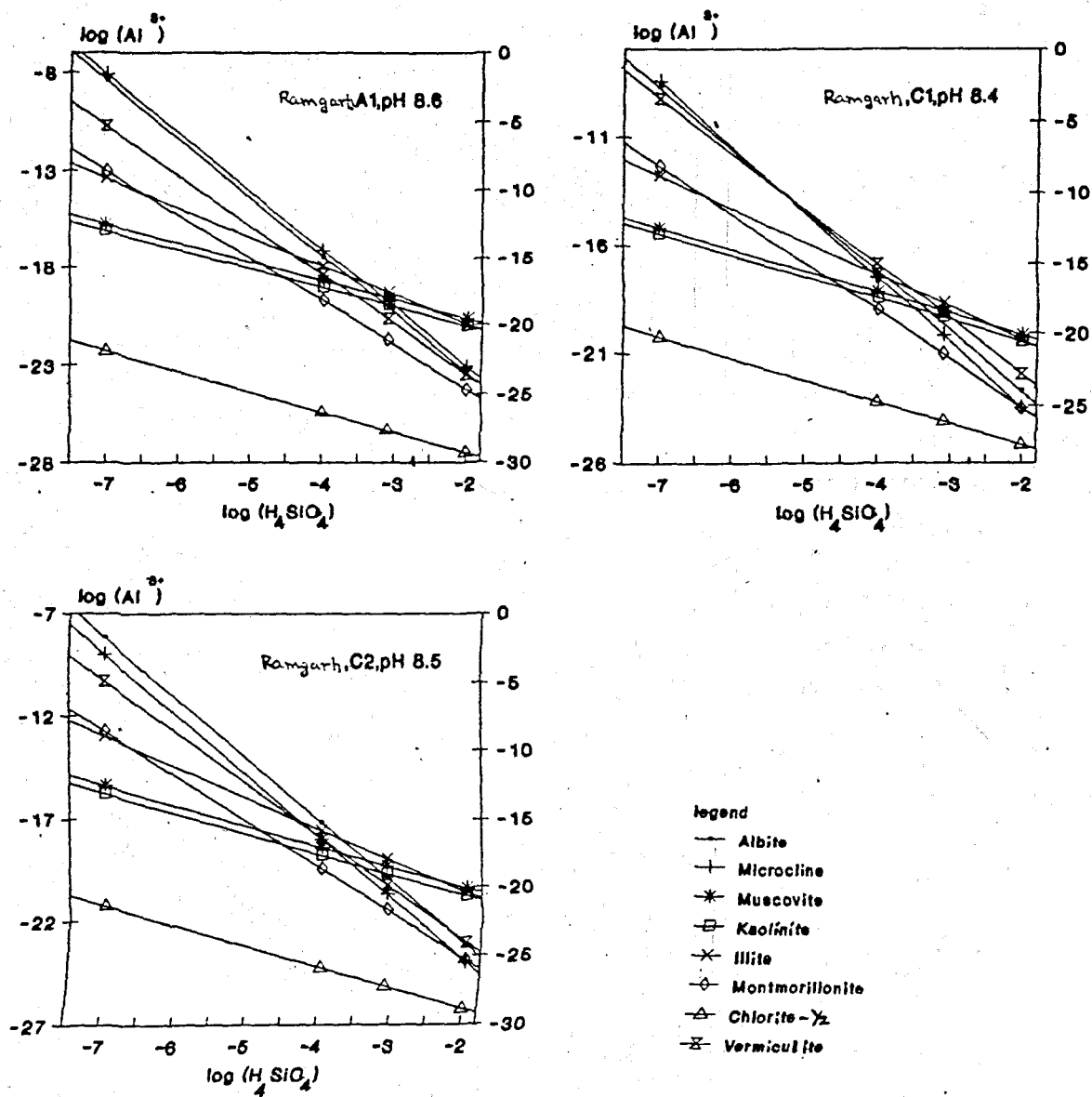
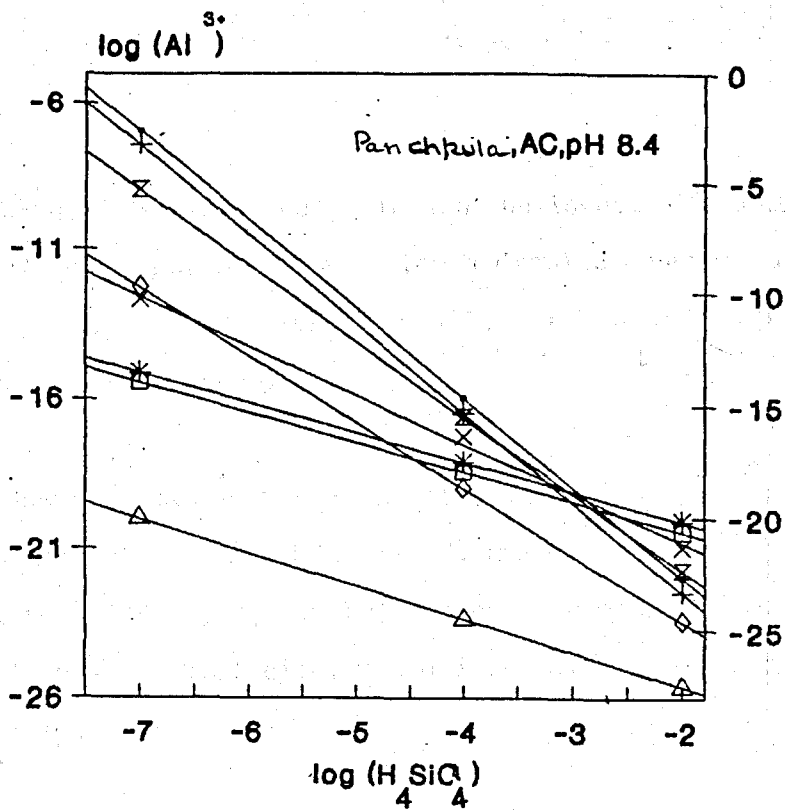


Fig. 4.13 Stability of aluminosilicates



legend

- Albite
- +— Microcline
- *— Muscovite
- Kaolinite
- x— Illite
- ◇— Montmorillonite
- △— Chlorite-γ₂
- x— Vermiculite

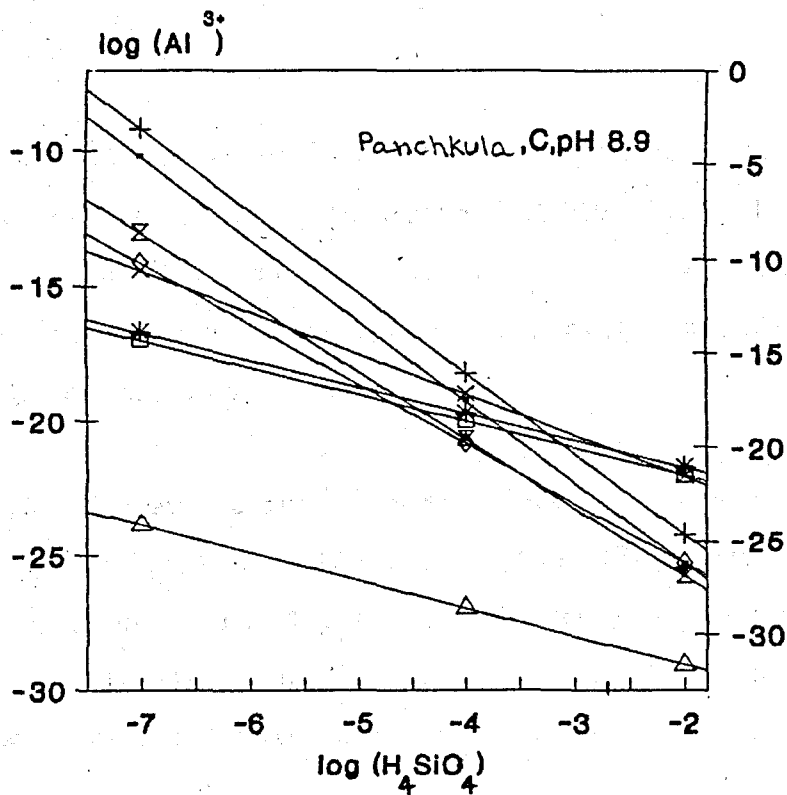


Fig. 4.18 Stability of aluminosilicates

soil solution. Minerals that maintain the lowest Al^{3+} activity at a given H_4SiO_4 activity are most stable. Due to low hydraulic conductivity and poor internal drainage of these soils, the activities of more soluble constituents are maintained at higher level.

At pHs 8.6 and constituent cation activity level in soil solution; under high activity of H_4SiO_4 ($10^{-2.74}M$), alumino-silicates in surface horizon of Ramgarh pedon (Fig. 4.13) can be arranged in order of increasing stability as: illite, muscovite, kaolinite, microcline, albite, vermiculite, montmorillonite and chlorite.

There was not much difference in relative stability of alumino-silicates in C_1 and C_2 horizon of this soil. The increasing order of stability was: illite, muscovite, kaolinite albite, vermiculite, microcline, montmorillonite and chlorite.

At pHs 8.9 and activity level of constituent cations in soil solutions under high activity of H_4SiO_4 (amorphous $SiO_2=10^{-2.74}M$), the alumino-silicates in C horizon of Panchkula pedon (Fig. 4.18), can be arranged in order of increasing stability as: muscovite, illite, kaolinite, microcline, albite, montmorillonite, vermiculite and chlorite.

At pHs 8.4 and activity level of constituent cations in soil solution, under high activity of H_4SiO_4 (amorphous $SiO_2 = 10^{-2.74}M$), common alumino-silicates in AC horizon of Panchkula pedon (Fig. 4.18) can be arranged in order of increasing stability as: muscovite, kaolinite, illite, albite, vermiculite, microcline, montmorillonite and chlorite.

Mineralogy: Qualitative and semi-quantitative estimates of mineralogy of sand, silt and clay fraction of Ramgarh pedon are presented in the succeeding

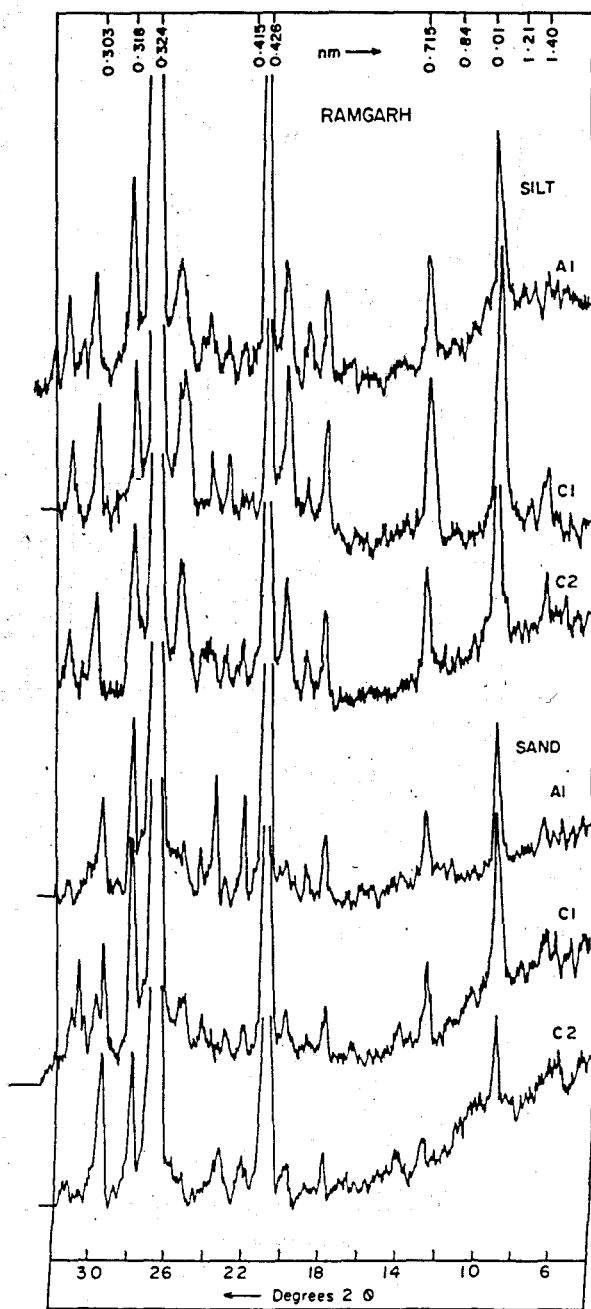


Fig. 4.14 XRD pattern of sand and silt minerals

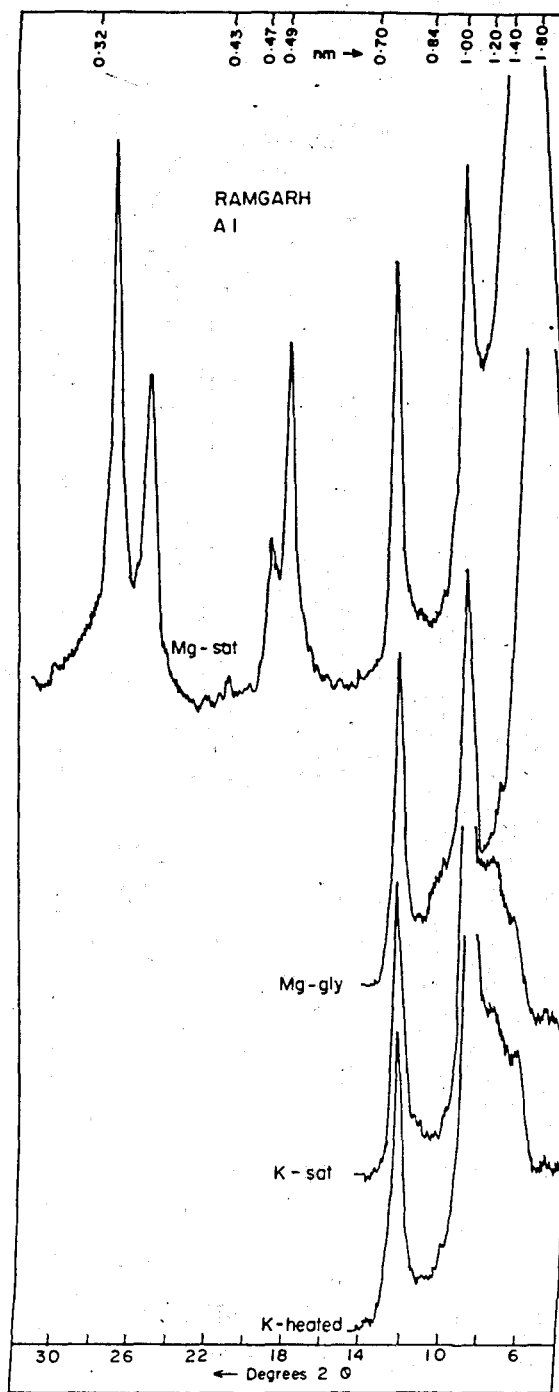


Fig. 4.15 XRD pattern of clay minerals

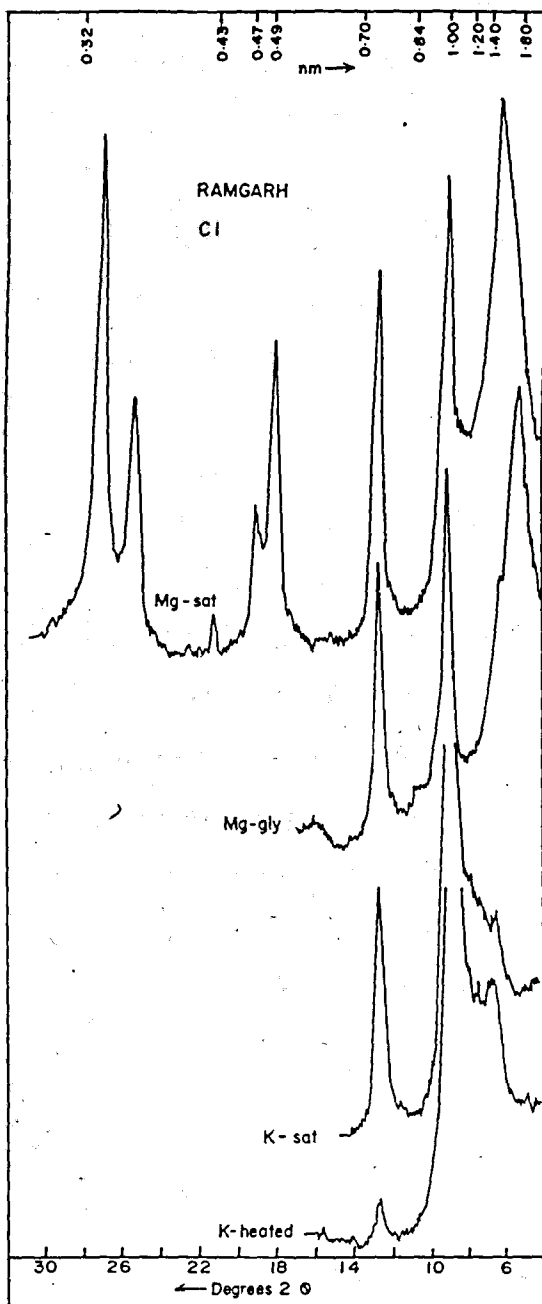


Fig. 4.16 XRD pattern of clay minerals

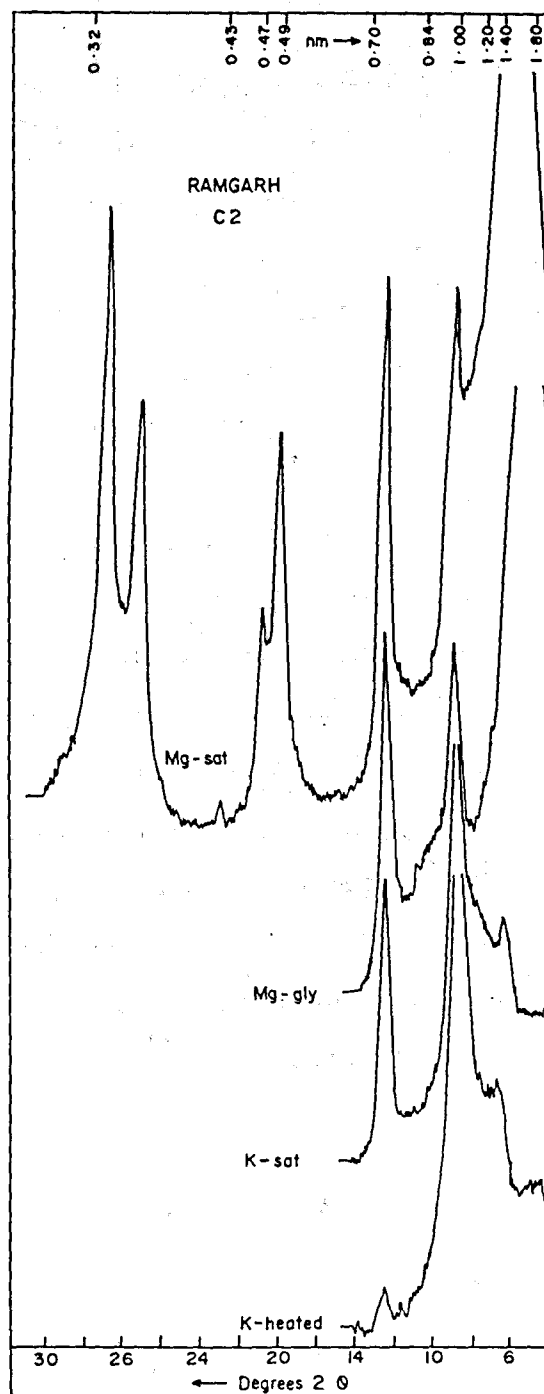


Fig. 4.17 XRD pattern of clay minerals

paragraphs.

Sand: In general (Fig. 4.14, table 4.6.10) the quartz was dominant followed by the mica, plagioclases, calcite, chlorite, mixed layers and amphiboles. However, in the middle C horizon, plagioclases were more than the mica.

Silt: Mineralogy of silt fraction (Fig. 4.14, Table 4.6.10) was similar to that of the sand fraction except that the mica and chlorite, kaolinite content increased and that of amphiboles and calcite decreased with fineness.

Clay: X-ray diffractograms of these clay (Fig. 4.15, 4.16, 4.17) indicated a very strong and well defined peaks for illite. A major portion of 1.4 nm peak resolved to 1.8 nm on glycerol solvation and was attributed to smectites. Remaining part of 1.4 nm remained unaffected by K-saturation and heating thus confirming the presence of chlorites and absence of vermiculites. In these clays chlorite and mica are both diocta type and smectite is fairly well organised. Mixed layer minerals are composed of mica-smectite and mica-chlorite type mainly. Persistence of 0.72 nm peak in HCl treated clays confirmed the presence of kaolinite in these soils. Sharp but small peaks at indicated the presence of minor amounts amphiboles, quartz and feldspars in these clays.

Semi-quantitative estimates of various minerals, as calculated from the corrected peak area value (Table 4.6.11) suggested the dominance of smectite followed by illite, chlorite, kaolinite and mixed layer minerals. Associated primary minerals contributed only minor proportions. Smectite contents of these clays ranged between 31 to 43 per cent.

Mineralogy: Results obtained from the qualitative and semi- quantitative estimates of XRD patterns of sand, silt and clay fractions of Panchkula pedon

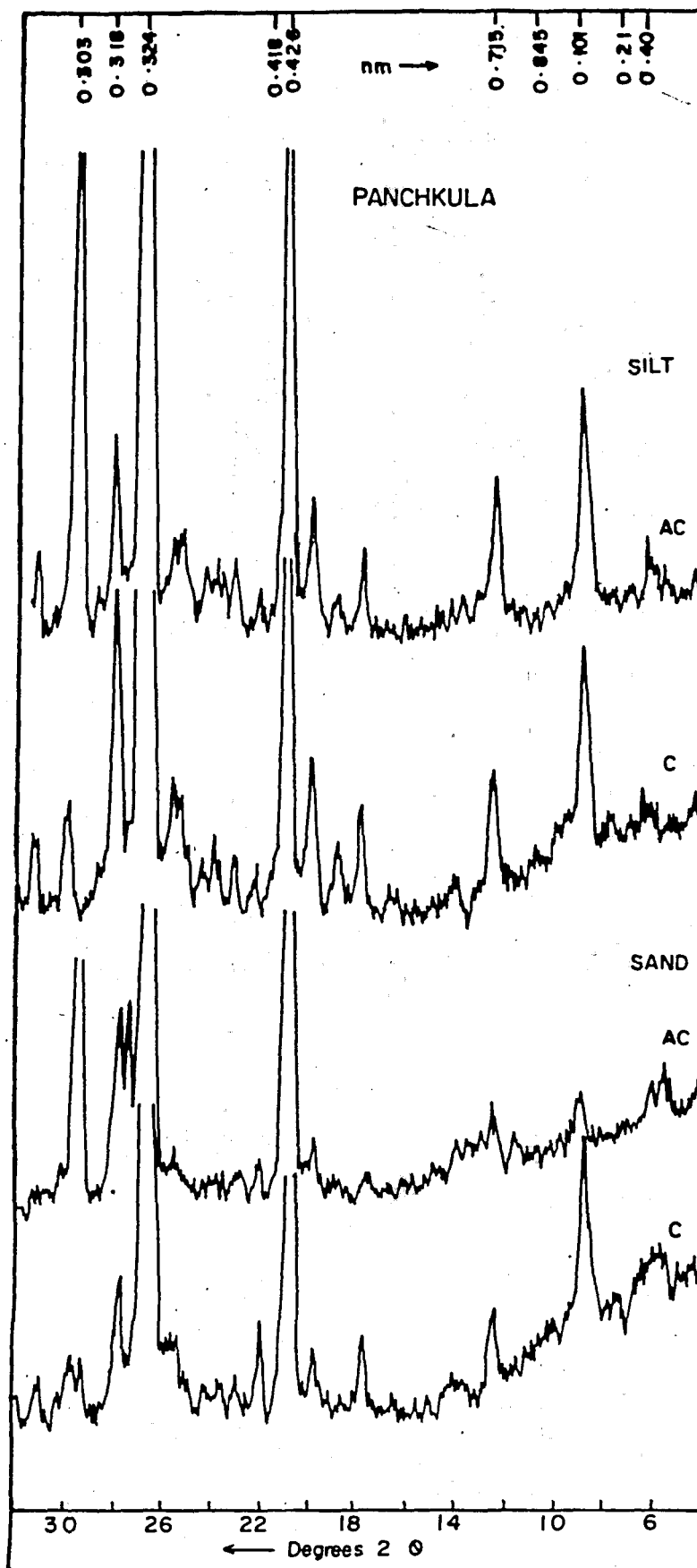


Fig. 4.19 XRD pattern of sand and silt minerals

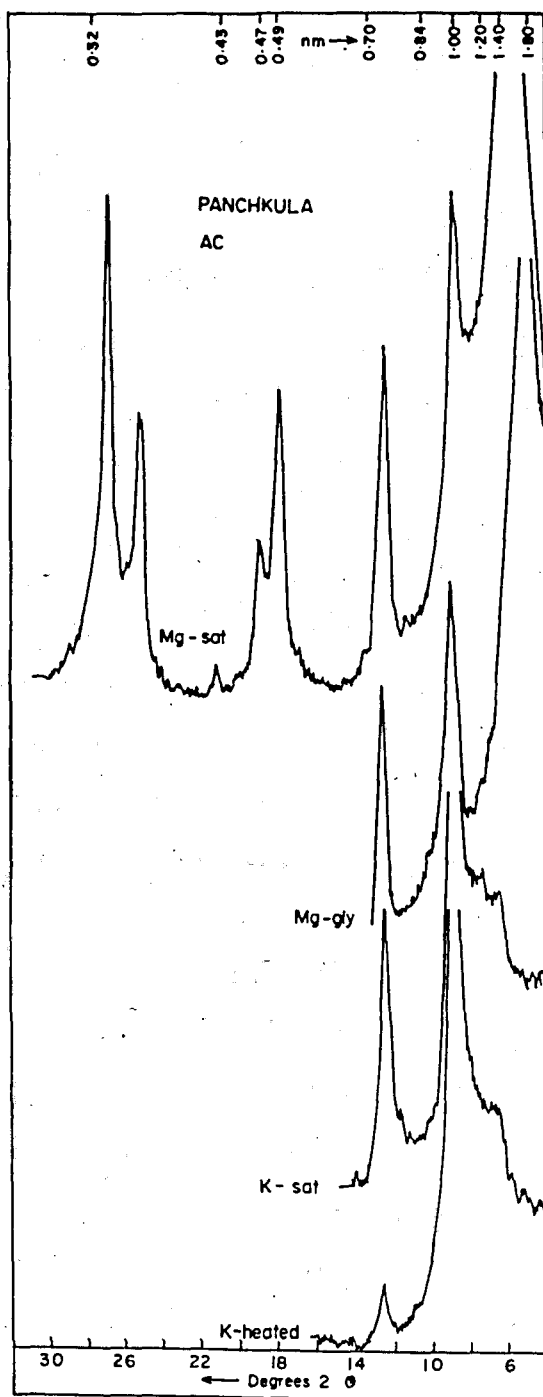


Fig. 4.20 XRD pattern of clay minerals

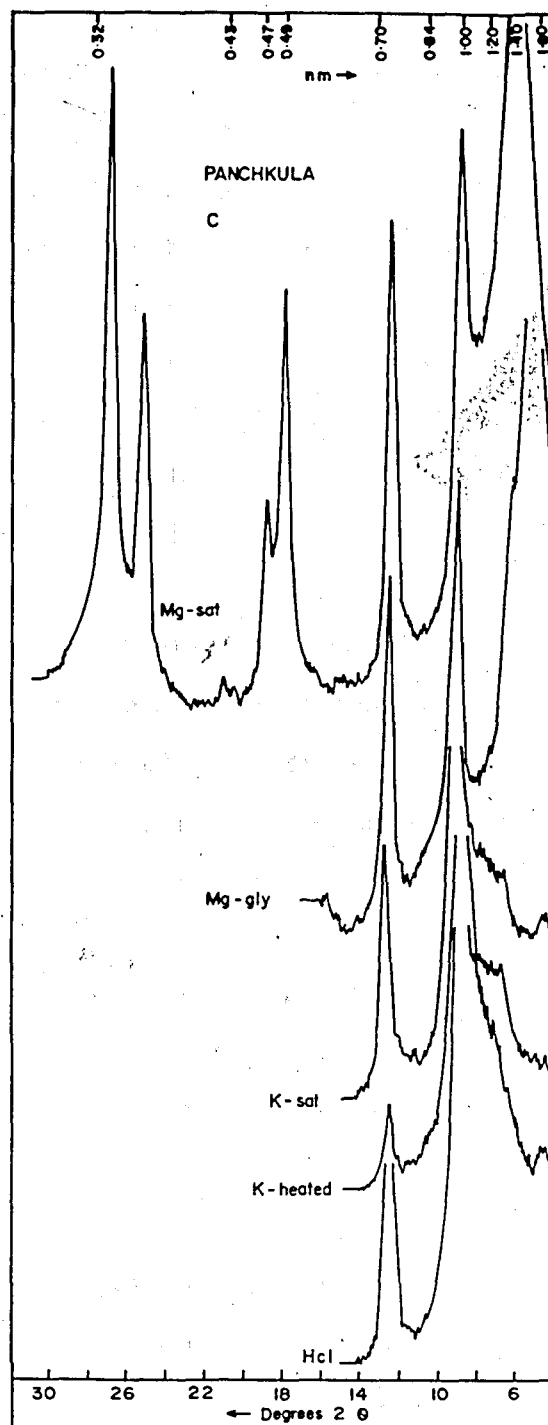


Fig. 4.21 XRD pattern of clay minerals

are presented below.

Sand: Semi-quantitative estimates of various minerals in sand fraction (Fig. 4.19, Table 3.5.10) indicated the dominance of quartz followed by calcite, orthoclase feldspars, plagioclases, mica and chlorite in the upper horizon. However, in lower horizon the general order of preponderance in decreasing order was quartz, mica, feldspars, calcite chlorite and mixed layers.

Silt: There was not much difference in the general order of preponderance of various minerals in silt fraction (Fig. 4.19, Table 4.5.10). However, amounts of plagioclase feldspars increased considerably in silt fraction.

Clay: X-ray diffractograms (Fig. 4.20, 4.21) of clay indicated a very strong and well defined peaks for illite. On glycerol solvation a major portion of 1.4 nm peak resolved to a maximum at 1.8 nm, which was termed as smectite. A part of remaining 1.4 nm, collapsed to 1.0 nm on K-saturation and heating of the sample, thereby confirming the presence of vermiculite. Residual 1.4 nm that persisted even after K-saturated clay was heated was attributed to chlorite. Mixed layer minerals registered peak around 1.2 nm. These were mostly mica-chlorite and mica-smectite type. Clay minerals are both di- and trioctahedral in nature. In general 1.0 and 1.4 nm diffractions were strong and peaks are symmetrical. Nature of minerals was mostly identical.

The 0.721 nm peak in the XRD pattern could possibly be either due to 002 of 14 Å or due to 001 of kaolinite. To identify kaolinite in the presence of chlorite, XRD pattern recorded after 4 N HCl treatment of clay were used. Persistence of 0.7 nm peak confirmed the presence of kaolinite. The amphiboles, quartz and feldspar registered small but sharp peaks.

Semi-quantitative estimates (Table 4.5.11) on the basis of corrected peak

Pedon No. 5 RAMGARH

Classification: Typic Udorthent, fine loamy, mixed, hyperthermic

Location: 76° 52' 53"E, 30° 38' 11"N, Panchkula to Yamunanagar road, 4 km to Panchkula

Physiography: Siwalik hills

Topography: Hill crest with 30 percent slope

Drainage: Excessively drained

Landuse: Scrubby forest

Elevation = 380 m

Rainfall: 1100 mm

Table 4.5.1 Morphology

Lab. No.	Depth (cm)	Horizon	Boundary	Colour (moist)	Texture (USDA)	Structure	Consistence (wet)	Cutans	Roots	Coarse fragments	Reaction
24	0-10	A1	cw	5YR 4/3	sil	-	ws,sp	-	f,f	-	4
25	10-46	C1	cw	7YR 6/4	sic	-	ws,wp	-	-	conca,m	3
26	46-100+	C2		10YR 5/4	sil	-	ws,wp	-	-	conca,m	3

Table 4.5.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)				Coarse fragments (%)	Water content (%)		
		Sand (2 - 0.05)	Silt (0.05 - 0.002)	Clay (< 0.002)	----- % of < 2 mm -----		1/3 bar	15 bar	Available
24	0-10	14.5	59.2	26.3		-	22.9	9.3	13.6
25	10-46	6.1	43.2	50.7		10	24.5	16.2	8.3
26	46-100+	16.0	62.9	21.1		33	21.2	12.2	9.0

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)			
								Fe	Mn	Cu	Zn
24	0-10	0.11	0.7	9.7	0.44	1.67	0.047	2.8	1.6	0.34	0.32
25	10-46	0.05	1.3	9.5	0.48	1.65	0.123	2.8	1.8	0.30	0.22
26	46-100+	0.05	1.9	9.5	0.51	1.68	0.038	2.8	2.0	0.38	0.22

Table 4.5.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)				CEC (c mol kg ⁻¹)	ESP
		Na	Mg	Ca	K		
24	0-10	4.5	3.2	11.0	0.21	18.9	24
25	10-46	3.3	4.8	15.2	0.35	23.6	14
26	46-100+	3.8	2.8	11.2	0.25	18.5	20

Table 4.5.4 Saturation extract analysis

Lab. No.	Depth (cm)	Saturation (%)	pH _s	EC _e dSm ⁻¹	Saturation extract analysis (me/l)							SAR	
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl		SO ₄
24	0-10	43	8.6	1.08	6.02	4.5	1.0	0.05	1.4	4.5	5.5	1.40	3.63
25	10-46	46	8.4	1.12	7.11	4.5	1.3	0.12	1.4	3.1	4.5	2.68	4.18
26	46-100+	46	8.5	1.43	8.48	6.8	0.8	0.06	1.4	3.1	7.0	1.26	2.25

Table 4.5.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
24	0-10	89.3	3.14	1.43	0.81	1.50	1.19	0.46	tr.	0.045	1.64
25	10-46	85.2	3.42	2.03	0.26	1.50	1.24	0.56	tr.	0.059	3.86
26	46-100+	88.5	2.53	1.35	0.39	2.50	1.01	0.32	tr	0.107	1.77

Table 4.5.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	NaO	K ₂ O			
								P ₂ O ₅	MnO		
24	0-10	72.2	13.5	3.25	0.0	2.09	1.58	1.86	0.01	0.030	3.34
25	10-46	71.3	12.6	4.06	0.0	2.66	0.96	2.66	0.04	0.041	4.86
26	46-100+	72.8	14.5	2.60	0.0	1.75	1.16	1.69	tr.	0.035	3.56

Table 4.5.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	
24	0-10	53.1	23.2	4.79	0.5	2.56	0.10	1.53	0.039
25	10-46	51.4	22.9	4.84	0.0	9.52	0.12	1.69	0.034
26	46-100+	49.9	23.6	5.10	0.0	2.19	0.12	1.36	0.031
									0.080
									0.065
									0.074
									10.0
									9.3
									10.9

Table 4.5.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	
24	0-10	68.8	14.2	4.24	0.0	1.64	0.39	0.79	0.041
25	10-46	62.3	17.5	6.05	0.0	2.27	0.21	0.33	0.108
26	46-100+	70.1	13.5	4.38	0.0	1.49	0.35	0.71	0.084
									5.02
									6.95
									4.44

Table 4.5.9 Elemental composition of lime concretions

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	
26	46-100+	61.6	2.1	2.80	14.0	1.37	0.18	0.52	0.181
									0.06
									4.12

Table 4.5.10 Semi-quantitative estimates of sand and silt minerals

Lab.No.	Depth (cm)	Chlorite	Mixed layer	Mica	Amphibole	Chlorite + Kaolinite	Quartz	Orthoclases	Plagioclases	Calcite
Sand										
24	0-10	++	++	+++	+	++	+++++	++	+++	+++
25	10-46	++	++	+++	++	++	+++++	++	++++	++
26	46-100+	++	++	+++	++	++	+++++	++	+++	+++
Silt										
24	0-10	++	++	++++	++	+++	+++++	++	+++	+
25	10-46	++	++	++++	-	+++	++++	++	+++	-
26	46-100+	++	++	++++	-	++	+++++	++	+++	-

4.1.11 Semi quantitative estimates of clay minerals

Lab. No.	Depth (cm)	Smectite	Chlorite	Vermiculite	Illite	Mixed layer	Kaolinite	Quartz	Feldspar	Amphibole
%										
24	0-10	40	7	-	36	5	8	1	2	1
25	10-46	31	8	-	45	6	6	2	2	-
26	46-100+	43	8	-	34	5	7	1	1	1

Pedon No. 6 PANCHKULA

Classification: Typic Udorthent, loamy mixed, hyperthermic

Location: 76° 54' 54"E, 30° 44' 47"N, cut on Ghaggar river bank, Panchkula - Morni road, 3 km

Physiography: Siwalik hills Topography: Vertical cut

Drainage: Excessively drained Landuse: Scrubby vegetation

Elevation: 480 m Rainfall: 1125 mm

Table 4.6.1 Morphology

Lab. No.	Depth (cm)	Horizon	Boundary	Colour (moist)	Texture (USDA)	Structure	Consistence (wet)	Cutans	Roots	Coarse fragments	Reaction
16	0-50	AC	gw	7.5YR 4/4	sl	3c,sbk	wss,wsp	-	f,f	conca,m	3
17	50-200+	C		7.5YR 4/4	sil	3c,sbk	ws,wp	-	-	-	1

Table 4.6.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)			Coarse fragments (%)	Water content (%)		
		Sand (2 - 0.05)	Silt (0.05 - 0.002)	Clay (< 0.002)		1/3 bar	15 bar	Available
		% of < 2 mm						
16	0-50	55.6	31.6	12.8	36	16.6	4.8	11.8
17	50-200+	23.8	55.4	20.8	-	25.0	9.5	15.5

Table 4.6.2 Physico chemical characteristics contd.....

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)			
								Fe	Mn	Cu	Zn
16	0-50	0.30	9.2	8.8	0.20	1.89	0.636	2.2	2.8	0.40	0.18
17	50-200+	0.09	0.5	9.8	1.36	1.69	-	2.2	2.6	0.24	0.20

Table 4.6.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)				CEC (c mol kg ⁻¹)	ESP
		Na	Mg	Ca	K		
16	0-50	0.8	0.8	7.6	0.14	9.3	9
17	50-200+	5.5	1.2	5.4	0.12	12.2	45

Table 4.6.4 Saturation extract analysis

Lab. No.	Depth (cm)	Saturation (%)	pH _s	EC _e dSm ⁻¹	Saturation extract analysis (me/l)							SAR	
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl		SO ₄
16	0-50	44	8.4	0.69	1.41	3.5	2.5	0.08	-	4.2	3.0	0.66	0.81
17	50-200+	54	8.9	3.49	26.70	4.0	3.3	0.04	-	5.4	26.0	1.16	14.00

Table 4.6.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	
16	0-50	90.5	2.98	1.33	0.7	1.58	1.16	0.33	1.25
17	50-200+	88.1	3.34	1.58	0.0	1.17	1.23	0.44	1.29
								tr.	
								0.25	
								0.061	
								0.030	

Table 4.6.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	
16	0-50	72.1	12.8	3.65	0.4	2.22	1.49	1.80	4.35
17	50-200+	73.1	13.3	3.06	0.0	2.97	1.14	1.67	2.63
								0.102	
								0.065	
								0.03	
								0.03	

Table 4.6.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	
16	0-50	52.2	23.1	4.64	0.2	3.14	0.12	1.47	9.82
17	50-200+	53.1	24.2	4.85	0.0	2.34	0.16	1.62	7.94
								0.034	
								0.025	
								0.17	
								0.13	
								0.080	
								0.066	

Table 4.6.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
16	0-50	77.4	9.5	3.21	1.43	1.15	0.28	0.45	0.04	0.071	5.75
17	50-200+	72.8	13.9	4.42	0.00	1.35	0.49	0.81	0.06	0.080	4.48

Table 4.6.9 Elemental composition of lime concretions

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O			
								P ₂ O ₅	MnO		
16	0-50	76.7	1.96	2.42	11.8	2.17	0.19	0.45	0.12	0.232	4.93

Table 4.6.10 Semi-quantitative estimates of sand and silt minerals

Lab.No.	Depth (cm)	Chlorite	Mixed layer	Mica	Amphibole	Chlorite + Kaolinite	Quartz	Orthoclases	Plagioclases	Calcite
Sand										
16	0-50	++	+	++	-	++	++++++	+++	++	++++
17	50-200+	++	++	++++	-	++	++++++	++	++	++
Silt										
16	0-50	++	-	+++	-	+++	+++++	++	+++	++++
17	50-200+	++	-	++++	-	+++	+++++	++	++++	+

4.6.11 Semi quantitative estimates of clay minerals

Lab. No.	Depth (cm)	Smectite	Chlorite	Vermiculite	Illite	Mixed layer	Kaolinite	Quartz	Feldspar	Amphibole
%										
16	0-50	20	13	9	43	8	4	1	1	2
17	50-200+	19	11	10	44	7	5	1	2	1

area values suggested the dominance illite followed by smectite, chlorite, vermiculite and kaolinite. Smectite content in these clays ranged between 19-20 percent.

4.32 Lower piedmont: Lalru, Sherpur and Saha pedons represent soils of the lower piedmont. However, due to wide differences in characteristics, these are discussed here separately.

Lalru soils: Elevation of these moderately to gently sloping lands was around 285 m. Present geomorphic position did not indicate any chance of standing water on these soils. Water table is more than 70m deep. These soils have Ustic moisture regime and hyperthermic temperature regime.

Morphology These soils have colours of yellowish brown at surface, brown to dark brown in middle and dark brown to dark yellowish brown colours in lower horizons (Table 4.7.1). Like colours texture also varied from sandy loam in upper, loam to silt loam in lower horizons. Soft powder lime concretions were present in 10-25 cm (IICCa) and 39-97 cm (IIIC3Ca) horizons. Platy structure was present immediately below the thin surface horizon. Structure within the profile varied from moderate, medium sub- angular blocky to moderate coarse sub-angular blocky. Flood coatings were also observed on the peds of IIIC3 Ca (39-97 cm) horizon. Soils were highly calcareous through out. Two lithological discontinuities were present at 10-25 cm and 39-97 cm horizons.

Physical characteristics: A perusal of Table 4.7.2 indicated that sand, silt and clay were irregularly distributed within the profile. Sand and silt content varied from 17.6 to 63.9 and 29.6 to 71.9 per cent, respectively. Hydraulic conductivity varied from almost nil to 0.24 cm hr^{-1} . It indicated a very poor internal drainage conditions within the profile. Bulk density ranged from 1.21 to 1.76 Mg m^{-3} . Available moisture varied from 11.6 to 17.7 per cent.

Chemical Characteristics Akin to morphological and physical characteristics various soil chemical parameters (Table 4.7.2) were also irregularly distributed. Organic carbon and CaCO_3 varied from 0.04 to 0.47 and 6.40 to 14.95, respectively. pH_2 ranged between 9.75 to 10.70. EC_2 ranged between 1.13 to 7.32 dSm^{-1} .

Micro-nutrients: DTPA-extractable Fe, Mn, Cu were in sufficient amounts. Excepting surface horizon amounts of DTPA-extractable Zn were below the critical limit of 0.6 mg kg^{-1} (Table 4.7.2).

Exchangeable cations Sodium dominated among the exchangeable cations and it occupied 54 to 87 per cent of exchange complex. Magnesium was in minimum, contents varying from 0.2 to 0.7 cmol kg^{-1} . CEC ranged between 4.9 to 14.7 cmol kg^{-1} (Table 4.7.3).

Saturation extract: The pHs and ECe (Table 4.7.4) were high. pHs varied from 9.2 to 10.4. EC_2 ranged between 1.81 to 21.90 dSm^{-1} . Sodium among cations and carbonate followed by chloride among the anions dominated the saturation extract analysis. Na varied from 12.96 to 229.6 me/l . CO_3 and Cl ranged between 7.0 to 214.2 and 8.0 to 42.5 me/l . SAR of this soils solutions varied from 11 to as high as 144.

Elemental composition (per cent)

Sand The SiO_2 and Al_2O_3 (Table 4.7.5) ranged between 82.40 to 88.26 and 3.12 to 5.21, respectively. Fe_2O_3 and CaO varied from 0.96 to 2.45 and 0.49 to 1.21, respectively. Na_2O content ranged between 1.3 to 2.05. MgO and K_2O varied from 1.58 to 2.25 and 0.42 to 0.70, respectively. All the elements were irregularly distributed with depth. Loss on ignition varied from 1.02 to 1.79 per cent.

Silt: The SiO_2 and Al_2O_3 (Table 4.7.6) ranged between 68.39 to 72.63 and 14.23 to 17.71, respectively. Fe_2O_3 and CaO varied from 2.12 to 3.09 and 0.22 to 0.99, respectively. K_2O ranged from 1.11 to 1.58. MgO and Na_2O varied from 2.17 to 2.76 and 1.22 to 1.72, respectively. P_2O_5 and MnO contents ranged between 0.046 to 0.089 and 0.005 to 0.030, respectively. Loss on ignition in the silt fraction of these soils varied from 2.87 to 4.63 per cent. All the elements were irregularly distributed with depth.

Clay: The SiO_2 and Al_2O_3 contents (Table 4.7.7) varied from 50.26 to 56.36 and 19.94 to 22.45, respectively. Fe_2O_3 and CaO ranged between 5.00 to 5.49 and 0.0 to 0.56, respectively. MgO and K_2O contents varied from 2.82 to 4.59 and 1.52 to 1.80, respectively. Na_2O contents was very less than 0.23. P_2O_5 ranged between 0.165 to 0.362. ZnO and MnO varied from 0.015 to 0.045 and 0.046 to 0.097, respectively. Loss on ignition of clay fraction was quite high and varied from 8.55 to 13.56 per cent respectively.

A comparison of elemental composition of three fractions indicated that contents of Al_2O_3 , Fe_2O_3 , MgO , K_2O and P_2O_5 increased whereas, SiO_2 , CaO and Na_2O decreased with increase in fineness of mineral fraction.

Soil: A perusal of table 4.7.8 indicated that almost all the elements were irregularly distributed with depth. SiO_2 and Al_2O_3 ranged between 66.48 to 81.05 and 7.68 to 15.88. Fe_2O_3 and CaO varied from 2.23 to 4.26 and 0.81 to 1.09, respectively. Na_2O and K_2O content ranged between 0.53 to 0.80. P_2O_5 and MnO varied from 0.060 to 0.110 and 0.056 to 0.092. Loss of ignition of this soil varied from 0.92 to 5.44 per cent.

Soil Taxonomy: Based on macro-morphology, physical and chemical characteristics and as per the norms of Soil Survey Staff (1975), these soils have been classified as: coarse loamy mixed hyperthermic, Typic Ustifluvent. However this

classification did not indicate the soil management problems due to the presence of large amounts of salts in these soils.

Stability of alumino-silicates: Very low hydraulic conductivity and presence of large amounts of soluble salts, even in an area of high rainfall, indicated a very poor internal drainage condition of these soils. Under such an environment high pHs soil solution with high level of cations and H_4SiO_4 is bound to have a marked effect on the solubility of various alumino-silicates. Same has been evaluated and presented in figure 4.22.

At pHs 9.2 and constituent cations activity levels, under high H_4SiO_4 activity ($10^{-2.74}\text{M}$ = amorphous SiO_2); common alumino-silicates in Ap horizon of Lalru pedon, can be arranged in order of increasing stability as: kaolinite, muscovite, illite, albite, microcline, montmorillonite, vermiculite and chlorite.

At pHs 10.4 and constituent cations activity levels, under high activity of H_4SiO_4 ($10^{-2.74}\text{M}$ = amorphous SiO_2), the alumino-silicates in II ClCa horizon of Lalru pedon change in stability in the increasing order as: kaolinite, muscovite, illite, microcline, montmorillonite, albite, vermiculite, chlorite.

Similarly at pHs 9.9 and constituent cation activity levels in soil solution, under high activity of H_4SiO_4 ($10^{-2.74}\text{M}$ = amorphous SiO_2), common alumino-silicates in IIIC5 horizon of Lalru pedon, can be arranged in order of increasing stability as: kaolinite, muscovite, illite, microcline, albite, montmorillonite, vermiculite and chlorite.

A comparison of mineral stabilities, solubilities in the three horizon indicated that with increase in pHs from 9.2 to 10.4 the equilibrium Al^{3+} activity as maintained by sodium containing mineral albite decreased from $10^{-23.5}\text{M}$

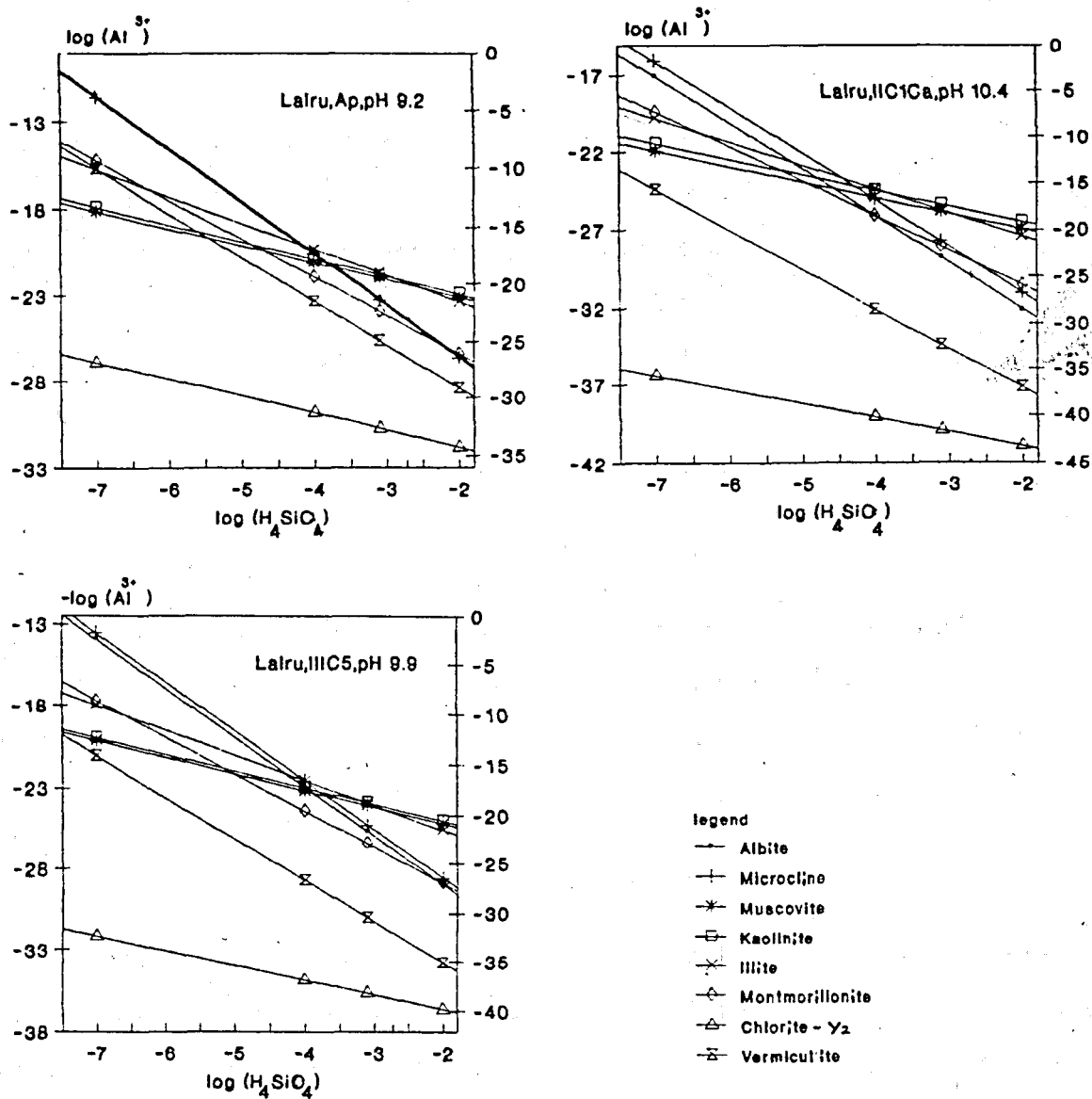


Fig. 4.22 Stability of aluminosilicates

to 10^{-29} M. Thus its stability increased with increasing pH of soil solution and Na activity.

Mineralogy: Information obtained from the qualitative and semi- quantitative estimates of minerals from the interpretation of x- ray diffractograms of selected horizons of Lalru pedon are presented below:

Sand: In general quartz was dominant (Fig. 4.23, Table 3.7.9) followed by plagioclases, mica, orthoclase feldspars, calcite, chlorite+kaolinite, mixed layer minerals and amphiboles. However, in the middle IIC1Ca horizon, calcite closely followed quartz.

Silt: Estimates from the diffractogram of silt (Fig. 4.23, Table 4.7.9) indicated almost similar trends except that amphiboles were absent and kaolinite+chlorite contents were higher. In IIC1Ca, calcite content was even more than quartz, confirming the presence of lithological discontinuity in these soils.

Clay: X-ray diffractograms (Fig. 4.24, 4.25, 4.26) of these soils indicated that 1.8 nm was very prominently resolved in the lower IIIC5 horizon, in which smectite seemed to be fairly well organised and 1.0 nm and 1.4 nm peaks were symmetrical. Mixed layer component seemed to be both mica-smectite and mica-chlorite type.

Semi-quantitative estimates (Table 4.7.10) calculated on the basis of corrected peak area value suggested the dominance of illite followed by mixed layers, vermiculite, kaolinite and smectite. However, in the IIC1Ca and IIIC5 horizons, smectite and vermiculite were the most dominant mineral after the illite. Primary minerals contributed only minor proportions. Mineralogical composition of IIIC5 horizon of these soils was similar to that of lower horizon of Panchkula pedon.

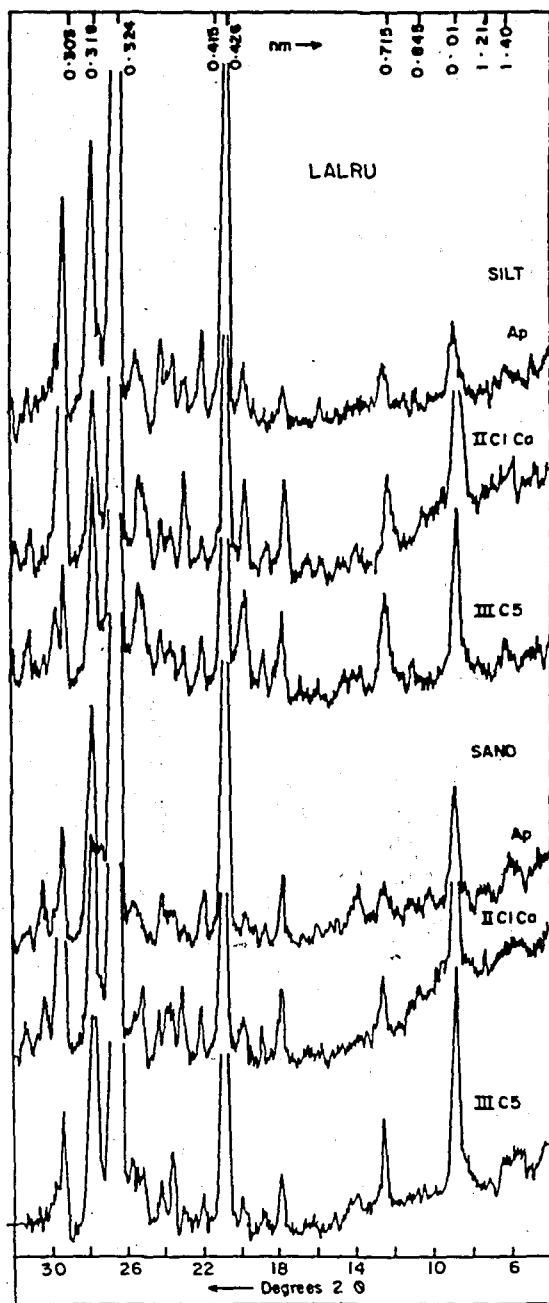


Fig. 4.23 XRD pattern of sand and silt minerals

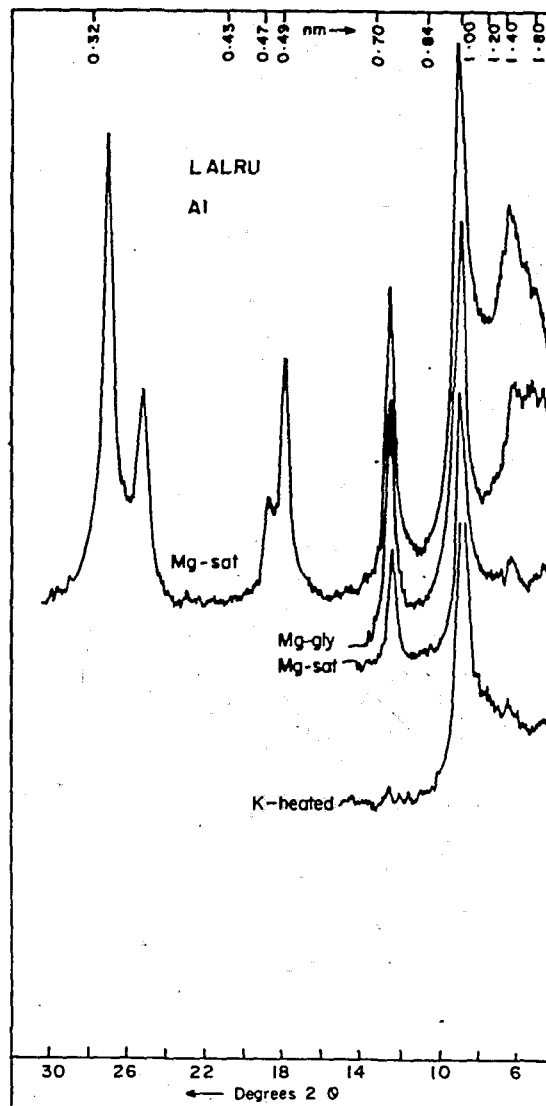


Fig. 4.24 XRD pattern of clay minerals

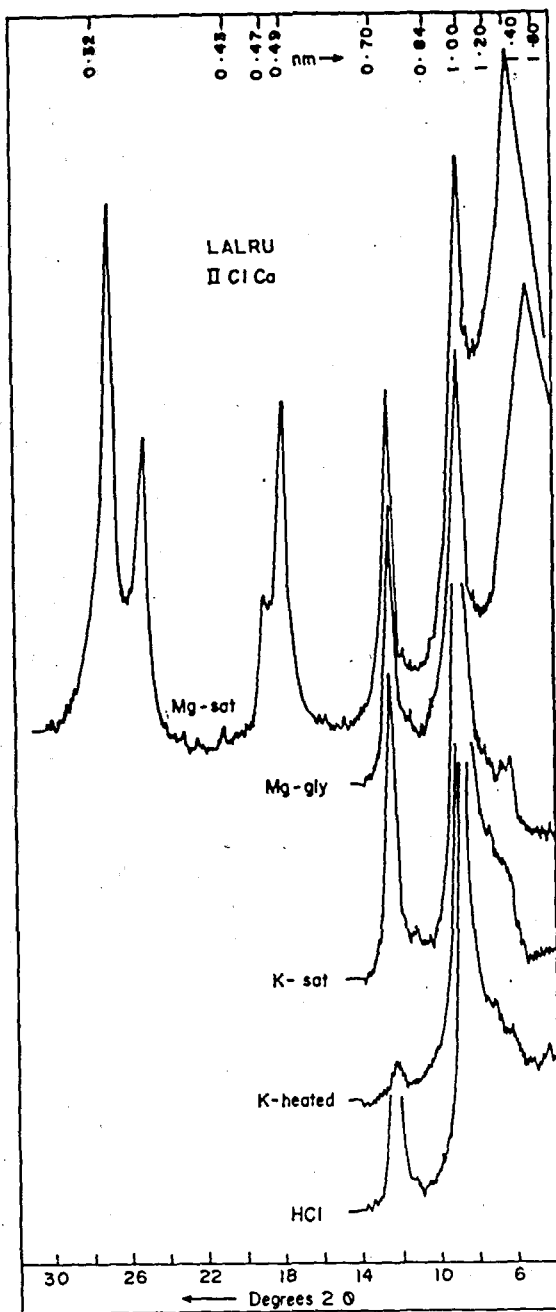


Fig. 4.25 XRD pattern of clay minerals

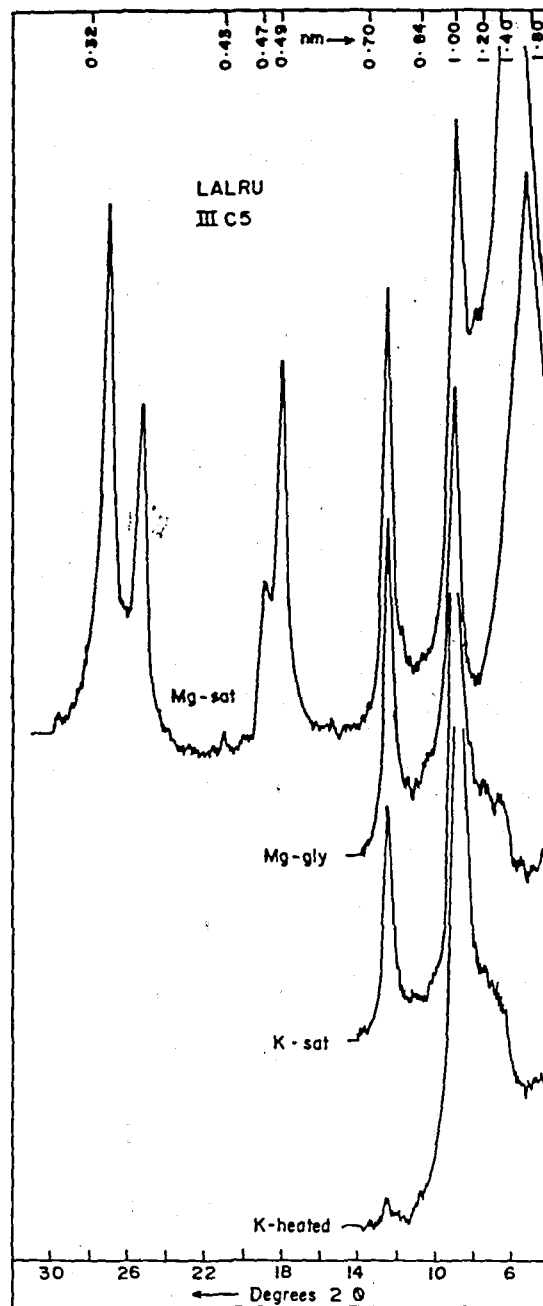


Fig. 4.26 XRD pattern of clay minerals

Pedon No. 7 LALRU

Classification: Typic Ustifluvent, coarse loamy, mixed, hyperthermic

Location: 76° 49' 22"E, 30° 21' 16"N, village Lalru, on Ambala to Chandigarh road

Physiography: Lower piedmont

Topography: Gently sloping levee, 3 per cent slope

Drainage: Moderately well drained

Landuse: Cultivated

Elevation: 285 m

Rainfall: 1050 mm

Table 4.7.1 Morphology

Lab. No.	Depth (cm)	Horizon	Boundary	Colour (moist)	Texture (USDA)	Structure	Consistence (wet)	Cutans	Roots	Coarse fragments	Reaction
27	0-5	Ap	cw	10YR 5/3	sl	1f, sbk	ws, wpo	-	f, bf	-	4
28	5-10	A3	gw	10YR 5/4	sl	1f, pl	ws, wpo	-	s, f	-	4
29	10-25	IIC1Ca	cw	7.5YR 5/4	l	2m, sbk	wss, wsp	-	f, f	conca, m	4
30	25-39	IIC2	gw	7.5YR 4/4	sil	2m, sbk	wss, wsp	-	f, f	-	4
31	39-97	IIIC3Ca	cw	7.5YR 3/4	sil	2m, sbk	ws, wp	-	-	conca, m	4
32	97-108	IIIC4	gw	10YR 4/4	sil	2c, sbk	ws, wp	-	-	-	4
33	108-120+	IIIC5		7.5YR 4/4	sil	2c, sbk	ws, wp	-	-	-	4

Table 4.7.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)			Coarse fragments (%)	Water content (%)		
		Sand	Silt	Clay		1/3 bar	15 bar	Available
		(2 - 0.05)	(0.05 - 0.002)	(< 0.002)				
-----% of < 2 mm-----								
27	0-5	63.9	29.6	6.5	2	18.8	4.4	14.4
28	5-10	56.2	33.8	10.0	-	10.4	5.1	14.3
29	10-25	20.9	50.8	28.3	19	28.8	11.5	17.7
30	25-39	30.0	45.1	24.9	-	27.6	11.6	16.0
31	39-97	17.3	67.5	15.2	17	28.4	13.7	14.7
32	97-108	27.9	61.1	11.0	4	27.6	11.7	15.9
33	108-120+	17.6	71.9	10.5	3	28.5	16.9	11.6

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)			
								Fe	Mn	Cu	Zn
27	0-5	0.47	6.4	9.8	0.73	1.21	0.239	3.0	6.0	0.48	0.64
28	5-10	0.14	7.5	10.6	3.60	1.41	0.022	8.4	6.1	0.52	0.54
29	10-25	0.11	16.8	10.7	5.20	1.61	0.002	8.4	2.3	0.96	0.36
30	25-39	0.06	7.8	10.7	5.85	1.65	0.007	8.8	2.3	0.88	0.38
31	39-97	0.09	15.0	10.5	5.10	1.57	0.003	10.6	2.1	0.60	0.30
32	97-108	0.04	7.3	10.6	2.47	1.76	0.005	11.4	3.4	0.48	0.24
33	108-120+	0.08	5.8	10.2	0.52	1.67	-	3.8	2.6	0.34	0.20

Table 4.7.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)				CEC (c mol kg ⁻¹)	ESP
		Na	Mg	Ca	K		
27	0-5	2.6	0.7	1.1	0.49	4.9	54
28	5-10	6.0	0.2	1.3	0.25	7.8	77
29	10-25	12.4	0.2	1.7	0.30	14.6	85
30	25-39	12.7	0.2	1.4	0.35	14.7	87
31	39-97	12.0	0.2	1.2	0.37	13.8	87
32	98-108	11.0	0.2	1.3	0.38	12.9	85
33	108-120+	7.0	0.7	1.6	0.21	9.5	73

Table 4.7.4 Saturation extract analysis

Lab. No.	Depth (cm)	Saturation (%)	pH _s	EC _e dSm ⁻¹	Saturation extract analysis (me/l)								SAR
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl	SO ₄	
27	0-5	22	9.2	3.92	30.1	5.3	0.8	0.64	12.8	10.7	10.5	1.7	17
28	5-10	48	10.2	13.69	139.1	4.0	0.5	0.26	83.8	17.2	42.5	4.6	92
29	10-25	47	10.4	20.63	227.8	2.5	2.5	0.29	193.2	26.6	37.0	7.6	144
30	25-39	43	10.4	21.90	229.6	6.0	1.0	0.37	214.2	28.7	40.0	5.8	122
31	39-97	46	10.2	19.40	215.8	3.6	0.7	0.47	211.4	21.7	40.0	8.8	147
32	97-108	41	10.3	10.48	121.2	2.8	1.5	0.30	92.4	16.1	25.0	4.9	83
33	108-120+	39	9.9	1.81	12.9	5.0	1.0	0.09	7.0	6.7	8.0	3.8	11

Table 4.7.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	
27									
28	0-5	87.9	3.84	1.22	0.49	1.75	1.62	0.42	0.050
29	5-10	88.3	3.12	0.96	0.70	1.58	1.30	0.34	0.039
30	10-25	85.2	4.58	2.23	0.82	2.25	1.74	0.67	0.044
31	25-39	83.2	5.21	2.51	0.13	2.25	2.05	0.69	0.066
32	39-97	84.4	4.98	2.45	0.53	2.33	1.92	0.70	0.086
33	97-108	82.4	5.05	2.26	1.21	2.17	1.98	0.68	0.093
	108-120+	85.2	3.76	1.60	0.98	1.58	1.51	0.47	0.072

Table 4.7.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	
27									
28	0-5	73.2	14.2	2.39	0.9	2.17	1.67	1.30	0.014
29	5-10	72.4	14.8	2.12	0.2	2.76	1.72	1.11	0.014
30	10-25	70.1	16.8	2.72	0.3	2.59	1.22	1.58	0.022
31	25-39	68.4	17.7	2.96	1.0	2.17	1.72	1.53	0.005
32	39-97	72.3	15.2	2.62	1.0	2.34	1.56	1.47	0.014
33	97-108	71.9	15.2	3.09	0.8	2.67	1.41	1.64	0.021
	108-120+	72.6	15.4	2.63	0.5	2.51	1.33	1.60	0.030

Table 4.7.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		ZnO	MnO
27	0-5	53.2	19.9	5.22	0.6	3.69	0.23	1.73	0.30	0.045	0.097	9.96
28	5-10	52.2	20.1	5.50	0.1	2.96	0.21	1.80	0.22	0.039	0.090	10.61
29	10-25	55.4	21.2	5.00	0.0	2.71	0.16	1.68	0.17	0.015	0.056	8.55
30	25-39	56.4	21.2	5.13	0.3	3.22	0.16	1.62	0.19	0.020	0.057	8.68
31	39-97	51.5	22.2	5.30	0.2	2.87	0.16	1.62	0.23	0.020	0.040	9.31
32	97-108	51.5	22.5	5.42	0.3	4.59	0.19	1.52	0.36	0.019	0.046	10.19
33	108-120+	50.3	22.4	5.01	0.2	2.82	0.23	1.62	0.22	0.035	0.061	13.56

Table 4.7.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O		P ₂ O ₅	MnO
27	0-5	81.1	7.7	2.23	1.1	1.02	0.70	0.45	0.06	0.092	4.74
28	5-10	79.4	8.7	2.59	1.6	1.65	0.70	0.50	0.07	0.067	4.92
29	10-25	66.5	15.6	4.29	0.8	2.05	0.50	0.71	0.19	0.056	5.39
30	25-29	68.5	14.3	4.26	1.0	2.62	0.72	0.71	0.26	0.507	3.05
31	29-97	70.7	14.3	3.90	0.8	1.85	0.56	0.70	0.11	0.065	4.62
32	97-108	72.9	12.9	3.92	0.8	1.79	0.80	0.72	0.11	0.072	4.45
33	108-120+	71.8	13.9	3.99	0.8	1.49	0.53	0.72	0.10	0.067	5.44

Table 4.7.9 Semi quantitative estimates of sand and silt minerals

Lab.No.	Depth (cm)	Chlorite layer	Mica	Amphibole	Chlorite + Kaolinite	Quartz	Orthoclases	Plagioclases	Calcite
Sand									
27	0-5	++	+++	++	++	+++++	++	++++	+++
29	10-25	++	++++	-	++	+++++	++	+++	++++
33	97-108	+	++++	+	++	+++++	++	++++	++
Silt									
27	0-5	++	+++	-	++	+++++	++	++++	+++
29	10-25	++	++++	-	++	+++++	++	+++	+++++
33	97-108	+	+++	-	+++	+++++	++	++++	+++

Table 4.7.10 Semi-quantitative estimates of clay minerals

Lab.No.	Depth (cm)	Smectite	Chlorite	Vermiculite	Illite	Mixed layer	Kaolinite	Quartz	Feldspar	Amphibole
%										
27	0-5	5	4	7	68	8	7	-	1	-
29	10-25	11	8	10	56	7	5	1	2	-
33	97-108	18	11	12	44	6	5	1	2	1

Sherpur and Saha soils

Sherpur-alkali and Saha-normal soils represented the soils of lower piedmont. Elevation of these level to gently sloping lands varied between 2.75 m to 285 m. Rainfall ranged between 950 to 1000 mm approximately. Under the present topographical conditions some surface ponding does take place in in Sherpur soils situated in a micro-depression. However, same is not true of Saha soils. Water table in this area is about 60 m deep. These soils have Ustic moisture regime and hyperthermic temperature regime.

Morphology: Moist colours in Sherpur alkali soils (Table 4.8.1) varied from light olive brown to strong brown. Few to common, fine to moderate, faint to prominent mottles with colours varying from yellowish brown to reddish brown, were present below 16 cm. Texture varied from loam to silty loam. Structure ranged between moderate, medium, sub-angular blocky to strong, coarse, columnar. Consistence of these soils was most very sticky and very plastic under wet conditions. Thin patchy to thick broken cutans were present in 16-121 cm depth. Soils were calcareous through out the pedon.

In contrast Saha-normal pedon (Table 4.9.1) has dark yellowish brown colours through out. Mottles, cutans and coarse fragments were absent. Lithological discontinuity was present between 46-59 cm. Texture above the discontinuity varied from loamy sand to sand loam; whereas, below, it was loam to silty loam. Soils were moderately calcareous.

Physical characteristics: A perusal of table 4.8.2 indicate higher clay content in the B horizon of Sherpur alkali pedon. Bulk density of these soils ranged from 1.63 to 1.82 Mgm^{-3} . Available moisture varied from 2.4 to 17.6 per cent. It was minimum in the B horizons. Hydraulic conductivity was almost nil excepting the surface horizon ($0.0019 \text{ cm hr}^{-1}$).

In comparison to above alkali soils, adjoining normal soils of Saha (Table 4.9.2) showed an irregular distribution of all the fractions. Bulk density varied from 1.44 to 1.71 Mgm^{-3} . Available moisture was maximum in the silt loam layer below the lithological discontinuity. However, hydraulic conductivity of these layers was minimum in the pedon. Hydraulic conductivity of upper horizon varied from 1.371 to 1.692 cm/hr.

Chemical characteristics: The pH_2 and EC_2 of Sherpur alkali soils (Table 4.8.2) ranged between 9.55 to 10.25 and 1.25 to 2.04 dSm^{-1} , respectively. Distribution of O.C. decreased regularly with depth. At surface its content was 0.34 per cent. CaCO_3 varied from 0.85 to 13.20 per cent. DTPA extractable Fe, Mn and Cu were sufficient however Zn was deficient in these soils.

In contrast to above alkali soils pH_2 and EC_2 of Saha normal soils (Table 4.9.2) varied from 7.20 to 9.50 and 0.08 to 0.35 dSm^{-1} , respectively. P_2O_5 was maximum in the horizons below the lithological discontinuity. Unlike, Sherpur alkali soils, organic carbon was irregularly distributed with depth. CaCO_3 content was less in these soils. DTPA extractable micronutrient status was similar to adjoining alkali soils of Sherpur-alkali.

Exchangeable cations: The Na dominated on the exchange complex of the Sherpur-alkali soils (Table 4.8.3). CEC of the soils varied from 7.05 to 16.84 cmol kg^{-1} . ESP of these soils was high and varied from 47 to 92.

In contrast, Ca followed by Mg dominated the exchange complex of the soils of Saha-normal (Table 4.9.3). However, exchangeable Na was maximum in the horizon below the lithological discontinuity. CEC and ESP of these soils varied from 1.02 to 13.79 cmol kg^{-1} and 8 to 20, respectively. Both these characteristics were maximum in the layers below the lithological discontinuity.

Saturation extract: pHs and EC_e of Sherpur alkali soils varied from 8.9 to 9.7 and 2.06 and 2.06 to 4.76 dSm^{-1} , respectively (Table 4.8.4). Na followed by Mg and HCO_3 dominated among the cations and anions in the saturation extract. In addition chlorides appreciable amounts of carbonates and sulphates were also present. SAR of these soils varied from 8.8 to 21.4.

In the Saha normal soils (Table 4.9.4) Mg followed by Ca dominated above the lithological discontinuity however Na became dominant below the discontinuity. Among the anions HCO_3 followed by Cl increased considerably below the discontinuity. SAR of these soils varied from 0.15 to 3.26 with maximum values in the horizons below the discontinuity.

Elemental composition (per cent):

Sand: The SiO_2 , Al_2O_3 and Fe_2O_3 content of these soils (Table 4.8.5 and 4.9.5) varied from 86.06 to 90.88, 2.62 to 4.02 and 0.55 to 2.16, respectively. MgO and K_2O ranged between 0.83 to 4.00 and 0.26 to 0.59, respectively. Na_2O content of sand ranged between 1.11 to 1.59. P_2O_5 was low and loss on ignition of these sands ranged between 0.45 to 4.64 per cent.

Silt: The SiO_2 , Al_2O_3 and Fe_2O_3 content of silt fraction of these soils (Table 4.8.6 and 4.9.6) ranged from 69.14 to 77.28, 9.13 to 16.73 and 2.06 to 3.39, respectively. MgO and K_2O content varied from 1.50 to 2.67 and 1.01 to 1.46, respectively. Na_2O content varied from 0.021 to .098 and loss on ignition of these silts ranged between 0.76 to 5.81 per cent.

Clay: The SiO_2 , Al_2O_3 and Fe_2O_3 content of the clay fraction of these soils (Table 4.8.7 and 4.9.7) varied 50.04 to 54.59, 20.13 to 24.16 and 4.72 to 7.58, respectively. CaO contents were very low. MgO and K_2O ranged between 2.09 to 3.16 and 1.28 to 1.68, respectively. Na_2O contents very low and ranged between 0.16 to 0.28. P_2O_5 content of clay varied from 0.087 to 0.309. ZnO and MnO

varied from 0.016 to 0.045 and 0.058 to 0.090, respectively. Loss on ignition of these clays ranged between 5.72 and 12.43. Loss on ignition values were comparatively higher in horizons below the lithological discontinuity.

Soil: Elemental composition of both the soils was quite different so discussed separately. SiO_2 , Al_2O_3 and Fe_2O_3 content of Sherpur alkali soils (Table 4.8.8) ranged between 70.40 to 73.96, 13.15 to 14.54 and 2.73 to 4.22, respectively. MgO and Na_2O varied from 1.54 to 2.82 and 0.54 to 0.84, respectively. K_2O and P_2O_5 ranged between 0.42 to 0.62 and 0.110 to 0.188, respectively. Loss on ignition ranged between 3.38 to 6.55 per cent.

The SiO_2 , Al_2O_3 and Fe_2O_3 content of Saha-normal soils (table 4.9.8) varied between 70.98 to 86.61, 5.64 to 14.23, and 2.02 to 4.30, respectively. MgO and Na_2O ranged between 0.77 to 1.80 and 0.43 to 0.73, respectively. K_2O and P_2O_5 varied from 0.33 to 0.73 and 0.041 to 0.80, respectively. MnO content ranged between 0.018 to 0.062. Loss on ignition of these soils ranged between 1.55 to 4.24 per cent.

Coarse fragments: There were no coarse fragments in the Saha-normal soil. However, in Sherpur-alkali soil two types of concretions: lime concretions and ferro-magnesian-grains were present. Both are being discussed here respectively.

Conca: The SiO_2 , Al_2O_3 , Fe_2O_3 of lime concretions (Table 4.8.9, 4.9.9) ranged between 38.02 to 38.28, 1.37 to 1.43 and 2.30 to 2.40, respectively. CaO content varied from 24.75 to 25.70. MgO , Na_2O , K_2O ranged between 1.14 to 1.15, 0.28 to 0.39 and 0.33 to 0.38, respectively. P_2O_5 and MnO content varied from 0.071 to 0.151 and 0.182 to 0.238, respectively. Loss on ignition of lime concretions ranged between 6.93 to 7.58 per cent.

Ferro-magnesian grains: The SiO_2 and Al_2O_3 content of these grain (Table 4.8.10) was 71.51 and 3.12, respectively. Fe_2O_3 , MnO and MgO content was 8.68, 5.59 and 2.14, respectively. Contents of CaO , Na_2O , K_2O , P_2O_5 , ZnO and CuO were 0.11, 0.97, 0.54, 0.85, 0.024 and 0.038, respectively. Loss of on ignition of these grains was 8.95 per cent only.

Soil Taxonomy: Based on the macromorphology, physical and chemical characteristics, Sherpur alkali soils qualify for the Natric diagnostic horizon. Thus, as such these soils have been classified as fine loamy, mixed hyperthermic, Typic Natrustalf.

Similarly, Saha normal soils have irregular distribution of organic carbon and lithological discontinuity, thus as such these have been classified as coarse loamy, mixed hyperthermic, Typic Ustifluvent. However, this classification of Saha soils did not highlight the alkali nature of these soils below the lithological discontinuity.

As a significant pointer towards genesis of alkali soils the presence of alkali soil below a lithological discontinuity questions the widely held view of release of Na from alumino-silicates and subsequent carbonation (Bhargava and Bhattacharjee, 1982).

Stability of alumino-silicates: Occurrence of Sherpur soils in micro-depression and their almost zero hydraulic conductivity are bound to have significant effect on the solubility of alumino-silicates under these high H_4SiO_4 level. Same has been presented (Fig. 4.27) and discussed here.

At pHs 8.9 and at constituent cations activity levels, under high H_4SiO_4 activity ($10^{-2.74}\text{M}$ = amorphous SiO_2); common alumino-silicates in Ap horizon of Sherpur alkali pedon, can be arranged in order of increasing stability as:

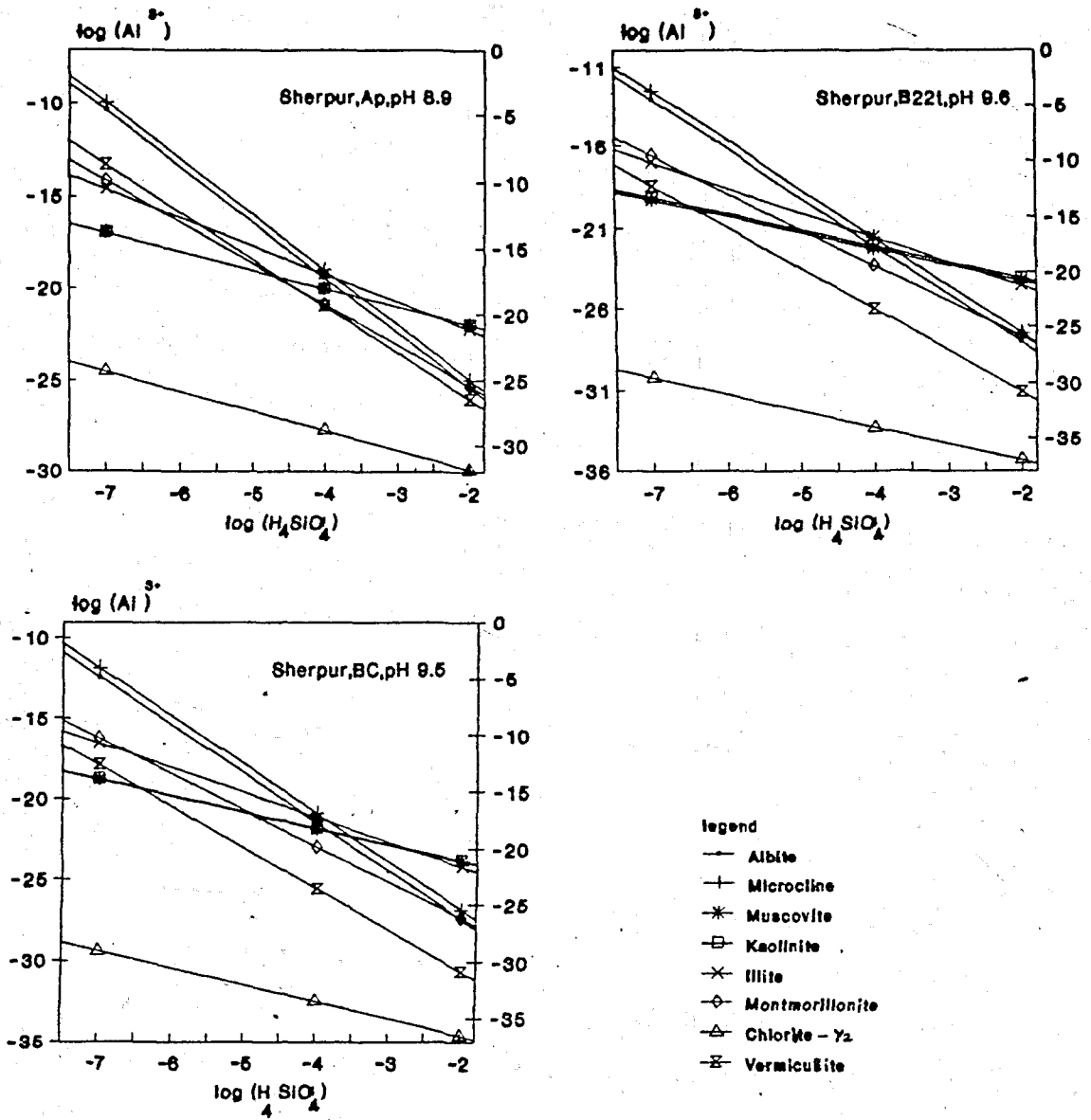


Fig. 4.27 Stability of aluminosilicates

illite, muscovite, kaolinite, microcline, albite, montmorillonite, vermiculite and chlorite.

At pHs 9.6 and 9.5 at respective cations activity levels in soil solution, under high H_4SiO_4 activity ($10^{-2.74}M$ = amorphous SiO_2); alumino-silicates in B22t and BC horizons of Sherpur alkali pedon, can be arranged in order of increasing stability as: muscovite, kaolinite, illite, microcline, albite, montmorillonite, vermiculite and chlorite.

Although, there was not much change in the relative stability order; yet, a comparison of equilibrium Al^{3+} activity as maintained by various alumino-silicates indicated its decrease by $10^{-2}M$ to $10^{-5}M$ times with increase in pH with in the profile with depth. Thus, stability of alumino-silicates increased with increasing depth or conversely, more weathering is taking place at the surface horizon than within the profile.

Saha normal soils occurring in nearly level piedmont plain, presented a very peculiar situation for comparison of stability of alumino-silicates (Fig. 4.32). Its upper two horizons Ap and IIC1 are highly porous, have high hydraulic conductivity and thus good internal drainage. Thus these horizons maintain a low H_4SiO_4 level. However, the IIIC3 horizon below the lithological discontinuity has exactly reverse soil physical conditions and maintain a high level of H_4SiO_4 activity due to poor internal drainage.

Thus, at pH_i 7.2 and at constituent cations activity levels, under low H_4SiO_4 activity ($10^{-5}M$), common alumino-silicates in Ap horizon of Saha normal pedon, can be arranged in order of increasing stability as: vermiculites albite, microcline, illite, montmorillonite, muscovite, kaolinite and chlorite.

At pHs 8.4 and at constituent cations activity levels, under low H_4SiO_4

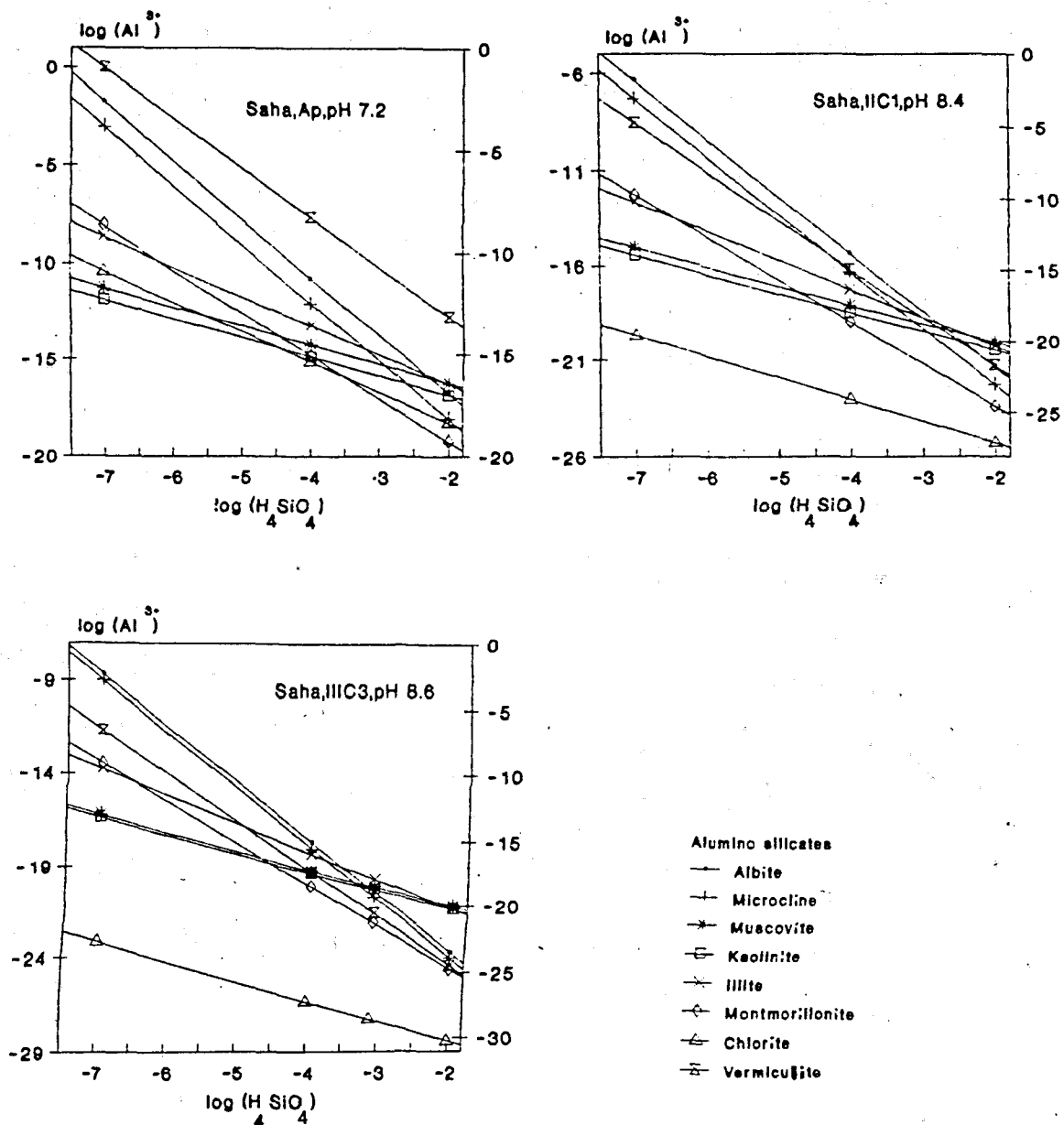


Fig. 4.32 Stability of aluminosilicates

activity ($10^{-5}M$), common alumino-silicates in IIC, horizon of Saha-normal pedon, can be arranged in order of increasing stability as: albite, microcline, vermiculite, illite, montmorillonite, muscovite, kaolinite and chlorite. Thus at lower pHs vermiculites are less stable.

In the IIIC3 horizon below the lithological discontinuity at pHs 8.6 under high H_4SiO_4 activity ($10^{-2.74}M$ = amorphous SiO_2 level) common alumino-silicates can be arranged in order of increasing stability as: illite, muscovite, kaolinite, albite, microcline, vermiculite, montmorillonite and chlorite.

Thus, a comparison of mineral stabilities of common alumino-silicates under the existing field conditions indicated increased stability of muscovite, kaolinite and chlorite under relatively lower pH and well drained conditions.

However, under poorly drained conditions or in soils with restricted internal drainage as is the case with most alkali soils vermiculite, montmorillonite and chlorite becomes more stable.

Mineralogy: Qualitative and semi-quantitative estimates of minerals in sand, silt and clay fraction of selected horizons of Sherpur soils, as obtained from the interpretation of x-ray diffractograms are presented below.

Sand: A perusal of figure 4.28 and table 4.8.11 indicated that quartz was the dominant mineral followed by plagioclases, mica and orthoclases in Ap and B22 horizon. In the BC horizon calcite was the most dominant mineral. It was closely followed by quartz. Contents of mica and plagioclases were lower in this horizon as compared to surface horizon.

Silt: Mineralogy of silt fraction (Fig. 4.28, Table 4.8.11) was similar to that of sand fraction except that amphiboles were present in noticeable proportions

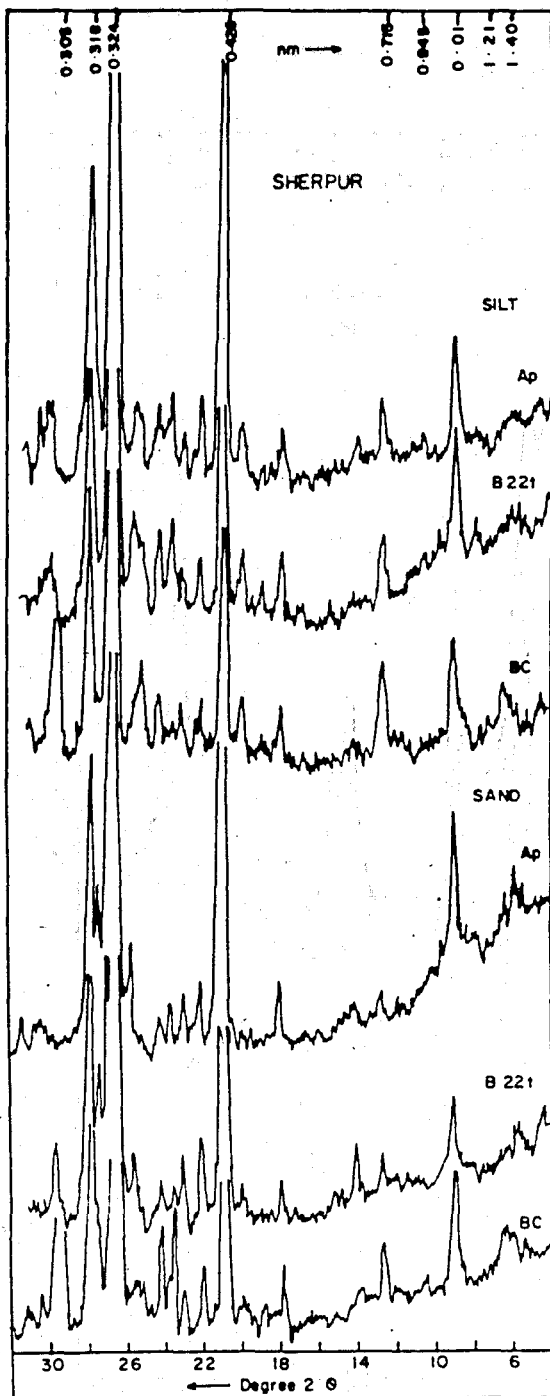


Fig. 4.28 XRD pattern of sand and silt minerals

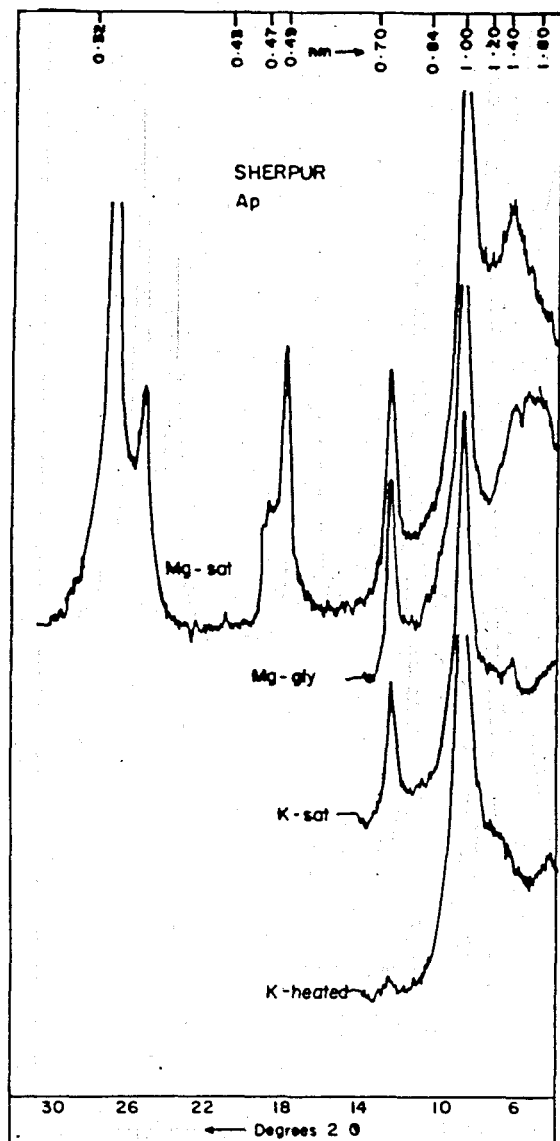


Fig. 4.29 XRD pattern of clay minerals

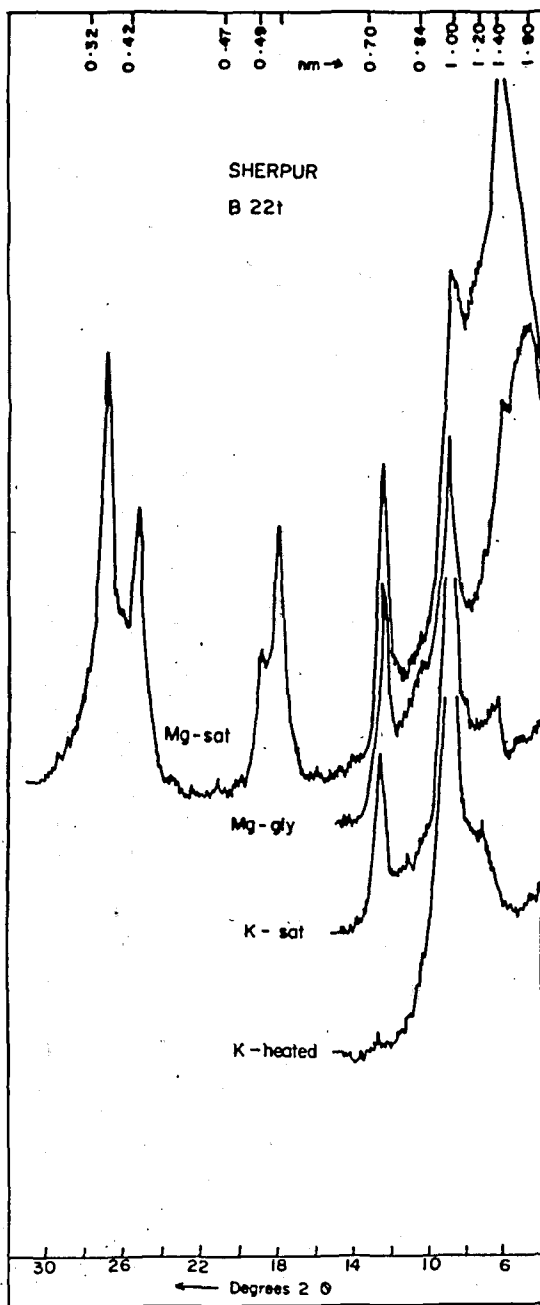


Fig. 4.30 XRD pattern of clay minerals

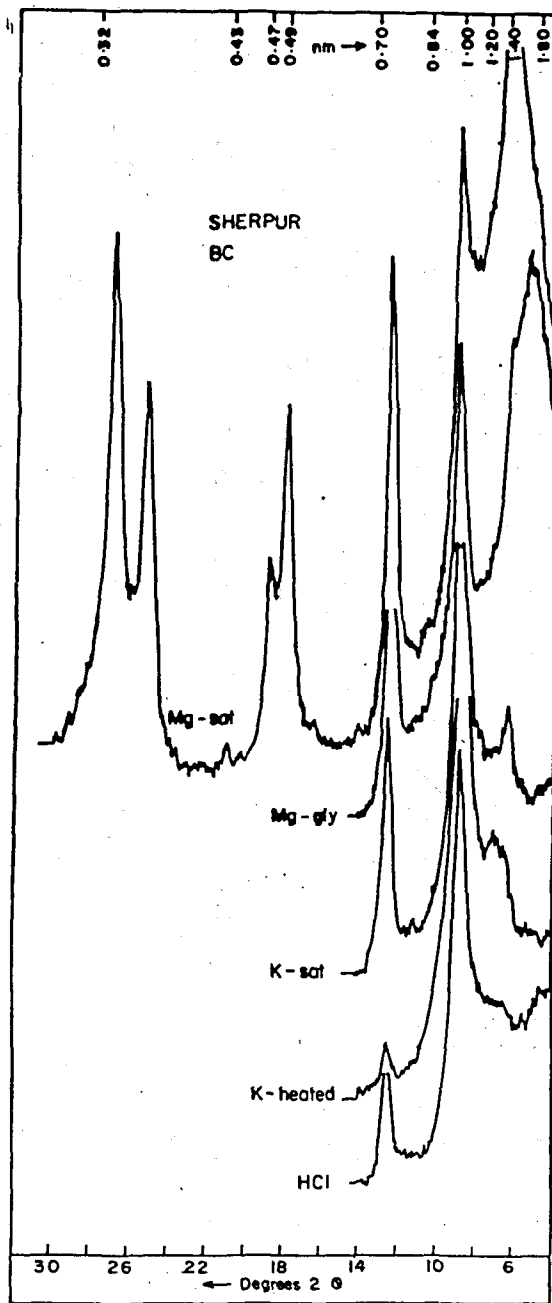


Fig. 4.31 XRD pattern of clay minerals

Pedon No. 8 SHERPUR

Classification: Typic Natrustalf, fine loamy, mixed, hyperthermic

Location: 77° 1' 28"E, 30° 21' 16"N, village Sherpur, district Ambala

Physiography: Lower piedmont

Topography: Micro-depression

Drainage: Poorly drained

Landuse: Cultivated

Elevation 285 m

Rainfall: 1050 mm

Table 4.8.1 Morphology

Lab. Depth	Horizon	Boundary	Colour (moist)	Mottling	Texture (USDA)	Consistence (wet)	Cutans	Roots	Coarse Reaction fragments
1	0-7	Ap	dw	2.5Y 5/4	-	2m, sbk	wss, wvp	-	f, f - / 2
2	7-16	AB	gw	2.5Y 5/4	-	2m, sbk	wvs, wvp	-	f, f - 3
3	16-58	B21t	cw	10YR 5/4	10YR 5/6 f, fn, ft	3c, cr	wvs, wvp	p, tn	f, f conir, f 3
4	58-106	B22t	cw	10YR 4/4	10YR 5/8 m, md, dt	3c, cr	wvs, wvp	p, tn	- conir, f 3
5	106-121	B3t	cw	7.5YR 4/6	5YR 5/4 c, md, pt	3c, sbk	wvs, wvp	b, tk	- conca, c 4
6	121-151+	BC		10YR 4/4	7.5YR 5/4 f, md, ft	3c, sbk	wvs, wvp	-	- conca, c 4

Table 4.8.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)				Coarse fragments (%)	Water content (%)		
		Sand (2 - 0.05)	Silt (0.05 - 0.002)	Clay (< 0.002)	(< 0.002) % of < 2 mm		1/3 bar	15 bar	Available
1	0-7	30.4	54.3	15.3		-	23.7	6.1	17.6
2	7-16	26.1	52.6	21.3		-	22.7	11.8	10.9
3	16-58	28.2	47.1	24.7		-	24.9	21.3	3.6
4	58-106	28.5	39.1	32.4		-	31.0	28.6	2.4
5	106-121	24.1	50.4	25.5		22	28.2	23.2	5.0
6	121-151	33.5	44.1	22.4		38	27.6	21.1	6.5

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)		
								Fe	Mn	Cu Zn
1	0-7	0.34	1.12	9.6	1.34	1.63	0.002	8.0	6.2	1.20 0.56
2	7-16	0.15	0.90	10.1	1.25	1.70	-	7.6	8.3	1.00 0.42
3	16-58	0.09	1.15	10.3	1.56	1.72	-	5.2	4.0	0.80 0.36
4	58-106	0.08	0.85	10.2	2.04	1.82	-	6.2	3.6	0.44 0.28
5	106-121	0.06	13.20	10.3	1.73	1.80	-	4.0	1.3	0.28 0.32
6	121-151+	0.06	12.20	10.2	1.56	1.74	-	4.4	1.4	0.12 0.18

Table 4.8.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)				CEC (c mol kg ⁻¹)	ESP
		Na	Mg	Ca	K		
1	0-7	3.3	0.8	2.7	0.23	7.1	47
2	7-16	6.8	0.8	1.9	0.30	9.9	69
3	16-58	10.4	0.3	0.5	0.18	11.3	92
4	58-106	15.4	0.3	1.0	0.17	16.8	91
5	106-121	13.1	0.5	1.8	0.12	15.5	85
6	121-151+	11.0	0.7	1.9	0.12	13.7	80

Table 4.8.4 Saturation extract analysis

Lab. No.	Depth (cm)	Saturation (%)	pH _s	EC _e dSm ⁻¹	Saturation extract analysis (me/l)							SAR	
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl		SO ₄
1	0-7	32	8.9	4.76	38.9	5.3	1.3	0.23	1.4	19.1	8.0	18.2	21.4
2	7-16	30	9.5	2.06	15.3	4.4	1.6	0.26	2.1	8.8	3.0	6.2	8.8
3	16-58	35	9.7	3.30	30.1	3.3	2.8	0.40	5.6	16.9	4.0	10.2	17.4
4	58-106	51	9.6	3.44	30.1	3.3	1.0	0.14	8.4	12.6	4.5	4.7	20.6
5	106-121	46	9.7	2.64	22.4	3.5	1.0	0.07	7.0	12.6	4.0	3.4	14.9
6	121-151+	42	9.5	2.19	17.6	4.3	0.0	0.08	4.2	11.2	4.5	1.4	12.1

Table 4.8.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
1	0-7	89.1	3.12	0.57	0.0	1.00	1.27	0.29	0.02	0.023	0.59
2	7-16	90.3	3.14	0.73	0.0	1.00	1.30	0.27	0.01	0.028	0.50
3	16-58	90.9	3.88	0.55	0.0	0.83	1.53	0.41	0.05	0.014	0.66
4	58-106	88.4	4.02	1.27	0.0	0.92	1.59	0.42	0.00	0.000	1.54
5	106-121	86.1	3.44	1.62	0.2	1.50	1.34	0.36	0.03	0.023	4.64
6	121-151+	86.2	3.78	1.87	0.1	2.58	1.49	0.40	0.03	0.019	2.84

Table 4.8.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
1	0-7	73.5	15.9	2.29	0.0	1.59	1.40	1.01	0.21	0.088	2.24
2	7-16	70.9	16.7	2.25	0.0	1.59	2.01	1.13	0.09	0.045	2.01
3	16-58	73.7	16.4	2.06	0.0	1.50	1.78	1.02	0.06	0.035	0.76
4	58-106	74.1	16.7	2.23	0.0	1.67	1.51	1.08	0.08	0.034	2.77
5	106-121	70.1	15.5	3.22	0.6	2.51	1.33	1.18	0.09	0.034	5.29
6	121-151+	69.6	15.3	2.97	0.7	2.67	1.73	1.06	0.10	0.031	5.81

Table 4.8.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)									Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	ZnO		MnO
1	0-7	54.6	22.1	7.38	0.0	2.92	0.23	1.66	0.18	0.067	0.080	6.91
2	7-16	54.4	20.1	7.58	0.0	2.59	0.21	1.54	0.16	0.029	0.065	12.43
3	16-58	53.6	22.3	7.22	0.0	2.09	0.22	1.44	0.13	0.019	0.065	11.93
4	58-106	52.6	22.8	6.41	0.0	3.16	0.28	1.21	0.09	0.016	0.065	10.45
5	106-121	50.0	23.1	6.57	0.0	2.69	0.21	1.40	0.13	0.017	0.058	11.06
6	121-151+	51.2	22.3	5.79	0.0	2.56	0.22	1.36	0.25	0.019	0.067	10.46

Table 4.8.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
1	0-7	73.9	13.2	2.73	0.3	2.82	0.81	0.57	0.12	0.034	3.38
2	7-16	72.1	14.0	3.30	0.4	1.54	0.84	0.42	0.13	0.061	3.86
3	16-58	71.9	14.0	3.34	0.0	0.90	0.75	0.57	0.11	0.046	3.91
4	58-106	70.4	14.4	4.22	0.0	2.40	0.70	0.62	0.14	0.075	4.37
5	106-121	71.1	14.5	3.90	0.6	1.55	0.54	0.61	0.19	0.034	6.18
6	121-151+	71.0	13.7	3.45	0.7	2.15	0.72	0.57	0.14	0.039	6.55

Table: 4.8.9 Elemental composition of lime concretions

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
5	106-121	38.0	1.4	2.40	25.7	1.15	0.28	0.33	0.07	0.238	6.93
6	121-151	38.3	1.4	2.30	24.8	1.14	0.39	0.38	0.15	0.182	7.58

Table 4.8.10 Elemental composition of ferro-magnesian grains

Lab. No.	Depth (cm)	Elemental composition (%)											Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	ZnO	CuO	MnO	
5	106-121	71.5	3.1	8.68	0.11	2.14	0.97	0.54	0.09	0.024	0.038	5.59	8.95
6	121-151+	75.8	2.7	6.07	0.08	1.28	0.72	0.45	0.04	0.019	0.030	4.33	8.95

Table 4.8.11 Semi quantitative estimates of sand and silt minerals

Lab.No.	Depth (cm)	Chlorite	Mixed layer	Mica	Amphibole	Chlorite + Kaolinite	Quartz	Orthoclases	Plagioclases	Calcite
Sand										
1	0-7	++	-	+++	-	++	+++++	++	+++	-
4	58-106	+	-	++	-	++	+++++	+++	+++++	++
6	121-151	+	+	+++	+	++	+++++	++	++	+++++
Silt										
1	0-7	-	-	+++	++	++	+++++	++	++++	-
4	58-106	-	-	+++	++	++	+++++	++	++++	-
6	121-151	++	+	+++	-	+++	++++	++	++	++++

4.8.12 Semi quantitative estimates of clay minerals

Lab. No.	Depth (cm)	Smectite	Chlorite	Vermiculite	Illite	Mixed layer %	Quartz	Feldspar	Amphibole
1	0-7	5	5	5	64	11	1	2	2
4	58-106	15	4	12	50	10	1	2	2
6	121-151	16	7	8	51	7	1	3	2

Pedon No. 9 SAHA

Classification: Typic Ustifluent, coarse, loamy, mixed, hyperthermic

Location: 76° 58' 9"E, 30° 18' 25"N, village Saha, district Ambala, on Narayangarh road

Physiography: Lower piedmont

Topography: Level plain

Drainage: Well drained

Landuse: Cultivated (rainfed)

Elevation 276 m

Rainfall: 1050 mm

Table 4.9.1 Morphology

Lab. Depth	Horizon	Boundary	Colour	Mottling	Texture	Structure	Consistence	Cutans	Roots	Coarse	Reaction
No. (cm)			(moist)		(USDA)		(wet)			fragments	
18	0-15	Ap	gs	10YR 3/4	-	1s	1m, sbk	wss, wsp	-	c, vf-f	0
19	15-46	AC	cw	10YR 4/4	-	sl	2m, sbk	wss, wsp	-	c, f	2
20	46-59	IIC1	cw	10YR 5/4	-	1s	1m, sbk	wso, wpo	-	f, f	2
21	59-101	IIIC2	gs	10YR 4/4	-	1	2m, sbk	wss, wsp	-	f, f	3
22	101-147	IIIC3	gs	10YR 4/4	-	sil	massive	ws, wp	-	-	3
23	147-167+	IIIC4	gs	10YR 4/4	-	sil	massive	ws, wp	-	-	2

Table 4.9.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)			Coarse fragments (%)	Water content (%)		
		Sand (2 - 0.05)	Silt (0.05 - 0.002)	Clay (< 0.002)		1/3 bar	15 bar	Available
-----% of < 2 mm -----								
18	0-15	80.1	12.9	7.0	-	12.9	2.8	10.1
19	15-46	71.0	21.5	7.5	-	13.2	2.5	10.7
20	46-59	77.6	20.7	1.7	-	8.2	2.2	6.0
21	59-101	52.2	37.6	10.2	-	21.7	4.0	17.7
22	101-147	17.0	60.6	22.4	-	28.9	7.9	21.0
23	147-167+	13.7	60.7	25.6	-	22.5	6.8	15.7

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)			
								Fe	Mn	Cu	Zn
18	0-15	0.22	0.00	7.2	0.23	1.45	1.371	8.4	6.7	0.62	0.42
19	15-46	0.06	1.04	8.9	0.08	1.44	1.418	3.0	2.4	0.48	0.24
20	46-59	0.10	1.22	9.0	0.07	1.71	1.692	2.8	2.3	0.34	0.22
21	59-101	0.14	2.86	9.1	0.06	1.52	1.285	3.6	1.9	0.32	0.26
22	101-147	0.11	2.14	9.5	0.28	1.58	0.097	4.2	2.2	0.44	0.30
23	147-167+	0.15	0.00	9.5	0.22	1.64	0.003	4.8	3.2	0.62	0.26

Table 4.9.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)				ESP
		Na	Mg	Ca	K	CEC (c mol kg ⁻¹)
18						
19	0-15	0.4	1.0	3.0	0.17	4.9
20	15-46	0.6	0.8	3.4	0.10	4.9
21	46-59	0.1	0.3	0.7	0.10	1.0
22	59-101	0.6	1.0	1.3	0.10	6.9
23	101-147	1.7	3.0	8.6	0.12	13.4
	147-167+	2.4	2.5	7.8	0.12	11.8
						20

Table 4.9.4 Saturation extract analysis

Lab. No.	Depth (cm)	Satur- ation (%)	pH _S	EC _e dSm ⁻¹	Saturation extract analysis (me/l)							SAR		
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl		SO ₄	
18														
10	0-15	30	7.2	0.97	0.52	5.8	4.5	0.18	-	4.8	4.0	1.5	0.2	0.2
20	15-46	31	8.5	0.34	0.20	2.3	1.5	0.04	-	1.8	1.5	0.3	0.2	0.2
21	46-59	26	8.4	0.38	0.33	2.2	1.5	0.05	-	1.9	1.6	0.2	0.2	0.2
22	59-101	37	8.4	0.34	0.71	2.0	1.0	0.02	-	1.7	1.6	0.4	0.6	0.6
23	101-147	44	8.7	0.89	4.40	5.0	0.5	0.16	-	3.5	4.5	0.5	2.7	2.7
	147-167+	30	8.6	0.90	5.03	3.5	1.3	0.06	-	3.9	5.5	0.9	3.3	3.3

Table 4.9.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O		P ₂ O ₅	MnO
18	0-15	90.1	3.00	0.96	0.0	0.75	1.31	0.27	0.00	0.034	0.45
19	15-46	90.9	2.62	0.97	0.0	0.83	1.11	0.27	0.01	0.035	0.95
20	46-59	89.5	2.62	0.99	0.0	4.00	1.12	0.26	0.00	0.031	0.85
21	59-101	88.6	3.63	1.53	0.0	1.58	1.54	0.48	0.44	0.049	1.49
22	101-147	87.5	3.82	2.16	0.1	2.25	1.53	0.59	0.00	0.030	1.04
23	147-167+	89.5	3.13	1.61	0.4	1.42	1.15	0.50	0.38	0.054	1.51

Table 4.9.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
18	0-15	71.3	15.2	3.22	0.0	1.90	1.09	1.60	0.03	0.048	2.18
19	15-46	69.1	16.2	2.98	0.0	2.04	1.24	1.61	0.02	0.005	2.38
20	46-59	75.0	13.1	3.21	0.0	1.84	1.46	1.57	0.04	0.000	2.52
21	59-101	72.9	13.8	2.68	0.0	1.84	1.46	1.39	0.04	0.014	2.46
22	101-147	76.8	11.5	3.23	0.0	1.97	1.42	1.90	0.03	0.049	2.02
23	147-167+	77.3	9.1	3.39	0.0	2.37	1.61	2.10	0.07	0.036	3.86

Table 4.9.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		ZnO	MnO
18	0-15	54.4	23.8	6.49	0.5	2.69	0.21	1.68	0.29	0.045	0.088	7.60
19	15-46	55.3	23.2	5.53	0.8	2.49	0.22	1.66	0.25	0.030	0.081	5.72
20	46-59	53.1	24.2	6.09	0.2	3.14	0.23	1.68	0.31	0.025	0.090	6.93
21	59-101	52.5	23.2	5.39	0.2	3.14	0.19	1.62	0.20	0.032	0.077	10.49
22	101-147	51.9	22.8	5.02	0.2	2.42	0.19	1.65	0.17	0.032	0.067	10.80
23	147-167+	52.8	23.5	4.72	0.5	2.40	0.16	1.51	0.30	0.034	0.068	9.64

Table 4.9.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
18	0-15	84.6	5.9	2.02	0.0	1.00	0.58	0.33	0.06	0.018	2.15
19	15-46	83.1	6.9	2.42	0.0	1.12	0.48	0.36	0.06	0.053	2.04
20	46-59	85.3	5.6	2.25	0.0	0.77	0.43	0.34	0.03	0.056	2.02
21	59-101	79.8	8.9	3.15	0.3	1.17	0.38	0.50	0.08	0.059	1.55
22	101-147	72.2	13.6	4.30	0.0	1.80	0.73	0.73	0.06	0.062	3.18
23	147-167+	70.9	14.2	3.10	0.0	1.22	0.65	0.57	0.04	0.019	4.24

Table 4.9.9 Semi quantitative estimates of sand and silt minerals

Lab.No.	Depth (cm)	Chlorite	Mixed layer	Mica	Amphibole	Chlorite + Kaolinite	Quartz	Orthoclases	Plagioclases	Calcite
Sand										
18	0-15	-	+	++	++	++	+++++	+++	+++	-
20	46-59	-	+	++	+	++	+++++	+++	+++	++
22	101-147	-	-	++++	+	+++	+++++	++	++	++
Silt										
18	0-15	++	+	+++	-	++	+++++	++	++++	-
20	46-59	++	++	+++	++	++	+++++	++	+++	++
22	101-147	++	+	++++	-	+++	++++	++	+++	++

4.9.10 Semi quantitative estimates of clay minerals

Lab. No.	Depth (cm)	Smectite	Chlorite	Vermiculite	Illite	Mixed layer	Kaolinite	Quartz	Feldspar	Amphibole
%										
18	0-15	8	7	6	59	10	6	1	1	2
20	26-59	13	7	12	50	9	6	1	2	-
22	101-147	19	6	6	45	8	13	1	2	-

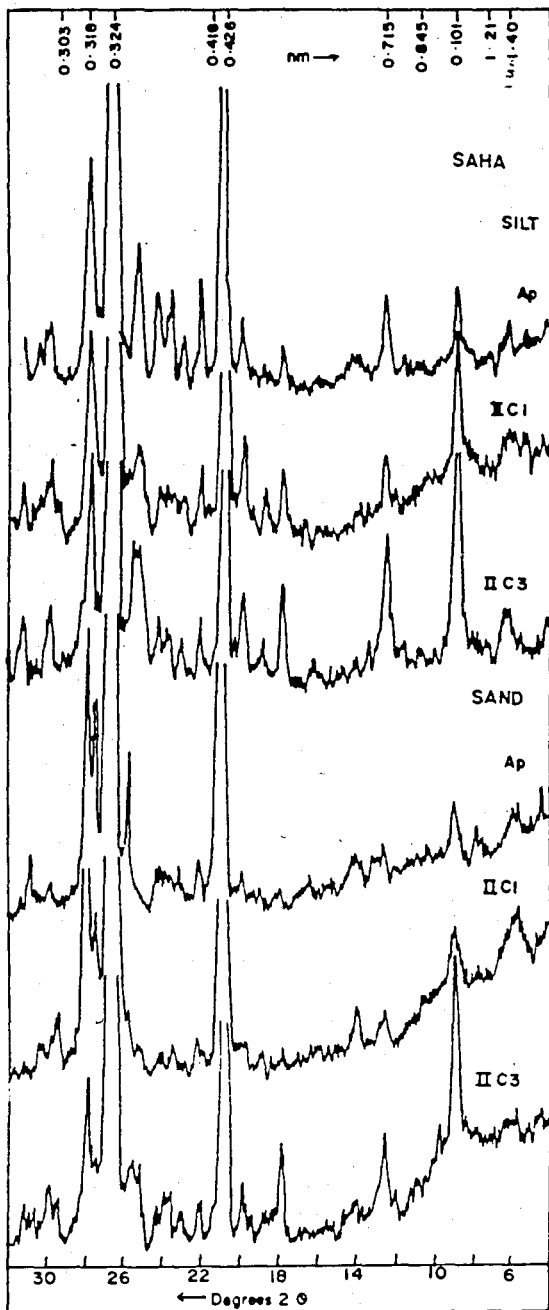


Fig. 4.33 XRD pattern of sand and silt minerals

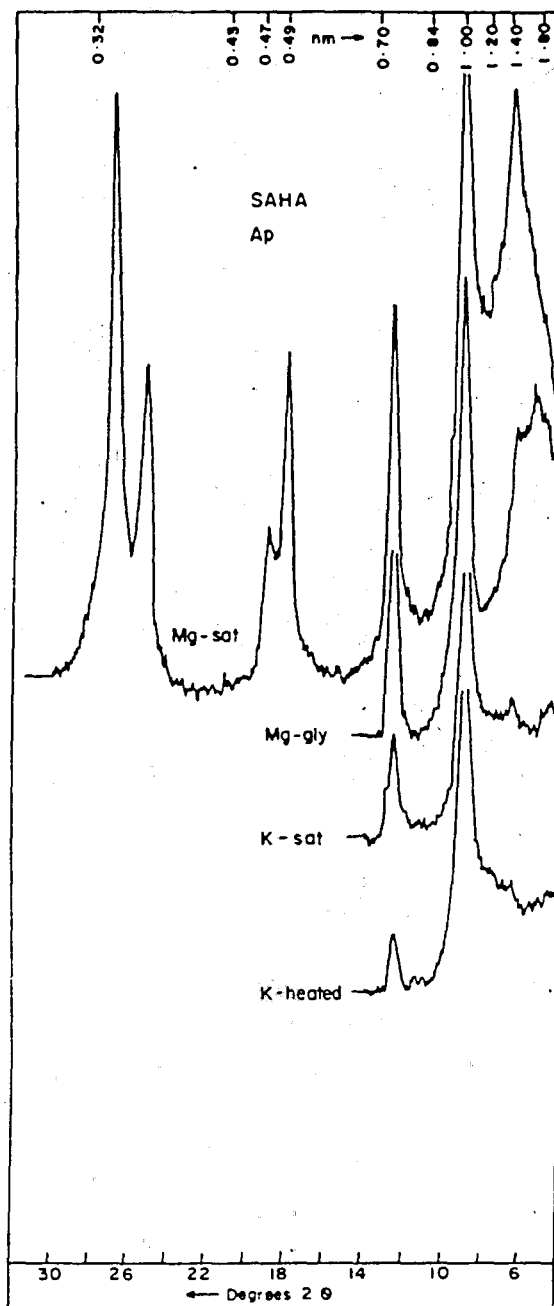


Fig. 4.34 XRD pattern of clay minerals

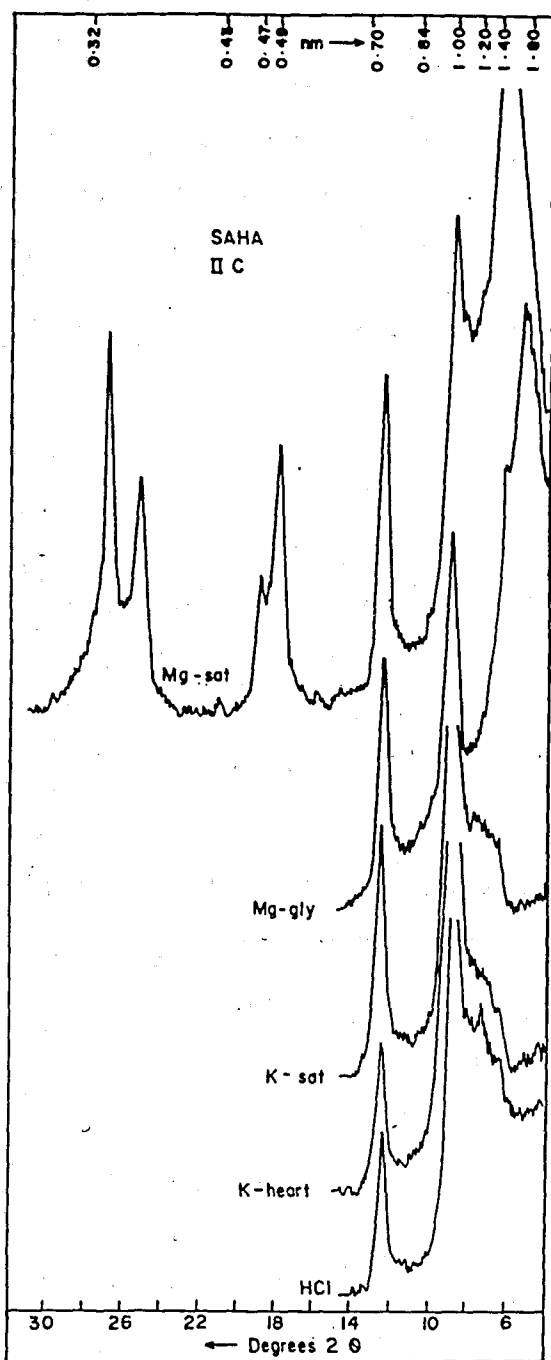


Fig. 4.35 XRD pattern of clay minerals

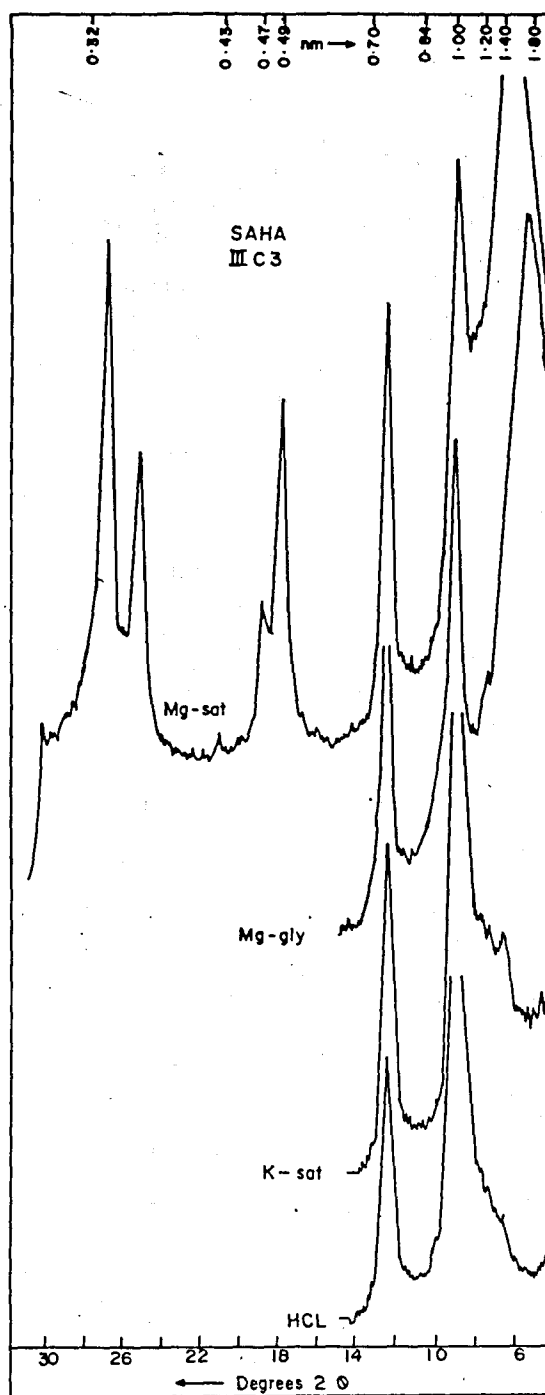


Fig. 4.36 XRD pattern of clay minerals

and kaolinite+chlorite content was relatively higher.

Clay: Semi-quantitative estimates calculated on the basis of corrected peak area (Fig. 4.29, 4.30, 4.31) suggested the dominance of illite followed by mixed layers smectite, kaolinite, vermiculite and chlorite in Ap horizon (Table 4.8.12). In the lower horizons i.e. dominant illite was followed by smectite, vermiculite, mixed layers, chlorite and kaolinite. Smectite content in lower horizons varied from 15 to 16 per cent, which was almost three times that of Ap horizon. Primary minerals associated with these clays contributed only minor amounts. Smectite increased and illite decreased with depth.

Mineralogy: Results obtained from the x-ray diffraction analysis of various fractions of Saha normal pedon are presented below.

Sand and Silt: Qualitative and semi-quantitative estimates from the XRD pattern of sand and silt fraction (Fig.4.33, Table 4.9.10) indicated close resemblance with that of Sherpur soils occurring in similar physiography but alkali in nature. Only notable difference was the absence of chlorite in sand fraction and presence of comparatively lower calcite content in these soils.

Clay: A perusal of x-ray diffractogram of clay fractions (Fig. 4.34, 4.35, 4.36, Table 4.9.11) of Saha soils indicated a close similarity to Sherpur soils. In Saha soils also smectite increased and illite decreased with depth. Most notable difference in Saha soils was the presence of relatively higher amounts of kaolinite in the IIIC3 horizon.

4.33 Alluvial plain: Geomorphic unit of alluvial plain has been sub-divided into two parts i.e. upper and lower. Characteristics of representative soils of these units are discussed in subsequent pages.

4.331 Alluvial plain - upper: Problem of soil alkalinity was maximum in this unit. Therefore, detailed investigation was undertaken in these areas. Elevation in this nearly level to gently sloping unit varied from 215 to 250 m. Rainfall ranged between 360 to 730 mm. Temperature regime of the soils is hyperthermic and moisture regime is Ustic. Internal drainage of alkali soils of this area is poor. These soils are represented by CSSRI-alkali (Central Soil Salinity Research Institute, Karnal), CSSRI-fenced alkali, CSSRI-reclaimed alkali (20 years), CSSRI-normal, Gudda-alkali, Gudda-reclaimed alkali (10 years), Samdhan alkali and Samdhan reclaimed alkali (5 year) Narnaund normal pedons. All the CSSRI-profiles are within 250-700 m distance from each other. Due to wide variations in characteristics, Narnaund pedons are being described separately.

Morphology: Moist colours of these soils (Table 4.10.1 to 4.17.1) were dominantly dark yellowish brown with 2.5Y or 10Y hue, value varying from 4 to 5 and Chroma ranging from 2 to 4. However, in the upper few centimetres of CSSRI-fenced alkali (Table 4.10.1) CSSRI-alkali (Table 4.11.1), colours were lighter with 2.5Y hue, value varying from 5-6 and chroma ranging between 2 to 4. Mottling was generally absent. However, few to many, fine and faint mottles with yellowish brown to strong brown colours were present in the B22 (41-73 cm) horizon of CSSRI-reclaimed alkali (Table 4.12.1) and BC (124-160 cm) horizon of Gudda-alkali soils (Table 4.14.1). Texture of these soils was dominantly loam with grading from sandy loam in upper few horizons of CSSRI fenced alkali and Samdhan reclaimed alkali, surface horizon of CSSRI-alkali and all the horizons of Samdhan alkali (Table 4.16.1) to silty loam and clay loam in the Gudda-alkali soils. Structure in these soils was mainly moderately to strong, medium to coarse sub-angular blocky. However, weak, fine, platy structure immediately below Ap horizon in the CSSRI-alkali, Gudda-alkali and Gudda-reclaimed alkali (Table 4.15.1) and moderate medium, columnar structure was also noticed in the CSSRI-alkali soils. Thin patchy to thin broken cutans were present in the B

horizons of all the pedons including the CSSRI-normal (Table 4.13.1) soils but excepting the Samdhan alkali soils. Coniars were present in all the normal, alkali and reclaimed alkali soils of CSSRI and Gudda. Same were absent in all the soils of Samdhan. Lime concretions were present in all soils excepting the CSSRI-fenced alkali and CSSRI-normal soils. All the soils were calcareous excepting the CSSRI-normal soils.

Physical characteristics: Textural variations were equally reflected in the amounts of various soil separates. In general the clay content increased in all the pedons upto B horizon (Table 4.10.2 to 4.17.2) indicating eluviation of clay from A horizon. Presence of illuvial clay in B horizon has been further confirmed by the presence of cutans and increasing fine clay to total clay ratio as investigated in the CSSRI-fenced alkali and CSSRI-alkali soils (Table 4.10.2, 4.11.2). In general the silt amount, were high and varied from 23 to 69 per cent. Undisturbed bulk density was relatively higher and ranged between 1.53 to 1.90 Mgm^{-3} . Hydraulic conductivity of all the horizons of alkali soils (barring A1 horizon of CSSRI fenced-alkali) was almost zero. Surface horizon of CSSRI fenced alkali had a good hydraulic conductivity of 2.107 cm hr^{-1} due to self reclamation by dense grassy vegetation under fenced conditions.

Reclamation of these alkali soils with gypsum application did result in increased hydraulic conductivity as indicated by CSSRI-20 years (Table 4.12.2) reclaimed alkali and surface layers of Gudda-10 year reclaimed alkali (Table 4.15.2) and Samdhan 5 year reclaimed alkali soils. However, the lower horizons still had a very low to almost nil hydraulic conductivity indicating reclamation effects only in surface horizons.

CSSRI-normal (Table 4.13.2) soils which exist very close to the CSSRI-fenced alkali soils (Table 4.10.2) is in cultivation process for the last 80 + years. This soil has a good hydraulic conductivity ranging from 0.412 to

0.921 cm hr⁻¹. It is quite possible that irrigated agriculture for such a long time might have resulted in improved soil conditions. Available water in all these soils varied from 4.6 to 17.1 per cent. Available water values were minimum in B horizon.

Chemical characteristics: The pH₂ and EC₂ of the four alkali soils excepting surface horizon of CSSRI-fenced alkali (Table 4.10.2) varied from 9.9 to 10.8 and 0.55 to 5.20 dSm⁻¹, respectively (Table 4.11.2 to 4.17.2).

In case of three gypsum reclaimed alkali profiles (Table 4.12.2, 4.15.2, 4.17.2) pH₂ and EC₂ ranged from 8.7 to 10.4 and 0.73 to 1.89 dSm⁻¹, respectively. Minimum values of pH₂ and EC₂ were in upper horizons and maximum being in lower horizons.

The pH₂ and EC₂ of surface horizon of CSSRI-fenced (Table 4.10.2) alkali and all horizons of CSSRI normal (Table 4.13.2) which represent natural reclamation processes, ranged between 8.3 to 8.8 and 0.37 to 0.86 dSm⁻¹, respectively.

The O.C. decreased with depth and its contents ranged between 0.60 to 0.03 per cent with maximum values in the surface horizons of CSSRI-fenced alkali and CSSRI-normal soils.

Excepting the CSSRI-normal pedon and surface horizon of CSSRI-fenced alkali, CaCO₃ content in all other soils of this geomorphic unit varied from 0.30 to 9.75 per cent.

Micro-nutrients: These soils contained fairly good amounts of DTPA-extractable Fe, Mn and Cu. Available Zn was deficient in all the samples excepting the surface horizons of all the reclaimed alkali soil and the CSSRI-normal soils.

It was due to supplementary addition of ZnSO_4 as fertilizer (Table 4.10.2 to 4.17.2).

Exchangeable cations: Excepting the surface horizon of CSSRI- fenced alkali soil (Table 4.10.3). Sodium was the dominant cation on the exchange complex of all the alkali soils (Table 4.10.3 to 4.17.3) and it ranged from 3.1 to 14.8 cmol kg^{-1} . All other cations were in fractions only. CEC of these soils varied from 4.22 to 15.31 cmol kg^{-1} . ESP of these soils varied from 45 to 93.

Calcium followed by magnesium were the dominant cations only on the exchange complex of Gudda reclaimed alkali soils and upper layers of other two reclaimed alkali soils (Table 4.12.3, 4.15.3, and 4.17.3). Exchangeable Na decreased significantly in these horizons. However, in the lower horizons sodium was still the dominant cation. ESP of these reclaimed alkali soils varied from 10 to 85. Lowest values being in the upper reclaimed horizons: 10-18 ESP of CSSRI (20 years) reclaimed alkali soil (Table 4.12.3) under high level of management. This indicated an almost thorough reclamation of these previously alkali soils. However, same was not observed in Gudda- reclaimed-alkali-10 yr (Table 4.15.3) and Samdhan reclaimed alkali-5 yr (Table 4.17.3) soils.

CEC of surface horizon of CSSRI fenced alkali (Table 4.10.3) was 5.6 cmol kg^{-1} and it varied from 11.2 to 17.4 cmol kg^{-1} in the CSSRI normal profile (Table 4.13.3). In all these horizons which are representative of the natural reclamation processes similar to gypsum reclaimed alkali profiles, calcium followed by magnesium was the dominant cations. ESP in these horizons was low and varied from 5 to 12 only.

Saturation extract: pHs and EC_e of the four alkali soils (Table 4.10.4, 4.11.4, 4.14.4, 4.16.4) excepting the surface horizon of CSSRI-fenced alkali varied from

9.1 to 10.4 and 0.8 to 16.8 dSm^{-1} , respectively. Sodium and carbonate + bicarbonate were respectively the dominant cations and anions in the saturation extract. Chloride was the next dominant anion. SAR of these saturation extracts ranged between 9 to 109.

In case of three reclaimed alkali pedons (Table 4.12.4, 4.15.4 and 4.17.4), pHs and EC_e ranged from 8.2 to 9.4 and 0.9 to 2.96 dSm^{-1} , respectively. Lower values being in the surface few horizons only. EC_e values have decreased considerably as compared to alkali profiles. Excepting the CSSRI-reclaimed alkali, sodium and bicarbonate were the dominant cation and anion, respectively in the saturation extract of other two reclaimed alkali soils. SAR of these extracts varied from 4 to 13. In the CSSRI reclaimed alkali (20 yr) the dominant cation in the saturation extract were Mg and Ca. Amounts of carbonates were low and SAR varied from 0.9 to 3.4 only.

In case of surface horizon of CSSRI-fenced alkali and CSSRI-normal soils, which represented the natural processes of reclamation pHs and EC_e varied from 7.6 to 8.4 and 0.9 to 1.8 dSm^{-1} , respectively. Magnesium followed by sodium and chloride were dominant cation and anions in the saturation extract of CSSRI-normal soils and their SAR varied from 1.8 to 2.1 only. However, in case of upper horizon of CSSRI-fenced alkali Na was still dominant but was less than Ca + Mg. SAR of this horizon was only 4.

Elemental composition (per cent):

Sand: The SiO_2 and Al_2O_3 of all the soils (Table 4.10.5 to 4.17.5) of this geomorphological unit varied from 80.82 to 87.58 and 4.72 to 5.85, respectively. Fe_2O_3 and MnO ranged between 1.09 to 4.86 and 0.005 to 0.359, respectively. High values of CSSRI-alkali (Table 4.11.5) and Gudda-alkali (Table 4.14.5) soils is due to the presence of sand size ferro-magnesian grains in these

soils. Similarly, a high content of Fe_2O_3 (2.66) in surface horizon of CSSRI-fenced alkali (Table 4.10.5) is due to movement of Fe from sub-soil back to surface soil by plant absorption and its release through plant decomposition (Bear, 1976). CaO was absent in the sands of CSSRI-normal soils. CaO and MgO varied from traces to 0.89 and 0.83 to 4.59, respectively. Weighted average of Na_2O content varied from 2.04 to 2.22 in these soils. Weighted average of Na_2O content of CSSRI-fenced alkali, CSSRI-alkali, CSSRI-reclaimed alkali and CSSRI-normal was, 2.105, 2.043, 2.081 and 2.087 per cent, respectively. These similar amounts of total Na in sand fraction of alkali reclaimed as well as normal soils questions the validity of Gupta and Gupta (1989) conclusion that albite acted as diffused source of Na in alkali soils. K_2O and P_2O_5 content of the sands of these soils varied from 0.51 to 0.99 and traces to 1.028, respectively. High amount of P_2O_5 in sand fraction CSSRI-reclaimed alkali soils was due to fertilizer additions. Loss on ignition of sand in these soils varied from 0.27 to 2.79 per cent.

Silt: The SiO_2 , Al_2O_3 and Fe_2O_3 content of silt fraction of these soils (Table 4.10.6 to 4.17.6) varied from 70.12 to 78.11, 9.01 to 14.89 and 2.69 to 4.34, respectively. CaO was present only in traces. MgO, Na_2O and K_2O contents ranged between 1.59 to 3.34, 1.37 to 2.47 and 1.17 to 2.28, respectively. P_2O_5 and MnO content of silt fraction of these soils varied from traces to 0.153 and 0.015 to 0.101, respectively. Loss on ignition of the silt fraction of these soils varied from 0.63 to 4.11.

Clay: The SiO_2 , Al_2O_3 and Fe_2O_3 of the clay fraction of these soils (Table 4.10 to 4.17.7) varied from 48.63 to 54.93, 19.89 to 24.18 and 6.52 to 8.68. Relatively higher value of Fe_2O_3 in surface horizons may be due to the same reasons as discussed under sand. CaO and MgO content ranged between traces to 0.67 and 2.35 to 4.81, respectively. Na_2O , K_2O and P_2O_5 content of clay fraction of these soils varied from 0.10 to 0.39, 1.34 to 1.66 and 0.018 to

0.240, respectively. Loss on ignition of clay fraction of these soils varied from 7.23 to 12.04 per cent.

Soil: The SiO_2 , Al_2O_3 and Fe_2O_3 content of these soils (Table 4.10.8 to 4.17.8) ranged between 68.13 to 80.03, 8.21 to 14.63 and 2.47 to 4.58, respectively. In general the contents of Al_2O_3 and Fe_2O_3 increased upto B horizon of these soils. However, reverse was observed in case of SiO_2 distribution. CaO contents were generally low. MgO , Na_2O and K_2O varied from 0.92 to 2.42, 0.69 to 1.28 and 0.56 to 0.88, respectively. P_2O_5 and MnO content of soil ranged between 0.026 to 0.181 and 0.048 to 0.176, respectively. Loss on ignition of these soils varied from 1.56 to 5.88 per cent.

Coarse fragments: Both lime concretions and ferro-magnesian grains were present in the soils of upper alluvial plain. Elemental composition of these is being discussed here separately.

Conca: The SiO_2 , Al_2O_3 and Fe_2O_3 content of lime concretions of three CSSRI profiles (Table 4.10.9 to 4.12.9) varied from 36.64 to 46.24, 1.53 to 2.14 and 1.94 to 2.72, respectively. Similarly, SiO_2 , Al_2O_3 and Fe_2O_3 contents in the lime concretions of Gudda alkali, Gudda reclaimed land Samdhan reclaimed (Table 4.14.9, 4.15.9, 4.17.9) ranged between 28.84 to 33.13, 1.79 to 1.93 and 1.63 to 4.49, respectively. CaO content of all these concretions varied from 19.49 to 31.00. MgO , Na_2O , K_2O content ranged between 1.22 to 3.31, 0.35 to 0.66 and 0.34 to 0.57, respectively. P_2O_5 and MnO varied from 0.064 to 0.133 and 0.054 to 0.287, respectively. Loss on ignition of these concretions ranged between 2.52 to 8.64 per cent.

Ferro-magnesian grains: The SiO_2 and Al_2O_3 content of ferro-magnesian grains (Table 4.10.10 to 4.12.10; 4.13.9, 4.15.10) varied from 71.80 to 74.86 and 2.86 to 3.71, respectively. Fe_2O_3 , MnO and MgO content of these grains ranged

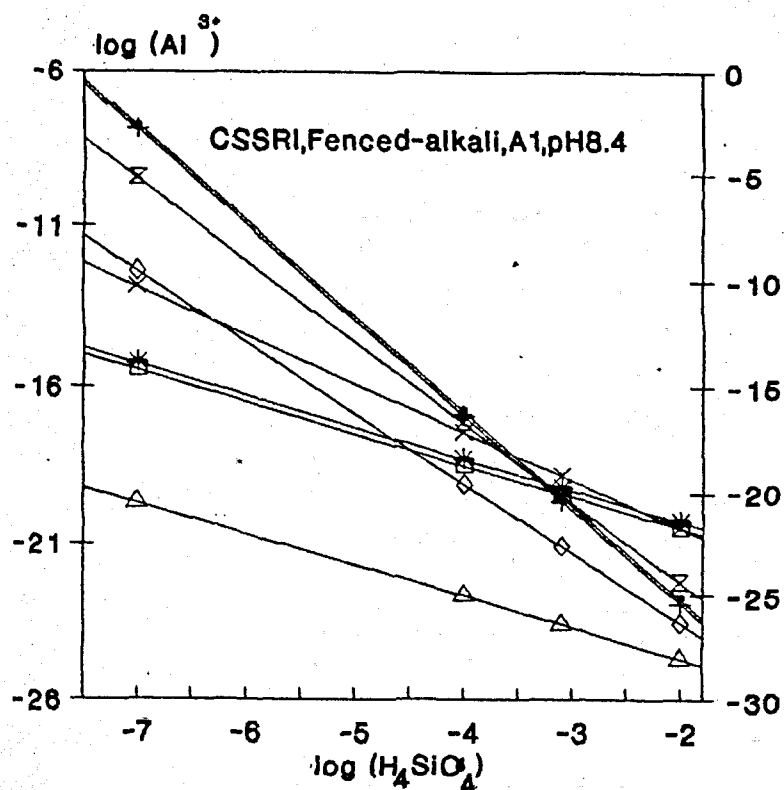
between 5.71 to 10.97, 2.04 to 3.52 and 1.29 to 3.61, respectively. CaO and Na_2O content varied from traces to 0.74 and 0.45 to 1.07, respectively. These grains also contained high amounts of phosphorus. P_2O_5 and ZnO content varied from 0.110 to 0.169 and 0.014 to 0.044, respectively. Loss on ignition of these grains ranged between 8.02 to 9.10 per cent only.

Soil Taxonomy: Based on the norms of Soil Survey Staff (1975) and morphological, physical and chemical characteristics these soils have been classified as below.

CSSRI fenced alkali and CSSRI alkali soils had argillans and required amounts of clay (illuvial nature not confirmed) in B horizon and the ESP; as such these soils qualified for the natric diagnostic horizon. Criteria of prismatic, columnar structure was loosely followed in these cases as per the suggestions of Sehgal et al. (1975). Accordingly, both these soils have been classified as coarse loamy, mixed, hyperthermic, Typic Natrustalfs. Question of illuvial nature of clay and the so called argillans is discussed in detail in the next chapter.

CSSRI reclaimed alkali, Gudda alkali, Gudda reclaimed alkali, Samdhan alkali and Samdhan reclaimed alkali soils did not have the qualifying amounts of illuvial clay and other evidences for natric diagnostic horizon, thus, as such taking into account their calcareous nature and presence of cambic horizon these have been classified as coarse loamy, mixed, hyperthermic, Typic Ustochrepts with the exception of Gudda alkali soil having fine loamy textural family. However, this classification failed to highlight the alkali nature of these soils.

CSSRI-normal soils were having well developed cambic B horizon. Presence of cutans was owed to the fact that these were under irrigation since the last



legend

- Albite
- +— Microcline
- *— Muscovite
- Kaolinite
- x— Illite
- ◇— Montmorillonite
- △— Chlorite
- x— Vermiculite

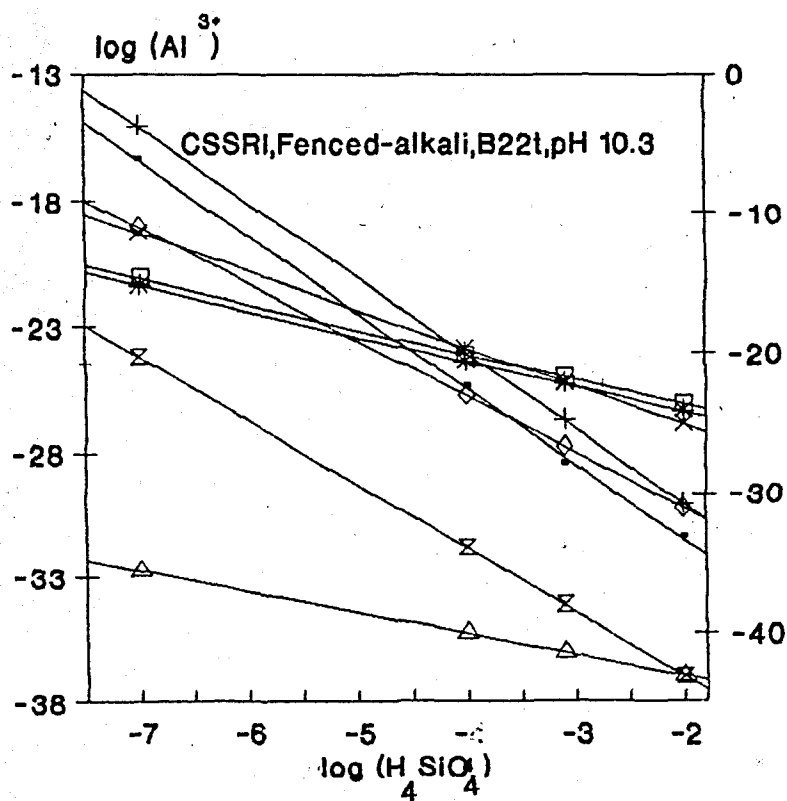


Fig. 4.37 Stability of aluminosilicates

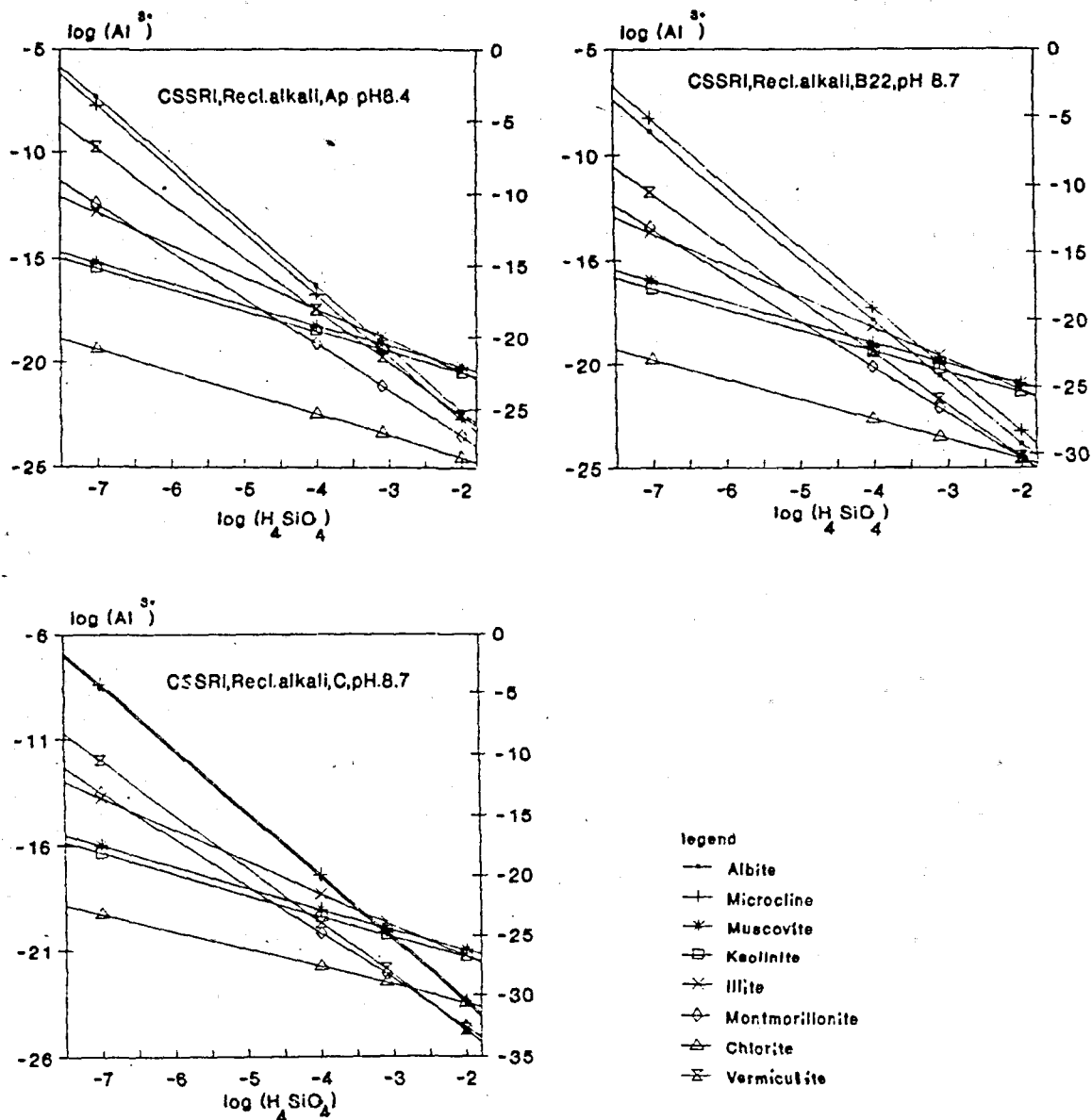


Fig. 4.41 Stability of aluminosilicates

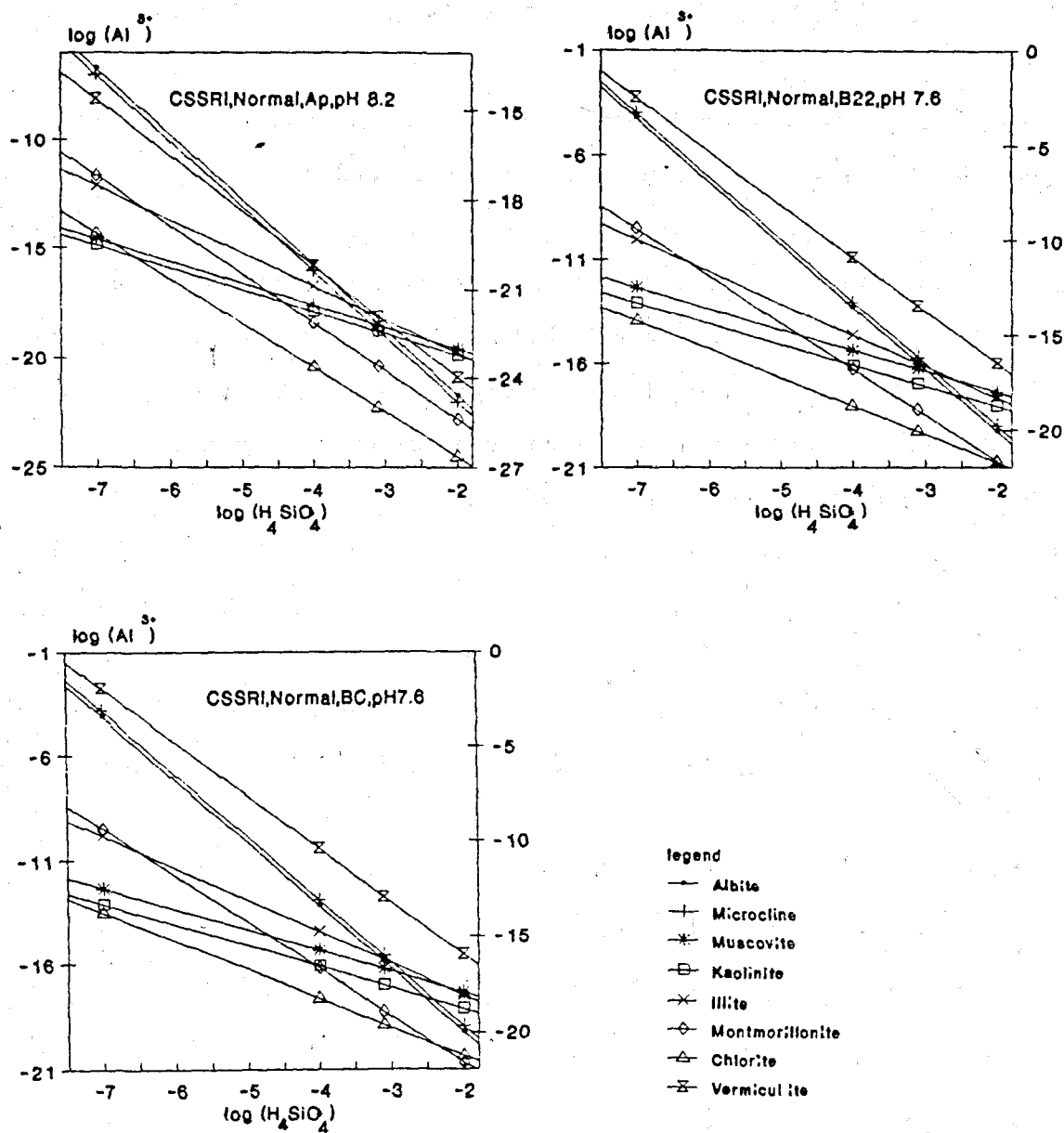


Fig. 4.46 Stability of aluminosilicates

8 decades or more. Thus taking into account the non-calcareous nature, these soils have been classified as fine loamy, mixed, hyperthermic, Udic Ustochrept.

Stability of alumino-silicates: Stability of various alumino- silicates in the soils of this geomorphic unit has been compared by taking into account the present hydraulic conductivity of concerned horizon of a soil. Horizons which have high hydraulic conductivity are certain to maintain a low level of H_4SiO_4 activity e.g. A1 horizon of CSSRI fenced alkali and all the horizons of CSSRI normal soils and upper horizons of reclaimed alkali soils. Similarly, soil horizons which have very poor hydraulic conductivity are likely to maintain a high activity of H_4SiO_4 e.g. the alkali soils and the lower horizons of reclaimed alkali soils. Results of comparison of alumino-silicate stability, thus obtained are presented in the subsequent paragraphs.

(i) **Alkali soils with poor hydraulic conductivity:** At pHs 10.2 and 10.3, and at constituent cations activity levels in soil solution under high H_4SiO_4 activity ($10^{-2.74}M$), common alumino-silicates in Ap horizon of Gudda alkali (Fig. 5.6) and B22+ horizon of CSSRI fenced-alkali pedons (Fig.4.37), can be arranged in order of increasing stability as: kaolinite, muscovite, illite, microcline, montmorillonite, albite, vermiculite and chlorite.

Similarly at 9.2 and 9.1 and at constituent cations activity levels under high H_4SiO_4 activity ($10^{-2.74}M$), alumino-silicates in Ap horizon of Samdhan alkali (Fig. 4.51) and B22 horizon of Samdhan reclaimed alkali (Fig. 4.55) pedons, can be arranged in order of increasing stability as: illite, muscovite, kaolinite, microcline, albite, montmorillonite, vermiculite and chlorite.

At pHs 9.9 and at constituent cations activity levels under high H_4SiO_4 activity ($10^{-2.74}M$), alumino-silicates in B22 horizon of Samdhan reclaimed alkali

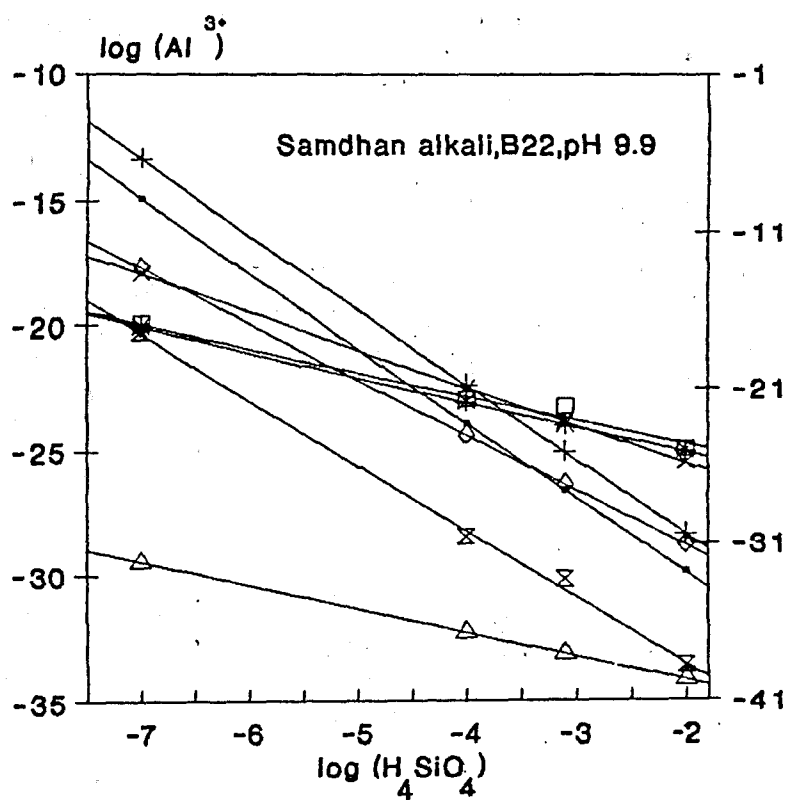
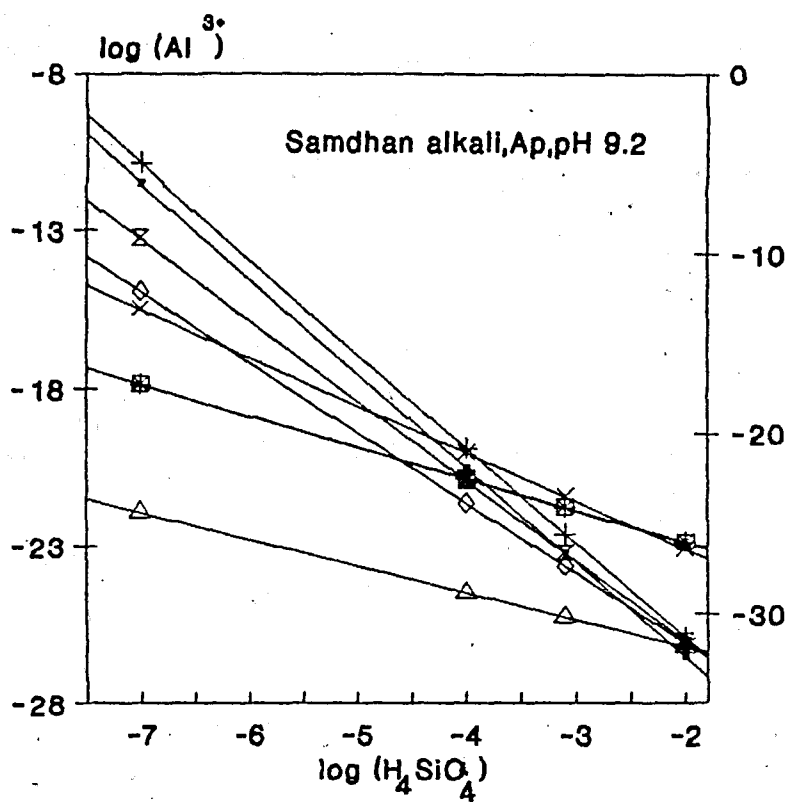
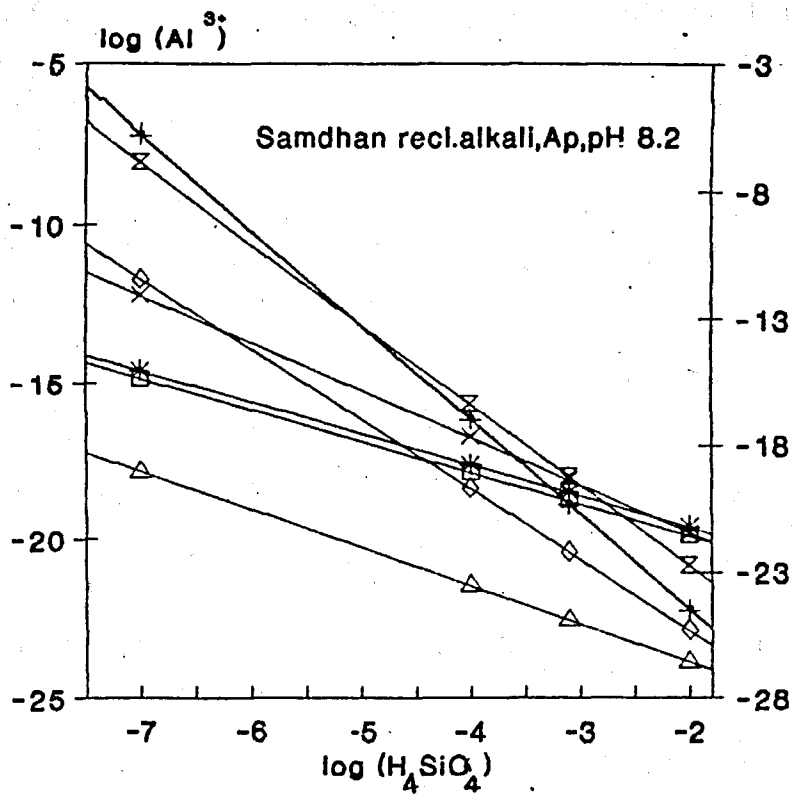


Fig. 4.51 Stability of aluminosilicates



legend

- Albite
- + Microcline
- * Muscovite
- Kaolinite
- × Illite
- ◇ Montmorillonite
- △ Chlorite
- ⊗ Vermiculite

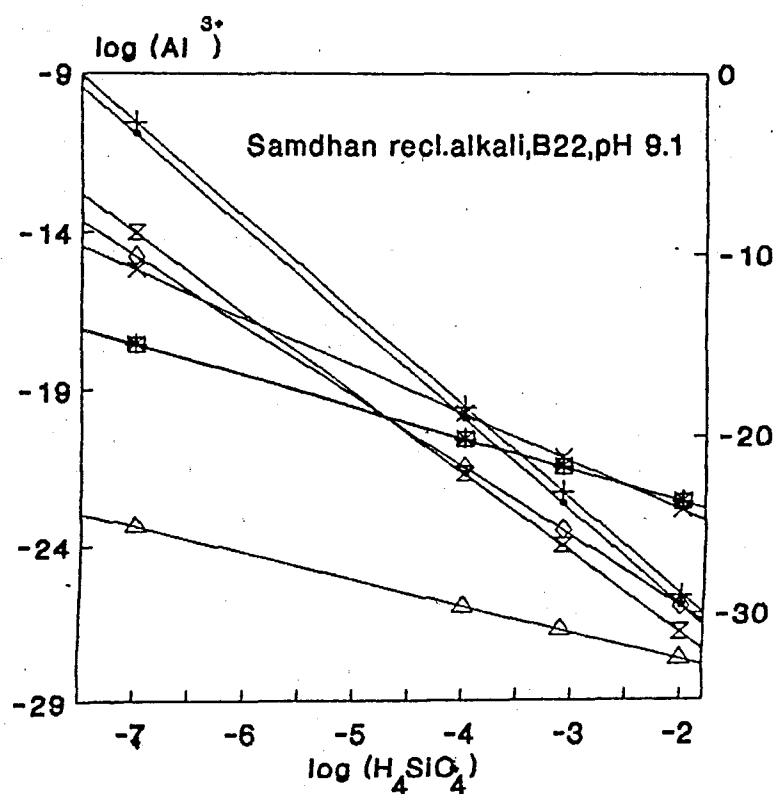


Fig. 4.55 Stability of aluminosilicates

(Fig. 4.55) pedons increase in stability in the same order, as the B22t horizon of CSSRI fenced alkali at pH 10.3. However, these soils maintain relatively lower equilibrium Al^{3+} activity by $10^{-1.5}M$ to $10^{-3.3}M$ times.

Thus, at high pH and under poor internal drainage, albite, montmorillonite, vermiculite and chlorite are highly stable.

(ii) Reclaimed alkali soils with good hydraulic conductivity: At pHs 8.2, 8.3 and 8.4 and at respective constituent cations activity level in soil solution under low H_4SiO_4 activity ($10^{-5}M$), common alumino-silicates in Ap horizons of Samdhan reclaimed alkali (Fig. 4.55), Gudda reclaimed alkali (Fig. 5.6) and CSSRI reclaimed alkali (Fig. 4.41), respectively, can be arranged in order of increasing stability as: albite, microcline, vermiculite, illite, montmorillonite, kaolinite, muscovite and chlorite. At pHs 8.7 and at constituent cations activity level under low H_4SiO_4 activity ($10^{-5}M$), alumino-silicates in B22 horizon of CSSRI reclaimed alkali soils (Fig. 4.41), can be arranged in order of increasing stability as: microcline, albite, illite, vermiculite, montmorillonite, muscovite, kaolinite and chlorite.

Thus, with improvement in internal drainage and lowering of pH due to reclamation kaolinite, muscovite and chlorite become more stable.

(iii) Normal soils with good hydraulic conductivity: At pHs 8.2 and 8.4 and at respective constituent cations activity levels under low H_4SiO_4 activity ($10^{-5}M$), common alumino-silicates in Ap horizons of CSSRI normal soil (Fig. 4.46) and A1 (self reclaimed) horizon of CSSRI-fenced alkali soil (Fig. 4.37), can be arranged in order of increasing stability as: albite, microcline, vermiculite, illite, montmorillonite, muscovite, kaolinite and chlorite.

At pHs 7.6 and at constituent cations activity level under low H_4SiO_4

activity ($10^{-5}M$), alumino-silicates in B22 and BC horizons of CSSRI-normal pedon (Fig. 4.46), can be arranged in order of increasing stability as: vermiculite, microcline, albite, illite, montmorillonite, muscovite, kaolinite and chlorite.

Chlorite maintained lower equilibrium Al^{3+} activity at pH 8.2 than at pHs 7.6. Under similar conditions there was not much change in equilibrium Al^{3+} activity. Thus chlorite is more stable at relatively higher pH when compared with kaolinite. Thus, in normal soils and soils undergoing natural reclamation processes with good internal drainage, muscovite, kaolinite and chlorite are more stable.

Mineralogy: Information obtained from the qualitative and semi-quantitative interpretation of x-ray diffractogram of selected horizons of the CSSRI-fenced alkali, CSSRI-reclaimed alkali, and CSSRI-normal pedons are presented below.

Sand: Comparison of mineralogy of sand fraction of three pedon (Fig. 4.38, 4.42, 4.47, Table 4.10.11, 4.12.11, 4.13.10) indicated quartz to be most dominant mineral followed by plagioclase feldspars, mica, orthoclases, and chlorite + kaolinite, amphiboles and mixed layer minerals. Amphiboles were absent in CSSRI-normal soils. Calcite was present only in CSSRI-reclaimed alkali soil.

Silt: Mineralogy of silt fraction (Fig. 4.38, 4.42, 4.47, Table 4.10.11, 4.12.11, 4.13.10) of these soils was similar to that for the sand fraction except that the calcite was almost absent in all the pedons. In CSSRI-normal soil chlorite and amphiboles were present in small amounts only.

Clay: X-ray diffractograms of clay fraction of these soils indicated a strong and well defined peaks for illite accompanied by a moderate 1.4 nm peak in surface horizon of CSSRI-fenced alkali (Fig. 4.39, 4.40), CSSRI-reclaimed alkali

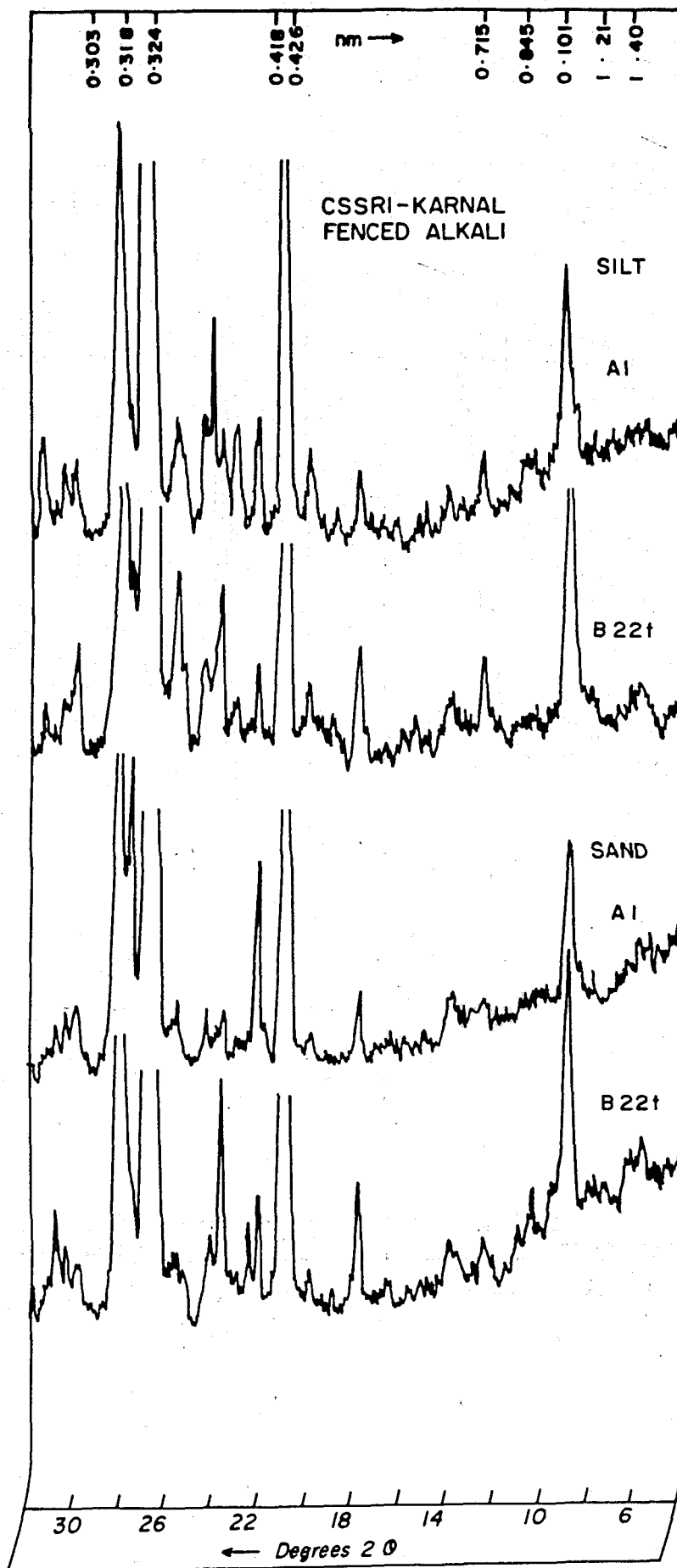


Fig. 4.38 XRD pattern of sand and silt minerals

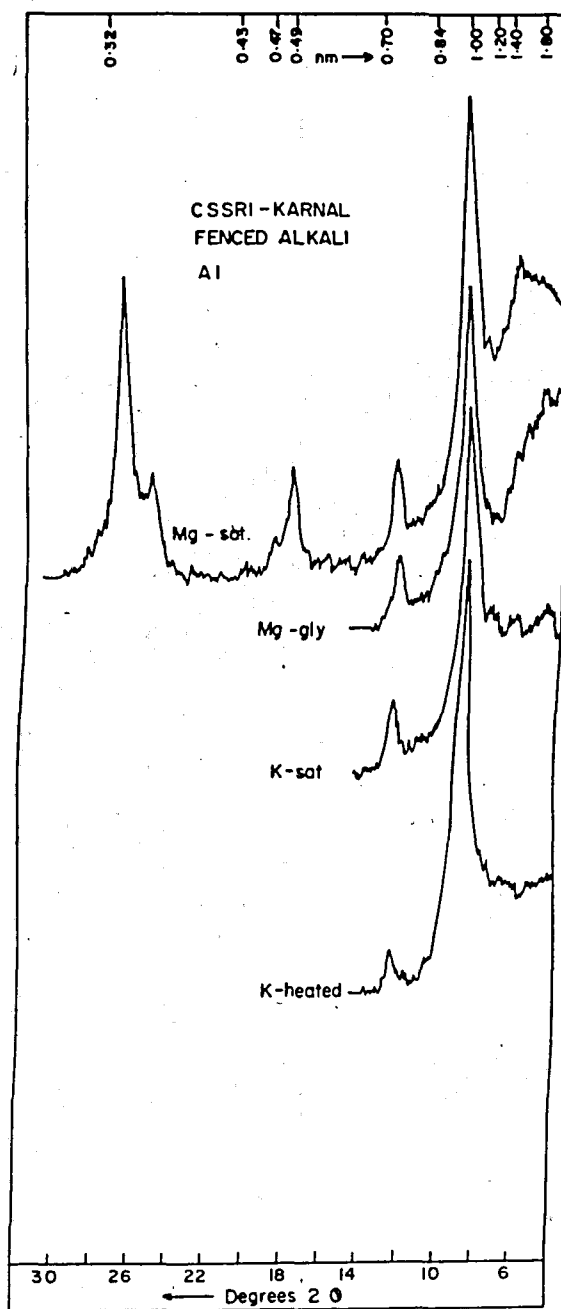


Fig. 4.39 XRD pattern of clay minerals

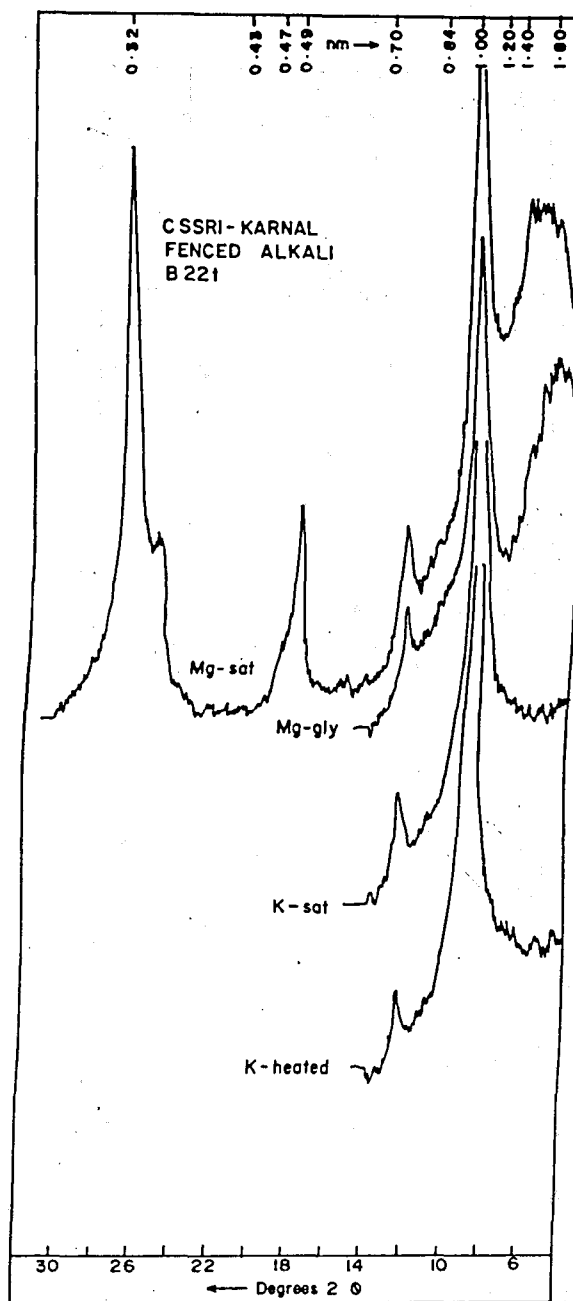


Fig. 4.40 XRD pattern of clay minerals

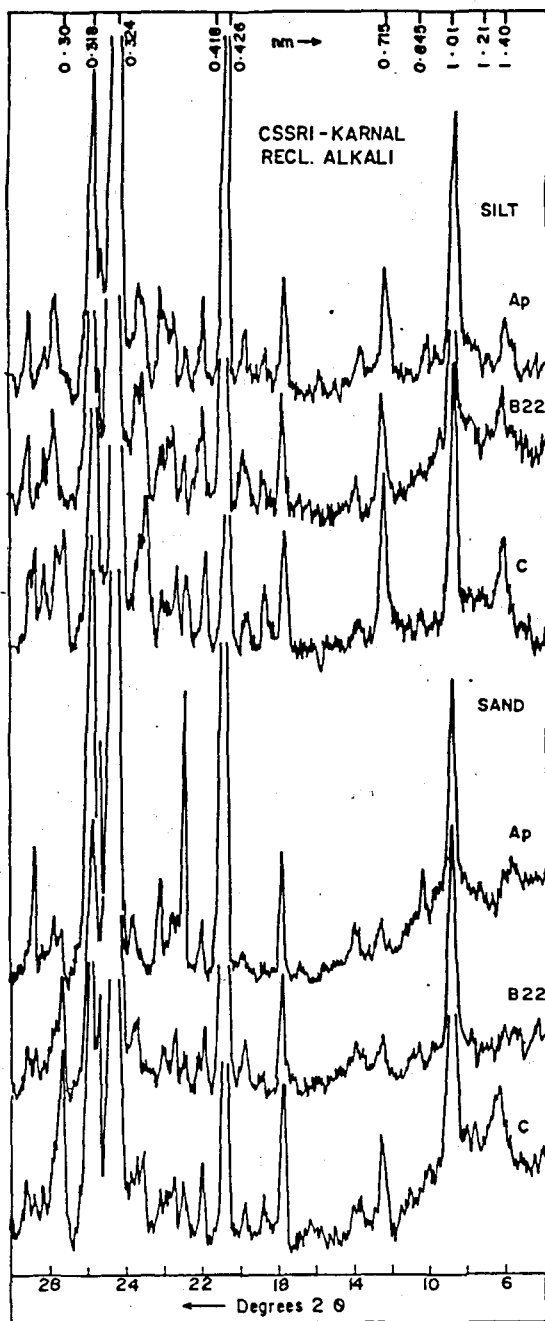


Fig. 4.42 XRD pattern of sand and silt minerals

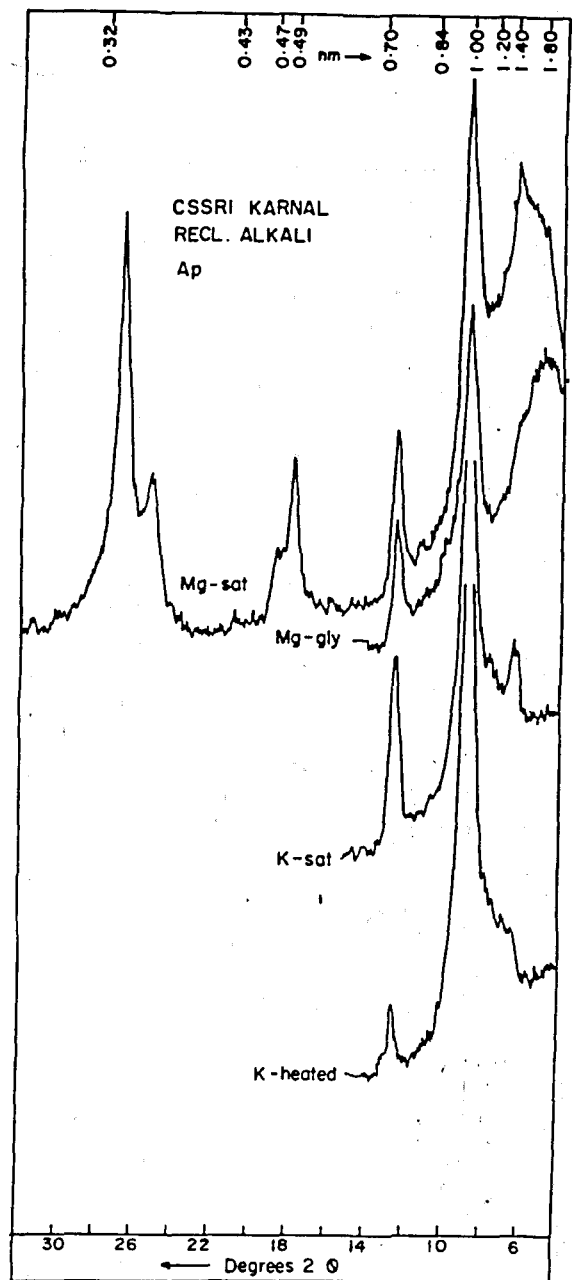


Fig. 4.43 XRD pattern of clay minerals

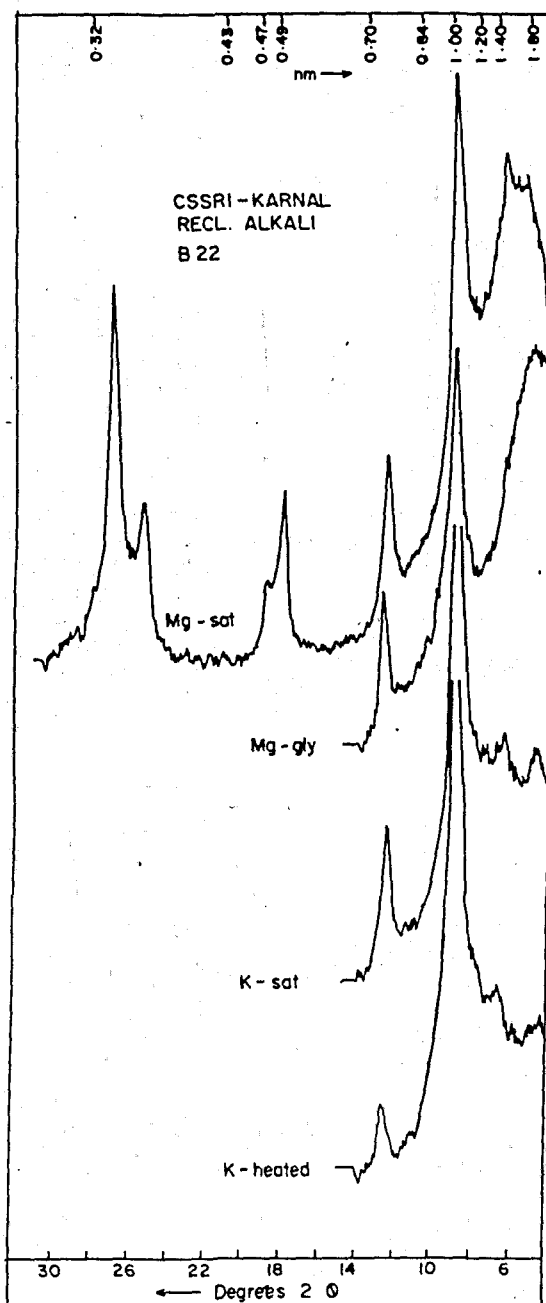


Fig. 4.44 XRD pattern of clay minerals

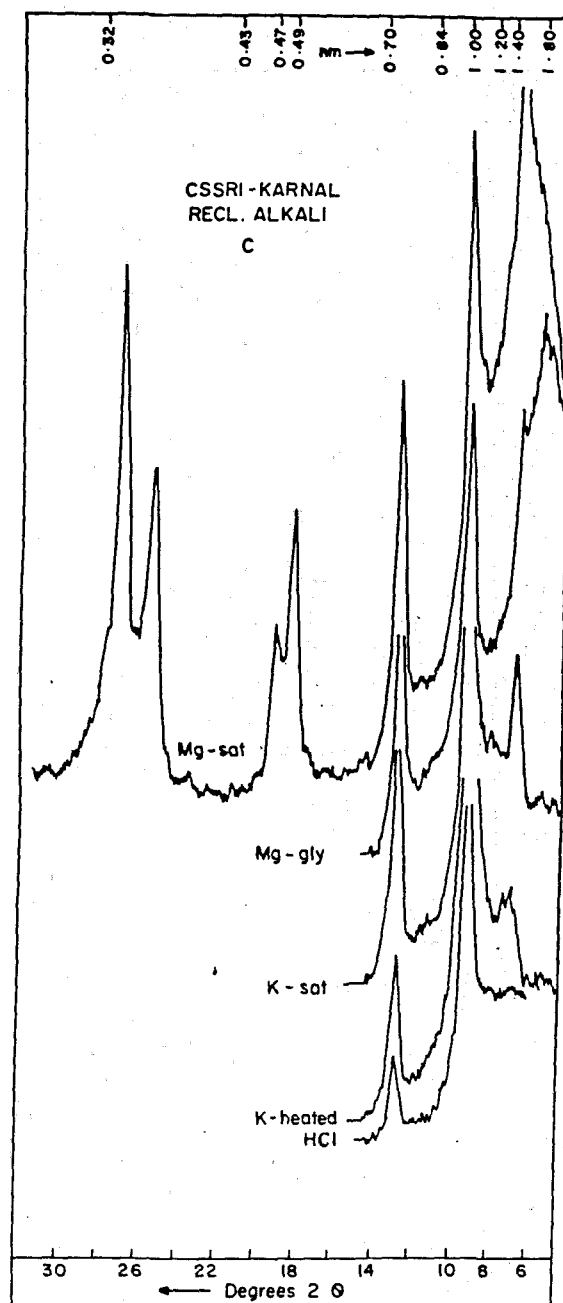


Fig. 4.45 XRD pattern of clay minerals

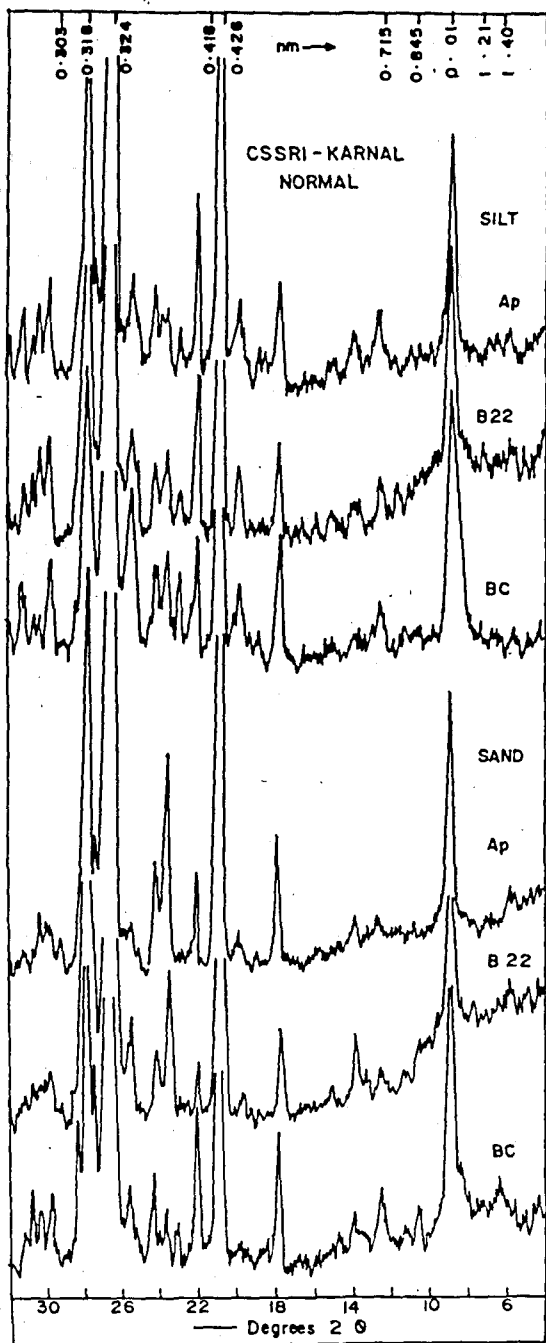


Fig. 4.47 XRD pattern of sand and silt minerals

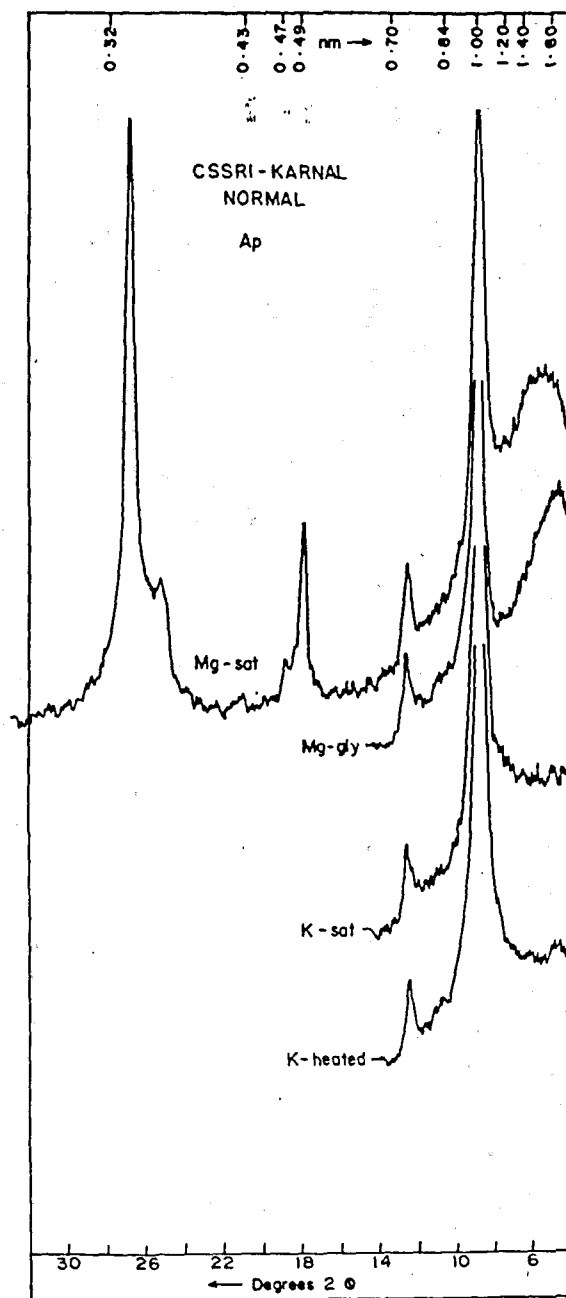


Fig. 4.48 XRD pattern of clay minerals

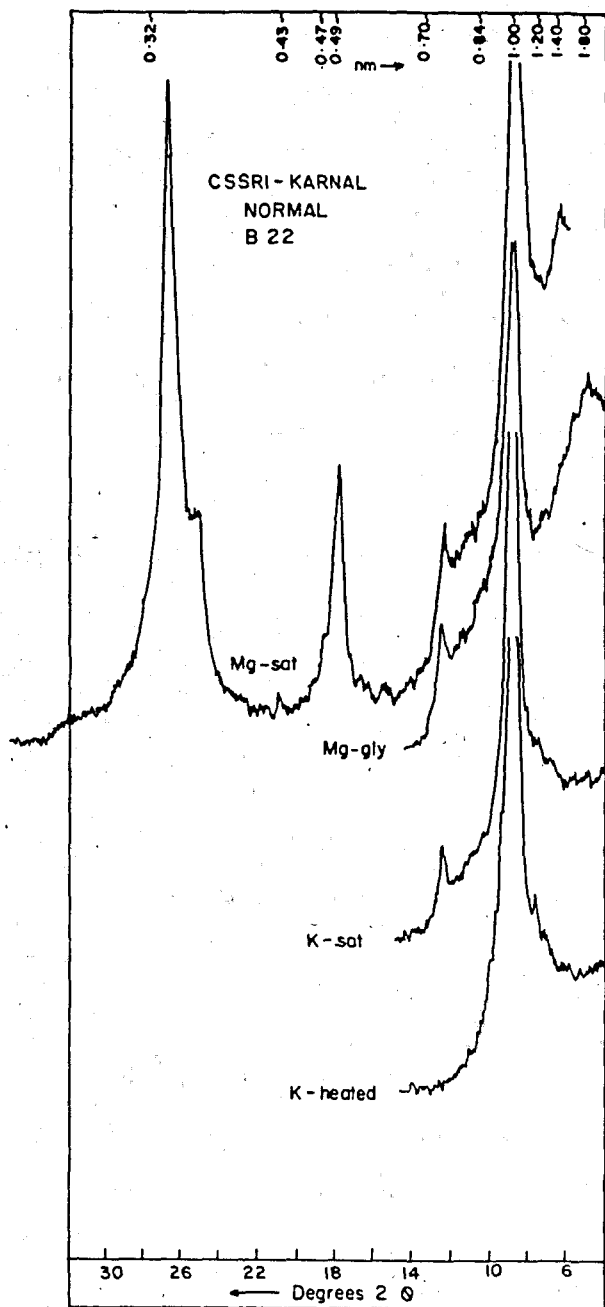


Fig. 4.49 XRD pattern of clay minerals

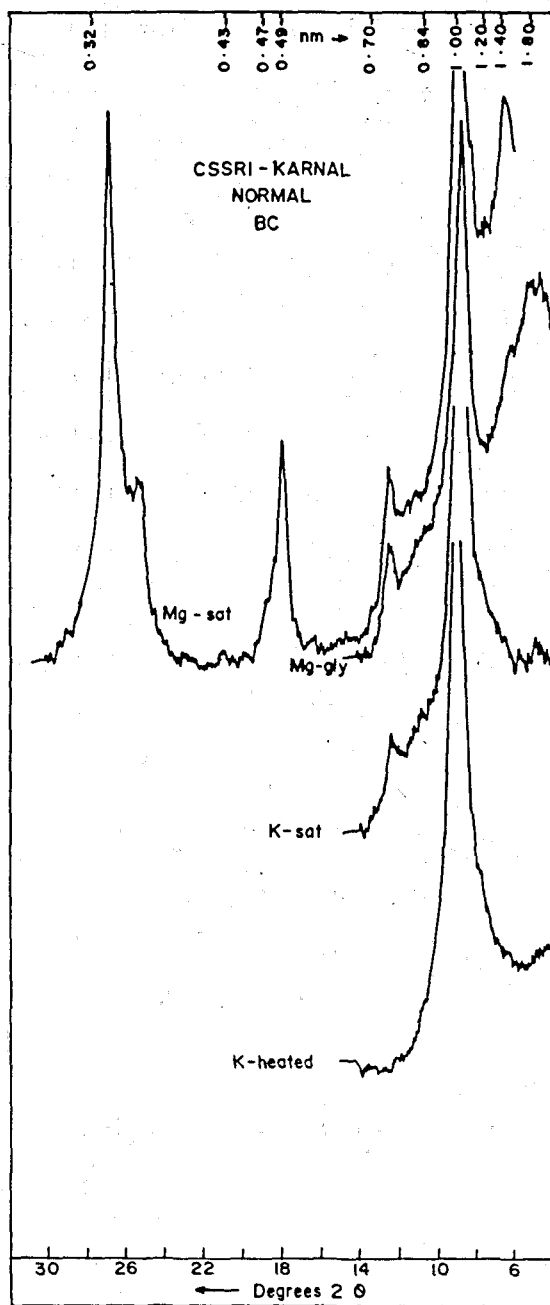


Fig. 4.50 XRD pattern of clay minerals

(Fig. 4.43, 4.44, 4.45), all the horizons of CSSRI-normal soils (Fig. 4.48, 4.49, 4.50) and strong 1.4 nm peak in all other horizons along with its higher orders at 0.472 nm and 0.354 nm in Mg-treated samples. The 1.4 nm peak resolved partially into a maximum at 1.8 nm on glycerol solution and was thus attributed to the presence of smectites. Smectite was irregular towards lower angle in CSSRI-fenced alkali. 002 order was not very strong.

A part of 1.4 nm collapsed to 1.0 nm on heating and K-saturation, confirming the presence of vermiculite. Residual 1.4 nm that remained unaffected by K-saturation or heating treatment was attributed to chlorite. Chlorite is basically dioctahedral in nature. XRD pattern also showed the presence of mixed layer minerals registering peaks around 1.2 nm region. Mixed layer mineral component seemed to be mostly mica-smectite and mica-chlorite type. Mixed layers are mostly irregular. In addition to above clay minerals, diffractograms also recorded small peaks at 0.845, 0.426 and 0.323 nm thus indicating the presence of amphiboles, quartz and feldspars.

Semi-quantitative estimates, calculated on the basis of corrected peak area value for three pedons are presented below in decreasing order of mineral preponderance.

CSSRI-fenced alkali (Table 4.10.12)

Ap: Illite, kaolinite, mixed layer, smectite, vermiculite and chlorite.

B22t: Illite, smectite, kaolinite, vermiculite, mixed layers and chlorite

CSSRI-reclaimed alkali (Table 4.12.12)

Ap: Illite, chlorite, mixed layer, kaolinite, smectite and vermiculite

B22,C: Illite, smectite, mixed layer, chlorite, mixed layer and vermiculite

CSSRI-normal(Table 4.13.11):

Ap: Illite, mixed layer, kaolinite, smectite, vermiculite and chlorite

B22,BC: Illite, mixed layer, smectite, kaolinite, chlorite and vermiculite

Primary minerals contributed only minor proportions in these soils.

Mineralogy: Data obtained from the qualitative and semi- quantitative interpretation of x-ray diffractograms of selected horizons of Samdhan-alkali pedon is presented in the subsequent paragraphs.

Sand: A perusal of results in (Fig. 4.52, Table 4.16.9) indicated the dominance of quartz followed by almost similar proportions of plagioclases and mica, orthoclases, chlorite + kaolinite, mixed layer component and calcite.

Silt: Semi-quantitative estimates of XRD pattern for silt fraction (Fig. 4.52, Table 4.16.9) showed trends similar to the sand fractions, however, calcite was absent.

Clay: Semi-quantitative estimates (Table 4.16.10, Fig. 4.53, 4.54) of clay minerals calculated on the basis of corrected peak area are presented below in the decreasing order:

Ap: Illite, mixed layer, kaolinite, chlorite, smectite

B22: Illite, smectite, mixed layers, chlorite and kaolinite.

In general the smectite content increased and illite content decreased considerably with depth. There was no change in kaolinite content with depth. Primary minerals contributed only minor proportions.

Mineralogy: Information obtained from the qualitative and semi- quantitative interpretation of x-ray diffractograms of selected horizons of Samdhan-reclaimed alkali pedon is presented below.

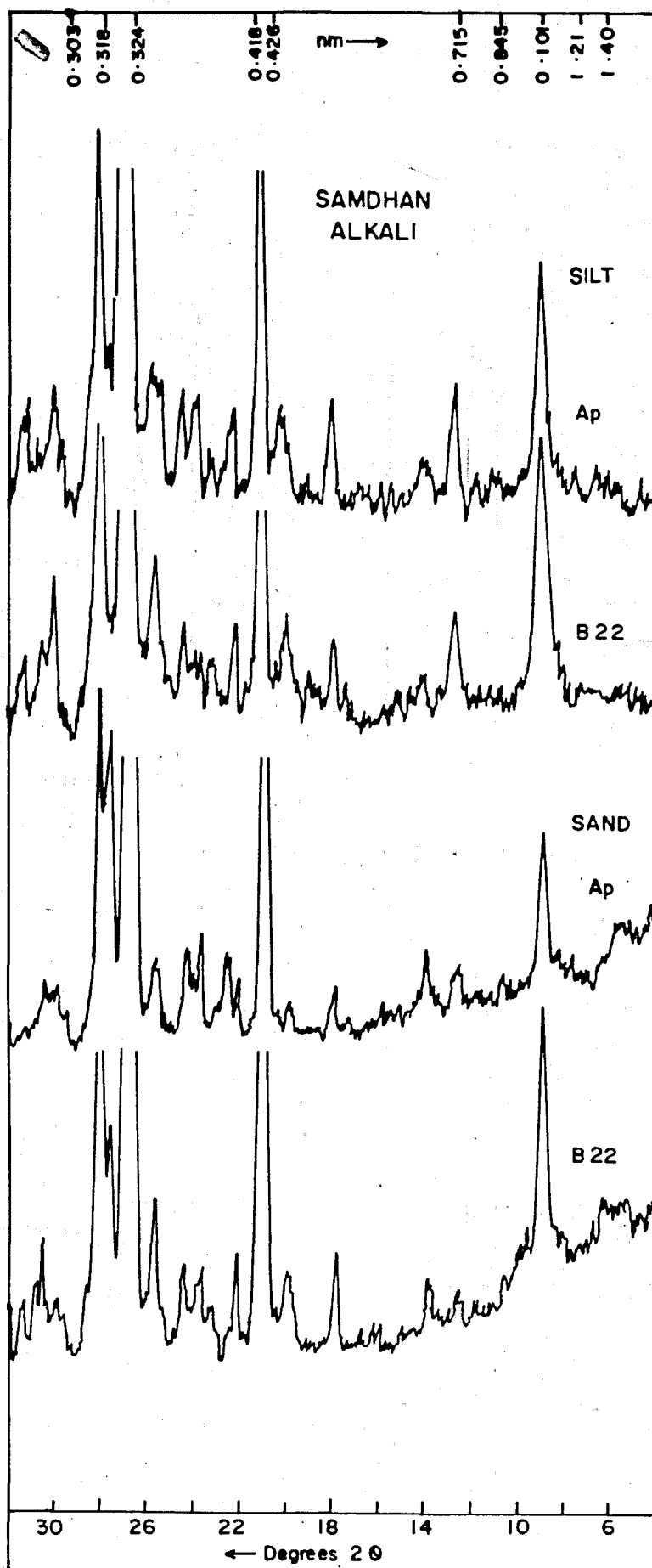


Fig. 4.52 XRD pattern of sand and silt minerals

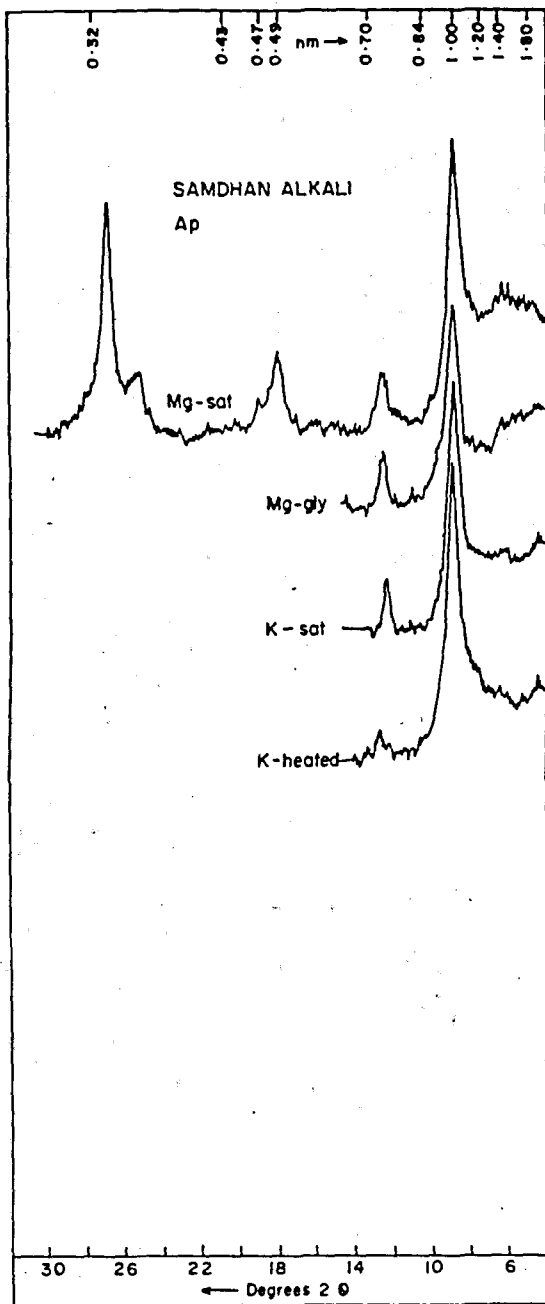


Fig. 4.53 XRD pattern of clay minerals

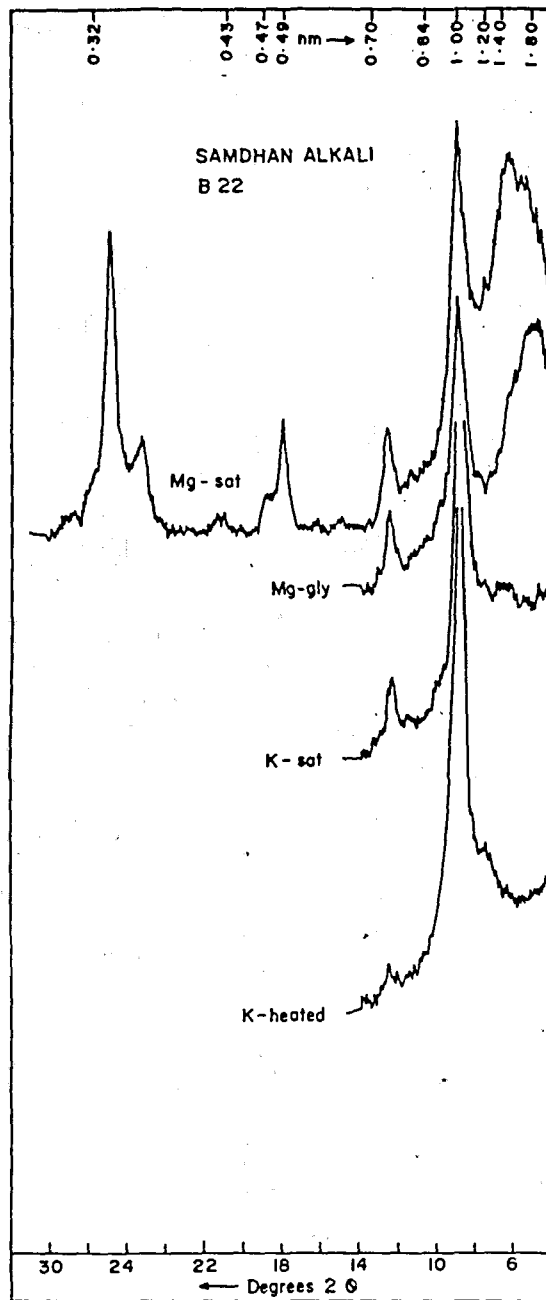


Fig. 4.54 XRD pattern of clay minerals

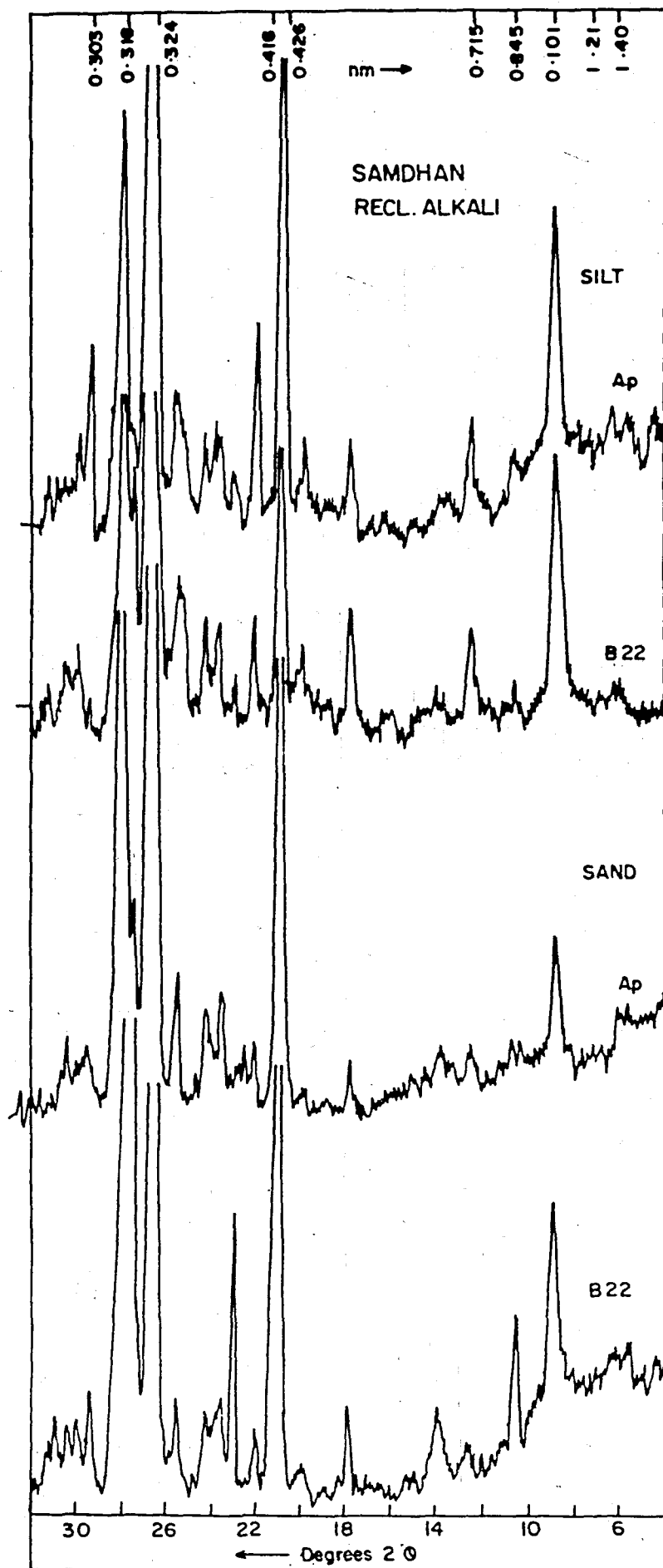


Fig. 4.56 XRD pattern of sand and silt minerals

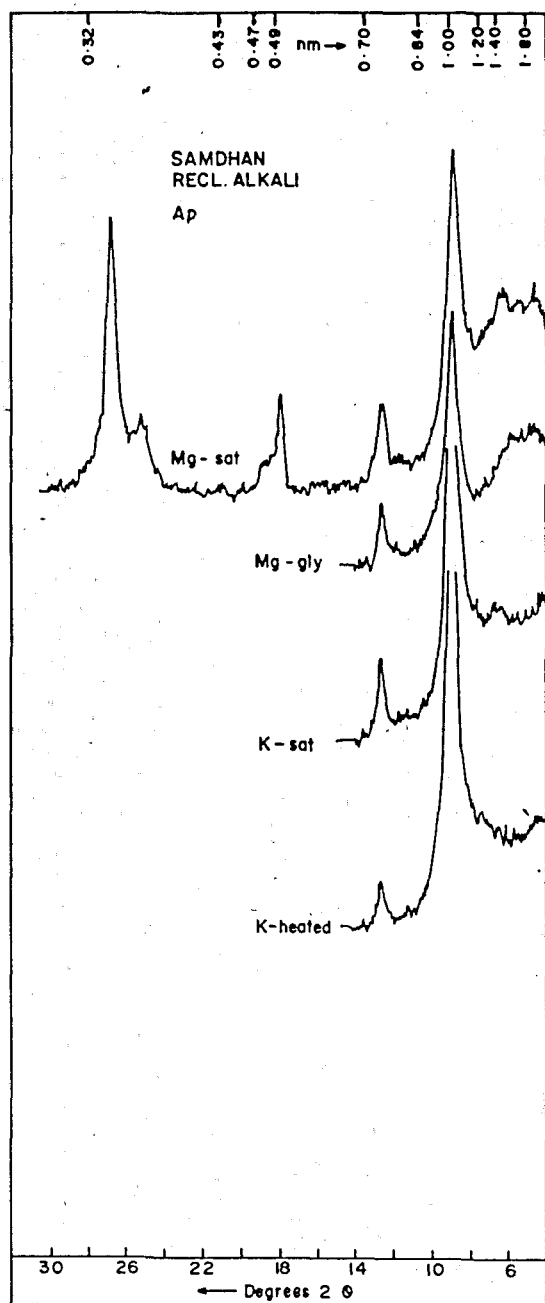


Fig. 4.57 XRD pattern of clay minerals

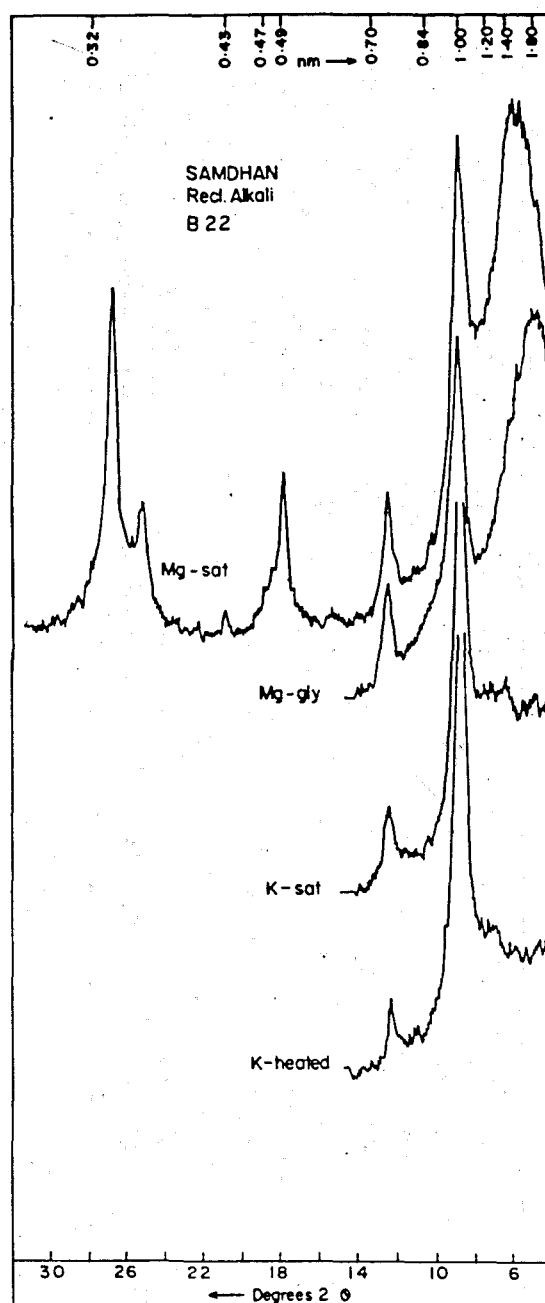


Fig. 4.58 XRD pattern of clay minerals

Pedon No. 10 CSSRI-FENCED ALKALI

Classification: Typic Natrustalf, coarse loamy, mixed, hyperthermic

Location: 76° 57'13"E, 29° 42' 8"N, south-west of CSSRI farm fenced alkali area, Karnal

Physiography: Upper alluvial plain

Topography: Gently sloping

Drainage: Poorly drained

Landuse: Natural grasses

Elevation 245 m

Rainfall: 711 mm

Table 4.10.1 Morphology

Lab.Depth	Horizon	Boundary	Colour (moist)	Mottling	Texture (USDA)	Structure	Consistence (wet)	Cutans	Roots	Coarse	Reaction	
No. (cm)										fragments		
50	0-8	A1	cw	2.5Y 6/4	-	s1	1m, sbk	wss, wpo	-	m, f	-	0
51	8-18	AB	gw	2.5Y 6/4	-	s1	2m, sbk	wss, wsp	-	m, f	-	1
52	18-33	B1	gw	10YR 5/4	-	s1	2m, sbk	ws, wp	-	c, f	-	2
53	38-58	B21	gw	10YR 5/4	-	1	2m, sbk	ws, wp	p, tn	c, f	-	3
54	58-81	B22t	gw	10YR 6/4	-	1	2m, sbk	ws, wp	p, tn	c, f	-	4
55	81-117	B3	gw	10YR 6/4	-	1	3m, sbk	ws, wp	-	c, f	conir, f	2
56	117-152+	C		10YR 6/4	-	s1	3m, sbk	ws, wp	-	-	-	3

Table 4.10.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)			Coarse fragments (%)	Water content (%)		
		Sand	Silt	Clay		1/3 bar	15 bar	Available
		(2 - 0.05)	(0.05 - 0.002)	(< 0.002)				
-----% of < 2 mm -----								
50								
51	0-8	69.6	25.3	5.1	-	17.3	5.2	12.1
52	8-18	57.7	32.6	9.7	-	20.1	9.1	11.0
53	18-33	55.5	33.9	10.6	-	21.0	10.8	10.2
54	33-58	50.6	31.0	18.4	-	22.8	13.2	9.6
55	58-81	47.2	33.1	19.7	-	24.6	13.1	11.5
56	81-117	48.6	34.8	16.6	< 1	24.7	15.7	9.0
	117-152	61.8	26.7	11.5	< 1	21.5	11.2	10.3

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)			
								Fe	Mn	Cu	Zn
50	0-8	0.60	0.00	8.8	0.44	1.54	2.107	12.8	4.6	2.32	0.46
51	8-18	0.08	0.55	10.4	1.19	1.66	-	6.2	7.9	0.66	0.18
52	18-33	0.09	0.30	10.6	2.25	1.70	-	10.4	13.4	1.22	0.18
54	33-58	0.06	0.65	10.8	3.83	1.67	-	20.4	12.0	0.92	0.20
55	58-81	0.06	0.67	10.7	3.47	1.78	-	16.8	11.9	0.82	0.20
56	81-117	0.06	0.52	10.6	2.92	1.90	-	13.8	5.9	0.70	0.24
	117-152	0.05	1.59	9.7	1.83	1.81	-	3.8	3.8	0.30	0.18

Table 4.10.3: Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)				CEC (c mol kg ⁻¹)	ESP
		Na	Mg	Ca	K		
50	0-8	0.7	1.5	3.2	0.11	5.6	12
51	8-18	6.3	0.6	1.6	0.17	8.6	73
52	18-33	9.7	0.2	1.5	0.15	11.6	83
53	33-58	12.0	0.3	0.8	0.15	13.3	90
54	58-81	14.0	0.2	0.5	0.17	14.4	93
55	81-117	12.4	0.3	0.6	0.14	13.4	93
56	117-152+	5.2	2.2	4.0	0.15	11.6	45

Table 4.10.4 Saturation extract analysis

Lab. No.	Depth (cm)	Satur- ation%	pH _s	EC _e dSm ⁻¹	Saturation extract analysis (me/l)							SAR	
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl		SO ₄
50	0-8	38	8.4	1.8	8.8	6.0	3.0	0.21	2.1	7.4	7.0	2.0	4
51	8-18	28	9.5	2.9	21.2	6.0	5.0	0.14	2.8	16.1	8.0	6.0	9
52	18-33	26	10.3	6.6	53.7	11.0	6.0	0.07	39.2	16.8	10.0	6.0	18
53	33-58	33	10.4	11.9	139.7	4.0	12.0	0.07	75.2	39.2	28.0	8.0	49
54	58-81	37	10.3	11.1	118.3	5.0	4.0	0.08	61.2	28.2	20.0	11.0	56
55	81-117	42	10.2	3.6	26.2	3.0	4.0	0.07	8.4	18.2	7.0	2.0	14
56	117-152+	39	8.9	2.9	22.4	5.0	3.0	0.08	1.4	6.3	10.0	14.0	16

Table 4.10.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
50	0-8	84.1	5.09	2.66	0.0	1.25	2.11	0.57	0.48	0.053	0.67
51	8-18	84.0	5.21	1.29	0.2	1.17	2.15	0.59	tr.	0.052	1.06
52	18-33	85.8	5.21	1.23	0.3	0.92	2.21	0.54	tr.	0.039	0.98
53	33-58	86.8	4.98	1.23	0.2	0.92	2.04	0.58	0.05	0.014	0.58
54	58-81	86.9	5.34	1.43	0.1	1.05	2.20	0.61	0.06	0.005	0.57
55	81-117	84.3	4.90	1.98	0.4	1.33	1.93	0.65	0.08	0.005	0.83
56	117-152+	84.0	5.41	1.82	0.2	1.25	2.21	0.65	0.06	0.005	0.67

Table 4.10.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
50	0-8	73.2	13.1	2.88	0.0	1.92	1.89	1.69	0.05	0.015	3.27
51	8-18	72.5	13.3	2.95	0.0	2.00	1.92	1.81	0.02	0.015	1.78
52	18-33	73.0	13.8	3.26	0.0	1.92	1.90	2.01	0.01	0.035	0.63
53	33-58	70.4	14.2	3.22	0.0	2.51	1.98	2.03	0.01	0.034	1.23
54	58-81	70.9	14.4	3.30	0.0	2.34	1.93	2.02	tr.	0.062	1.07
55	81-117	70.9	13.8	3.41	0.0	2.34	2.01	2.15	tr.	0.050	2.72
56	117-152+	71.7	13.1	4.05	0.0	2.51	2.03	1.98	0.03	0.053	2.29

Table 4.10.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		ZnO	MnO
50	0-8	51.0	24.2	8.12	0.2	2.96	0.12	1.42	0.23	0.052	0.058	11.62
51	8-18	49.5	23.5	7.94	0.0	3.19	0.15	1.50	0.06	0.031	0.061	10.57
52	18-33	51.9	22.2	8.08	0.1	3.16	0.16	1.47	0.02	0.030	0.056	9.09
53	33-58	52.3	23.4	7.70	0.1	3.14	0.18	1.46	0.02	0.026	0.054	8.58
54	58-81	53.2	21.7	7.80	0.2	3.17	0.18	1.42	0.03	0.031	0.045	8.90
55	81-117	53.2	22.1	7.72	0.2	2.72	0.16	1.47	0.02	0.034	0.049	8.76
56	117-152+	51.5	21.5	7.11	0.1	4.19	0.21	1.40	0.06	0.050	0.052	9.72

Table 4.10.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	MnO
50	0-8	80.0	8.2	2.47	0.0	0.92	1.07	0.56	0.08	0.053
51	8-18	77.5	9.6	2.79	0.0	1.17	0.97	0.65	0.05	0.063
52	18-33	77.0	9.9	2.94	0.0	1.34	0.95	0.67	0.06	0.056
53	33-58	74.9	11.1	3.16	0.0	1.35	0.91	0.67	0.06	0.056
54	58-81	74.1	11.5	3.55	0.1	1.00	0.91	0.70	0.07	0.070
55	81-117	75.0	11.0	3.89	0.1	1.44	0.88	0.73	0.27	0.094
56	117-152+	77.7	9.4	3.06	0.3	1.05	1.28	0.67	0.09	0.067

Table 4.10.9 Elemental composition of lime concretions

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O		P ₂ O ₅	MnO
56	117-152+	46.2	1.8	2.17	20.12	1.87	0.47	0.41	0.064	0.056	7.19

Table 4.10.10 Elemental composition of ferro-magnesian grains

Lab. No.	Depth (cm)	Elemental composition (%)										Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	ZnO	CuO		MnO
55	81-117	73.6	3.5	10.97	0.11	1.49	1.07	0.74	0.013	0.024	0.010	3.16	9.10

Table 4.10.11 Semi quantitative estimates of sand and silt minerals

Lab.No.	Depth (cm)	Chlorite	Mixed layer	Mica	Amphibole	Chlorite + Kaolinite	Quartz	Orthoclases	Plagioclases	Calcite
Sand										
50	0-8	++	+	+++	++	++	+++++	+++	+++++	-
54	58-81	++	++	++++	++	++	+++++	+++	+++++	-
Silt										
50	0-8	++	++	+++	++	++	+++++	++	++++	-
54	58-81	++	+	++++	++	++	+++++	+++	++++	-

4.10.12 Semi quantitative estimates of clay minerals

Lab. No.	Depth (cm)	Smectite	Chlorite	Vermiculite	Illite	Mixed layer	Kaolinite	Quartz	Feldspar	Amphibole
%										
50	0-8	7		7	4	61	8	tr.	3	2
54	58-81	9		5	7	59	7	tr.	3	2

Pedon No. 11 CSSRI-ALKALI

Classification: Typic Natrustalf, coarse loamy, mixed, hyperthermic

Location: 76° 57'13"E, 29° 42' 8"N, north-east of CSSRI farm, Karnal

Physiography: Upper alluvial plain

Topography: Level to gently sloping

Drainage: Moderately well drained

Landuse: Cultivated

Elevation 245 m

Rainfall: 711 mm

Table 4.11.1 Morphology

Lab. Depth	Horizon	Boundary	Colour (moist)	Mottling	Texture (USDA)	Structure	Consistence (wet)	Cutans	Roots	Coarse fragments	Reaction
38	0-13	Ap	cw	2.5Y 5/2	-	sl	2m, sbk	wso, wpo	-	c, f	1
39	13-25	AB	cw	2.5Y 5/2	-	1	1f, pl	wss, wpo	-	c, f	2
40	25-56	B21	gw	2.5Y 5/4	-	1	2m, sbk	ws, wp	-	f, f	conir, m 2
41	56-89	B22t	gw	10YR 5/4	-	1	2m, cr	wvs, wvp	tn, b	f, f	2
42	89-119	B23t	gw	10YR 5/4	-	1	2m, cr	wvs, wvp	tn, b	-	conir, m 2
43	119-135	B3	cw	10YR 5/4	-	1	2m, sbk	wvs, wvp	-	-	3
44	1350155+	C		10YR 5/3	-	1	2m, sbk	wvs, wvp	-	-	conca, c 4

Table 4.11.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)			Coarse fragments (%)	Water content (%)		
		Sand (2 - 0.05)	Silt (0.05 - 0.002)	Clay (< 0.002)		1/3 bar	15 bar	Available
38	0-13	55.2	37.2	7.6	-	19.0	8.1	10.9
39	13-25	51.3	40.7	8.0	-	20.5	10.5	10.0
40	25-56	43.5	37.9	19.6	-	24.5	17.8	6.7
41	57-89	32.5	45.8	21.7	-	26.5	18.7	7.8
42	89-119	36.8	40.8	22.4	2	29.1	20.3	8.8
43	119-135	36.6	44.3	19.1	6	29.1	20.8	8.3
44	135-155+	47.5	38.7	13.8	38	26.4	17.7	8.7

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)			
								Fe	Mn	Cu	Zn
38	0-13	0.22	0.83	9.9	0.55	1.59	-	8.4	6.1	0.72	0.26
39	13-25	0.05	1.00	10.4	1.59	1.77	-	6.0	8.2	0.70	0.30
40	25-56	0.08	1.50	10.5	2.19	1.88	-	9.4	10.4	1.12	0.30
41	56-89	0.06	1.37	10.6	2.37	1.83	-	11.0	9.8	1.24	0.28
42	89-119	0.02	1.20	10.5	2.01	1.74	-	7.2	10.8	1.00	0.36
43	119-135	0.05	2.75	10.3	2.00	1.69	-	5.6	7.2	0.76	0.26
44	135-155+	0.03	3.78	10.3	2.01	1.74	-	5.8	5.8	0.50	0.30

Table 4.11.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)				CEC (c mol kg ⁻¹)	ESP
		Na	Mg	Ca	K		
38	0-13	3.3	0.9	3.0	0.18	6.4	52
39	13-25	4.3	0.6	2.0	0.20	7.1	61
40	25-56	11.4	0.4	1.3	0.17	13.3	86
41	56-89	13.8	0.4	1.0	0.15	15.4	90
42	89-119	13.5	0.5	1.1	0.12	15.1	89
43	119-135	13.1	0.7	1.4	0.14	15.3	85
44	135-155+	9.4	1.0	1.3	0.14	11.8	80

Table 4.11.4 Saturation extract analysis

Lab. No.	Depth (cm)	Saturation (%)	pH _s	EC _e dSm ⁻¹	Saturation extract analysis (me/l)								SAR
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl	SO ₄	
38	0-13	29	9.1	0.8	5.9	2.0	4.0	0.13	0.0	6.8	4.0	-	3
39	13-25	25	9.6	3.1	22.4	7.0	5.0	0.23	5.6	14.7	11.0	2.0	9
40	25-56	30	9.7	4.5	36.7	3.0	9.0	0.08	16.8	19.6	10.0	-	15
41	56-89	34	9.8	4.6	42.2	4.0	6.0	0.28	22.4	12.6	12.0	-	19
42	89-119	38	9.6	2.9	22.6	7.0	5.0	0.05	5.6	9.1	8.0	10.0	8
43	119-135	39	9.7	4.1	35.5	8.0	4.0	0.08	11.2	13.3	14.0	12.0	15
44	135-155+	40	9.5	3.6	28.8	1.0	5.0	0.05	11.2	5.6	11.0	11.0	16

Table 4.11.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
38	0-13	86.7	5.40	1.30	0.2	1.00	2.05	0.64	0.00	0.025	0.88
39	13-25	86.9	5.50	1.39	0.2	1.08	2.13	0.65	0.00	0.035	1.02
40	25-56	84.0	5.44	3.22	0.2	1.50	2.04	0.68	0.30	0.019	0.88
41	56-89	84.7	5.20	3.31	0.3	1.08	1.96	0.64	0.00	0.018	1.50
42	89-119	83.2	5.38	4.08	0.4	1.50	2.05	0.64	0.00	0.359	2.36
43	119-135	81.1	5.44	4.86	0.2	1.67	1.98	0.74	0.00	0.190	2.79
44	135-155+	80.8	5.78	2.74	0.8	1.92	2.12	0.77	0.06	0.018	2.13

Table 4.11.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
38	0-13	78.1	9.1	2.94	0.0	1.75	2.22	1.88	0.03	0.026	1.82
39	13-25	77.8	9.0	3.40	0.0	2.51	2.18	2.04	0.02	0.015	1.86
40	25-56	74.5	12.4	2.95	0.0	2.25	1.89	2.04	0.06	0.037	2.17
41	56-89	74.1	13.1	3.33	0.0	2.17	1.78	2.24	0.05	0.035	1.89
42	89-119	75.9	12.5	2.86	0.0	1.92	1.91	1.99	0.05	0.021	2.94
43	119-135	75.1	11.2	3.52	0.0	3.34	2.30	2.15	0.04	0.030	2.51
44	135-155+	75.2	11.6	3.69	0.1	2.59	1.90	2.07	0.06	0.040	2.87

Table 4.11.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		ZnO	MnO
38	0-13	49.5	22.9	8.49	0.3	3.04	0.19	1.56	0.24	0.032	0.039	10.87
39	13-25	48.6	23.8	8.56	0.0	2.35	0.15	1.38	0.19	0.040	0.059	12.04
40	20-56	50.9	22.5	8.08	0.1	3.01	0.16	1.44	0.19	0.044	0.045	10.81
41	56-89	49.2	23.1	8.00	0.2	2.74	0.20	1.41	0.15	0.032	0.053	8.37
42	89-119	49.1	23.4	7.55	0.2	3.94	0.20	1.39	0.17	0.017	0.062	9.84
43	119-135	52.9	22.2	7.56	0.4	2.84	0.21	1.39	0.17	0.032	0.081	9.67
44	135-155+	51.8	23.9	7.38	0.0	0.66	0.19	1.35	0.15	0.031	0.041	10.46

Table 4.11.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
38	0-13	78.1	8.8	2.83	0.1	1.22	0.93	0.70	0.08	0.062	1.56
39	13-25	78.0	9.1	3.19	0.1	1.39	0.97	0.74	0.08	0.058	1.56
40	25-56	74.4	10.9	3.94	0.1	1.60	0.87	0.77	0.04	0.048	2.99
41	56-89	73.0	11.8	4.04	0.0	1.34	0.89	0.79	0.03	0.035	3.42
42	89-119	72.2	11.6	4.30	0.0	1.94	0.87	0.74	0.03	0.103	5.67
43	119-135	73.9	11.2	4.36	0.3	1.55	0.83	0.79	0.07	0.085	3.46
44	135-155+	76.2	10.0	4.19	0.3	1.74	0.85	0.78	0.07	0.061	3.01

Table 4.11.9 Elemental composition of lime concretions

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
43	119-135	36.6	1.7	2.72	23.84	1.22	0.54	0.41	0.11	0.47	3.94
44	135-155	37.0	1.7	1.94	22.96	2.04	0.48	0.48	0.09	0.10	4.57

Table 4.11.10 Elemental composition of ferro-magnesian grains

Lab. No.	Depth (cm)	Elemental composition (%)											Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	ZnO	CuO	MnO	
42	89-119	72.9	3.1	8.82	0.74	1.37	0.85	0.71	0.147	0.014	0.019	2.775	8.44

Pedon No. 12 CSSRI-RECLAIMED ALKALI (20 yr)

Classification: Typic Ustochrept, coarse loamy, mixed, hyperthermic

Location: 76° 57' 13"E, 29° 42' 8"N, south-west of CSSRI farm, Karnal

Physiography: Upper alluvial plain

Topography: Level to gently sloping

Drainage: Poorly drained

Landuse: Cultivated

Elevation 245 m

Rainfall: 711 mm

Table 4.12.1 Morphology

Lab.Depth No. (cm)	Horizon Boundary	Colour (moist)	Mottling	Texture (USDA)	Structure	Consistence (wet)	Cutans	Roots	Coarse fragments	Reaction
45 0-20	Ap	cw								
46 20-41	B21	gw			1 2m, sbk	ws, wp	-	f, f	-	3
47 41-73	B22	gw			1 2m, sbk	ws, wp	p, tn	f, f	conir, m	3
48 73-100	BC	gw	7.5YR 5/8 f, fn, ft		1 2m, sbk	ws, wp	-	-	conir, m	3
49 100-148+	C	gw			sl 2m, sbk	wss, wsp	-	-	conca, c	4
					sl massive	wss, wsp	-	-	conca, c	5

Table 4.12.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)			Coarse fragments (%)	Water content (%)		
		Sand (2 - 0.05)	Silt (0.05 - 0.002)	Clay (< 0.002)		1/3 bar	15 bar	Available
45	0-20	42.0	49.1	8.9	-	24.4	8.4	16.0
46	20-41	35.5	45.5	19.0	3	23.5	11.0	12.5
47	41-73	38.8	39.9	21.3	13	25.1	15.9	9.2
48	73-100	44.1	48.4	7.5	32	25.4	9.3	16.1
49	100-148	59.6	30.4	10.0	26	23.5	6.4	17.1

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)			
								Fe	Mn	Cu	Zn
45	0-20	0.31	3.16	8.7	0.38	1.75	0.746	11.8	7.2	1.14	1.72
46	20-41	0.05	2.61	8.9	0.46	1.63	0.788	4.4	4.8	0.72	0.30
47	41-73	0.02	1.87	9.3	0.57	1.89	0.032	4.4	2.5	0.36	0.32
48	73-100	0.03	6.74	9.3	0.37	1.88	0.663	3.6	1.9	0.08	0.36
49	100-148+	0.05	9.75	9.3	0.39	1.58	1.198	1.8	1.2	0.14	0.22

Table 4.12.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)				CEC	ESP
		Na	Mg	Ca	K		
		(c mol kg ⁻¹)					
45	0-20	0.9	1.4	4.5	0.25	7.3	12
46	20-41	1.6	4.2	8.6	0.28	14.7	10
47	41-73	2.6	3.3	8.0	0.18	14.1	18
48	73-100	0.5	1.5	2.2	0.14	4.3	11
49	100-148+	0.7	1.3	3.3	0.28	5.8	12

Table 4.12.4 Saturation extract analysis

Lab. No.	Depth (cm)	Saturation (%)	pH _s	EC _e dSm ⁻¹	Saturation extract analysis (me/l)							SAR	
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl		SO ₄
45	0-20	37	8.4	1.5	3.1	9.0	4.0	0.14	1.4	9.5	4.0	1.0	1.2
46	20-41	39	8.2	1.3	2.1	4.0	6.0	0.03	0.0	3.5	4.0	6.0	0.9
47	41-73	39	8.7	1.5	7.3	6.0	3.0	0.03	2.8	6.3	3.0	3.0	3.4
48	73-100	38	8.6	0.9	3.1	4.0	3.0	0.08	0.0	3.5	4.0	1.0	1.7
49	100-148+	37	8.7	1.2	3.1	8.0	2.0	0.04	0.0	4.2	3.0	6.0	1.4

Table 4.12.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O		P ₂ O ₅	MnO
45	0-20	85.0	5.41	1.73	0.0	1.42	2.15	0.70	1.03	0.019	1.80
46	20-41	83.4	5.30	1.79	0.4	1.67	2.11	0.68	0.70	0.020	1.93
47	41-73	83.2	5.28	3.53	0.0	1.67	2.00	0.74	0.02	0.018	1.89
48	73-100	81.1	5.59	3.43	0.6	3.17	2.06	0.88	0.05	0.028	2.02
49	100-148+	81.4	5.82	3.58	0.5	2.75	2.08	0.83	0.01	0.059	1.90

Table 4.12.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
45	0-20	72.5	12.6	3.42	0.1	2.76	2.28	2.04	0.03	0.015	2.93
46	20-41	71.2	13.1	3.53	0.0	2.09	2.47	1.92	0.01	0.020	3.66
47	41-73	71.2	13.7	4.15	0.1	2.69	2.05	1.93	0.12	0.057	3.10
48	73-100	72.7	12.5	3.99	0.1	2.86	2.12	1.98	0.08	0.034	3.21
49	100-148+	72.1	12.2	3.96	0.1	2.96	2.13	1.99	0.12	0.044	4.11

Table 4.12.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)										Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	ZnO	MnO	
45	0-20	52.3	22.2	7.77	0.0	3.11	0.23	1.58	0.22	0.029	0.045	7.23
46	20-41	50.3	23.1	7.66	0.0	3.44	0.23	1.58	0.16	0.034	0.075	8.78
47	41-73	51.8	22.9	7.12	0.0	3.61	0.21	1.45	0.19	0.030	0.061	9.69
48	73-100	49.2	23.4	6.47	0.0	3.49	0.18	1.42	0.16	0.030	0.063	10.97
49	100-148+	50.1	23.1	6.52	0.0	4.33	0.21	1.45	0.19	0.040	0.057	11.17

Table 4.12.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
45	0-20	74.7	10.7	3.33	0.5	1.55	0.92	0.70	0.18	0.056	3.42
46	20-41	71.8	12.2	3.82	0.1	1.94	0.85	9.79	0.05	0.086	2.62
47	41-73	71.7	12.2	4.50	0.1	1.97	0.80	0.76	0.05	0.176	3.68
48	73-100	73.2	10.4	4.36	0.4	2.42	0.89	0.79	0.03	0.059	4.81
49	100-148+	72.4	9.5	4.06	1.5	2.30	0.96	0.80	0.10	0.068	6.41

Table 4.12.9 Elemental composition of lime concretions

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	
48	73-100	40.9	1.5	2.27	22.27	2.20	0.41	0.51	5.11
49	100-148	41.3	1.6	2.30	22.04	1.77	0.45	0.53	4.10

Table 4.12.10 Elemental composition of ferro-magnesian grains

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	
P12	0-148	3.3	5.71	0.11	3.61	0.59	0.63	0.110	8.31

Table 4.12.11 Semi quantitative estimates of sand and silt minerals

Lab.No.	Depth (cm)	Chlorite	Mixed layer	Mica	Amphibole	Chlorite + Kaolinite	Quartz	Orthoclases	Plagioclases	Calcite
Sand										
45	0-20	++	++	+++	++	++	+++++	+++	++++	++
47	41-73	++	+	+++	++	++	+++++	++++	+++	++
49	100-148	++	++	++++	-	++	+++++	+++	++++	++
Silt										
45	0-20	++	++	++++	++	+++	+++++	+++	++++	-
47	41-73	+++	++	++++	++	+++	+++++	+++	++++	-
49	100-148	+++	++	++++	-	+++	++++	++	++++	++

4.12.12 Semi quantitative estimates of clay minerals

Lab. No.	Depth (cm)	Smectite	Chlorite	Vermiculite	Illite	Mixed layer	Kaolinite	Quartz	Feldspar	Amphibole
%										
45	0-20	8	10	4	58	9	8	tr.	2	1
47	41-73	11	9	4	57	8	8	tr.	2	1
49	100-148	16	10	4	52	8	7	tr.	2	1

Pedon No. 13 CSSRI-NORMAL

Classification: Udic Ustochrept, fine loamy, mixed, hyperthermic

Location: 76° 57'13"E, 29° 42' 8"N, north-west of CSSRI farm, Karnal

Physiography: Upper alluvial plain

Topography: Level to gently sloping

Drainage: Well drained

Landuse: Cultivated grasses

Elevation 245 m

Rainfall: 711 mm

Table 4.13.1 Morphology

Lab.Depth	Horizon	Boundary	Colour (moist)	Mottling	Texture (USDA)	Structure	Consistence (wet)	Cutans	Roots	Coarse fragments	Reaction
57	0-16	Ap	cs	10YR 5/2	-	1	1m,sbk	ws,wp	-	f,vf-f	0
58	16-37	B1	gs	10YR 4/3	-	1	1m,sbk	ws,wp	p,tn	f,f	0
59	37-66	B21	gs	10YR 4/4	-	1	2m,sbk	ws,wp	p,tn	-	0
60	66-99	B22	gs	10YR 4/4	-	1	2m,sbk	ws,wp	p,tn	-	0
61	99-125	B3	ds	10YR 5/4	-	1	2m,sbk	ws,wp	p,tn	-	0
62	125-160+	Bc		10YR 5/4	-	1	1m,sbk	ws,wp	p,tn	conir,m	0
									-	-	0

*flood cutans

Table 4.13.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)				Coarse fragments (%)	Water content (%)		
		Sand (2 - 0.05)	Silt (0.05 - 0.002)	Clay (< 0.002)	1/3 bar		15 bar	Available	
									-----% of < 2 mm-----
57	0-16	46.6	43.6	15.8	-	24.6	9.7	14.9	
58	16-37	34.7	45.2	20.1	-	25.5	12.2	13.3	
59	37-66	38.4	39.8	21.8	-	25.0	13.4	11.6	
60	66-99	36.1	40.0	23.9	-	24.4	13.3	11.1	
61	99-125	36.2	39.2	22.6	<1	25.3	13.6	11.7	
62	125-160+	43.4	37.2	19.4	-	28.7	10.5	18.2	

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)			
								Fe	Mn	Cu	Zn
57	0-16	0.52	0.0	8.6	0.82	1.75	0.724	10.8	7.7	0.94	0.92
58	16-37	0.28	0.0	8.6	0.48	1.69	0.480	8.4	11.8	0.98	0.18
59	37-66	0.24	0.0	8.5	0.38	1.75	0.456	7.6	12.1	0.66	0.14
60	66-99	0.18	0.0	8.5	0.37	1.79	0.412	7.6	11.4	0.66	0.14
61	99-125	0.14	0.0	8.4	0.35	1.84	0.546	5.6	8.8	0.56	0.40
62	125-160+	0.10	0.0	8.3	0.86	1.78	0.921	5.4	9.6	0.56	0.08

Table 4.13.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)					CEC (c mol kg ⁻¹)	ESP
		Na	Mg	Ca	K			
57	0-16	1.0	2.7	7.1	0.35		11.2	9
58	16-37	1.0	2.7	9.5	0.23		30.4	8
59	37-66	1.0	2.7	9.0	0.18		12.8	7
60	66-99	0.8	2.7	9.5	0.15		13.1	6
61	99-125	0.8	3.3	11.0	0.15		15.3	5
62	125-160+	0.8	3.4	13.0	0.15		17.4	5

Table 4.13.4 Saturation extract analysis

Lab. No.	Depth (cm)	Saturation (%)	pH _s	EC _e dSm ⁻¹	Saturation extract analysis (me/l)								SAR
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl	SO ₄	
57	0-16	35	8.2	1.5	4.7	8.0	5.0	0.17	0.0	6.8	8.4	2.0	2
58	16-37	40	8.2	1.5	5.1	8.0	3.0	0.11	0.0	7.0	8.0	2.0	2
59	37-66	35	7.6	1.2	3.0	6.0	2.0	0.04	0.0	4.2	6.0	2.0	2
60	66-99	39	7.6	1.3	4.2	7.0	2.0	0.04	0.0	4.2	5.0	4.0	2
61	99-125	42	7.6	0.9	3.0	3.0	2.0	0.03	0.0	4.9	5.0	1.0	2
62	125-160+	40	7.6	1.1	3.3	4.0	3.0	0.03	0.0	4.9	4.0	0.0	2

Table 4.13.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
57	0-16	87.6	4.74	1.25	0.0	0.83	2.04	0.67	0.07	0.010	0.84
58	16-37	86.8	4.82	1.30	0.0	0.40	2.05	0.64	0.07	0.014	0.65
59	37-66	88.6	4.84	1.32	0.0	0.92	2.02	0.64	0.04	0.020	0.66
60	66-99	86.5	4.94	1.76	0.0	1.33	2.01	0.68	0.04	0.039	1.05
61	99-125	84.9	5.24	2.30	0.0	2.25	2.06	0.88	0.06	0.005	0.42
62	125-160+	84.4	5.54	2.59	0.0	1.75	2.28	0.80	0.13	0.005	0.59

Table 4.13.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
57	0-16	72.9	13.5	3.28	0.0	2.34	1.80	2.05	0.01	0.062	2.14
58	16-37	73.1	13.8	3.12	0.0	2.09	1.81	1.94	0.01	0.035	2.74
59	37-66	74.7	13.6	3.08	0.0	1.59	1.91	1.86	tr.	0.044	2.14
60	66-99	74.2	14.1	3.42	0.0	1.75	2.28	2.11	0.03	0.044	1.62
61	99-125	73.3	13.9	3.49	0.0	1.92	1.24	2.21	0.04	0.050	2.12
62	125-160+	70.8	13.1	4.03	0.0	2.17	1.54	2.20	0.03	0.068	2.32

Table 4.13.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)										Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	ZnO	MnO	
57	0-16	52.1	22.1	8.68	0.2	3.59	0.15	1.58	0.09	0.049	0.041	11.97
58	16-37	51.6	22.5	7.92	0.0	2.92	0.15	1.60	0.03	0.030	0.053	9.48
59	37-66	51.5	22.8	7.61	0.0	2.69	0.10	1.51	0.03	0.046	0.034	9.58
60	66-99	51.9	23.1	7.35	0.0	2.89	0.12	1.36	0.04	0.042	0.072	11.52
61	99-125	52.7	22.7	6.77	0.1	2.61	0.17	1.36	0.05	0.026	0.053	9.94
62	125-160+	51.7	22.5	7.08	0.1	2.84	0.15	1.38	0.24	0.027	0.107	9.72

Table 4.13.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O		P ₂ O ₅	MnO
57	0-16	74.6	11.5	3.22	0.1	1.27	0.89	0.76	0.08	0.056	3.58
58	16-37	72.8	12.4	3.49	0.0	1.09	0.97	0.78	0.08	0.094	3.16
59	37-66	77.9	12.2	3.80	0.0	1.37	0.87	0.80	0.04	0.099	3.89
60	66-99	72.2	12.6	3.89	0.1	1.15	0.75	0.75	0.04	0.074	5.88
61	99-125	70.9	12.2	4.20	0.0	1.37	0.70	0.76	0.04	0.145	4.78
62	125-160+	73.9	11.6	3.95	0.1	1.67	0.78	0.75	0.03	0.077	12.08

Table 4.13.9 Elemental composition of ferro-magnesian grains

.13.9 Elemental composition of ferro-magnesian grains													
Lab. No.	Depth (cm)	Elemental composition (%)											Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	ZnO	CuO	MnO	
P-13	99-125	74.1	2.9	9.24	tr.	1.50	0.45	0.76	0.17	0.019	0.029	3.09	8.82
	0-160	73.0	3.2	8.48	0.15	1.95	0.56	0.75	0.12	0.022	tr.	3.52	8.02

Table 4.13.10 Semi quantitative estimates of sand and silt minerals

Lab.No.	Depth (cm)	Semi quantitative estimates of sand and silt minerals										Calcite
		Chlorite	Mixed layer	Mica	Amphibole	Chlorite + Kaolinite	Quartz	Orthoclases	Plagioclases			
57												
60	0-16	-	-	++++	-	Sand	++++	+++	++++	-		
62	66-99	-	++	++++	-	+	++++	++	++++	-		
	125-160	++	+	++++	-	++	++++	+++	+++	-		
60	0-16	-	-	++++	-	Silt	++++	+++	++++	-		
62	66-99	-	++	++++	-	++	++++	++	++++	-		
	125-160	-	+	++++	++	++	++++	+++	++++	-		

4.13.11 Semi quantitative estimates of clay minerals

Lab. No.	Depth (cm)	Semi quantitative estimates of clay minerals										Amphibole
		Smectite	Chlorite	Vermiculite	Illite	Mixed layer	Kaolinite	Quartz	Feldspar			
57												
60	0-16	7	5	2	64	11	8	tr.	1			2
62	66-99	8	4	3	66	10	6	1	1			1
	125-160	11	4	3	62	11	7	tr.	1			1

Pedon No. 14 Gudda-ALKALI

Classification: Typic Ustochrept, fine loamy, mixed, hyperthermic

Location: 76° 56'45"E, 29° 30' 8"N, CSSRI experimental farm, village Gudda, Karnal to Panipat road

Physiography: Upper alluvial plain

Topography: Micro depression, 1-2 per cent slope

Drainage: Imperfectly drained

Landuse: Cultivated

Elevation 237 m

Rainfall: 711 mm

Table 4.14.1 Morphology

Lab. Depth	Horizon	Boundary	Colour (moist)	Mottling	Texture Structure (USDA)	Consistence (wet)	Cutans	Roots	Coarse	Reaction fragments
91	0-20	Ap	gw	10YR 5/4	-	ws,wp	-	f,vf	-	3
92	20-69	B1	gw	10YR 4/3	-	ws,wp	-	-	conca,m-c	4
93	69-124	B2	gw	10YR 4/3	-	ws,wp	p,tn	-	conir,f-m	2
94	124-160+	BC	10YR 4/3	10YR 5/8 c-m,fn,ft	sil	ws,wp	-	-	-	2

Table 4.14.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)			Coarse fragments (%)	Water content (%)		
		Sand (2 - 0.05)	Silt (0.05 - 0.002)	Clay (< 0.002)		1/3 bar	15 bar	Available
-----% of < 2 mm -----								
91	0-20	35.9	52.1	12.0	2	25.1	8.5	16.6
92	20-69	19.6	52.0	28.4	5	28.2	19.6	8.6
93	69-124	20.7	48.5	30.8	7	32.2	24.4	7.8
94	124-160+	14.4	57.0	26.6	2	32.7	25.7	7.0

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)		
								Fe	Mn	Zn
91	0-20	0.16	1.23	10.7	4.75	1.56	0.015	9.4	3.3	1.12
92	20-69	0.15	3.05	10.7	5.20	1.71	-	12.0	2.0	1.04
93	69-124	0.07	0.70	10.4	2.37	1.73	-	7.4	2.3	0.82
94	124-160+	0.10	0.37	10.3	2.46	1.67	-	5.2	2.2	0.52

Table 4.14.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)				CEC	ESP
		Na	Mg	Ca	K		
		(c mol kg ⁻¹)					
91	0-20	9.1	2.1	0.5	0.23	9.9	92
92	20-69	14.2	0.1	0.7	0.20	15.2	93
93	69-124	14.8	0.2	0.9	0.15	16.0	92
94	124-160+	11.5	0.7	1.2	0.12	13.6	85

Table 4.14.4 Saturation extract analysis

Lab. No.	Depth (cm)	Saturation (%)	pH _s	EC _e dSm ⁻¹	Saturation extract analysis (me/l)								SAR
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl	SO ₄	
91	0-20	32	10.2	16.8	224	4.0	5.0	0.12	119	31.5	55	33	105
92	20-69	38	10.2	14.9	190	3.0	3.0	0.11	109	22.4	21	35	109
93	69-124	49	9.7	5.3	47	5.0	1.0	0.11	11	18.2	13	16	27
94	124-169+	43	9.3	3.9	40	4.0	2.0	0.04	9	14.0	10	11	23

Table 4.14.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
91	0-20	84.2	5.37	1.59	0.0	1.92	2.19	0.71	0.04	0.009	1.17
92	20-69	82.8	5.22	2.46	0.7	2.34	2.15	0.64	0.05	0.014	3.37
93	69-124	83.1	5.42	2.49	0.0	1.59	2.19	0.68	0.02	0.010	1.88
94	124-160+	82.2	5.85	3.33	0.0	2.17	2.11	0.97	0.03	0.030	1.39

Table 4.14.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
91	0-20	72.2	14.7	2.69	0.0	2.17	1.27	1.74	0.09	0.065	2.25
92	20-69	72.3	13.8	4.34	0.1	2.42	1.37	2.18	0.06	0.056	2.31
93	69-124	72.1	14.1	3.95	0.0	2.59	1.56	1.90	0.06	0.061	2.31
94	124-160+	72.8	14.7	4.16	0.0	2.25	1.45	1.76	0.07	0.051	2.43

Table 4.14.7 Elemental composition of clay fraction

Lab. No. Depth (cm)	Elemental composition (%)										Loss on ignition (%)
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	ZnO	MnO	
91	52.4	20.2	8.48	0.4	3.32	0.36	1.65	0.07	0.024	0.085	8.87
92	52.1	22.9	8.18	0.2	3.49	0.26	1.52	0.04	0.017	0.085	9.76
93	51.4	21.7	7.40	0.2	4.24	0.26	1.41	0.02	0.019	0.076	9.09
94	50.2	22.2	7.15	0.2	4.19	0.29	1.43	0.01	0.034	0.085	9.05

Table 4.14.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
91	0-20	73.8	11.9	3.35	0.2	1.60	0.90	0.76	0.12	0.058	3.43
92	20-69	68.6	14.5	4.23	0.2	2.81	0.75	0.88	0.10	0.080	5.22
93	69-124	68.1	14.5	4.50	0.0	3.94	0.69	0.86	0.11	0.076	4.58
94	124-160+	68.6	14.6	4.58	0.0	2.44	0.71	0.87	0.13	0.068	4.17

Table 4.14.9 Elemental composition of lime concretions

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
92	20-69	28.8	1.9	2.46	21.84	2.71	0.66	0.52	0.126	0.217	6.44
93	69-124	31.7	1.8	4.49	19.49	2.79	0.54	0.53	0.128	0.299	8.64
94	124-160+	32.1	1.9	2.87	22.36	3.12	0.53	0.57	0.105	0.287	6.63

Pedon No. 15 GUDDA-RECLAIMED ALKALI (10 yr)

Classification: Typic Ustochrept, coarse loamy, mixed, hyperthermic

Location: 76° 56'45"E, 29° 30' 8"N, village Gudda, CSSRI experimental farm, Karnal to Panipat Road

Physiography: Upper alluvial plain

Topography: Micro depression, 1-2 per cent slope

Drainage: Moderately well drained

Landuse: Cultivated

Elevation 237 m

Rainfall: 711 mm

Table 4.15.1 Morphology

Lab. No.	Depth (cm)	Horizon	Boundary	Colour (moist)	Mottling	Texture (USDA)	Structure	Consistence (wet)	Cutans	Roots	Coarse fragments	Reaction
84	0-16	Ap	cw	2.5Y 4/2	-	1	1m, sbk	wss, wsp	-	m, vf-f	-	3
85	16-28	B1	cw	10YR 5/4	-	1	1f, pl	wss, wsp	-	m, f	-	3
86	28-50	B21	gw	10YR 4/4	-	1	2m, sbk	ws, wp	p, tn	f, f-m	-	2
87	50-77	B22	gw	10YR 4/3	-	1	2m, sbk	ws, wp	p, tn	f, m-c	-	2
88	77-97	B23	gw	10YR 4/3	-	1	2m, sbk	ws, wp	-	f, f	conir, f-m	3
89	97-133	B3	gw	10YR 4/3	-	1	2m, sbk	ws, wp	-	-	conca, m-c	4
90	133-148+	C		10YR 4/3	-	sil	massive	ws, wp	-	-	conca, m-c	4

Table 4.15.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)			Coarse fragments (%)	Water content (%)		
		Sand (2 - 0.05)	Silt (0.05 - 0.002)	Clay (< 0.002)		1/3 bar	15 bar	Available
84	0-16	47.8	44.8	7.5	-	23.3	7.5	15.8
85	16-28	37.7	47.5	14.8	-	24.7	11.9	12.8
86	28-50	35.1	46.3	18.6	-	24.8	16.8	8.0
87	50-77	33.5	49.3	17.2	-	26.3	21.7	4.6
88	77-97	36.4	45.2	18.4	3	27.5	18.4	9.1
89	97-133	33.9	48.1	18.0	5	25.4	19.3	6.1
90	133-148+	30.4	52.3	17.3	16	26.8	16.8	10.0

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)			
								Fe	Mn	Cu	Zn
84	0-16	0.50	1.17	9.2	0.50	1.63	0.429	7.6	3.7	1.42	1.46
85	16-28	0.15	0.41	9.7	0.70	1.63	-	3.0	3.2	0.92	0.20
86	28-50	0.09	0.33	10.0	1.20	1.71	-	3.6	3.0	0.78	0.26
87	50-77	0.07	0.37	10.1	1.39	1.66	-	4.8	4.0	0.62	0.22
88	77-97	0.10	0.33	10.2	1.56	1.71	-	3.4	4.2	0.70	0.26
89	97-133	0.07	2.05	10.1	1.81	1.70	-	3.2	3.0	0.72	0.24
90	133-148+	0.07	3.67	10.0	1.35	1.76	0.001	3.2	3.7	0.88	0.34

Table 4.15.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)				CEC (c mol kg ⁻¹)	ESP
		Na	Mg	Ca	K		
84	0-16	0.7	1.3	1.7	0.22	3.9	18
85	16-28	2.1	2.3	2.5	0.17	5.4	39
86	28-50	4.0	0.6	2.4	0.14	7.1	56
87	50-77	5.0	0.5	1.8	0.12	7.4	67
88	77-97	5.5	0.4	1.8	0.12	7.8	70
89	97-133	5.0	0.6	2.5	0.12	8.2	61
90	133-148+	4.0	0.6	2.3	0.12	7.0	57

Table 4.15.4 Saturation extract analysis

Lab. No.	Depth (cm)	Saturation (%)	pH _s	EC _e dSm ⁻¹	Saturation extract analysis (me/l)								SAR
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl	SO ₄	
84	0-16	35	8.3	1.5	8.1	4.0	4.0	0.14	0.0	9.8	4.0	2.0	4
85	16-28	27	8.5	2.2	10.4	2.1	10.2	0.04	0.0	7.1	5.2	10.3	4
86	28-50	26	8.5	2.4	13.1	9.2	4.1	0.09	0.0	8.0	6.3	9.2	5
87	50-77	27	8.9	2.4	13.3	10.1	4.2	0.05	1.4	8.1	5.3	10.1	5
88	77-97	29	8.8	2.7	17.2	12.1	2.3	0.04	2.8	9.8	9.4	8.4	6
89	97-133	31	8.9	3.0	16.5	8.4	10.6	0.05	5.6	9.9	9.5	10.7	6
90	133-148+	34	8.7	2.2	12.4	9.2	2.4	0.04	1.4	9.1	8.5	7.2	5

Table 4.15.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	MnO	
84	0-16	85.5	5.03	1.58	0.1	1.59	2.17	0.64	0.07	0.009	1.21
85	16-28	86.4	5.24	1.42	0.0	1.17	2.17	0.69	0.07	0.005	0.27
86	28-50	86.6	5.54	1.53	0.0	1.67	2.17	0.76	0.07	0.003	1.03
87	50-77	85.8	5.45	1.33	0.1	1.34	2.09	0.75	0.06	0.005	0.70
88	77-97	84.9	5.53	1.51	0.4	1.50	2.15	0.76	0.06	0.007	0.65
89	97-133	83.9	5.39	2.15	0.4	1.84	2.04	0.77	0.04	0.006	1.37
90	133-148+	81.8	5.78	2.89	0.0	2.00	2.00	0.99	0.05	0.007	2.53

Table 4.15.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O		P ₂ O ₅	MnO
84	0-16	71.7	13.5	3.30	0.0	2.09	1.69	1.70	0.23	0.101	3.27
85	16-28	71.0	12.3	3.33	0.0	2.09	1.56	1.74	0.06	0.065	2.95
86	28-50	73.5	12.7	3.29	0.0	1.92	1.70	1.69	0.07	0.063	2.44
87	50-77	73.1	12.9	3.50	0.0	2.17	1.70	2.28	0.05	0.086	1.64
88	77-97	73.5	12.1	3.26	0.0	2.25	1.60	2.08	0.03	0.048	1.95
89	97-133	73.9	13.6	3.80	0.0	2.67	1.21	1.95	0.05	0.080	2.53
90	133-148+	73.1	12.3	4.03	0.0	2.76	1.72	2.01	0.07	0.093	2.86

Table 4.15.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	
84	0-16	50.9	22.1	8.14	0.4	3.32	0.26	1.64	0.037
85	16-28	51.7	22.6	8.28	0.4	3.92	0.29	1.66	0.034
86	28-50	51.4	21.5	8.17	0.5	3.21	0.26	1.59	0.029
87	50-77	52.8	20.4	8.05	0.4	4.81	0.22	1.58	0.027
88	77-97	52.0	20.2	7.61	0.8	3.97	0.26	1.50	0.029
89	97-133	52.1	20.2	7.50	0.5	3.57	0.29	1.47	0.030
90	133-148+	52.8	20.9	6.36	0.4	4.71	0.26	1.50	0.020
									0.019
									0.000
									0.025
									0.028
									0.021
									0.036
									0.040

Table 4.15.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	
84	0-16	77.4	9.8	2.76	0.3	1.54	0.96	0.65	0.062
85	16-28	74.7	11.1	3.35	0.2	1.19	0.87	0.74	0.062
86	28-50	73.5	11.6	3.55	0.0	1.90	0.88	0.75	0.090
87	50-77	73.7	11.6	3.63	0.1	1.75	0.84	0.76	0.105
88	77-97	73.7	11.5	3.99	0.1	1.54	0.83	0.76	0.103
89	97-133	73.5	11.6	4.02	0.3	1.97	0.81	0.75	0.083
90	133-148+	74.2	12.0	4.06	0.6	2.71	0.82	0.77	0.074
									0.14
									0.12
									0.11
									0.09
									0.09
									0.09
									0.11

Table 4.15.9 Elemental composition of lime concretions

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	
90	133-148+	30.3	1.9	2.07	27.79	2.02	0.45	0.44	4.66
								0.143	
								0.085	

Table 4.15.10 Elemental composition of ferro-magnesian grains

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	
88	77-97	71.8	3.7	8.62	0.31	2.14	0.74	0.83	8.27
								0.151	
								0.044	
								0.019	
								2.89	

Pedon No. 16 SAMDHAN-ALKALI

Classification: Typic Ustochrept, coarse loamy, mixed, hyperthermic

Location: 76° 12'13"E, 29° 11' 3"N, village Samdhan; 0.5 km east of Urlana, district Kaithal

Physiography: Upper alluvial plain

Topography: Micro-depression, 1-2 per cent slope

Drainage: Poorly drained

Landuse: Cultivated

Elevation 228 m

Rainfall: 700 mm

Table 4.16.1 Morphology

Lab.Depth No. (cm)	Horizon	Boundary	Colour (moist)	Mottling	Texture (USDA)	Structure	Consistence (wet)	Cutans	Roots	Coarse fragments	Reaction
95	0-14	Ap	cw								
			10YR 4/4	-	s1	2m,sbk	wso,wpo	-	f,vf	-	3
96	14-68	B21	gw								
			10YR 4/4	-	s1	3c,sbk	wss,wsp	-	-	conca,f	4
97	68-140+	B22									
			10YR 4/4	-	s1	3c,sbk	wss,wsp	-	-	-	3

Table 4.16.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)			Coarse fragments (%)	Water content (%)		
		Sand (2 - 0.05)	Silt (0.05 - 0.002)	Clay (< 0.002)		1/3 bar	15 bar	Available
95	0-14	56.0	39.3	4.7	-	16.4	6.6	9.8
96	14-68	52.1	38.4	9.5	-	17.1	9.8	7.3
97	68-140+	53.4	32.0	14.6	-	23.9	10.4	13.5

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)			
								Fe	Mn	Cu	Zn
95	0-14	0.18	2.12	10.2	1.17	1.80	-	4.0	4.8	0.60	0.12
96	14-68	0.06	1.19	10.8	3.97	1.71	0.009	12.0	3.5	1.24	0.28
97	68-140+	0.03	1.37	10.7	4.19	1.73	0.008	5.0	4.0	0.78	0.36

Table 4.16.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)				CEC (c mol kg ⁻¹)	ESP
		Na	Mg	Ca	K		
95	0-14	3.1	0.3	0.6	0.15	4.2	74
96	14-68	7.0	0.1	0.8	0.10	8.1	86
97	68-140+	11.4	0.1	0.9	0.15	12.5	90

Table 4.16.4 Saturation extract analysis

Lab. No.	Depth (cm)	Saturation%	pH _s	EC _e dSm ⁻¹	Saturation extract analysis (me/l)								SAR
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl	SO ₄	
95	0-14	24	9.2	2.9	32.6	0.4	0.5	0.13	0.0	18.2	11.0	2.0	48
96	14-68	31	9.8	12.6	141.3	2.0	3.0	0.08	121.6	8.4	21.1	0.0	89
97	68-140+	25	9.9	13.1	154.0	4.0	3.0	0.06	96.2	9.8	16.0	34.0	97

Table 4.16.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O		P ₂ O ₅	MnO
95	0-14	82.4	4.72	1.09	0.5	4.43	2.11	0.53	0.03	0.005	1.14
96	14-68	83.9	5.21	1.48	0.1	2.51	2.28	0.53	0.06	0.009	0.98
97	68-140+	84.2	5.62	1.89	0.4	1.50	2.30	0.69	0.04	0.005	1.02

Table 4.16.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O		P ₂ O ₅	MnO
95	0-14	74.6	11.3	3.72	0.0	2.09	1.84	1.64	0.11	0.048	3.49
96	14-68	75.2	11.2	3.79	0.0	1.92	2.10	1.61	0.07	0.071	2.46
97	68-140+	73.5	12.7	4.25	0.0	2.09	2.31	1.17	0.07	0.076	2.96

Table 4.16.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	ZnO MnO (%)
95	0-14	54.9	20.1	7.11	0.3	3.57	0.39	1.59	0.22	0.031 0.115 11.39
96	14-68	54.3	19.9	7.85	0.3	3.67	0.29	1.46	0.03	0.034 0.074 11.80
97	68-140+	52.1	22.8	7.24	0.2	2.82	0.27	1.34	0.07	0.031 0.066 10.75

Table 4.16.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	MnO (%)
95	0-14	78.4	8.4	2.77	0.6	1.44	0.17	0.61	0.16	0.067 3.20
96	14-68	77.0	9.1	3.16	0.2	1.09	1.03	0.64	0.14	0.097 3.86
97	68-140+	76.1	9.5	3.63	0.2	1.37	1.04	0.68	0.13	0.130 3.71

Table 4.16.9 Semi quantitative estimates of sand and silt minerals

Lab.No.	Depth (cm)	Chlorite	Mixed layer	Mica	Amphibole	Chlorite + Kaolinite	Quartz	Orthoclases	Plagioclases	Calcite
Sand										
95	0-14	++	++	++++	-	++	++++	++++	++++	+
97	68-140	++	++	++++	-	++	++++	+++	++++	+
Silt										
95	0-14	-	+	++++	-	++	++++	+++	++++	-
97	68-140	-	-	++++	-	++	++++	+++	++++	-

4.16.10 Semi quantitative estimates of clay minerals

Lab. No.	Depth (cm)	Smectite	Chlorite	Vermiculite	Illite	Mixed layer	Kaolinite	Quartz	Feldspar	Amphibole
%										
95	0-14	4	8	2	66	10	7	1	1	1
97	68-140	16	5	1	59	8	7	1	1	1

Pedon No. 17 SANDHAN RECLAIMED ALKALI

Classification: Typic Ustochrept, coarse loamy, mixed, hyperthermic

Location: 76° 12'13"E, 29° 11' 3"N, village Samdhan, 0.5 km east of Urlana, district Kaithal

Physiography: Upper alluvial plain

Topography: Gently slopping, 1-2 per cent slope

Drainage: Moderately well drained

Landuse: Cultivated

Elevation 228 m

Rainfall: 700 mm

Table 4.17.1 Morphology

Lab. Depth	Horizon	Boundary	Colour (moist)	Mottling	Texture (USDA)	Structure	Consistence (wet)	Cutans	Roots	Coarse fragments	Reaction
98	0-15	Ap	cw	10YR 4/3	-	s1	1m, sbk	wso, wpo	-	m, vf-f	- 3
99	15-43	B1	gw	10YR 5/4	-	s1	1m, sbk	wss, wsp	-	c, vf-f	- 2
100	43-75	B21	gw	10YR 5/4	-	1	2m, sbk	wss, wsp	p, tn	f, vf-f	- 2
101	75-116	B22	gw	10YR 4/4	-	1	2c, sbk	ws, wp	p, tn	-	- 3
102	116-140+	BC	10YR 4/4	-	-	1	massive	ws, wp	-	- conca, c	3

Table 4.17.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)				Coarse fragments (%)	Water content (%)		
		Sand (2 - 0.05)	Silt (0.05 - 0.002)	Clay (< 0.002)	% of < 2 mm		1/3 bar	15 bar	Available
98	0-15	69.6	23.6	6.8		-	15.2	7.2	8.0
99	15-43	51.7	36.3	12.0		-	21.3	13.6	7.7
100	43-75	45.1	35.5	19.4		-	23.4	17.1	6.3
101	75-116	44.0	41.5	14.5		2	25.0	16.0	9.0
102	116-140+	36.3	46.2	17.5		2	24.7	19.4	15.3

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)			
								Fe	Mn	Cu	Zn
98	0-15	0.36	2.44	8.8	0.73	1.86	1.354	6.6	5.7	1.20	0.76
99	15-43	0.07	2.26	10.2	1.30	1.83	-	5.0	4.1	1.20	0.44
100	43-75	0.05	0.98	10.3	1.52	1.82	-	4.0	4.7	1.10	0.40
101	75-116	0.05	2.19	10.4	1.41	1.79	-	2.6	5.7	0.84	0.38
102	116-140+	0.05	3.81	10.4	1.38	1.62	-	2.4	4.9	0.50	0.34

Table 4.17.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)				CEC	ESP
		Na	Mg	Ca	K		
(c mol kg ⁻¹)							
98	0-15	1.0	1.5	2.0	0.33	4.8	21
99	15-43	7.8	0.5	2.0	0.18	10.4	75
100	43-75	10.7	0.2	1.4	0.15	12.5	85
101	75-116	9.4	0.2	1.4	0.14	10.9	85
102	116-140+	9.1	0.4	1.5	0.12	11.2	82

Table 4.17.4 Saturation extract analysis

Lab. No.	Depth (cm)	Saturation (%)	pH _s	EC _e dSm ⁻¹	Saturation extract analysis (me/l)							SAR	
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl		SO ₄
98	0-15	32	8.2	2.2	13.3	7.0	5.0	0.23	0.0	5.6	8.0	10.1	5
99	15-43	27	9.0	2.1	15.9	2.1	2.1	0.21	1.4	12.6	8.2	0.0	11
100	43-75	28	8.9	2.5	20.2	3.1	2.2	0.20	2.8	12.6	12.1	0.0	13
101	75-116	35	9.1	2.5	19.6	2.2	5.1	0.14	2.8	12.6	12.1	0.0	11
102	116-140+	24	9.4	2.4	21.8	3.1	2.2	0.06	2.8	12.6	7.0	0.0	13

Table 4.17.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
98	0-15	83.7	5.69	2.15	0.5	1.59	2.33	0.71	0.06	0.015	0.80
99	15-43	84.9	4.99	1.30	0.7	1.42	2.12	0.52	0.04	0.040	1.09
100	43-75	85.8	4.92	1.36	0.5	1.59	2.15	0.51	0.05	0.025	0.77
101	75-116	83.2	4.86	1.64	0.8	4.59	2.08	0.48	0.03	0.031	1.22
102	116-140+	82.5	5.23	2.17	0.9	2.09	2.35	0.64	0.04	0.025	1.67

Table 4.17.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
98	0-15	71.9	13.2	4.12	0.0	2.09	2.19	1.30	0.15	0.065	4.11
99	15-43	70.1	13.9	3.65	0.0	2.17	2.20	1.12	0.08	0.061	2.72
100	43-75	71.8	14.1	3.78	0.0	1.84	1.72	1.26	0.06	0.077	1.67
101	75-116	72.9	14.7	4.24	0.0	2.25	1.61	1.44	0.08	0.102	2.47
102	116-140+	72.7	14.9	4.33	0.0	2.25	1.54	1.56	0.11	0.111	2.60

Table 4.17.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		ZnO	MnO
98	0-15	53.4	21.4	7.37	0.7	2.47	0.31	1.61	0.24	0.037	0.067	10.42
99	15-43	53.1	21.2	7.94	0.4	3.17	0.34	1.54	0.18	0.030	0.086	10.56
100	43-75	51.9	22.4	7.41	0.6	3.92	0.30	1.35	0.10	0.020	0.071	10.46
101	75-116	51.6	23.1	7.20	0.3	3.51	0.30	1.34	0.12	0.034	0.062	9.79
102	116-140+	52.6	22.8	6.94	0.6	3.76	0.31	1.35	0.17	0.055	0.048	10.52

Table 4.17.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	MnO
98	0-15	78.9	10.5	2.59	0.7	1.49	0.96	0.58	0.20	0.105
99	15-43	75.6	10.5	3.03	0.3	1.17	0.96	0.64	0.21	0.098
100	43-75	73.4	11.7	3.66	0.2	2.29	0.91	0.66	0.17	0.080
101	75-116	74.2	11.4	3.72	0.5	1.40	0.89	0.67	0.15	0.074
102	116-140+	72.8	12.3	3.68	0.7	2.37	0.88	0.69	0.16	0.083

Table 4.17.9 Elemental composition of lime concretions

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	MnO
101	75-116	33.6	1.9	1.63	31.00	3.31	0.39	0.34	0.133	0.081
102	116-140	33.1	1.8	1.64	29.80	1.49	0.35	0.35	0.112	0.088

Table 4.17.10 Semi-quantitative estimates of sand and silt minerals

Lab.No.	Depth (cm)	Chlorite + Kaolinite							Calcite
		Mixed layer	Mica	Amphibole	Chlorite	Quartz	Orthoclases	Plagioclases	
98	0-15	+	++	+	++	++++	+++	+++++	++
101	75-116	++	+++	++	++	+++++	+++++	++++	++
98	0-15	++	++++	++	++	+++++	++	++++	++
101	75-116	+	++++	++	+++	+++++	+++	++++	+

Table 4.17.11 Semi-quantitative estimates of clay minerals

Lab. No.	Depth (cm)	%								Amphibole
		Smectite	Chlorite	Vermiculite	Illite	Mixed layer	Kaolinite	Quartz	Feldspar	
98	0-15	6	7	2	65	10	7	1	1	1
101	75-116	14	6	3	68	9	7	1	1	1

Sand: Quartz was the most dominant mineral (Fig. 4.56, Table 4.17.10) followed by plagioclases, orthoclases, mica, chlorite + kaolinite, calcite, mixed layers and amphiboles. These sands contained very large amounts of plagioclase feldspars.

Silt: Mineralogy of silt fraction (Fig. 4.56 and Table 4.17.10) was similar to the sand fraction excepting that the feldspars decreased and mica content increased relatively.

Clay: Qualitative and semi-quantitative estimates from XRD patterns (Fig. 4.57, 4.58) indicated a close resemblance between the Samdhan alkali and Samdhan reclaimed alkali excepting that vermiculite was also present in these soils.

Semi-quantitative estimates of clay fraction (Table 4.17.11) minerals calculated on the basis of corrected peak area are presented below in decreasing order.

Ap: Illite, mixed layers, chlorite, kaolinite, smectite and vermiculite

B22: Illite, smectite, mixed layer, kaolinite, chlorite and vermiculite.

Primary minerals associated with clay contributed only minor proportions.

Narnaund pedons: Narnaund alkali and Narnaund normal pedons were taken in the south-west of the Haryana state. These salt affected soils exist in the paleo-channels of Drsadvati-Chautang river system. Elevation of these level to gently sloping land plains is around 219 m and average rainfall is approximately 360 mm and water table is within 8 m. These soils have Ustic moisture regime and hyperthermic temperature regime.

Morphology: These soils (Table 4.18.1, 4.19.1) have dominantly brown to yellowish brown colours with 10YR hue, value 4 to 5 and chroma ranging from 2 to 4. Both these soils have a lithological discontinuity. Texture above the

discontinuity varies from sandy loam to loam and below it is, mainly silt loam. Structure of the B horizon of these soils moderate, medium to coarse, sub-angular blocky. Lime concretions at lower depth are present. Narnaund-alkali soils also have brownish yellow, few to common, fine to coarse, faint to prominent mottles. Both the soils are calcareous throughout.

Physical characteristics: In both the pedons (Table 4.18.2, 4.19.2) horizons below the lithological discontinuity have large amount of silt (53 to 67 per cent). Bulk density of these soils vary from 1.46 to 1.87 Mg m^{-3} . Hydraulic conductivity of Narnaund alkali soils is low; so much so that horizons below lithological discontinuity had very poor hydraulic conductivity. However, the same for Narnaund normal soils was better. Available moisture in these soils ranged between 13.4 to 20.1 per cent.

Chemical characteristics: The pH_2 and EC_2 of Narnaund alkali (Table 4.18.2, 4.19.2) varied from 9.5 to 10.1 and 2.19 to 36.50 dSm^{-1} . However, pH_2 and EC_2 of Narnaund normal soils was 8.8 to 9.1 and 1.57 to 2.56 dSm^{-1} , respectively. Organic carbon generally decreased with depth and its content varied between 0.02 to 0.40 per cent. CaCO_3 contents varied from 0.18 to 19.56 per cent with higher amounts being in lower horizons.

Micro-nutrients: DTPA-extractable Fe, Mn and Cu were sufficient in these soils (Table 4.18.2, 4.19.2). However, DTPA-extractable Zn was deficient in all the horizons excepting the surface horizon of Narnaund normal where farmer had added Zn as fertilizer.

Exchangeable cations: Sodium was the dominant cation on the exchange complex of Narnaund-alkali pedon (Table 4.18.3). CEC of these soils varied from 2.11 to 10.94 cmolkg^{-1} . ESP of these soils varied from 46 to 85.

In case of Narnaund-normal pedon (Table 4.19.3) calcium and magnesium were the dominant cations and their CEC varied from 6.77 to 9.05 cmolkg⁻¹. ESP of these soils ranged between 14 to 21.

Saturation extract: The pHs and EC_e of Narnaund-alkali pedon (Table 4.18.4) varied from 8.8 to 9.6 and 5.1 to 76.7 dSm⁻¹, respectively. Na was the dominant cation and varied from 42.6 to 1179.0 me/l with in the profile. Among the anions carbonate and bicarbonate both were present but chloride was dominant and ranged between 23 to 1050 me/l with in the profile. SAR of saturation extract of this soil varied from 102 to 456.

In contrast pHs and EC_e of Narnaund-normal soils (Table 4.19.4) varied from 8.2 to 8.6 and 3.3 to 5.8 dSm⁻¹, respectively. Sodium was the dominant cation. Chloride followed by sulphate were dominant among the anions. SAR of saturation extract of this soil varied from 8 to 12.

Elemental composition:

Sand: The SiO₂, Al₂O₃ and Fe₂O₃ content of these soils (Table 4.18.5, 4.19.5) varied from 76.84 to 84.90, 4.79 to 5.64 and 1.32 to 2.65, respectively. CaO content ranged between 0.06 to 0.67. MgO, Na₂O and K₂O content varied from 1.17 to 6.42, 2.01 to 2.50 and 0.56 to 0.67, respectively. P₂O₅ and MnO content of these soils ranged between 0.071 to 0.167 and 0.010 to 0.068, respectively. A comparison of horizons below lithological discontinuity show close resemblance in elemental composition. Loss on ignition of these sands varied from 0.82 to 4.77 per cent, with higher values being in horizons below the lithological discontinuity.

Silt: The SiO₂, Al₂O₃ and Fe₂O₃ content of these soils (Table 4.18.6 and 4.19.6) varied from 63.26 to 74.56, 12.63 to 14.21 and 3.09 to 4.43, respectively. CaO content of these soils ranged between traces to 1.53. MgO, Na₂O and K₂O

contents varied from 2.09 to 5.43, 1.04 to 2.36 and 1.30 to 1.80, respectively. P_2O_5 and MnO content of silt fraction these soils ranged from 0.066 to 0.252 and 0.054 to 0.098, respectively. Loss on ignition of the silt fraction of these soils varied from 1.52 to 7.51 with higher values being in the horizon below the lithological discontinuity.

Clay: The SiO_2 , Al_2O_3 and Fe_2O_3 content of the clay fraction of these soils (Table 4.18.7 and 4.19.7) ranged between 47.89 to 51.69, 20.18 to 22.78 and 5.18 to 8.48, respectively. CaO content ranged between 0.15, 0.14 to 0.23 and 1.35 to 1.80, respectively. P_2O_5 varied from 0.019 to 0.039. ZnO and MnO varied from 0.019 to 0.039 and 0.032 to 0.080, respectively. Loss on ignition of these clay ranged between 8.75 to 13.25 per cent.

Soil: The SiO_2 , Al_2O_3 and Fe_2O_3 content of these soils (Table 4.18.8, 4.19.8) varied from 62.36 to 78.00, 8.68 to 16.14 and 2.33 to 3.85, respectively. CaO ranged between 0.13 to 1.06. MgO, Na_2O and K_2O content of these soils varied between 1.35 to 4.28, 0.53 to 1.16 and 0.54 to 0.82, respectively. P_2O_5 and MnO content of these soils ranged between 0.037 to 0.506 and 0.045 to 0.111, respectively. Loss on ignition of these soils varied from 1.29 to 7.96 per cent.

Coarse fragments: Only lime concretions (conca) were present in these pedons. Elemental composition of these is discussed below.

Conca: The SiO_2 , Al_2O_3 and Fe_2O_3 content of the conca of these pedons (Table 4.18.9 and 4.19.9) varied from 32.48 to 45.50, 1.91 to 2.41 and 1.77 to 2.93, respectively. CaO content of these concretions ranged from 18.34 to 26.88. MgO, Na_2O and K_2O content of these concretions varied from 2.07 to 8.25, 0.26 to 0.46 and 0.30 to 0.48, respectively. P_2O_5 and MnO content ranged between 0.030 to 0.117 and 0.128 to 0.547, respectively. **Soil Taxonomy:** These soils had

well developed cambic B horizon and were calcareous in nature throughout the profile. Based on the norms of Soil Survey Staff (1975) and keeping in view the soil characteristics of these have been classified as coarse loamy, mixed, hyperthermic, Typic Ustochrepts. However, this classification failed to highlight the alkali nature and presence of salts, which are so important for plant growth.

Stability of alumino-silicates: Stability of common alumino- silicate minerals (Fig. 4.59) has been evaluated only in case of Narnaund alkali soils due to the limited availability of x-ray diffraction facility. All the horizons of this soil had low hydraulic conductivity and thus maintained a high level of H_4SiO_4 activity in soil solution.

At pHs 9.3 and at the constituent cations activity levels in soil solution, under high H_4SiO_4 ($10^{-2.74}M$) activity, alumino- silicates in Ap horizon of Narnaund alkali soils, can be arranged in order of increasing stability as: kaolinite, illite, muscovite, montmorillonite, microcline, albite, vermiculite and chlorite.

Similarly, at pHs 9.4 and at constituent cations activity levels in soil solution, under high H_4SiO_4 ($10^{-2.74}M$) activity, common alumino-silicates in B1 horizon of Narnaund alkali pedon, can be arranged in order of increasing stability as: kaolinite, illite, muscovite, microcline, montmorillonite, albite, vermiculite and chlorite.

At pHs 9.0 and at activity level of the constituent cations, under high H_4SiO_4 ($10^{-2.74}M$) activity; alumino-silicates in IIBC horizon of Narnaund-alkali pedon, can be arranged in order of increasing stability as: illite, muscovite, kaolinite, microcline, albite, montmorillonite, vermiculite and chlorite.

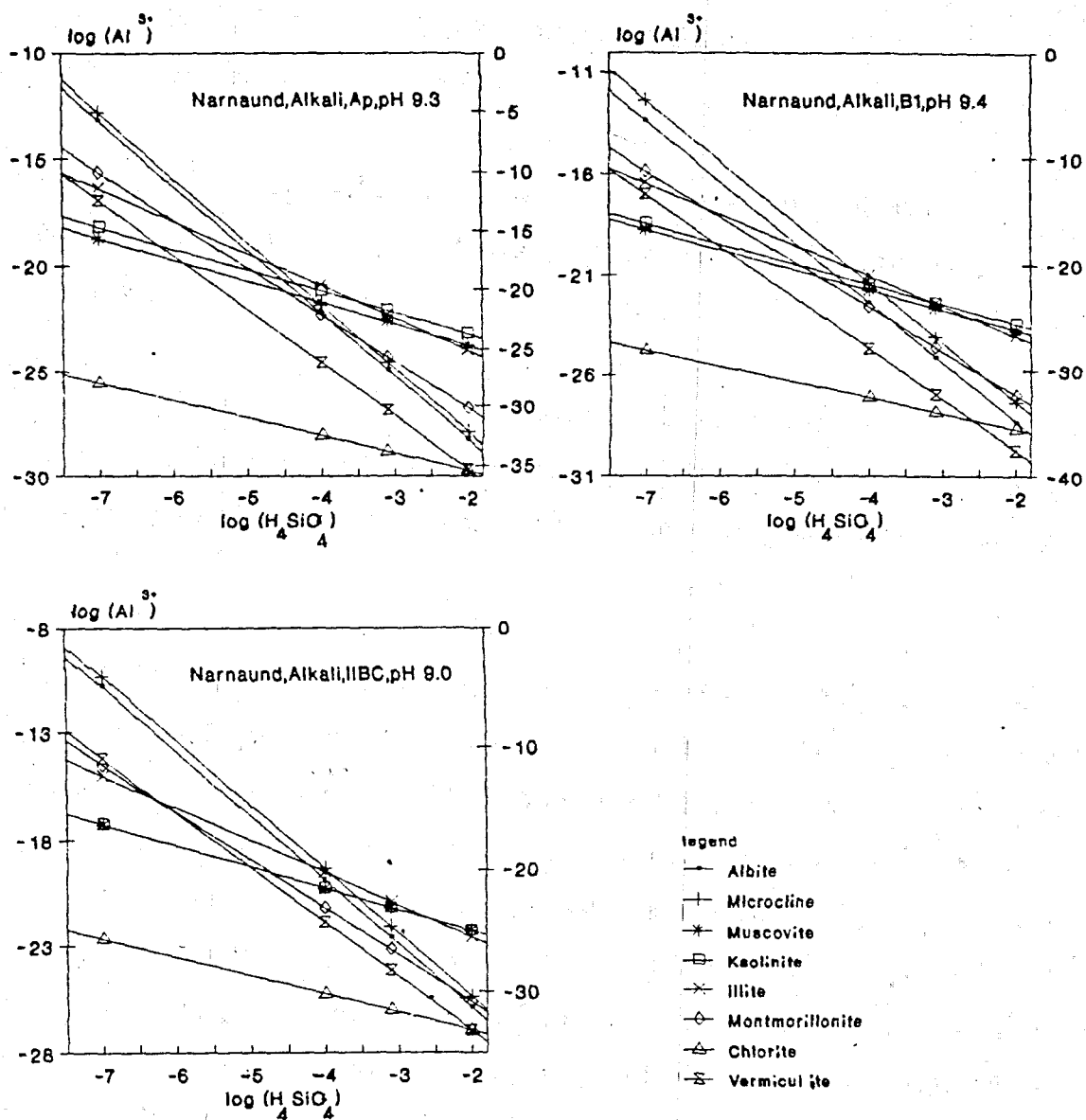


Fig. 4.59 Stability of aluminosilicates

Mineralogy: Qualitative and semi-quantitative interpretation of x-ray diffractograms of sand, silt and clay fractions of Narnaund- alkali pedon are presented in the succeeding paragraphs.

Sand: A perusal of figure 4.60 and table 4.18.10 indicated quartz as the dominant mineral followed by plagioclases, mica, orthoclases, mixed layers, calcite and chlorite + kaolinite.

Silt: Mineralogy of silt fraction (Fig. 4.60, Table 4.18.10) was similar to that of sand fraction except that the plagioclases decreased considerably with depth. An increase in mica, calcite and kaolinite and chlorite content was also noticed.

Clay: X-ray diffractogram of these clays (Fig. 4.61, 4.62, 4.63) indicated a strong and well defined peak for mica along with a moderately strong (in Ap and B1 horizon) and a very strong and well defined (in II BC horizon) 1.4 nm peak along with its higher orders in Mg-treated samples. Presence of smectite, chlorite and kaolinite was confirmed by glycerol solvation, K-saturation and heating and HCl treatment respectively. No part of 1.4 nm collapsed on K saturation and heating thus indicating the absence of vermiculites in these clays. Mixed layers were highly irregular and were mostly composed of mica-smectites and mica-chlorites. Small peaks at 0.845, 0.426 and 0.323 nm indicated the presence of amphiboles, quartz and feldspars.

Semi-quantitative estimates of clay minerals (Table 4.18.11) calculated on the basis of corrected peak area value are presented below in decreasing order.

Ap: Illite, chlorite, smectite, mixed layers and kaolinite

B1: Illite, chlorite, smectite, kaolinite and mixed layers

II BC: Illite, smectite, chlorite, kaolinite and mixed layers.

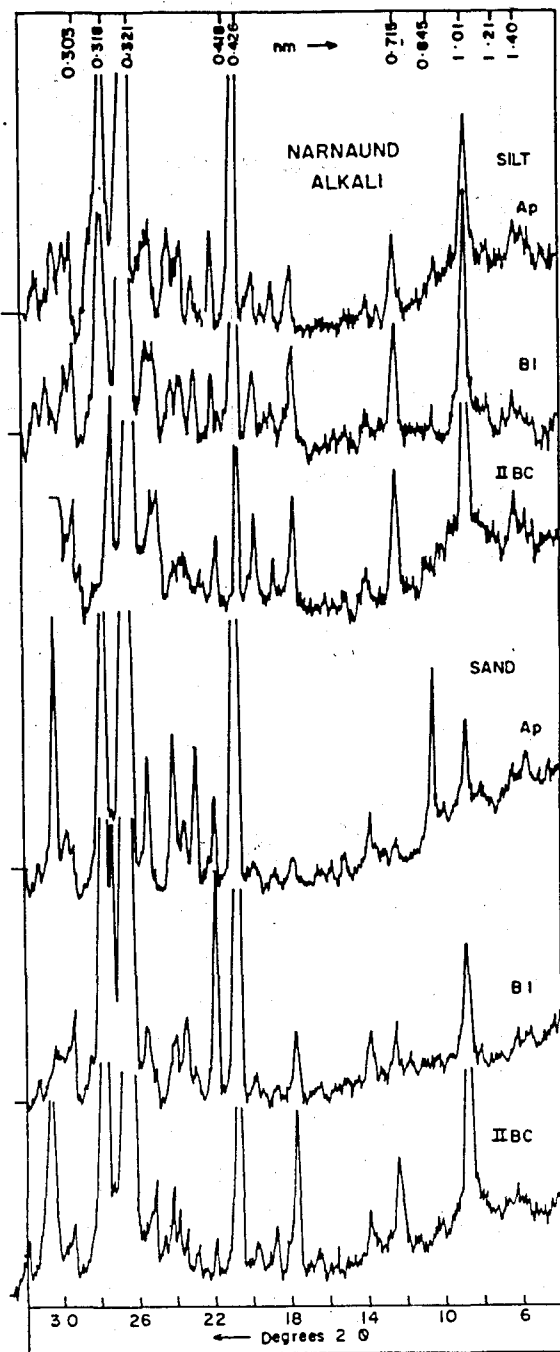


Fig. 4.60 XRD pattern of sand and silt minerals

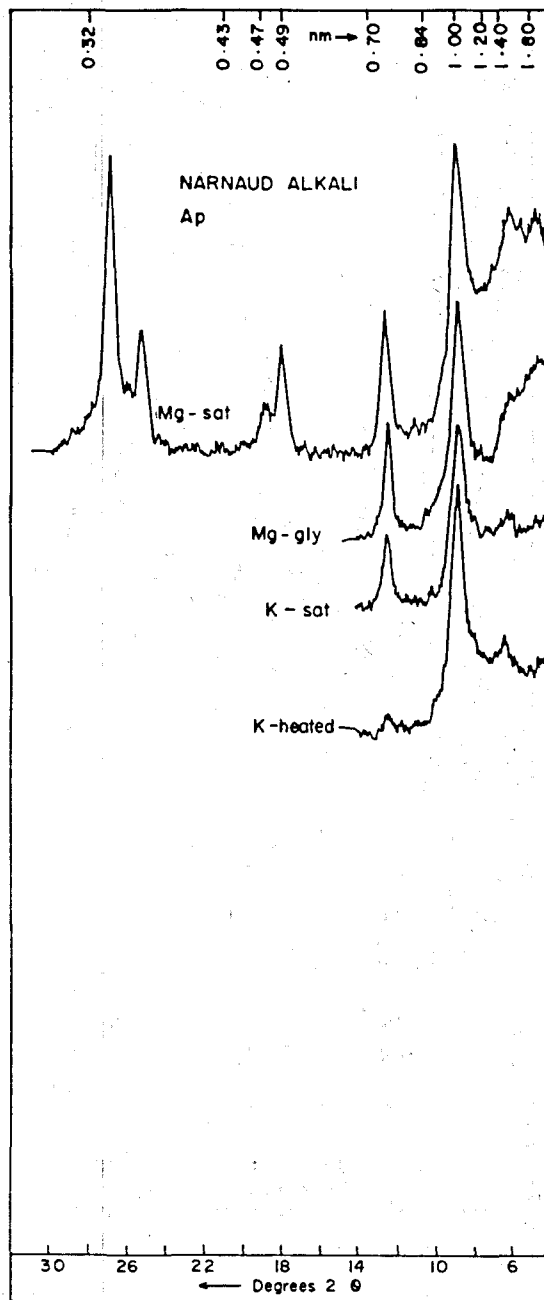


Fig. 4.61 XRD pattern of clay minerals

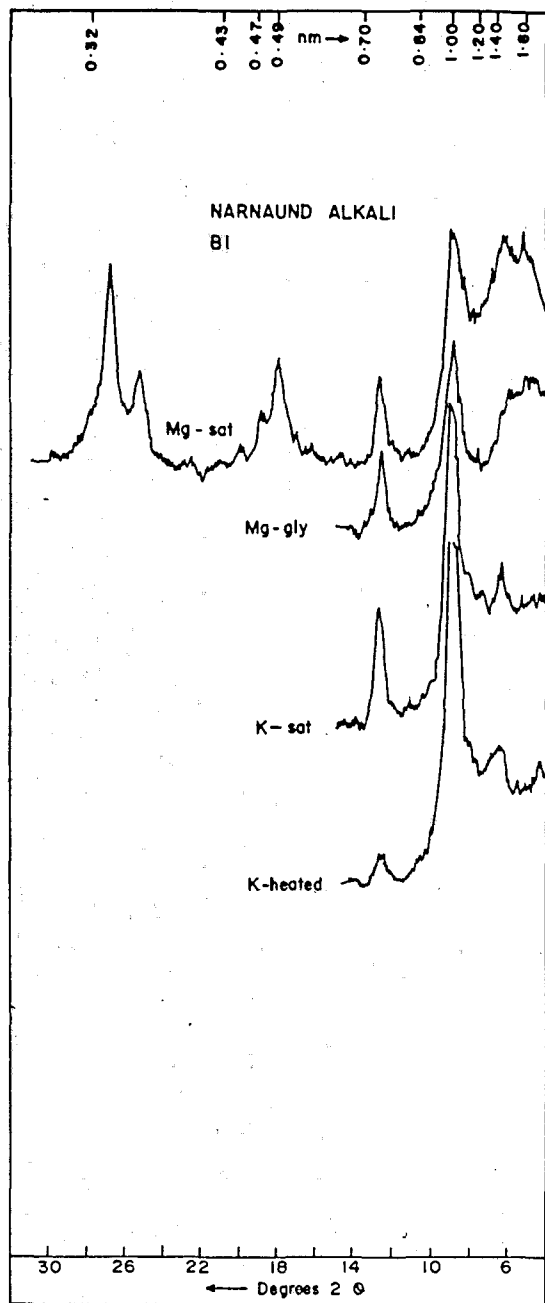


Fig. 4.62 XRD pattern of clay minerals

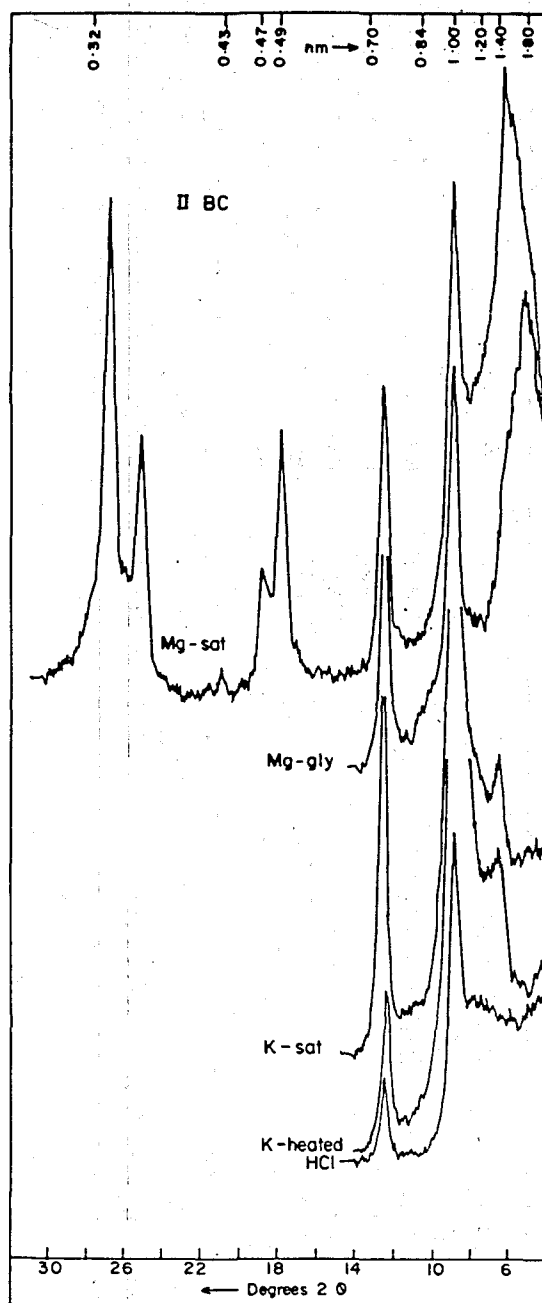


Fig. 4.63 XRD pattern of clay minerals

Pedon No. 18 NARNAUND-ALKALI

Classification: Typic Ustochrept, coarse loamy, mixed, hyperthermic

Location: 76° 6'39"E, 29° 12'25"N, 5 km west of Narnaund on Narnaund to Hansi road

Physiography: Alluvial plain, relict course of Chautang river

Topography: Level to gently sloping, 2 per cent slope

Drainage: Moderately well drained

Landuse: Wasteland patch in cultivated field

Elevation 219 m

Rainfall: 360 mm

Table 4.18.1 Morphology

Lab. Depth	Horizon	Boundary	Colour (moist)	Mottling	Texture Structure Consistence Cutans Roots Coarse Reaction		
					(USDA)	(wet)	fragments
63	0-4	Ap	2.5Y 5/4	-	sl	ws, wpo	-
64	4-12	A3	10YR 6/4	-	sl	ws, wso	-
65	12-23	B1	10YR 4/4	-	1	wss, wsp	f, f
66	23-56	B21	10YR 5/4	-	1	ws, wp	f, f
67	56-93	IIB22	10YR 5/4	10YR 6/6 f, fn, ft	sil	wvs, wvp	-
68	93-134	IIBC	10YR 5/4	10YR 6/6 c, md, dt	sil	wvs, wvp	conca, m
69	134-148+	IIC	10YR 4/3	10YR 5/6 c, co, pt	sil	wvs, wvp	conca, m
							conca, c

Table 4.18.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)			Coarse fragments (%)	Water content (%)		
		Sand (2 - 0.05)	Silt (0.05 - 0.002)	Clay (< 0.002)		1/3 bar	15 bar	Available
		% of < 2 mm						
63	0-4	65.5	31.9	2.6	< 1	22.0	4.5	17.5
64	4-12	55.0	36.4	8.6	< 1	21.5	5.7	15.8
65	12-23	47.9	41.1	11.0	< 1	21.5	5.7	15.8
66	23-56	47.4	38.1	14.5	< 1	22.3	8.9	13.4
67	56-93	18.7	63.8	17.5	16	33.2	15.1	18.1
68	93-134	10.4	66.2	23.4	17	35.6	19.1	16.5
69	134-148+	7.6	67.1	25.3	15	35.6	21.9	15.7

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)			
								Fe	Mn	Cu	Zn
63	0-4	0.31	2.66	10.0	16.5	1.46	0.014	6.8	7.9	0.62	0.40
64	4-12	0.18	3.31	10.1	12.3	1.86	0.012	5.8	8.6	0.76	0.26
65	12-23	0.13	5.10	10.0	8.3	1.77	0.009	5.6	8.6	0.98	0.16
66	23-56	0.13	11.34	10.0	4.1	1.63	0.009	4.0	5.2	0.78	0.18
67	56-93	0.07	19.56	10.0	1.8	1.70	0.003	3.8	3.0	0.40	0.22
68	93-134	0.05	16.02	9.8	1.5	1.71	-	4.8	3.3	0.60	0.18
69	134-148+	0.02	16.42	9.5	1.4	1.75	-	5.2	3.3	0.40	0.16

Table 4.18.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)				CEC (c mol kg ⁻¹)	ESP
		Na	Mg	Ca	K		
63	0-4	1.3	0.5	0.2	0.11	2.1	62
64	4-12	6.7	0.6	0.4	0.16	7.8	85
65	12-23	8.7	0.4	1.5	0.30	10.9	80
66	23-56	7.4	0.6	2.5	0.17	10.6	69
67	56-93	5.2	1.2	2.1	0.20	8.7	60
68	93-134	4.5	1.8	2.0	0.21	8.5	53
69	134-148+	4.0	1.9	2.5	0.21	8.5	46

Table 4.18.4 Saturation extract analysis

Lab. No.	Depth (cm)	Saturation (%)	pH _s	EC _e dSm ⁻¹	Saturation extract analysis (me/l)							SAR	
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl		SO ₄
63	0-4	32	9.3	76.7	1179	8.0	6.1	4.70	37.8	23.8	1050	38	446
64	4-12	40	9.6	53.2	854	4.1	3.2	2.30	31.5	22.8	783	17	456
65	12-23	35	9.4	39.4	476	4.0	2.1	0.61	11.2	15.4	424	34	275
66	23-56	36	9.4	17.1	176	2.0	4.1	0.14	2.8	14.7	144	26	102
67	56-93	48	9.2	5.5	49	6.1	4.0	0.17	0.0	11.2	34	21	218
68	93-134	53	9.0	5.1	48	9.0	1.0	0.24	0.0	10.5	26	28	218
69	134-148+	63	8.8	5.1	43	6.0	3.1	0.26	0.0	6.3	23	27	201

Table 4.18.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
63	0-4	83.2	5.36	1.69	0.6	1.50	2.47	0.56	0.10	0.015	1.22
64	4-12	82.6	5.64	1.98	0.2	1.50	2.50	0.65	0.09	0.015	1.13
65	12-23	84.9	5.51	1.82	0.6	3.00	2.29	0.61	0.09	0.030	0.82
66	23-56	83.1	5.64	1.79	0.7	2.00	2.29	0.56	0.11	0.043	2.21
67	56-93	76.8	4.79	2.65	0.6	5.83	2.02	0.62	0.12	0.046	4.77
68	93-134	79.0	5.14	2.33	0.7	3.17	2.11	0.65	0.09	0.050	2.76
69	134-148+	79.5	5.25	2.62	0.7	4.92	2.01	0.64	0.09	0.068	3.49

Table 4.18.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
63	0-4	72.5	14.4	3.09	0.6	2.17	1.57	1.30	0.25	0.054	3.28
64	4-12	71.2	14.2	3.68	0.4	5.51	1.69	1.51	0.13	0.061	3.09
65	12-23	69.9	13.8	3.43	0.5	2.76	1.93	1.72	0.12	0.068	3.67
66	23-56	70.6	13.5	3.75	1.0	4.34	1.72	1.53	0.21	0.072	4.37
67	56-93	64.4	13.2	3.39	1.4	5.43	1.62	1.45	0.08	0.063	6.83
68	93-134	64.4	13.7	3.73	1.5	4.68	1.72	1.80	0.11	0.058	7.51
69	134-148+	63.3	14.2	3.80	1.3	4.51	1.77	1.76	0.07	0.057	6.47

Table 4.18.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	ZnO	MnO	
63	0-4	50.8	21.6	6.75	0.2	4.18	0.15	1.80	0.22	0.039	0.084	13.25
64	4-12	51.9	21.9	7.65	0.2	4.46	0.15	1.59	0.21	0.039	0.063	10.95
65	12-23	50.9	21.9	7.28	0.2	3.67	0.15	1.68	0.22	0.026	0.080	9.78
66	23-56	50.5	21.5	6.45	0.3	5.11	0.16	1.56	0.17	0.029	0.039	8.48
67	56-93	48.4	22.5	5.64	0.3	5.64	0.19	1.53	0.03	0.022	0.037	12.10
68	93-134	48.2	22.7	5.18	0.3	4.38	0.21	1.55	0.08	0.035	0.036	11.25
69	134-148+	47.9	23.1	5.86	0.2	4.53	0.18	1.58	0.04	0.022	0.041	11.14

Table 4.18.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	MnO	(%)
63	0-4	78.0	8.7	2.33	0.7	1.50	1.16	0.54	0.51	0.093	4.19
64	4-12	75.5	10.0	2.65	0.9	1.47	1.08	0.63	0.28	0.093	3.33
65	12-23	73.9	10.7	3.20	1.1	1.44	1.02	0.68	0.46	0.104	3.03
66	23-56	73.4	11.0	3.06	0.6	3.31	0.85	0.62	0.16	0.088	4.22
67	56-93	65.1	14.4	3.60	0.3	4.28	0.66	0.70	0.17	0.099	5.23
68	93-134	63.0	15.7	3.85	0.4	3.91	0.64	0.77	0.07	0.096	7.71
69	134-148+	62.4	16.1	3.85	0.5	3.86	0.53	0.82	0.05	0.111	7.96

Table 4.18.9 Elemental composition of lime concretions

Lab. No.	Depth (cm)	Elemental composition (%)									Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	MnO	
64	4-12	35.9	2.2	2.17	25.07	2.79	0.43	0.38	0.117	0.467	8.29
65	12-23	39.8	2.1	2.15	23.50	5.68	0.45	0.39	0.113	0.547	8.10
66	23-56	36.35	1.9	2.35	22.01	5.21	0.35	0.40	0.103	0.324	8.23
67	56-93	34.0	2.1	2.25	18.34	7.98	0.38	0.45	0.089	0.309	10.06
68	93-134	32.5	2.1	2.70	18.60	8.25	0.27	0.48	0.078	0.285	10.67
69	134-148+	33.0	2.4	2.93	18.66	6.98	0.26	0.44	0.076	0.321	12.42

Table 4.18.10 Semi quantitative estimates of sand and silt minerals

Lab.No.	Depth (cm)	Chlorite	Mixed layer	Mica	Amphibole	Chlorite + Kaolinite	Quartz	Orthoclases	Plagioclases	Calcite
Sand										
63	0-4	++	++	+++	-	++	+++++	++	++++	++
65	12-23	+	+	+++	-	++	+++++	+++	+++++	++
68	93-134	+	+	+++	+	++	+++	++	+++++	++
Silt										
63	0-4	++	++	+++	++	++	+++++	+++	+++++	++
65	12-23	+	+	++++	+	+++	++++	+++	++++	++
68	93-134	+++	++	+++++	-	+++	++++	++++	++	++

Table 4.18.12 Semi quantitative estimates of clay minerals

Lab. No.	Depth (cm)	Smectite	Chlorite	Vermiculite	Illite	Mixed layer	Kaolinite	Quartz	Feldspar	Amphibole
%										
63	0-4	9	12	0	60	8	7	1	2	1
65	12-23	10	11	0	58	7	9	1	3	1
68	93-134	24	11	4	46	5	5	1	3	1

Pedon No. 19 NARNAUND-NORMAL

Classification: Typic Ustochrept, coarse loamy, mixed, hyperthermic

Location: 76° 6'39"E, 29° 12'25"N, 5 km west of Narnaund on Narnaund to Hansi road

Physiography: Alluvial plain, relict course of Chautang river

Topography: Level to gently sloping, 1-2 per cent slope

Drainage: Moderately well drained

Landuse: Cultivated field

Elevation 219 m

Rainfall: 360 mm

Table 4.19.1 Morphology

Lab. Depth No. (cm)	Horizon	Boundary	Colour (moist)	Mottling	Texture (USDA)	Structure (wet)	Consistence	Cutans	Roots	Coarse fragments	Reaction
70	0-18	Ap	cw	10YR 5/2	-	sl	1m, sbk	wss, wsp	-	f, vf-f	3
71	18-28	A3	gw	10YR 5/3	-	sl	1m, sbk	wss, wsp	-	f, f	3
72	28-68	B1	cs	10YR 4/4	-	sl	2m, sbk	wss, wsp	-	f, f	2
73	68-104	B2	gs	10YR 5/4	-	sil	2m, sbk	ws, wp	-	f, vf	4
74	104-140	IIC1	gs	10YR 5/4	-	sil	2m, sbk	ws, wp	-	-	conca, c
75	140-160	IIC2		10YR 4/4	-	sil	2m, sbk	ws, wp	-	-	conca, c

Table 4.19.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)			Coarse fragments (%)	Water content (%)		
		Sand (2 - 0.05)	Silt (0.05 - 0.002)	Clay (< 0.002)		1/3 bar	15 bar	Available
70	0-18	55.2	34.3	10.5	-	21.8	6.8	15.0
71	18-28	55.5	35.1	9.4	-	20.8	6.8	14.0
72	28-68	59.2	30.7	10.1	2	20.4	6.7	13.7
73	68-104	53.5	33.6	12.9	30	23.5	7.0	16.5
74	104-140	39.7	53.5	6.8	26	27.8	7.7	20.1
75	140-160	59.0	33.7	7.3	15	24.9	7.8	17.1

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)			
								Fe	Mn	Cu	Zn
70	0-18	0.40	1.32	9.0	2.19	1.58	0.038	7.8	7.9	0.92	0.60
71	18-28	0.19	0.78	9.0	1.59	1.80	0.034	6.2	7.5	0.84	0.22
72	28-68	0.13	0.18	8.8	1.57	1.84	0.138	4.4	4.9	0.56	0.12
73	68-104	0.11	8.94	8.8	2.56	1.83	0.317	3.2	1.8	0.46	0.24
74	104-140	0.09	14.56	9.0	2.19	1.77	0.116	3.6	1.3	0.32	0.20
75	140-160	0.07	3.52	9.1	2.03	1.87	0.107	3.4	1.4	0.34	0.16

Table 4.19.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)				CEC	ESP
		Na	Mg	Ca	K	(c mol kg ⁻¹)	
70	0-18						
71	18-28	1.7	3.5	3.5	0.31	9.1	19
72	28-68	1.0	3.0	3.0	0.21	7.3	14
73	68-104	1.5	3.6	3.5	0.18	8.7	17
74	104-140	1.3	2.9	3.1	0.10	7.4	17
75	140-160+	1.3	2.4	3.0	0.09	6.8	19
69	134-148+	1.7	3.2	3.0	0.14	8.1	21
		4.0	1.9	2.5	0.21	8.5	46

Table 4.19.4 Saturation extract analysis

Lab. No.	Depth (cm)	Saturation	pH _s	EC _e	Saturation extract analysis (me/l)								SAR
					dSm ⁻¹								
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl	SO ₄	
70	0-18	35			30.1	14.0	7.1	0.31	2.8	5.6	23	21	9
71	18-28	34	8.6	4.9	23.7	13.1	3.0	0.17	0.0	9.8	18	15	8
72	28-68	33	8.5	3.9	23.7	8.0	4.1	0.12	0.0	6.3	19	9	10
73	68-104	38	8.2	3.3	35.5	17.1	7.2	0.06	0.0	5.3	31	24	10
74	104-140	41	8.2	5.7	39.7	17.2	5.1	0.04	0.0	3.6	30	23	12
75	140-160+	41	8.3	5.8	32.8	13.1	3.2	0.07	0.0	3.2	25	18	12
			8.4	4.6									

Table 4.19.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O		P ₂ O ₅	MnO
70	0-18	84.0	5.23	1.72	0.1	1.17	2.36	0.56	0.07	0.037	1.20
71	18-28	84.4	5.33	1.32	0.1	1.25	2.38	0.58	0.15	0.015	0.72
72	28-68	84.4	5.39	1.39	0.1	1.33	2.32	0.59	0.16	0.009	0.73
73	68-104	83.9	5.34	1.94	0.2	1.83	2.20	0.61	0.09	0.010	1.95
74	104-140	78.2	5.18	2.20	0.8	6.42	2.12	0.63	0.07	0.035	2.40
75	140-160+	81.7	5.39	2.15	0.8	2.50	2.27	0.67	0.16	0.028	1.48

Table 4.19.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
70	0-18	71.1	12.6	3.90	tr.	3.01	2.36	1.58	0.15	0.061	1.52
71	18-28	74.6	12.7	4.43	tr.	2.42	2.37	1.67	0.08	0.065	1.81
72	28-68	73.5	13.1	3.92	tr.	2.09	1.97	1.51	0.07	0.063	2.69
73	68-104	71.8	12.9	3.38	1.2	2.59	1.37	1.32	0.11	0.096	3.38
74	104-140	67.2	12.7	3.26	1.5	4.01	1.04	1.35	0.09	0.090	5.01
75	140-160+	67.6	12.3	4.26	0.1	2.84	1.22	1.66	0.09	0.098	4.91

Table 4.19.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)		
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		ZnO	MnO
70	0-18	50.3	20.2	7.55	0.5	4.21	0.14	1.49	0.22	0.030	0.061	12.17
71	18-28	51.3	20.5	7.50	0.4	3.37	0.16	1.53	0.34	0.027	0.067	8.75
72	28-68	51.7	21.4	7.72	0.3	4.14	0.16	1.47	0.07	0.039	0.045	9.13
73	68-104	51.1	21.1	8.48	0.4	4.33	0.16	1.39	0.13	0.035	0.041	10.30
74	104-140	50.1	22.8	6.29	0.8	4.64	0.18	1.35	0.11	0.031	0.032	9.52
75	140-160+	49.9	22.6	7.55	0.5	4.14	0.23	1.41	0.11	0.019	0.075	19.08

Table 4.19.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	MnO
70	0-18	77.0	9.5	2.69	0.5	1.65	1.08	0.61	0.12	0.052
71	18-28	77.3	9.4	2.70	0.5	1.39	1.04	0.61	0.14	0.045
72	28-68	77.5	9.2	3.02	0.2	1.35	0.99	0.62	0.13	0.080
73	68-104	76.3	9.9	2.97	0.1	2.27	0.91	0.54	0.04	0.054
74	104-140	72.4	10.4	3.30	0.3	3.51	0.82	0.58	0.16	0.062
75	140-160+	74.1	8.9	3.45	0.7	2.25	1.01	0.63	0.13	0.067

Table 4.19.9 Elemental composition of lime concretions

Lab. No.	Depth (cm)	Elemental composition (%)							Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	
73	68-104	45.1	2.3	1.77	26.68	2.27	0.35	0.30	8.15
74	104-140	45.5	2.1	1.97	21.82	4.16	0.35	0.36	8.30
75	140-160+	44.2	2.4	1.77	24.05	3.91	0.46	0.41	7.83

In general the smectite content increased and illite decreased considerably with depth. Smectite content varied from 9 to 24 per cent. Primary minerals contributed only minor amounts.

4.32 Lower alluvial plain: Sirsa-upland, Sirsa-lowland pedons represented the soils of lower alluvial plain. Elevation of these gently sloping lands varied from around 195 to 220 m and average rainfall was about 410 mm.

Sirsa pedons: Water table in this area is about 20 m deep. No surface ponding occurs in Sirsa upland soils. However, surface ponding in case of Sirsa-lowland soils during rainy season is not ruled out. These soils have Ustic moisture regime and hyperthermic temperature regime.

Morphology: These soils had dark brown colours with hues ranging from 7.5YR to 10YR, value 4 and chroma varying from 3 to 4 (Table 4.20.1, 4.21.1). Mottles were absent. Texture was dominantly silt loam to silty clay. Structure was weak to strong, medium subangular blocky. Wet consistence of these soils varied from sticky and plastic to very sticky and very plastic. Soils were calcareous throughout.

Physical characteristics: Clay content in both the soils increased with depth and was maximum in Sirsa lowland soils (Table 4.20.2, 4.21.2). These soils had high amounts of silt which varied from 40.9 to 58.8 per cent. Bulk density of undisturbed soil varied from 1.68 to 1.84 Mg m⁻³. Hydraulic conductivity of these soils was low and varied from 0.002 to 0.329 cm hr⁻¹. Available water in these soils varied from 19.6 to 16.3 per cent.

Chemical characteristics: The pH_e and EC_e of these soils (Table 4.20.2, 4.21.2) varied from 8.5 to 9.4 and 0.89 to 4.62 dSm⁻¹, respectively. Organic carbon decreased regularly with depth. Its contents were higher in Sirsa lowland

soils. CaCO_3 in these soils varied from 0.80 to 2.67 per cent.

Micro-nutrients: The DTPA extractable Fe, Mn and Cu were in sufficient amounts. Available Zn was deficient in these soils excepting the surface horizon of Sirsa upland soils. It was due to supplementary ZnSO_4 additions by the farmer.

Exchangeable cations: The Sodium was always less than the calcium plus magnesium. Potassium varied from 0.12 to 0.26 cmol kg^{-1} . CEC of these soils (Table 4.20.3 to 4.21.3) ranged between 6.33 to 13.08 cmol kg^{-1} . ESP of these soils ranged between 20 to 46.

Saturation extract: The pHs and EC_e of these soils (Table 4.20.4, 4.21.4) ranged between 8.5 to 8.9 and 3.2 to 9.5 dSm^{-1} , respectively. Unlike exchange complex sodium dominated among the cations with contents ranging between 21.5 to 84.4 me/l . Among the anions chloride and sulphate dominated SAR of these soils ranged between 8 to 22.

Elemental composition (per cent);

Sand: The SiO_2 , Al_2O_3 and Fe_2O_3 contents of these soils (Table 4.20.5, 4.21.5) varied from 84.13 to 87.22, 4.04 to 5.26 and 1.26 to 1.79, respectively. CaO contents were low and ranged between 0.10 to 0.84 per cent.

The MgO , Na_2O and K_2O content of these soils varied from 1.25 to 1.67, 1.62 to 2.28 and 0.51 to 0.64, respectively. P_2O_5 content ranged between 0.080 to 0.131. Loss on ignition of sand fractions varied from 0.51 to 2.13 per cent.

Silt: The SiO_2 , Al_2O_3 and Fe_2O_3 contents of these soils (Table 4.20.6, 4.21.6) varied from 73.88 to 76.41, 11.89 to 12.90 and 2.76 to 3.79, respectively. Fe_2O_3 contents of Sirsa lowland was relatively higher. CaO was absent. MgO , Na_2O and K_2O content of the silt fraction of these soils ranged from 1.84 to

2.76, 1.12 to 1.56 and 1.30 to 2.15, respectively. K_2O contents were generally higher in Sirsa lowland soils. P_2O_5 and MnO content of these soils varied from 0.055 to 0.460 and 0.053 to 0.088, respectively. High P_2O_5 content in surface horizons was due to fertilizer additions by the farmers. Loss on ignition of silt fraction of these soils ranged between 1.79 to 3.66 per cent.

Clay: The SiO_2 , Al_2O_3 and Fe_2O_3 contents of the clay fraction of these soils (Table 4.20.7, 4.21.7) varied from 49.78 to 55.14, 21.75 to 24.19 and 6.05 to 7.60, respectively. CaO content ranged between traces to 0.32. MgO , Na_2O and K_2O contents varied from 2.22 to 3.99, 0.12 to 0.27 and 1.45 to 1.69, respectively. P_2O_5 content was higher in surface horizon and ranged between 0.052 to 0.240. ZnO and MnO varied from 0.022 to 0.035 and 0.010 to 0.059, respectively. Loss on ignition of the clay fraction of these soils ranged between 8.26 to 10.26 per cent.

Soil: The SiO_2 content of these soils (Table 4.20.8 and 4.21.8) decreased and Al_2O_3 , Fe_2O_3 contents increased with depth. SiO_2 , Al_2O_3 , Fe_2O_3 content of these soils ranged between 68.05 to 76.78, 10.96 to 15.19 and 3.07 to 4.60, respectively. CaO varied from traces to 0.43. MgO , Na_2O and K_2O ranged from traces to 0.43. MgO , Na_2O and K_2O ranged between 1.49 to 1.85, 0.52 to 0.95 and 0.59 to 0.87, respectively. P_2O_5 contents were higher in surface horizons and varied from 0.135 to 0.188. MnO content of these soils ranged between 0.045 to 0.080. Loss on ignition of these soils varied from 2.42 to 5.55 per cent.

Coarse fragments: Only lime concretions (conca) were present in these soils.

Conca: The SiO_2 , Al_2O_3 and Fe_2O_3 contents of conca in these soils (Table 4.20.9 and 4.21.9) ranged from 30.00 to 33.43, 1.78 to 1.98 and 1.72 to 3.07, respectively. CaO content of these nodules varied from 23.52 to 30.16, MgO , Na_2O and K_2O content of these concretions ranged from 1.54 to 4.34, 0.21 to 0.39

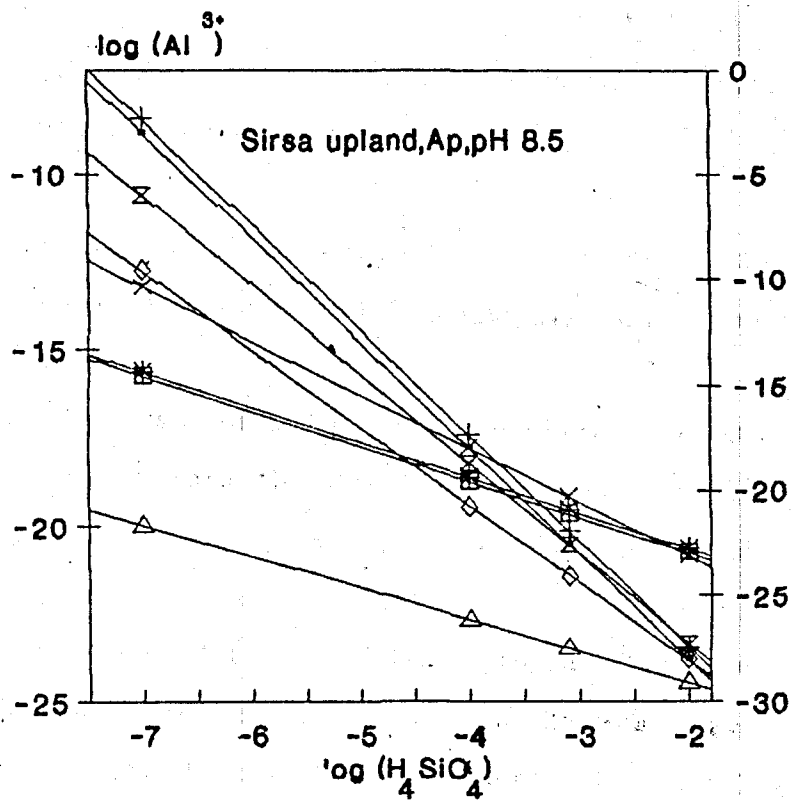
and 0.34 to 0.53, respectively. P_2O_5 and MnO content of these nodules was high and varied from 0.098 to 0.460 and 0.105 to 0.695, respectively. Loss on ignition of these lime concretions ranged between 6.11 to 7.52 per cent.

Soil Taxonomy: These soils have well developed cambic B horizon and are calcareous in nature throughout. So based on the norms of Soil Survey Staff (1975) and soil characteristics these soils have been classified as mixed, hyperthermic, Typic Ustochrepts. Textural family of Sirsa upland and Sirsa lowland was coarse loamy and fine loamy, respectively. However, this classification failed to indicate the alkali nature of these soils which is so important for plant growth.

Stability of alumino-silicates: Stability of alumino-silicates has been evaluated for only Sirsa upland soils (Fig. 4.64) because of limited access to x-ray diffraction facility. Ap horizon of Sirsa-upland had very low hydraulic conductivity and this maintained a high level of H_4SiO_4 activity in soil solution. However, hydraulic conductivity of B21 horizon of these soils is just moderate.

Thus at pHs 8.5 and at the constituent cations activity levels in soil solution, under high H_4SiO_4 ($10^{-2.74}M$) activity alumino-silicates in Ap horizon of Sirsa upland pedon can be arranged in increasing order of stability as: illite, muscovite, kaolinite, microcline, vermiculite, albite, montmorillonite and chlorite.

At pHs 8.8 and at the constituent cations activity levels in soil solution, under medium H_4SiO_4 ($10^{-3.11}M = \text{soil } SiO_2$) activity, alumino-silicates in B21 horizon of Sirsa upland pedon, can be arranged in increasing order of stability as: muscovite, kaolinite, microcline, albite, montmorillonite, vermiculite and chlorite.



legend

- Albite
- +— Microcline
- *— Muscovite
- Kaolinite
- x— Illite
- ◇— Montmorillonite
- △— Chlorite
- x— Vermiculite

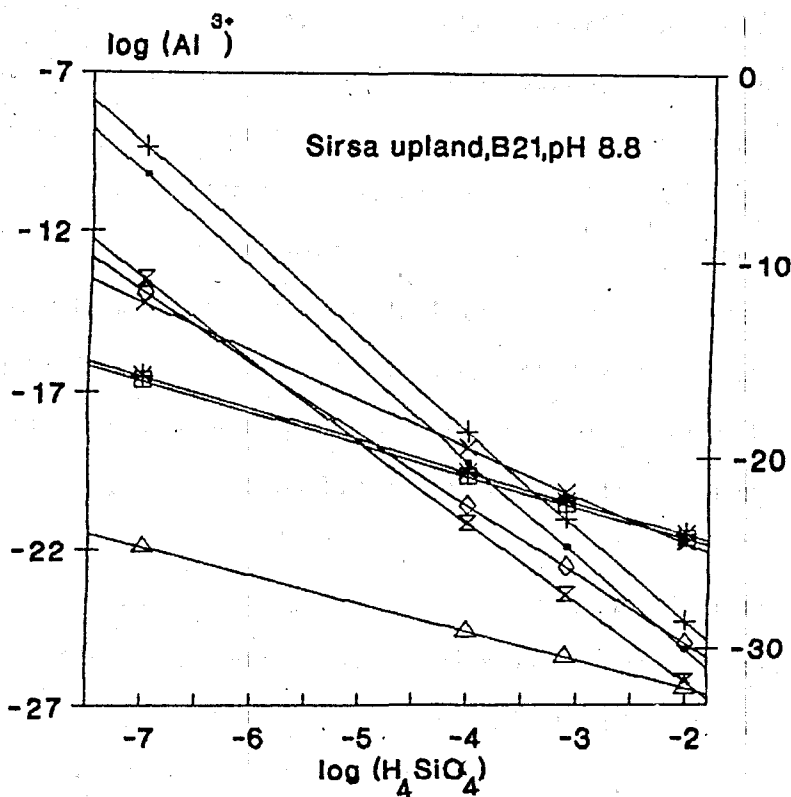


Fig. 4.64 Stability of aluminosilicates

Thus chlorite, vermiculite and montmorillonite are more stable under these soil solution compositions.

Mineralogy: Results obtained from the interpretation of XRD patterns of sand, silt and clay fractions of Sirsa upland pedon are presented below.

Sand: A perusal of XRD pattern and (Fig.4.65) data in table 4.20.10 indicated that the quartz was the most dominant mineral followed by plagioclase feldspars, mica, orthoclases, chlorite and kaolinite and calcite.

Silt: A study of the x-ray diffractogram (Fig. 4.65) and data in table 4.20.10 indicated trends similar to that in the sand fraction. However, the mica and kaolinite and chlorite contents were relatively higher than sand fraction.

Clay: X-ray diffractograms of clay revealed very strong strong and well defined peaks for illite accompanied by a strong 1.4 nm peak along with its higher orders in Mg-treated samples. The 1.4 nm peak resolved partially into a maximum at 1.8 nm on glycerol solvation and was thus attributed to the presence of smectites in these soils (Fig. 4.66,4.67). The remaining 1.4 nm partially collapsed to 1.0 nm on K-saturation and heating the sample, thereby confirming the presence of vermiculite. Residual 1.4 nm that persisted even after the K-saturation and heating treatment was attributed to chlorite XRD pattern also registered peaks around 1.2 nm indicating the presence of mixed layer minerals.

Mixed layer minerals are mostly mica-chlorite type with some mica-smectite type minerals. In general the clay minerals were both diocta and trioctahedral in nature. Minerals were mostly identical and 1.0 nm and 1.4 nm peaks were symmetrical.

Semi-quantitative estimates calculated on the basis of corrected peak area

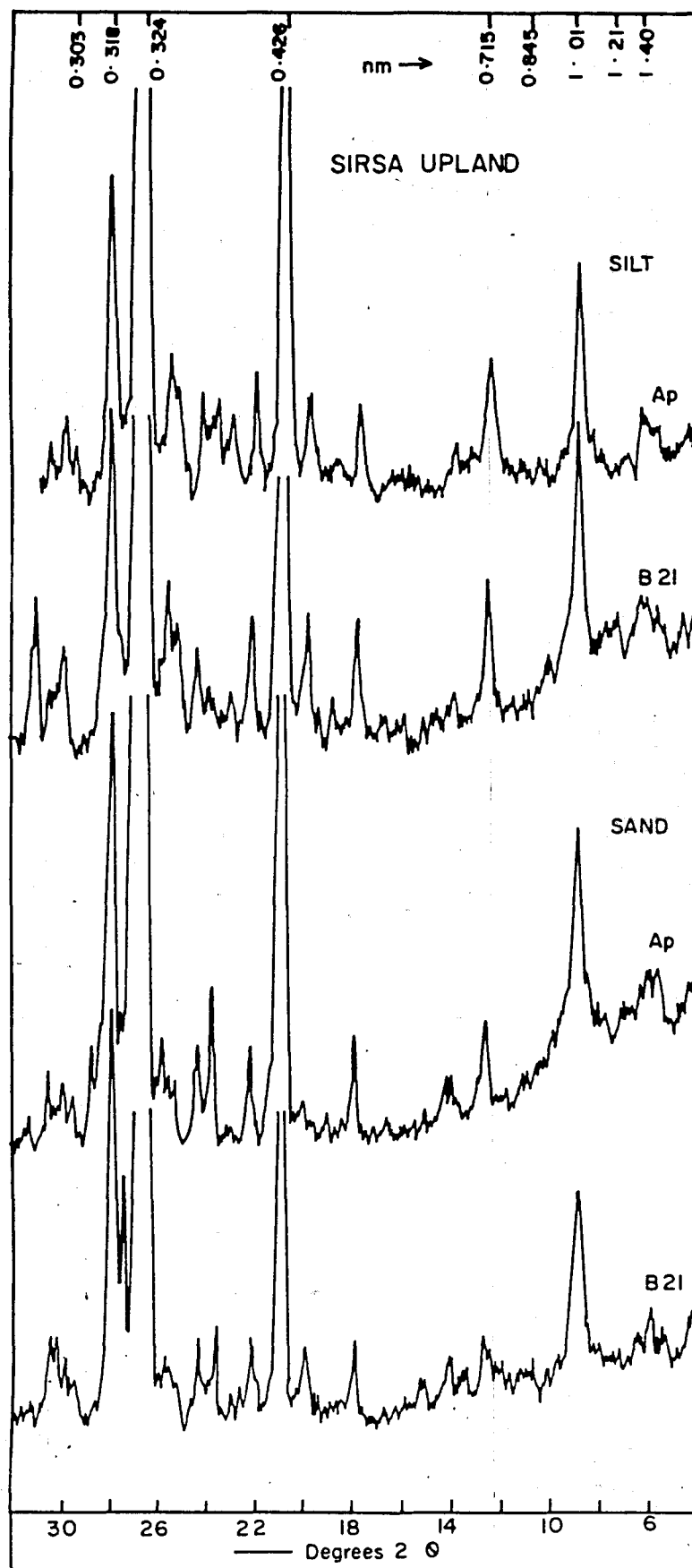


Fig. 4.65 XRD pattern of sand and silt minerals

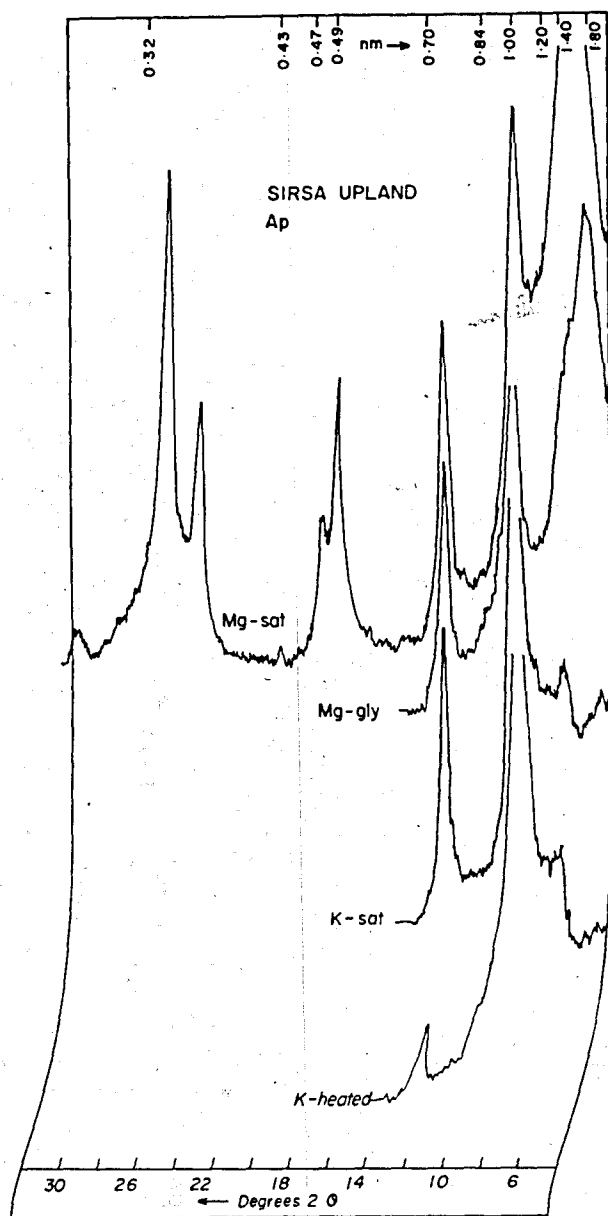


Fig. 4.66 XRD pattern of clay minerals

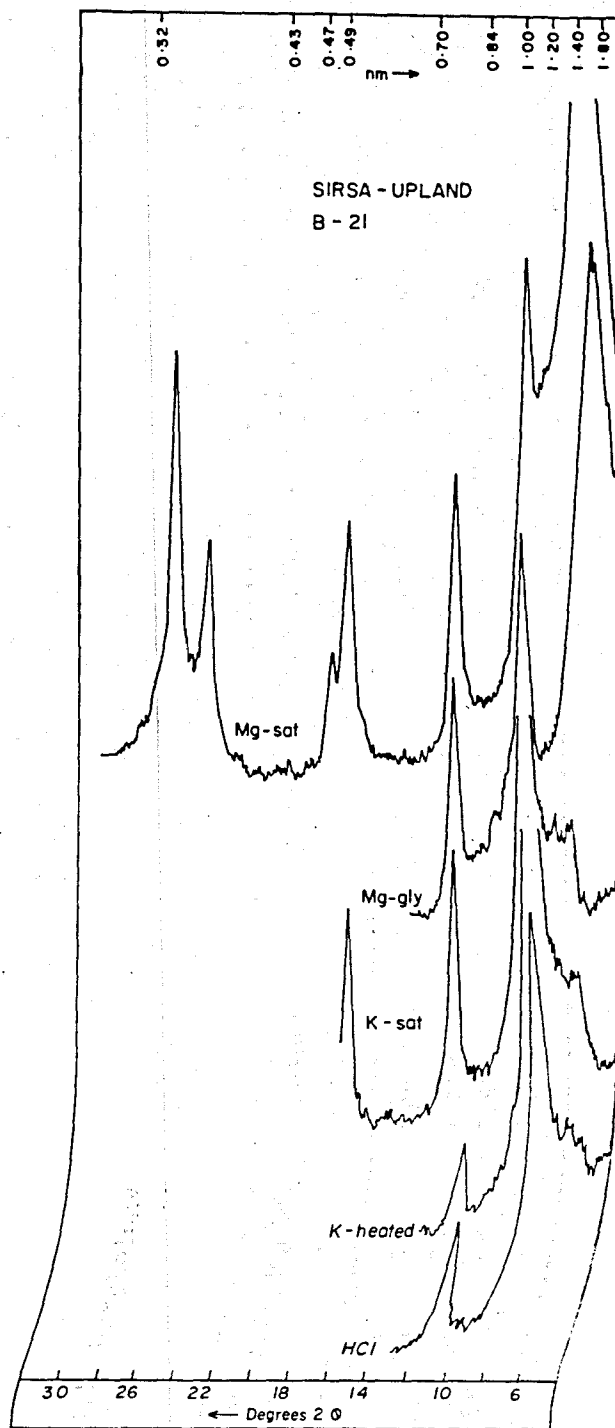


Fig. 4.67 XRD pattern of clay minerals

Classification: Typic Ustochrept, coarse loamy, mixed, hyperthermic

Location: 74° 54'1"E, 29° 26'11"N, Madhosingh wala village on Sirsa to Elnabad road, district Sirsa

Physiography: Levee

Topography: Upland with 1-3 per cent slope

Drainage: Moderately well drained

Landuse: Cultivated

Elevation 198 m

Rainfall: 410 mm

Table 4.20.1 Morphology

Lab. Depth	Horizon	Boundary	Colour (moist)	Mottling	Texture (USDA)	Structure	Consistence (wet)	Cutans	Roots	Coarse fragments	Reaction
76	0-15	Ap	Cw	-	sil	1m, sbk	ws, wp	-	f, f	-	3
77	15-57	B1	10YR 4/3	-	sil	2m, sbk	ws, wp	-	f, f	-	3
78	57-85	B21	7.5YR 4/4	-	sil	2m, sbk	ws, wp	-	f, f	conca, f-m	3
79	85-155+	B22	7.5YR 4/4	-	sil	2m, sbk	ws, wp	-	f, f	conca, f	3
			7.5YR 4/4	-	sil	2m, sbk	ws, wp	-	-	conca, f	3

Table 4.20.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)			Coarse fragments (%)	Water content (%)		
		Sand (2 - 0.05)	Silt (0.05 - 0.002)	Clay (< 0.002)		1/3 bar	15 bar	Available
-----% of < 2 mm -----								
76	0-15	30.8	58.5	10.7	-	27.0	12.8	14.2
77	15-57	31.1	53.8	15.1	-	26.8	10.8	16.0
78	57-85	24.2	58.8	17.0	1	28.3	12.0	16.3
79	85-155+	32.0	49.2	18.8	2	25.5	14.2	11.3

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)			
								Fe	Mn	Cu	Zn
76	0-15	0.37	2.67	8.8	1.82	1.68	0.002	15.8	7.3	0.88	0.96
77	15-57	0.16	2.33	8.8	4.21	1.75	0.329	4.6	1.8	0.44	0.24
78	57-85	0.13	1.61	8.9	4.38	1.75	0.260	5.4	2.2	0.50	0.28
79	85-155+	0.10	1.71	9.0	4.62	1.87	0.008	5.4	2.7	0.64	0.24

Table 4.20.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)				CEC (c mol kg ⁻¹)	ESP
		Na	Mg	Ca	K		
76	0-15	2.6	2.5	3.0	0.21	8.3	31
77	15-57	3.3	2.0	5.0	0.15	10.4	32
78	57-85	4.0	2.7	2.2	0.12	9.0	44
79	85-155+	4.5	2.9	2.3	0.14	9.9	46

Table 4.20.4 Saturation extract analysis

Lab. No.	Depth (cm)	Saturation (%)	pH _s	EC _e dSm ⁻¹	Saturation extract analysis (me/l)								SAR
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl	SO ₄	
76	0-15	40	8.5	4.9	41.2	9.0	3.0	0.27	2.8	11.9	15.0	21.1	17
77	15-57	41	8.6	8.3	61.1	15.0	13.1	0.17	0.0	9.2	38.2	42.0	16
78	57-85	41	8.8	8.9	72.9	19.1	18.2	0.14	0.0	8.2	45.2	44.3	17
79	85-155	37	8.9	9.5	84.4	18.2	11.1	0.13	0.0	4.2	56.8	57.0	22

Table 4.20.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)									Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	MnO	
76	0-15	86.1	4.29	1.78	0.2	1.50	1.77	0.64	0.13	0.034	2.13
77	15-57	86.9	4.14	1.60	0.8	1.67	1.62	0.62	0.10	0.031	1.28
78	57-85	87.2	4.04	1.62	0.1	1.59	1.63	0.51	0.08	0.030	0.51
79	85-155+	86.3	4.39	1.26	0.6	1.92	1.78	0.53	0.08	0.019	1.20

Table 4.20.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
76	0-15	75.4	12.6	2.83	0.0	2.76	1.39	1.44	0.46	0.081	2.35
77	15-57	75.7	12.1	2.92	0.0	1.84	1.46	1.48	0.14	0.075	2.25
78	57-85	76.3	12.8	2.76	0.0	2.00	1.46	1.30	0.06	0.065	2.17
79	85-155+	76.4	11.9	3.38	0.0	2.25	1.30	1.61	0.09	0.053	2.03

Table 4.20.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)										Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	ZnO	MnO	
76	0-15	49.8	24.2	6.05	0.3	2.81	0.16	1.55	0.23	0.024	0.059	10.26
77	15-57	50.7	23.9	6.57	0.2	2.99	0.15	1.50	0.24	0.022	0.057	9.09
78	57-85	52.3	22.2	7.07	0.2	3.12	0.14	1.61	0.11	0.024	0.056	9.87
79	85-155+	54.6	22.8	6.70	0.3	2.40	0.12	1.45	0.12	0.024	0.058	10.00

Table 4.20.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
76	0-15	76.8	11.2	3.12	0.4	1.82	0.70	0.59	0.17	0.066	2.42
77	15-57	75.5	11.7	3.07	0.4	1.70	0.56	0.58	0.14	0.080	3.48
78	57-85	74.3	12.4	3.53	0.2	1.67	0.56	0.68	0.16	0.045	4.30
79	85-155+	74.8	12.0	3.59	0.1	1.49	0.62	0.69	0.15	0.053	2.82

Table 4.20.9 Elemental composition of lime concretions

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
78	67-85	32.1	1.9	1.83	28.67	4.34	0.22	0.34	0.135	0.471	6.21
79	85-155+	33.4	1.9	1.87	23.52	3.67	0.34	0.40	0.204	0.263	7.14

Table-4.20.10 Semi-quantitative estimates of sand and silt minerals

Lab. No.	Depth (cm)	Chlorite	Mixed layer	Mica	Amphibole	Chlorite + Kaolinite	Quartz	Orthoclases	Plagioclases	Calcite
Sand										
76	0-15	++	++	++++	-	++	+++++	++	++++	+
78	57-85	+	-	+++	-	++	+++++	+++	++++	++
Silt										
76	0-15	+	+	+++	-	+++	+++++	++	++++	+
78	57-85	++	++	++++	-	+++	+++++	+++	+++	+

Table 4.20.11 Semi-quantitative estimates of clay minerals

Lab. No.	Depth (cm)	Smectite	Chlorite	Vermiculite	Illite	Mixed layer	Kaolinite	Quartz	Feldspar	Amphibole
%										
76	0-15	15	12	5	52	9	4	1	1	1
78	57-85	18	11	7	50	7	4	1	1	1

Pedon No. 21 SIRSA-LOWLAND

Classification: Typic Ustochrept, fine loamy, mixed, hyperthermic

Location: 74° 54'1"E, 29° 26'11"N, Madhosingh wala village on Sirsa to Elnabad road, district Sirsa

Physiography: Levee

Topography: Micro depression, 1-3 per cent slope

Drainage: Poorly drained

Landuse: Cultivated

Elevation 196 m

Rainfall: 410 mm

Table 4.21.1 Morphology

Lab.Depth	Horizon	Boundary	Colour (moist)	Mottling	Texture (USDA)	Structure	Consistence (wet)	Cutans	Roots	Coarse fragments	Reaction
No. (cm)											
80	0-17	Ap	gw	10YR 4/3	-	1	2m,sbk	ws.wp	-	c,vf	3
81	17-43	B1	gw	10YR 4/4	-	sil	2m,sbk	ws,wp	-	f,vf	3
82	43-86	B21	gw	10YR 4/4	-	sic	3m,sbk	wvs,wvp	p,tn	f,vf	conca,f-m
83	86-140+	B22		10YR 4/3	-	sic	3m,sbk	wvs,wvp	-	-	conca,f

Table 4.21.2 Physico-chemical characteristics

Lab. No.	Depth (cm)	Size class and particle diameter(mm)				Coarse fragments (%)	Water content (%)				
		Sand (2 - 0.05)	Silt (0.05 - 0.002)	Clay (< 0.002)	1/3 bar		15 bar	Available			
									(< 0.002)		
									% of < 2 mm		
80	0-17	42.1	40.9	17.0	-	23.8	12.4	11.4			
81	17-43	25.5	46.7	27.8	1	25.4	15.1	10.3			
82	43-86	16.0	43.1	40.9	2	26.9	17.3	9.6			
83	86-140+	17.8	42.5	39.7	2	26.9	16.6	10.3			

Lab. No.	Depth (cm)	Organic carbon (%)	Calcium carbonate (%)	pH ₂	EC ₂ dSm ⁻¹	Bulk density Mg m ⁻³	Hydraulic conductivity cm hr ⁻¹	DTPA extractable (mg kg ⁻¹)			
								Fe	Mn	Cu	Zn
80	0-17	0.56	1.61	9.4	0.89	1.84	0.007	18.2	8.7	1.36	0.30
81	17-43	0.24	2.20	9.4	1.70	1.78	-	7.2	3.2	0.74	0.20
82	43-86	0.19	0.78	8.5	3.65	1.84	0.048	7.0	1.4	0.76	0.20
83	86-140+	0.16	0.80	8.9	2.56	1.73	0.006	7.4	1.0	0.80	0.28

Table 4.21.3 Exchangeable cations

Lab. No.	Depth (cm)	Exchangeable cations (c mol kg ⁻¹)				CEC	ESP
		Na	Mg	Ca	K		
		(c mol kg ⁻¹)					
80	0-17	1.3	2.5	2.4	0.15	6.3	20
81	17-43	2.8	3.3	3.5	0.14	9.8	29
82	43-86	3.8	4.1	4.0	0.15	12.0	31
83	86-140+	4.2	4.6	4.0	0.26	13.1	32

Table 4.21.4 Saturation extract analysis

Lab. No.	Depth (cm)	Saturation (%)	pH _s	EC _e dSm ⁻¹	Saturation extract analysis (me/l)							SAR	
					Na	Mg	Ca	K	CO ₃	HCO ₃	Cl		SO ₄
80	0-17	32	8.5	3.2	21.5	11.0	4.1	0.13	0.0	11.2	12.0	12.1	8
81	17-43	32	8.5	7.0	58.5	12.0	5.0	0.11	0.0	7.0	23.1	39.2	20
82	43-86	48	8.3	7.7	70.5	16.0	8.2	0.14	0.0	3.5	35.1	44.3	20
83	86-140+	45	8.4	6.2	50.6	14.2	8.1	0.22	0.0	4.2	34.1	29.2	15

Table 4.21.5 Elemental composition of sand fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
80	0-17	85.9	5.21	1.79	0.1	1.67	2.28	0.64	0.09	-	1.20
81	17-43	83.4	5.26	1.78	0.3	1.34	2.20	0.63	0.09	-	1.98
82	43-86	84.1	4.89	1.59	0.8	1.25	2.01	0.53	0.10	0.010	0.99
83	86-140+	84.3	4.94	1.70	0.7	1.50	1.97	0.63	0.10	-	1.44

Table 4.21.6 Elemental composition of silt fraction

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅		MnO
80	0-17	74.6	12.1	3.69	0.0	2.59	1.43	1.65	0.11	0.079	1.79
81	17-43	74.4	12.3	3.60	0.0	2.51	1.39	1.76	0.07	0.086	2.70
82	43-86	75.1	12.9	3.79	0.0	2.59	1.12	2.01	0.05	0.088	2.91
83	86-140+	73.9	12.8	3.78	0.0	2.25	1.56	2.15	0.06	0.070	3.66

Table 4.21.7 Elemental composition of clay fraction

Lab. No.	Depth (cm)	Elemental composition (%)										Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	ZnO	MnO	
80	0-17	55.1	21.7	7.10	0.3	2.84	0.16	1.57	0.25	0.029	0.045	10.22
81	17-43	53.1	22.5	6.22	0.0	2.82	0.23	1.53	0.09	0.029	0.045	8.48
82	43-86	54.6	22.3	6.61	0.1	2.22	0.25	1.57	0.06	0.031	0.023	8.45
83	86-140+	52.9	22.2	7.60	0.2	2.49	0.27	1.69	0.05	0.035	0.010	8.26

Table 4.21.8 Elemental composition of soil

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	MnO
80	0-17	75.2	11.0	3.32	0.2	1.57	0.95	0.73	0.19	0.066
81	17-43	71.5	13.2	3.99	0.3	1.67	0.70	0.74	0.14	0.067
82	43-86	68.1	15.2	4.60	0.0	1.69	0.54	0.67	0.14	0.063
83	86-140+	68.5	14.9	4.49	0.0	1.85	0.52	0.87	0.15	0.058
										4.44

Table 4.21.9 Elemental composition of lime concretions

Lab. No.	Depth (cm)	Elemental composition (%)								Loss on ignition (%)
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	MnO
81	17-43	30.1	1.8	3.07	30.16	2.82	0.21	0.35	0.181	0.695
82	43-86	30.0	1.9	2.76	29.10	1.54	0.25	0.39	0.211	0.351
83	86-140+	31.7	1.9	2.33	25.61	3.24	0.22	0.53	0.460	0.205
										7.74

value (Table 4.20.11) suggested the dominance of illite followed by smectite, chlorite, vermiculite, mixed layers and kaolinite. Primary minerals associated with the clay contributed only minor proportions. Smectite content in these soils ranged between 15 to 18 per cent.

4.4 Water analysis

Water samples were collected from the source nearest to pedon site. Few samples from the important rivers i.e. Ghaggar and Tangri were also collected. Electrical conductivity and ionic composition of these waters are presented in the Table 4.22.1.

An attempt has been made to plot the electrical conductivity, dominant cation and anion in the water against the distance of point of collection from the nearest catchment area. Both the graphs have been plotted for those pedon sites for which soil geomorphology diagrams were prepared. A perusal of figure 4.68 which represents N-S transect covering a distance of about 135 km indicated that electrical conductivity, Mg and HCO_3 ions increased with increase distance from the nearest catchment area.

Similarly N-W transect sites (Fig. 4.69) covering a distance of 224 km revealed a similar trend as in the case of N-S transect except that samples from Samdhan alkali are had very high EC and Mg. This area is actually part of relicts of flood plain of Sarasvati river which desiccated long back. In this area Cl content was almost equal to HCO_3 content.

Samples from Narnaund area were having very high EC. Na followed by Mg dominated among cations and Cl followed by SO_4 dominated among the anions. This area lies in paleo-channel of the old Chautang river which desiccated long back.

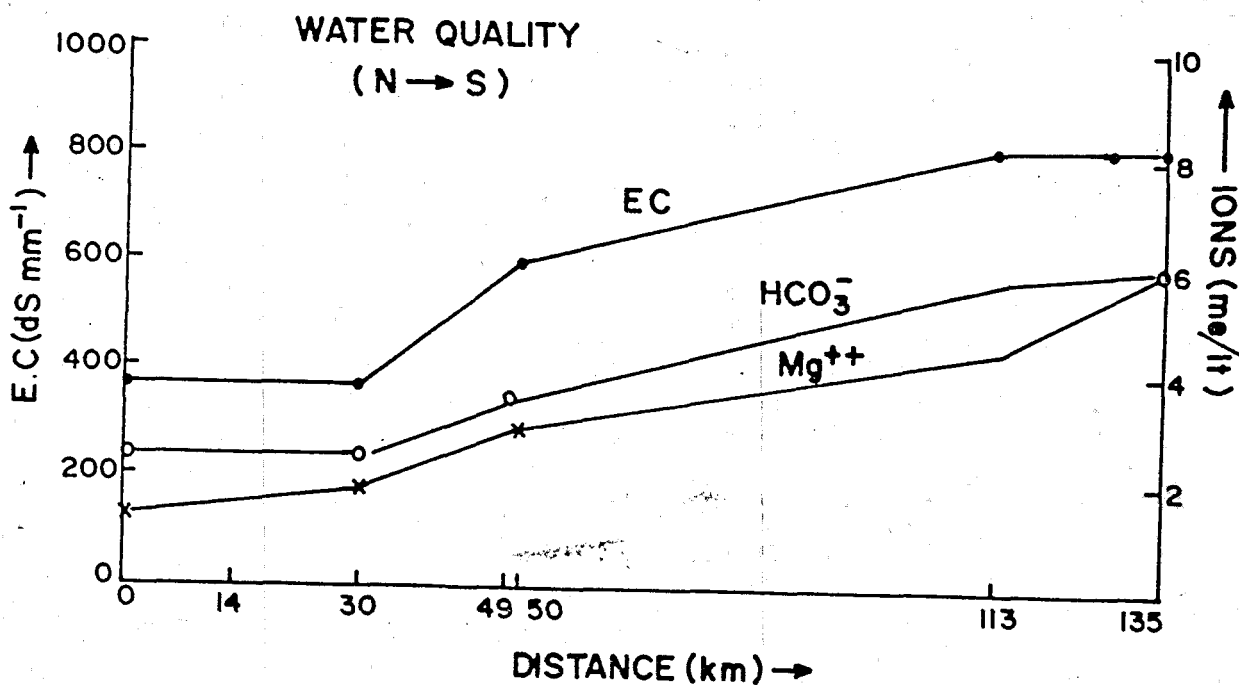


Fig.4.69 Water quality, North-West transect

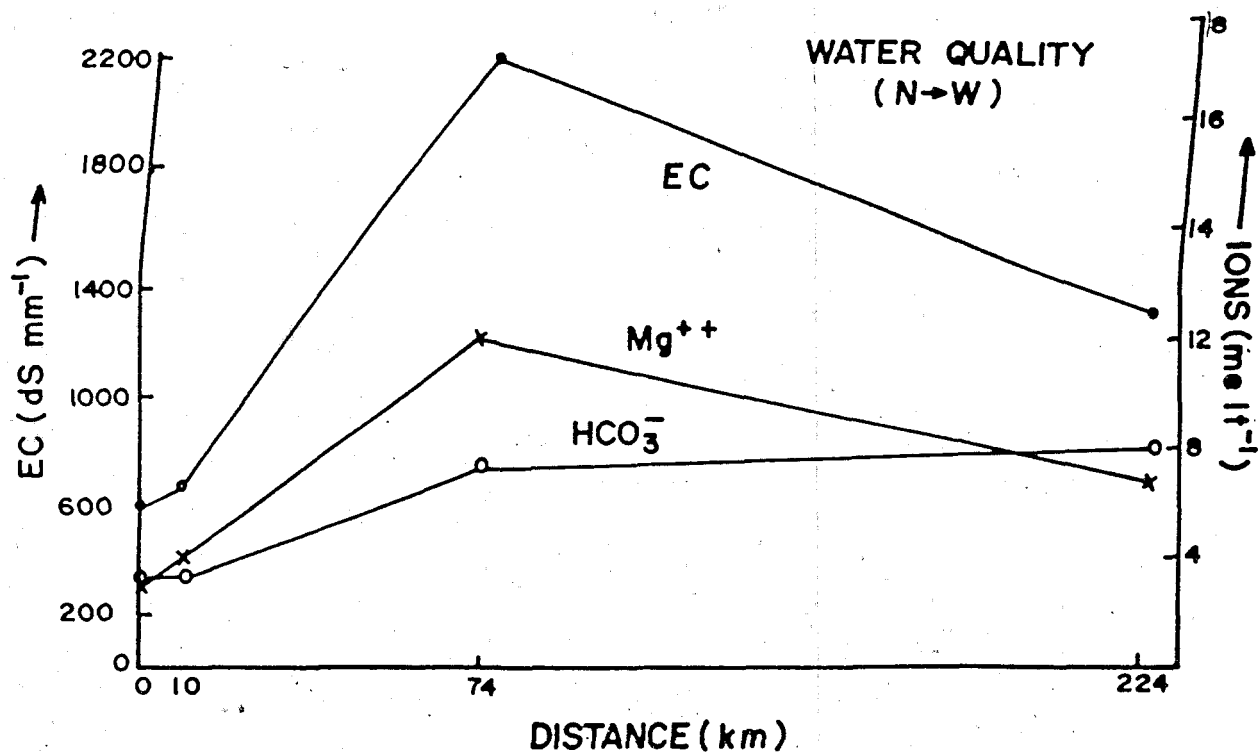


Fig.4.68 Water quality, North-South transect

Table 4.22.1 WATER ANALYSIS

Lab. No.	Location	pH	EC dSmm ⁻¹	Ionic compositions (me/l)							SAR	RSC	
				Na	Mg	Ca	K	CO ₃	HCO ₃	Cl			SO ₄
w-1	Sherpur	8.0	595	1.8	2.8	1.3	0.04	2.8	3.3	0.0	0.3	1.26	2.0
w-2	River Ghaggar	8.5	553	2.2	2.8	0.3	0.08	1.4	2.6	1.0	0.6	1.76	0.9
w-3	Saha	8.6	671	2.2	4.3	0.8	0.08	2.1	3.5	0.5	0.1	1.37	0.5
w-4	River Tangri	8.4	350	0.6	1.3	1.3	0.12	1.4	2.1	0.0	0.1	0.52	0.9
w-5	Panchkula (summer)	8.6	445	2.0	2.3	0.8	0.23	1.4	2.8	0.5	0.5	1.61	1.1
w-6	Panchkula (rainy)	8.5	374	0.4	1.3	1.8	0.06	0.7	2.4	0.0	0.7	0.32	0.0
w-7	Lalru (rainy)	8.5	185	0.4	1.0	0.3	0.06	0.0	1.4	0.5	0.3	0.50	0.1
w-8	Lalru (hand pump)	8.6	461	1.8	2.0	1.0	0.04	1.4	3.2	0.0	0.3	1.47	1.6
w-9	Lalru (Jhurmut nala)	8.5	378	1.6	1.8	2.3	0.19	0.4	2.4	0.5	0.5	1.56	0.7
w-10	Narnaund	8.9	4573	22.6	19.0	3.3	0.18	2.8	7.4	21.0	16.0	6.77	-
w-11	Sirsa	8.5	1362	3.6	6.8	3.3	0.10	2.1	8.1	3.8	0.0	1.60	0.1
w-12	Gudda	8.9	817	2.5	6.0	2.5	0.11	2.1	6.0	1.3	1.0	1.21	-
w-13	Samdhan	8.3	2238	2.8	12.5	5.0	0.03	2.8	7.4	7.3	0.2	0.94	-
w-14	CSSRI, Karnal-f. alkali	8.5	915	2.9	4.8	2.8	0.11	2.1	5.3	1.5	2.0	1.48	-
w-15	CSSRI, Karnal-alkali	8.5	823	1.1	4.0	3.5	0.10	2.1	5.3	1.5	0.0	0.56	-
w-16	CSSRI, Karnal-r. alkali	8.4	742	1.3	4.0	2.5	0.11	0.7	6.3	1.0	0.0	0.72	0.5
w-17	CSSRI, Karnal-normal	8.1	915	2.7	4.8	2.8	0.12	1.7	5.1	1.5	1.0	1.38	-

Water samples were further grouped on the basis of geomorphology of the area. Only EC and SAR values were compared based on the limits given by Richard (1954) in the Agril. Handbook No. 60 of USDA.

<u>Geomorphology</u>		<u>Water quality</u>
Piedmont		
-Upper	-	C1 S1
-Lower	-	C1 S1
Alluvial plain		
-Upper	-	C2 S1 to C3 S1
-Lower	-	C3 S1 to C4 S1

These results indicated that water remained normal upto piedmont plains. The moment these entered the alluvial plains, where most of the rivers have deposited their sediments (including the salts), waters got mixed with these salt impregnated material and their quality deteriorated. R.S.C. of all the water samples was low and varied from negative to 2.0 only.

4.41 Sediments: Water samples collected from the streams on the day of first monsoon shower of season on 29th June, 1990 contained a lot of sediments. Amounts of these sediments varied from 0.24 g/l in water sample of Jhurmut Nullah (near Lalru profile) to 30.1 g/l in the Ghaggar river near the Panchkula area. These sediments were further analysed without any pre-treatment for their total elemental composition (Table 4.23.1). SiO_2 , Al_2O_3 and Fe_2O_3 content of these sediments varied from 53.12 to 57.99, 21.38 to 23.70 and 6.71 to 10.47 per cent, respectively. CaO ranged from traces to 1.20. MgO, Na_2O and K_2O content of these sediments varied between 2.74 to 3.79, 0.31 to 0.73 and 1.33 to 1.63 per cent, respectively. ZnO and MnO content of these sediments ranged between 0.039 to 0.053 and 0.13 to 0.22 per cent, respectively. Loss on ignition of these sediments varied from 5.1 to 6.8 per cent. Analysis indicated that these sediments are quite rich in iron, magnesium and potassium.

Table 4.22.2 Elemental composition of water sediments

Lab. No.	Location	Elemental composition (%)								Loss on ignition (%)	
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	ZnO		MnO
w-4	River Tangri	57.9	21.4	7.33	0.45	2.74	0.49	1.33	0.053	0.13	5.4
w-5	Panchkula (summer)	56.6	22.1	10.47	0.32	3.29	0.31	1.63	0.048	0.14	5.1
w-6	Panchkula (rainy)	56.4	22.4	6.71	1.20	3.01	0.42	1.46	0.039	0.15	6.8
w-9	Lalru(Jhurmut nala)	53.1	23.7	8.04	0.00	3.79	0.73	1.45	0.048	0.22	6.4

CHAPTER V

DISCUSSION

- 5.1 Geomorphology, morphology and physico-chemical characteristics
- 5.2 Elemental composition
- 5.3 Origin of ferro-magnesian mineral grains
- 5.4 Origin of calcium carbonate concretions
- 5.5 Stability of alumino-silicates
- 5.6 Taxonomy of salt affected soils
- 5.7 Clay mineral genesis
 - 5.71 Ghaggar river basin
 - 5.72 Smectite controversy
 - 5.73 Drsadvati-Chautang basin
- 5.8 Mineralogy of coarse fraction
- 5.9 Source of salts
- 5.10 Mechanism of sodium carbonate formation
- 5.11 Mineralogical aspects of reclamation
- 5.12 Reclamation efforts in Haryana

5.1 Geomorphology, morphology and physico-chemical characteristics:

Macro-morphology and physico-chemical characteristics of various pedons located in different geomorphic locations have been described in the previous chapter. The results indicate that alkali soils in general have dark yellowish brown to olive brown colours. Reddish brown mottles are encountered in the pedons located in the micro-depressions. The B horizon texture mostly varies from loam to silty loam. Surface horizon texture is generally lighter than the B horizon. Thin patchy cutans are mostly present in the B horizon. Dark coloured ferro-magnesian grains (for details section 5.3) are present only in the pedons from Sherpur, Karnal and Gudda. Most of the soils are calcareous.

Presence of calcium carbonate rich calcic horizon at about one metre depth as reported by Bhargava et al. (1981) was observed only in few pedons and its depth varied widely.

Most of the physico-chemical characteristics of these soils are in consonance with the reports of Bhumbra et al. (1973), Abrol et al. (1972) and Bhargava et al. (1980). Hydraulic conductivity of these soils is very low. Acharya and Abrol (1991) have reported this to be due to the sealing of water conducting pores by the dispersed soil particles due to high sodium saturation. Another reason could be the presence of higher amounts of swelling and shrinking clay minerals like smectite in the B horizon as discussed in section 5.72.

Organic carbon generally decreases with depth, however, this decrease is irregular in soils with fluventic characteristics (Saha and Lalru pedons). Sodium is dominant on the exchange complex as well as in the saturation extract. The situation changes in favour of divalents upon reclamation by chemical amendments (CSSRI-reclaimed alkali; Gudda-reclaimed alkali, Samdhan-reclaimed alkali pedons) or by natural vegetation (epipedon of CSSRI fenced alkali, CSSRI normal pedons). Similarly carbonate + bicarbonate generally dominate among the anions in the saturation extract with chloride following closely.

Some of the observations made during the course of this study do not confirm to the earlier reports on this subject, e.g. alkali soils do occur in hilly areas as well as upland areas of alluvial plain, with rainfall more than 1125 mm (Panchkula, Ramgarh pedons) to less than 410 mm (Sirsa pedons) udic as well as ustic moisture regimes. This is contrary to the reports of Bhargava (1980), Bhargava et al. (1981), Vinayak et al. (1981), Bhargava and Bhattacharjee (1982) and Acharya and Abrol (1991). Thus geomorphology and/or semi-arid climate may not be completely responsible for the formation and

development of alkali soils in the Satluj-Yamuna divide of the alluvial plains. This observation has been discussed in detail in the geomorphology and soils section (4.2).

Alkali soils also exist below the lithological discontinuity in the normal soils (Saha and Lalru pedons). This observation does not support the belief of in-situ development of sodicity from the weathering products of alumino-silicates as held by Bhargava et al. (1980), Bhargava and Bhattacharjee (1982), Gupta and Gupta (1989) and Acharya and Abrol (1991). Occurrence of alkali soils (Lalru pedon) with pHs and EC_e ranging from 9.2 to 10.4 and 1.81 to 20.63 dSm^{-1} on a gently sloping pedon in a high rainfall (1050 mm) area has also been observed.

Another significant observation is the dominance of sodium and chloride ions in the saturation extract of the Panchkula, Ramgarh and Kaleshar pedons located in hilly areas of Siwaliks (discussed in detail in section 5.9). This should provide a reason for a fresh thinking on the genesis of these alkali soils of the Indo-Gangetic alluvium.

5.2 Elemental composition:

Total elemental analysis of sand, silt, clay and whole soil after removal of carbonates, organic matter, free iron oxides, exchangeable and water soluble cation has been presented in previous chapter. Keeping in view the objectives of the present investigation, discussion here will be mostly confined to sodium and calcium only. In the absence of analytical data on the resistant minerals like titanium and zircon, an attempt has been made to group pedons on the basis of their parent material. Na_2O content of the sand fraction has been used as a parameter on the grounds that plagioclases are maximum in this fraction. Owing to low CaO content of (< 1 per cent) minerals, it is obvious that these feldspars are mostly alkali-calcic and/or alkaline plagioclases which are more

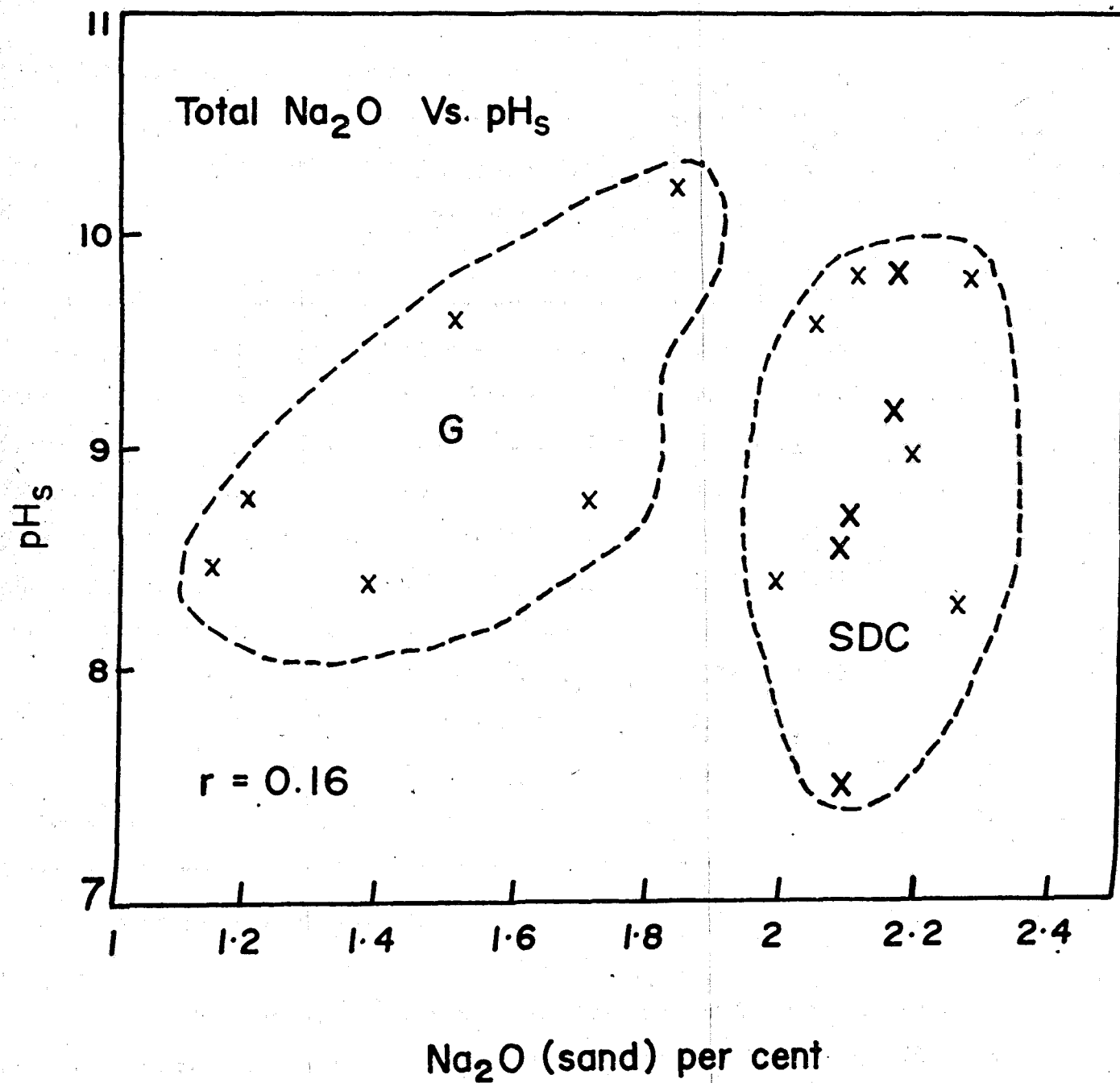


Fig.5.1 Na₂O content and pH_s of pedons

stable than the calcic and/or calcic- alkali plagioclases (Goldich 1938; Rai and Kittrick, 1989). Accordingly the weighted average of the Na_2O content of all the pedons excluding those in the hilly area is presented below.

Table 5.1 Na_2O and pHs of pedons

Pedons of	$\text{Na}_2\text{O}^{\dagger}$	pHs [†]	Pedons of Drsadvati	$\text{Na}_2\text{O}^{\dagger}$	pHs [†]
Ghaggar river	%		Chautang basin	%	
basin					
Panchkula	1.20	8.78	CSSRI-fenced alkali	2.10	9.80
Ramgarh	1.15	8.47	CSSRI-alkali	2.04	9.60
Lalru	1.84	10.20	CSSRI-recl. alkali	2.08	8.57
Sherpur	1.50	9.60	CSSRI-normal	2.09	7.46
Saha	1.38	8.40	Gudda-alkali	2.16	9.83
Sirsa-upland	1.71	8.76	Gudda-recl. alkali	2.10	8.71
Sirsa-lowland	1.98	8.40	Samdhan-alkali	2.27	9.79
			Samdhan recl. alkali	2.18	8.99
			Narnaund-alkali	2.15	9.19
			Narnaund-normal	2.25	8.31

$$r (\text{Na}_2 \times \text{pHs}) = 10$$

[†]weighted average of sand fraction

Lower Na_2O content of Ramgarh and Panchkula pedons may be due to their being very close representative of Subathu geological formation (details discussed in section 3.13) and their location in the sub-hilly areas. In the piedmont and alluvial plain soils Na_2O content increased owing to greater contributions from high plagioclase containing material from other geological formations like Siwaliks, as brought down by various rivers and streams.

Interestingly the above observation divides the pedons into two distinct groups i.e. the pedons located in the Ghaggar river course and those located in the Drsadvati-Chautang basin.

The pedons of Drsadvati-Chautang basin which have received greater contributions from Siwalik series and lesser from the Sirmurs contained relatively higher amounts of Na_2O as compared to those of the Ghaggar basin which incidentally has received more contribution from the Subathu as discussed in later section (5.7). Details about the plagioclases and orthoclases contributions by various geological formations are discussed in the sand mineralogy section (5.8).

A noticeable observation from the four pedons of CSSRI, Karnal is that the Na_2O content of sand fraction of fenced alkali, reclaimed alkali and CSSRI normal pedons is almost identical. This proves the uniformity of parent material of CSSRI pedons and eliminates the role of alkali plagioclases as the responsible mineral for the development of sodicity in these alkali soils as reported by Bhargava et al. (1981), Kapoor et al. and Abrol et al. (1981); Bhargava and Bhattacharjee (1982); and Gupta and Gupta (1981). Had it been so, the Na_2O content of CSSRI-normal pedon would have been entirely different from the adjoining CSSRI-alkali pedons. Further more, the data shows (Fig.5.1) that there is hardly any correlation ($r = 0.16$) between pHs and the Na_2O ; thus clearly indicating that mineral sodium (plagioclases) has hardly any role to play so far as the alkalinity of these soils is concerned.

An other significant observation emanating from the elemental analysis of sand, silt, clay and whole soil (after destruction of carbonates) is the extremely low CaO content (< 1 per cent) of these soils. This is true for both alkali and normal soils and irrespective of geomorphological position. Even if whole CaO content of the soils is taken to be transformed to CaCO_3 , it will only

account for a fraction of the calcium present in the lime concretions. Thus lime concretions in these pedons can not be pedogenic as reported by Kanwar and Sehgal (1962), Sehgal and Stoops (1972), Bhargava et al. (1981) and Bhargava and Bhattacharjee (1982).

Elemental composition of these soils as well as of the sand, silt and clay fraction also provides another important information regarding trends in Fe_2O_3 contents. Since the free sesquioxides had already been removed prior to analysis, the increase in Fe_2O_3 content with depth in different content pedon is indicative of increasing content of iron bearing minerals in different horizons and has nothing to do with the process of illuviation.

5.3 Origin of ferro-magnesian mineral grains:

It is interesting to note that these ferro-magnesian grains when analysed (Sherpur, CSSRI, Karnal and Gudda pedons) were found to be highly siliceous ($\text{SiO}_2 = 70-75$ per cent) and in addition contain bases (6-7%). Iron, manganese and zinc oxides make up less than 14.0 per cent of total mass. The loss on ignition values are also low (8-9 per cent). This explains why the name ferro-magnesian grain has been preferred over the iron-manganese concretions. The mineralogical analysis (Fig. 5.2) also indicated that these grains are basically composed of quartz, with goethite (0.418, 0.338, 0.269, 0.249, 0.245, 0.225 nm), ferrihydrite (0.254, 0.246, 0.224, 0.198, 0.173, 0.151, 0.147 nm), maghemite (0.252, 0.209, 0.182, 0.170, 0.161 nm) and riebeckite (0.84, 0.451, 0.342, 0.311, 0.273, 0.260 nm) contributing only minor proportions. This indicates that these ferro-magnesian grains were not of pedogenic origin and were possibly transported as part of alluvium.

Further, field observations show that none of these pedons had fluctuating water table or ferriargillans up to the studied depth. Under such conditions it is difficult to believe that these are concretions in the first instance, or

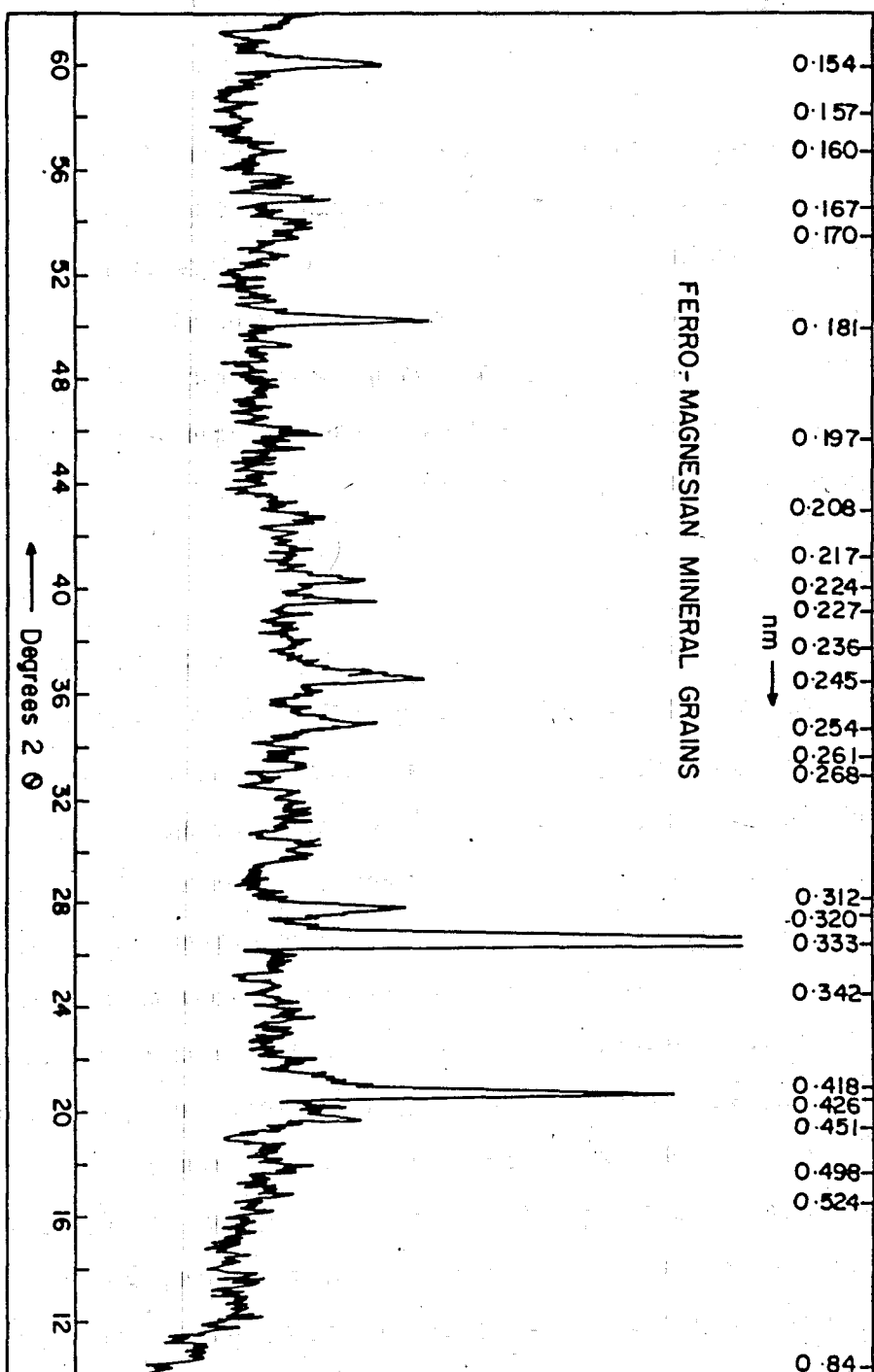


Fig.5.2 X-ray diffractogram of ferro-magnesian grains

have formed in- situ especially when these grains have such a low sesquioxide content and extremely high silica content along with the bases. On the contrary the geological formations (source of this alluvium) are rich in ferro-magnesian minerals besides ferruginous beds that are encountered in the Sirmur series as well as other geologic formations, which could have been transported along with the alluvium. Once deposited in the soil, these mineral grains can undergo minor changes in terms of oxidation of Fe, Mn and slight dissolution and release of alkali and alkaline earths, which is apparent from the presence of small amounts of goethite, ferrihydrite and meghamite in these samples. The riebeckite is an iron rich amphibole and is probably part of the original ferro-magnesian mineral grain. These slightly weathered ferro-magnesian mineral grains can easily be mistaken for iron-manganese concretions in the field. Under extreme weathering conditions complete loss of silica and bases accompanied by oxidation and preferential re-precipitation of the sesqui-oxides on the outer surface of respective mineral grain may result in the formation of the concretions (Arshad and Arnaud, 1980; Ghabru et al., 1990). However, such conditions are not prevalent in these soils especially with their strong alkaline environment.

5.4 Origin of calcium carbonate concretions

Geological formation contributing to the alluvium under study are rich in nummulitic limestone, nodular limestone, dolomite, calcareous and gypsiferous schist and shale. Most of the lime concretions encountered in both river basins also appear to have been transported as a part of the alluvium. In order to confirm their primary origin it is necessary to go through their chemical composition (Table 5.2) pedogenic environment and nature of the alluvium.

Table 5.2 Chemical composition of lime concretions

S.No.	Pedons	SiO ₂	Fe ₂ O ₃	MgO	CaO	CaCO ₃	P ₂ O ₅
%							
1.	Ramgarh, Panchkula	61-76	2.4-2.8	1.3-2.0	12-14	28-36	0.06-0.10
2.	Other pedons of Ghaggar basin	31-39	1.7-2.8	1.1-3.2	21-30	47-62	0.06-0.20
3.	Pedons of Drsadvati- Chautang basin	28-45	1.8-4.5	1.2-4.0	19-30	43-63	0.03-0.13

Chemical composition of the lime concretions of the Ramgarh and Panchkula pedons is entirely different. This is due to the fact these pedons are almost true representative of Subathu geological formations. Other pedons of Ghaggar basin which were located in relatively lower geomorphological positions had received contributions from various members of Siwalik and Sirmur series in addition to the Subathu as number of other streams joins these river down stream. Thus, leading to a variable dilution of siliceous matter.

The same can be said about concretions from the pedons of Drsadvati-Chautang river basin which got lesser contribution from Subathu and Sirmur but greater materials from the Siwaliks, Tal, Krol, Blaini, Navkot and Jutogh formations.

A perusal of the data indicate that these concretions contain large amounts of SiO₂ ranging between 28 to 76 percent. Furthermore, the

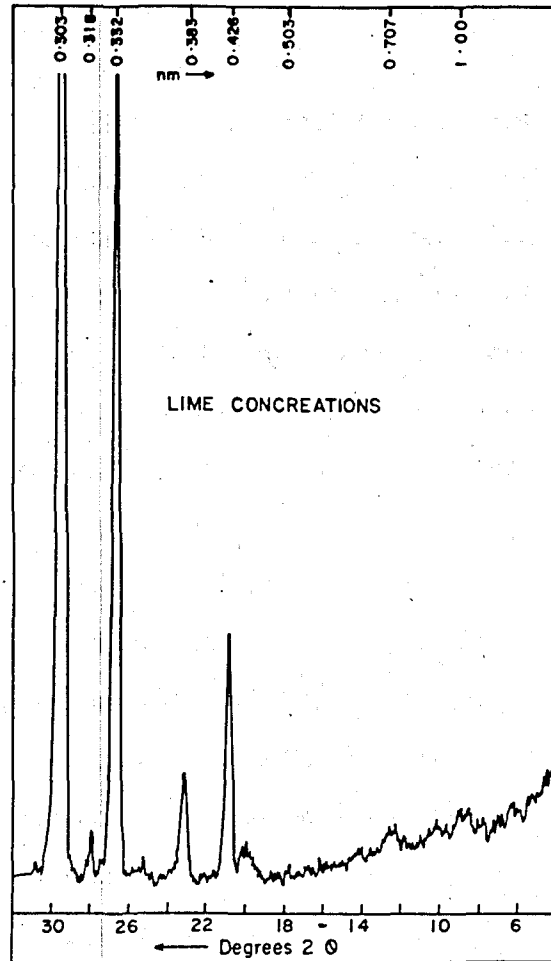
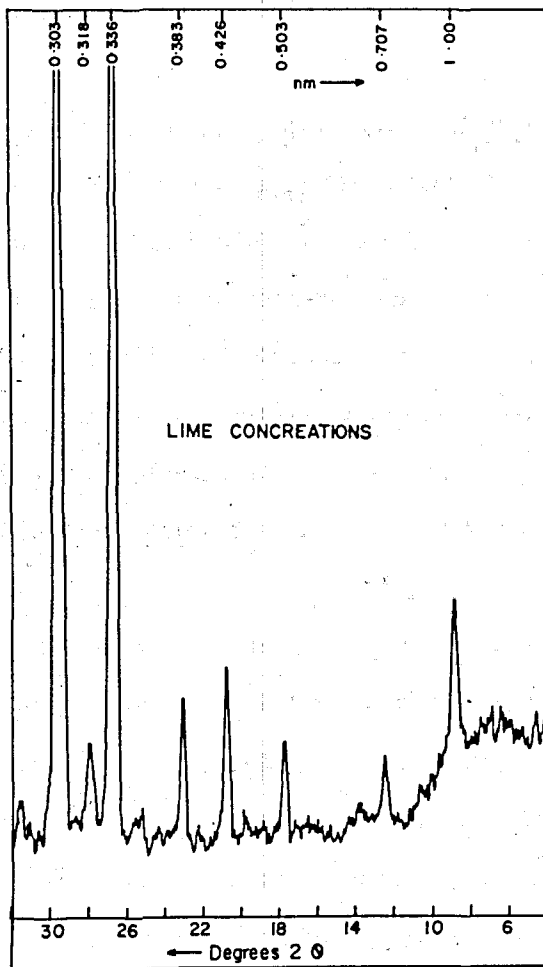


Fig.5.3 X-ray diffractogram of lime concretions

pseudo-mycellar lime indicating solubilization of lime was not observed in any of the pedons. These concretions are rich in calcite, dolomite and contain large amounts of silicates as well as phosphates (Fig. 5.3). Shape, size, abundance as well as silicate content of concretions found in pedons agree well with the nummulitic and nodular limestone present in various geological formations (Wadia, 1965).

A simple follow up of calcium carbonate solubility at the soil temperature commonly met in these soils strongly indicates that calcium carbonate can not remain in the soluble form in these soils because its solubility decreases with increase in temperature. In this context the reports of Kanwar and Sehgal (1962), Sehgal and Stoops (1972), Bhargava et al. (1981), and Bhargava and Bhattacharjee indicating pedogenic formation of CaCO_3 with fluctuating ground water table, in soils containing very low amounts of total calcium (< 1 per cent) do not seem convincing explanation.

Based on chemical and micro-morphological evidences, primary nature of calcium carbonate nodules in the soils of the Haryana has also been reported by Manchanda et al. (1984) and Ahuja and Khanna (1984). Presence of lime concretions at various depths upto 325m in a bore hole near Kaithal (Bhumbla et al., 1973) also shows their primary origin. Presence of calcium carbonate nodules in levees, channel (Manchanda 1978, Ahuja, 1981) canals and rivers of this area further confirms their origin from the geological formations.

Thus, when calcium carbonate concretions are abundantly present in Sirmur as well as Siwaliks, Tal, Krol, Blaini; and the pedogenic environment is hardly conducive, it may be safe to assume that these concretions are transported in nature. Their presence at certain depths in a certain profile is simply due to the nature of alluvium brought down by different rivers. It is obvious that calcium carbonate concretions that are much larger in size than soil matrix must

have been deposited during floods, whereas finer alluvium that might also contain powdered (during transport) concretions was laid down during lean periods.

5.5 Stability of alumino-silicates: Existing literature concerning weathering of soil minerals generally dwells upon the chemical composition of the minerals involved. The composition of soil solution has been usually considered in qualitative terms. Very low solubilities and slow rates of dissolution and precipitation of common soil minerals under most conditions have often obscured what is now becoming obvious, i.e. the equilibrium reactions of soil minerals with soil solution as described by thermo-dynamics (Kittrick 1971).

The pH and cation composition of the ambient soil solution control the solubility/weathering or stability of the common alumino-silicates. Weathering of minerals releases various ions into soil solution. Minerals that maintain the lowest Al^{3+} activity at a given H_4SiO_4 activity are most stable. Weathering sequence of well drained soils allowing leaching of cations and silica resulting in low H_4SiO_4 activity are different from those of poorly drained soils maintaining higher activities of cations and H_4SiO_4 .

Results of the thermodynamic stability of common soil minerals for selected samples of various pedons are described in the previous chapter. A perusal of these results indicate that:

- (1) With increase in pHs, at a given H_4SiO_4 activity the activity, of Al^{3+} decreases, resulting in increased stability of the alumino-silicates.
- (2) At the same pHs but with increased activities of cations and H_4SiO_4 , as is the case in poorly drained soils, the activity of Al^{3+} decreases manifolds, resulting in increased stability of the primary as well as

secondary minerals in these soils.

- (3) With change, in pHs 8.2 (CSSRI normal soil, Fig.4.46) under low H_4SiO_4 activity (10^{-5}) i.e. well drained, to pHs 10.3 (CSSRI- fenced alkali soil, Fig.4.37) under high H_4SiO_4 activity ($10^{-2.74}M$) i.e. poorly drained, the equilibrium Al^{3+} activity of various primary and secondary minerals decreases roughly by 10^{-12} to 10^{-22} of those at pHs 8.2. Thus, stability of common alumino- silicate increases manifolds under poorly drained alkali environment. Under the soil solution environments described above the stability of alumino-silicate (increasing order) changes from: (CSSRI-normal)-albite, microcline, vermiculite, illite, montmorillonite, muscovite, kaolinite and chlorite, to (CSSRI- fenced alkali)-kaolinite, muscovite, illite, microcline, montmorillonite, albite, vermiculite and chlorites.

Thus, montmorillonite, vermiculite, albite and chlorite become more stable under alkali environments and their higher contents are predicted in these soils.

Conversely, in the well drained environment illite, montmorillonite, muscovite, kaolinite and chlorite are more stable and their higher amounts can be expected under these environments.

- (4) With reclamation by chemical amendments or by natural vegetation relative stability of minerals (increasing order) changes from: (Gudda-alkali, Fig. 5.6; CSSRI fenced alkali, Fig.4.37; Samdhan alkali, Fig.4.51), albite, microcline, vermiculite, illite, montmorillonite, kaolinite, muscovite and chlorite;

to

(Gudda recl. alkali, Fig. 5.6; CSSRI recl. alkali, Fig. 4.41; Samdhan recl. alkali, Fig. 4.55) albite, microcline, vermiculite, illite, montmorillonite, kaolinite, muscovite and chlorite.

Thus, stability of kaolinite and muscovite increases along with other physico-chemical change in the soils due to reclamation by gypsum or natural vegetation. This indicates a possible break down or transformation of montmorillonite/smectite to kaolinite either through a chloritised component in independent phase or as a part of mixed layer component. Since climatic conditions in this area are not conducive to kaolinite formation, hence the transformation of smectite may proceed only upto mixed layer or chloritised component only. There are several reports in literature (Altschuler et al., 1963; Wilson and Cradwick, 1972; Sakhrov and Drits, 1973; Morgan et al., 1979, Karthansis and Hajek, 1983; Combs, 1982, Karthansis, 1991) indicating transformation of smectite to kaolinite plus iron oxide directly or via 0.74 nm mixed layer kaolinite-montmorillonite; upon improvements in drainage.

- (5) Under a highly leached environment and low pH as is the case with soils of Lal Dhang vermiculite, albite, chlorite and illite are least stable. However, muscovite and kaolinite are much stable under these soil solution environment.

Thus large amounts of muscovite-mica and kaolinite should be expected under these conditions.

- (6) Al^{3+} activity as maintained in all the studied soils at their constituent cations activity level and H_4SiO_4 activity of $10^{-4}M$ (quartz) has been plotted against the respective pHs (Fig. 5.4, 5.5). These figures clearly indicate that stability of primary as well as secondary alumino-silicate minerals increases with increase in pH. At pHs beyond 8.5; $Al(OH)^{2+}$ species dominates instead of Al^{3+} . Under such circumstances Al^{3+} activity will increase by (pH -5.02) log unit. However, there will be no change in the relative stability of these minerals. These results are in tune with the similar observations of Rai and Lindsay (1975), Lindsay (1979), Rai and Kittrick (1989).

Stability of Alumino - Silicates

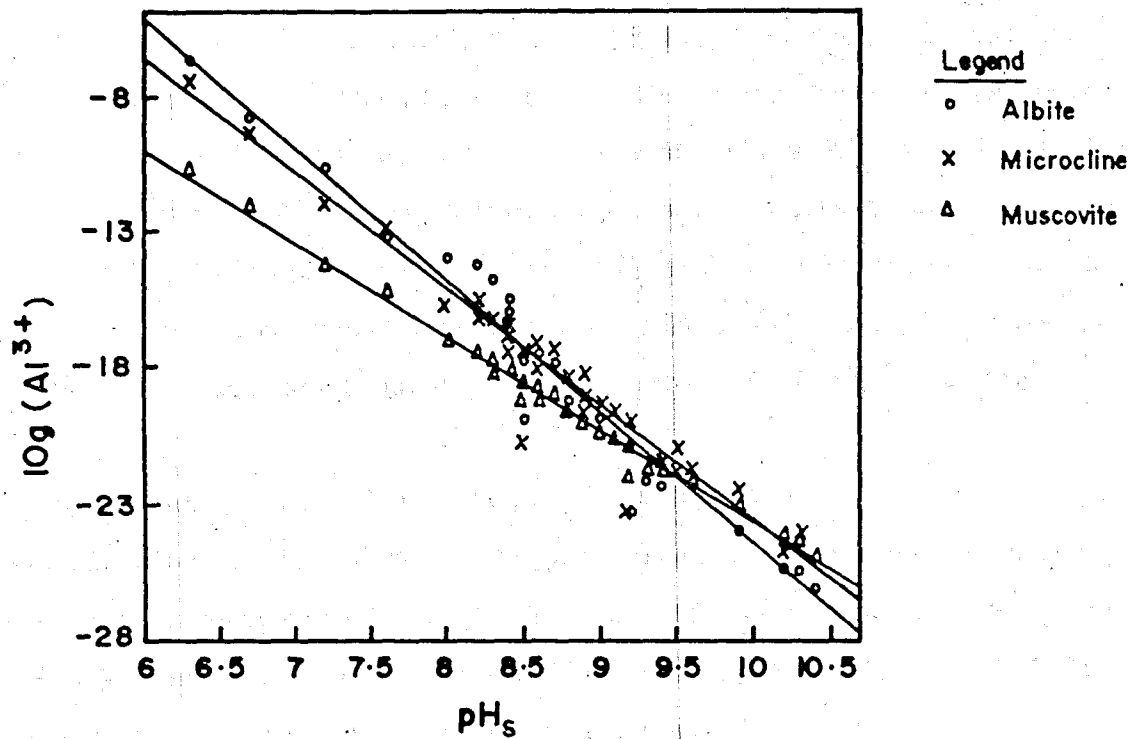


Fig.5.4 Stability of alumino- silicates and pH_s

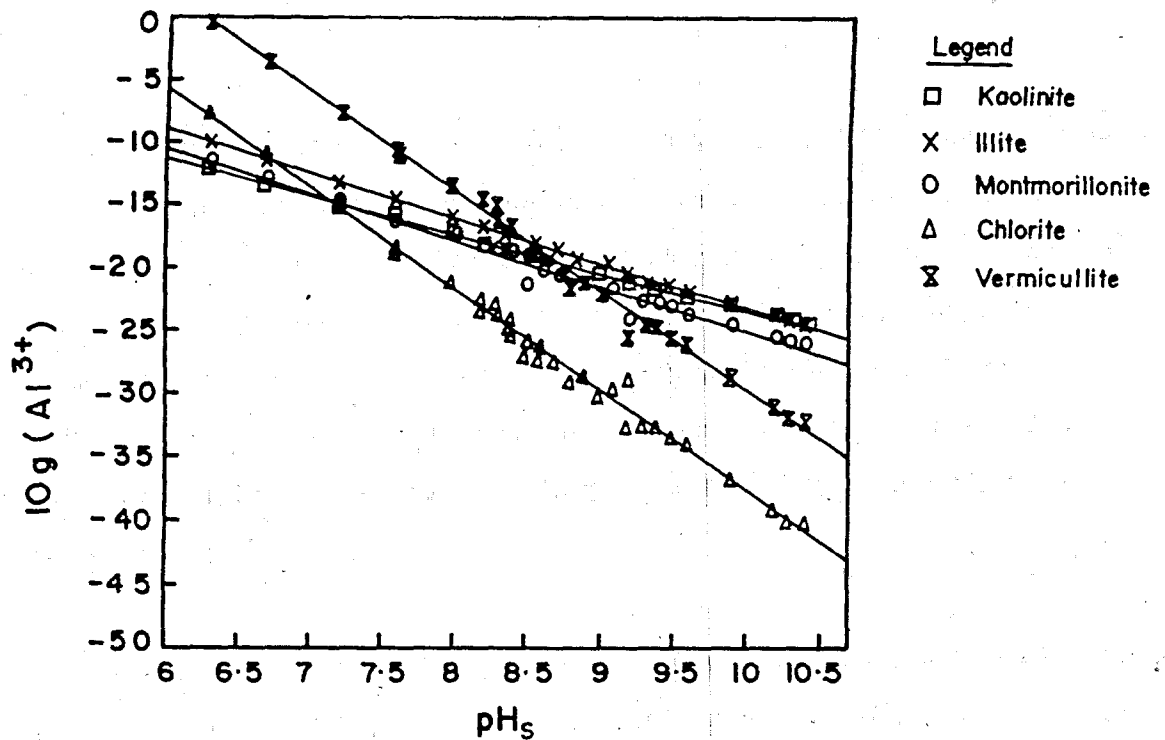


Fig.5.5 Stability of alumino- silicates and pH_s

However, the reports of Bhargava et al. (1981), Kapoor et al. and Abrol et al. (1981), Bhargava and Bhattacharjee (1982) indicating weathering of alumino-silicates in high pH environment, and low stability of albite in alkali soils (Gupta and Gupta, 1989) do not support the above results as well as those of Rai and Lindsay (1975), Lindsay (1979) and Rai and Kittrick (1989). Had the hypothesis behind the above reports been true the prevailing climate would not have permitted the presence of normal soils in the Indo-Gangetic plains.

5.6 Taxonomy of salt affected soils

Classification of all the pedons is presented in the preceding chapter. However, the same is reproduced here (Table 5.3) along with the classification of these soils by the U.S. Salinity Staff (1954) and by the C.S.S.R.I., Karnal for the purpose of reaching more meaningful conclusion.

It is noticeable that for most alkali soils of this region family ranges between coarse loamy to fine loamy, mixed hyperthermic. Similarly, great group of these soils varies from Ustifluvent, Udorthent, Udifluvent, Ustochrept, to NatrustalFs.

Natrustalf classification of these soils is questionable because, these soils are still impregnated with soluble salts and their hydraulic conductivity is very low to nil as described in Chapter 4. Under such environment leaching of clay from A to B horizon may not be feasible. However, morphological evidences point towards the presence of thin patchy to thick patchy argillans. Presence of argillans in these soils have been confirmed by Kooistra (1982) through micro-morphological analysis. It is only on this basis that these soils have been classified as NatrustalFs.

However, a detailed study of her micro-morphological observation for the Zarifa Viran-Benchmark soil of CSSRI farm indicate that argillans are present

in A as well as B horizons. This author suggests that this illuviation under high sodium saturation, be considered as a separate process. More over the observed cutans were mostly pure cutans and there was no coating on the sand grains. It seems probable that upon hydration, clay gets dispersed locally under sodic environment; upon dehydration as controlled by evapotranspiration demand it gets flocculated and deposited at the site of dispersion itself. Presence of argillan in both A and B horizons confirms the occurrence of local dispersion-flocculation-deposition cycles. Thus for all practical purposes these argillans should be considered as local depositions and termed as 'salt cutans' only. Secondly, this will also avoid the classification of two pedons in the same field in two different orders i.e. Inceptisol and Alfisol as the same appears illogical, especially when we know that alluvium in both cases is uniform, deposited by the same river under similar environment and at the same period of time.

However, a very important aspect i.e. presence of salts which is so important for plant growth is not indicated by the classification as per Soil Taxonomy of soil Survey Staff (1975). It is now confirmed that salts in these soils are not linked with alumino-silicates weathering but are of extraneous source as discussed in section 5.9 of this chapter.

To highlight the alkali or saline nature of these soils Ahuja and Khanna (1983) proposed Natric subgroup with Ustifluvents and Ustochrepts; Sehgal (1975) proposed modifications in Natric diagnostic horizon itself; Srinivasan (1976) proposed salic subgroup with NatrustalFs; Sehgal (1986) proposed Fluventic subgroup with Salorthids and Manchanda (1978) proposed epihalonatric, epinatric and episalic subgroups.

However, the difficulty with these proposals is that most of them will disappear once these soil are reclaimed. This is evident from the

classification of CSSRI-Karnal pedons where upon reclamation it changed from Typic Natrustalf to Typic Ustochrept on even to Udic Ustochrept. Classification should be such that (i) it should not change with short term management and (ii) it should reflect the management strategy for agricultural or non- agricultural uses.

Keeping in view the above facts, it is proposed to group the soils within a subgroup having similar physical and chemical properties that effect their response to management and manipulation for use. This is the family level of classification.

Accordingly, addition of alkali or saline class (as the case may be) at the family level is proposed along with other classes of the family differentia.

Alkali class: Soils with pHs > 8.2; ESP > 15; EC_e variable and preponderance of carbonates and bicarbonates of sodium as indicated by $[Na/(Cl + SO_4)] > 1.0$. This is as per the proposals of Bhargava et al. (1976), Abrol et al. (1980) and Gupta and Abrol (1989); Singh (1989).

Saline class: Soils with pHs < 8.2; ESP or SAR variable, $EC_e > 4 \text{ dSm}^{-1}$ and preponderance neutral salts of sodium, calcium and magnesium as indicated by $[Na/(Cl + SO_4)] < 1.0$. This is as per the proposals of Singh (1989) and Gupta and Abrol (1989).

Thus, the soils of Sirsa upland with all the characteristics of an alkali soil will be classified as: coarse loamy, alkali, mixed, hyperthermic family of Typic Ustochrept or the soil of Lalru will be classified as coarse loamy, alkali, mixed, hyperthermic family of Typic Ustifluvents and so on. Such a classification will ensure responses of comparable phases of all soils in a family nearly enough the same to meet, most of our needs for practical interpretations of the soil survey data.

Table 5.3 Soil classification

Geomorphology	Pedon	U.S.Salinity lab.	CSSRI	Soil Taxonomy [*]
Siwalik Hills	Morni-1	Normal	Normal	Fine loamy, Typic Eutrochrept
	Morni-2	Normal	Normal	Loamy skeletal, Typic Dystrochrept
	Kaleshar	Normal	normal	Silty over sandy, Typic Udorthent
	Lal Dhang	Normal	Normal	Coarse loamy, Typic Udorthent
Piedmont Upper	Panchkula	Alkali	Alkali	Coarse loamy, Typic Udorthent
	Ramgarh	Alkali	Alkali	Fine loamy, Typic Udorthent
Lower	Lalru	Saline- alkali	Alkali	Fine loamy, Typic Ustifluvent
	Sherpur	Alkali	Alkali	Fine loamy, Typic Natrustalf ^{**}
	Saha	Normal	Normal	Coarse loamy, Typic Ustifluvent
Alluvial plain Upper	CSSRI-fen.	Saline- alkali	Alkali	Coarse loamy, Typic Natrustalf ^{**}
	CSSRI- alkali	Alkali	Alkali	Coarse loamy, Typic Natrustalf ^{**}
	CSSRI-rec. alkali	Alkali	Alkali	Coarse loamy, Typic Ustochrept
	CSSRI- normal	Normal	Normal	Fine loamy, Udic Ustochrept
	Gudda- alkali	Saline- Alkali	Alkali	Fine loamy, Typic Ustochrept
	Gudda-rec. alkali	Alkali	Alkali	Coarse loamy, Typic Ustochrept
	Samdhan- alkali	Saline- alkali	Alkali	Coarse loamy, Typic Ustochrept
	Samdhan- rec.alkali	Alkali	Alkali	Coarse loamy, Typic Ustochrept
	Narnaund- upland	Saline- alkali	Alkali	Coarse loamy, Typic Ustochrept
	Narnaund- normal	Saline- alkali	Alkali	Fine loamy, Typic Ustochrept
Lower	Sirsa- upland	Saline- alkali	Alkali	Coarse loamy, Typic Ustochrept
	Sirsa- lowland	Saline- alkali	Alkali	Coarse loamy, Typic Ustochrept

^{*}Mineralogy class: mixed; temperature class: hyperthermic

^{**}Proposed classification: fine/coarse loamy, alkali, Typic Ustochrepts

5.7 Clay mineral genesis

It is well known that parent material of the soils in study area is the alluvium brought down by the rivers and that it is fairly uniform in composition. It is, however, interesting to note that slight differences in the relative contribution from different geological formations to the alluvium, have produced contrasting features in the resulting soils, as will be apparent from the discussion that follows. It is, therefore, essential to once again refresh our knowledge of important facets of geological formations directly related to soils under study.

Ghaggar basin	:	Sirmurs, Subathu, Dagshai, Kasaulis, Saline - series, Shali, Middle Siwaliks, Lower Siwaliks, Tal, Krol, Blaini, Panjal Trap.
Drsadvati- Chautang basin	:	Upper Siwaliks, Middle Siwaliks, Lower Siwaliks, Tal, Krol, Blaini, Panjal Trap, Jutogh, Navakot, Subathus, Gondwana, Salkhalas.

These formations are described in detail in section 3.13.

Results of mineralogical analysis of clay, silt and sand fractions from various pedons have been presented under the geomorphological sequence in the previous chapter. However, for the purpose of discussion on the sources or genesis of these minerals it will be convenient to describe the pedons falling (under Ghaggar course separately from those of the Drsadvati- Chautang river course. This is necessary also as the mineral distribution patterns have followed separate trends in the above two categories. The mineral assemblage seems to relate directly to the source of alluvium that form the parent material of these pedons irrespective of their geomorphological position.

5.71 Ghaggar basin: This area is represented by the Morni-I, Ramgarh, Panchkula, Lalru, Sherpur, Saha and Sirsa pedons located along the present

course of river Ghaggar. Clay minerals assemblage presented (Table 4.1.11, 4.5.11, 4.6.11, 4.7.10, 4.8.12, 4.9.11, 4.20.11) indicates the similarity of mineral nature in various pedons. By and large the soil clays are dominated by illite followed by smectite and also contain chlorite, vermiculite, mixed layer minerals and kaolinite in addition to small proportion of primary minerals like quartz, feldspars and amphiboles. Before discussing the origin and genesis of minerals in soil clays it is important to understand the nature of parent material as well as geological formation that constituted the source of parent material of these soil minerals. Geologically the area around Morni hills is covered primarily by the Sirmur series of sub-Himalayas including the Subathus, Murree hills -Dagshai and Kasauli series, and is also the point where saline series of the Salt Range merge with these formations (Gansser, 1964; Srikantia and Sharma, 1972).

The Panchkula and Ramgarh pedons lie at the foot of Morni Hills and represent the molasse like deposits of the Sirmur, where as the Morni-I profile lying at the top of the hills seems to have less contribution of Subathus and perhaps a greater contribution of Kasauli series with plenty of lime concretions.

These formations as described earlier (Gansser, 1964, Wadia, 1965) contain illite, kaolinite, chlorite as well as smectite clays along with the primary minerals like quartz, feldspars, mica and amphiboles etc. Invariably nummulitic limestone, calcite and dolomite also form a significant part of these formations. The high quantities of illite and smectite along with kaolinite, chlorite and vermiculite present in these clays are simply part of the parent material. Illite present in these soil clays has been inherited from the parent material as such. Distribution of illite throughout the course of Ghaggar river system indicates almost no variation in the Lalru, Sherpur, Saha and Sirsa pedons. Although, the illite content of Morni clays is higher (72 to 75 per

cent) and that of Ramgarh is lowest (34 to 45 per cent). However, it should be kept in mind that rivers responsible for deposition of alluvium at Lalru, Sherpur, Saha and Sirsa originate/originated far beyond the Morni hills and thus they have received contribution from the Subathus, Dagshai, Kasaulis and in addition from the Middle and Lower Siwaliks, Tal, Krol, Blaini, Panjal trap formation encountered in and around the Shimla hills (Gansser 1964; Wadia, 1965). All these formations contain illites, in the clay fraction as well as micas in coarse fractions. Presence of kaolinite in the soil, clays is also of detrital origin as the deposits at Morni, Ghaggar and Ramgarh also contain kaolinite in more or less similar proportion. The conditions of the present environment are not conducive to the formation of kaolinite and there are several reports to justify the detrital origin of kaolinite in these soils (Sidhu and Gilkes, 1977). Formation of kaolinite has taken place through complete hydrolysis of feldspars in ancient times.

It is possible that formation of vermiculite and mixed layer minerals are the result of weathering of mica but again much of this weathering has occurred in the geological formations itself prior to their transportation by the river network, and thus, pedogenesis in the piedmont and the alluvial plain zone if any, has very little to do with the in-situ formation of these minerals. Minor changes in this regard can not however be ruled out; because loss of potassium, hydration etc. to some extent can be caused under the biotic influence. This generalization is well supported by the fact that even sand sized mica particles in the fresh river sands were found to contain only 2.40 per cent K_2O instead of generally believed figure of 10.0 percent K_2O for unweathered micas.

Total elemental analysis of fresh sand Mica (per cent):

SiO_2 = 44.89	CaO = nil	K_2O = 2.40
Al_2O_3 = 37.71	MgO = 2.73	Loss on
FeO = 4.56	Na_2O = 0.76	ignition = 4.8

The distribution of kaolinite, vermiculite, chlorite and mixed layer minerals in the Lalru, Sherpur, Saha and Sirsa clays is more or less identical to those of Morni, Panchkula and Ramgarh clays. The presence of vermiculite, mixed layers and chlorite minerals (1.4 nm) in these soil clays is, therefore, due to inheritance in the alluvial parent material absence of vermiculite in the Ramgarh clays and higher content of smectite and lower content of illite is because, this deposit primarily belongs to Subathu and Dagshai series and has received little contribution from the micaceous sandstone. The layers of grey, red and purple clays and nodular lime are clearly visible.

5.72 The smectite controversy: The presence of sufficient proportion of smectite in Lalru, Sherpur and Saha clays is a question that needs to be examined thoroughly as there have been several reports suggesting the formation of smectite in the alkali soils of Haryana and other alluvial soils (Sehgal 1974; Ghosh et al. 1976; Kapoor et al. & Abrol et al. 1981; Sharma, 1989). No doubt it can be safely opined that poor drainage, high Si:Al ratio and presence of alkalis, alkaline earths and alkaline pH are the conditions most conducive and globally accepted for the in-situ formation of smectites (Corren, 1939; Grim, 1968); but such occurrences in the soils of this area seems doubtful. Had the alluvium that formed the parent material of these soils, been devoid of smectite, such a mechanism would have most logically justified the presence of smectite in these clays.

The situation in this particular case, however, seems quite contrary to the view point proposed by the earlier reports. The mineralogical data on soil clays from Panchkula pedon and more so from Ramgarh pedon, which are by no means affected by pedogenesis and are a part of only geologic formation (Subathu) that have contributed to the alluvium of the flood plains (Table 4.5.11, 4.6.11) clearly indicate the smectite richness of these deposits. If the mechanism

listed in the above mentioned reports are to be believed, it would be impossible to justify the presence of 19 to 20 per cent smectite in Panchkula clays and near dominance (31 to 43 per cent) of smectite in Ramgarh clays as these sites are located on the eroding hill tops. Present geomorphology of these sites does not allow stagnation of water or existence of poorly drained conditions. On the contrary the geological formations the Subathus and lower part of Dagshai are known to contain (Pascoe, 1959; Gansser, 1964; Wadia, 1979) red and purple shales, deep red and purple clays with abundance of nodular lime. These shales and clays are rich in smectite as they are marine/salt water lagoon sediments, contains large quantities of illites along with other clay minerals like kaolinite, chlorite and mixed layer minerals. The Subathus particularly contain very little proportion of vermiculite. Smectite present in these clays is not the result of any pedogenic activity and instead belongs to much older formation in the history, perhaps even prior to the period of deposition of the Murrees or the Sirmur series and must have occurred under marine environment of the Tethyan basin in the Eocene period.

Further, it is important to add that the Ramgarh site contains smectite as dominant or second dominant mineral. The amount of smectite detected (5-19 per cent) in the Lalru, Sherpur, Saha and Sirsa pedons is much lower than the source of alluvium. This reduction has occurred due to the dilution of smectite rich material (Subathu) by the contributions from other geological formations encountered in hills along the course of rivers in this area. It should also be noticed that even after being transported through piedmont zone to the lower flood plain (Sirsa upland) covering a distance of nearly 260 km, the nature and proportion of clay minerals had remained more or less unchanged. It is, therefore, fairly reasonable to state that the smectite present in these soils is merely transported just like the other component clay minerals. Further, it also seems logical that most of the smectite carried along with alluvium by Ghaggar must have been deposited in its basin as the geographic

features of entire Ghaggar basin allows average drop of only 0.7 m/km from the foot hills to Sirsa. Secondly Ghaggar alluvium does not go far ahead as its beds are occupied by sand in the lower reaches. If at all there have been any changes (transformations) as a result of only pedogenic activity, they must be extremely small and beyond detection by the routine mineralogical analysis. Since there is very little pedogenic activity noticeable in these pedons it is hard to believe large scale eluviation of clay from surface horizon to lower depth as all these profiles are still in the Inceptisol stage. Lower amounts of smectites in the surface horizons could be due to intensive cultivation and flood irrigation practices being followed in these areas which might lead to flushing of finer particles from surface horizons. This influence however, does not effect the lower depths because this alluvium does not permit free internal drainage.

5.73 Drsadvati-Chautang river course: Parent material of the soils encountered in this tract (CSSRI, Karnal, Samdhan and Narnaund) consists of the alluvium brought down from the Himalayan and sub-Himalayan heights by the ancient Sarasvati-Drsadvati-Chautang river system descending through Solan and Sirmur district of Himachal Pradesh. It is well known that Sarasvati was the mightiest river of the Vedic period and had its origin in the upper reaches of Himalayas. Due to the tectonic movements in the later stage and the raising of the Siwalik river bed, drastic changes occurred in the river courses leading to shifting of watershed in the upper catchment areas of the river Sarasvati (Bhardwaj, 1987). As a result of these events Sarasvati was reduced to a small stream; however, prior to this, the alluvium deposited by this river system consisted of soil material eroded from various geologic formations encountered along the course of these rivers.

This alluvium has largely been contributed by the upper, middle and lower Siwaliks, Tal, Krol and Blaini series, Panjal Trap, Gondwanas formations, Jutogh

and Navakot series, Darjeeling gneiss (Pascoe, 1959, Gansser, 1964, Wadia, 1965). Sarasvati- Drsadvati river system encircling the Vedic Aryavarata which seems to be responsible in good old days for this alluvium seems to have almost by passed a major contact with Sirmurs especially the Subathus (Bhardwaj, 1987). It is for this reason that soils of this basin are by and large much lighter in texture than the soils of Ghaggar basin. However, some contribution of the Sirmur series (Subathu, Dagshai and Krol) can not be ruled out.

The clay samples analysed from Lal Dhang pedon surprisingly contain a fairly simple clay mineral make up. These clays were found to be devoid of minerals like smectite, chlorite and vermiculite and were composed primarily of illite (39 to 40 per cent) and kaolinite group (34 to 36 per cent kaolinite and 17 to 18 per cent halloysite) only with 5 to 6 per cent of mixed layers. Such a mineral composition is indicative of presence of geological formations much different from that of the Siwaliks, Sirmur or Murrees. However, alien this clay mineral make up may seem to the beginner, such high proportions of kaolinite are indicative of the presence of much older rock formation perhaps of the Pre-Cambrian era. Incidentally there are reports of the presence of strips of Gondwana rock system sandwiched in between the tertiaries along the foot of Himalayas. These out crops appearing from under the eroded cover of over thrust sheet of the Pre-Cambrian window are oppressed against the Siwalik formation (Wadia, 1965). There are also reports of large scale kaolin deposits to the southern side of Indus basin on the Rajasthan shelf of the Peninsular India which are being commercially mined as kaolin, fire clay or ball clay (CMSI, 1991). Since the Peninsular Indian plate is known to be part of the ancient Gondwana land, occurrence of kaolinite in this area is not surprising (Wadia, 1965). It is also believed that ancient rivers draining the northern part of Gondwana land had deposited huge sediments in to the Tethyan basin these highly weathered sediments may have been raised during the upheavals in the Siwalik zone and thus contributed a Gondwana representative to the already

complex geological formations of the Siwalik, Sirmur or Murree series of the Tertiary period. The observations of disappearance of reddish hues from this soil material during DCB treatment is indicative of the presence of sufficient quantity of free iron oxides (sesquioxides) which have coated the soil mineral grains.

During this process there is possibility of some of the kaolinite being degraded/hydrated which is apparent from the presence of sufficient proportions of halloysite in the soil clay samples of Lal Dhang. Even otherwise, there could possibly be no explanation to the formation of such large quantities of kaolin under the climatic conditions that exist today or even in the known ancient past of this area. This finding of kaolin rich clays of Lal Dhang area can easily explain the universal presence of kaolinite in the alluvium of this basin and should therefore dispell speculation of formation of kaolinite in the present pedogenic environment.

The mineralogical make up of all soil clays in the Drsadvati-Chautang river basin (Table 4.4.10, 4.10.12, 4.12.12, 4.13.11, 4.16.10, 4.17.11 and 4.18.11) invariably contains 5 to 8 per cent kaolinite. These contributions must have been inherited along with the alluvium of this area. Presence of illite in the samples in relatively higher proportions (52 to 68 per cent) as compared to the pedon of the Ghaggar basin can also be explained on the basis of higher contributions of the Siwaliks, micaceous schist of the Jutogh and Salkhala series; Krol and Blaini formations as compared to the Sirmurs or the Murrees as has been pointed out earlier. On the same account these soils are comparatively coarse in textured and slightly less permeable as compared to the Ghaggar basin pedons. Presence of chlorite, smectite and possibly mixed layer minerals in these soils, also seems to be of detrital origin as the geological formations contributing to the alluvium are rich in these minerals. There is not much variation in the content of these minerals in the soil clays from

various sites along the flood plain of this river system. In fact the overall clay mineralogy is identical to that encountered in the geological formations.

Individual mineral variation within each of these profiles also does not allow much room for speculation on the in-situ formation or transformations as a result of pedogenic activity. Again all these pedons except CSSRI alkali pedons are at the Inceptisol stage. Even the presence of thin patchy clay skins observed in the CSSRI fenced alkali pedon need to be further examined. Doubts about the clays being locally dispersed and redeposited on ped surfaces as a result of highly sodic nature of these pedons need to be cleared as these soils have remained uncultivated in the recent past.

The only variation from the results discussed so far as regards to clay mineral distribution in this course was observed in the IIBC horizon of Narnaund alkali profile. Clay mineral composition as well as other morphological, physical and chemical characteristics of this layer (56-148 cm) closely resembles the Ghaggar alluvium. It seems that this deposit was overlain by the alluvium brought down by the Drsadvati-Chautang river network. There is enough evidence to show the west-ward migration of the Ghaggar (Bhardwaj, 1987). The higher amount of smectite in the clay fraction of this layer (56-148 cm) should not therefore, be mistaken to be a result of pedogenesis.

5.8 Mineralogy of coarse fraction:

Results of mineralogical assemblage of sand and silt fraction for various profiles have earlier been presented under the geomorphological sequence. However for the purpose of discussion on the sources or genesis of these minerals it will be convenient to describe pedons of the Ghaggar river course separately from those lying in the Drsadvati-Chautang river course.

A perusal of data on coarse fraction mineralogy (Table 4.1.10, 4.5.10,

4.6.10, 4.7.9, 4.8.11, 4.9.10, 4.20.10) indicate that sand and silt fraction of the soils of Ghaggar basin contained more of quartz, chlorite + kaolinite and calcite; and less of orthoclases and plagioclases. This major difference is traced to the differences in the parent material of these two alluviums. The Ghaggar alluvium has received major contribution from the Subathus (ferruginous quartzite, olive shale, sandstone and limestone); Shali (limestone, quartzite, clay); Kasauli (lacustrine sandstone); Dagshai (brackish water nodular bright red clay and sandstone), Tal (dolomitic limestone, carbonaceous shale micaceous shale, microcline), Blaini (conglomerate, limestone), Krol (Calcareous shale and sandstone), Panjal trap (volcanics- feldspars, Magnesite, augite); and minor contributions from the upper Siwaliks (boulder conglomerate), Middle Siwaliks (sand rock, clay shale) and Lower Siwaliks (micaceous sandstone) (Pascoe, 1959; Gansser, 1964, Wadia, 1965). Thus the Ghaggar alluvium had more of quartz, calcite and slightly less of feldspars.

However in contrast the alluvium of the Drsadvati-Chautang system (Table 4.4.9, 4.10.11, 4.12.11, 4.13.11, 4.16.9, 4.17.9, 4.18.9) received lesser contribution from Sirmurs (Subathu, Kasauli, Dagshai) and more contribution from siwaliks (Upper, Middle and Lower), Jutogh (plagioclases, quartz, hornblende, biotite, garnet, tourmaline, sphene, microcline, muscovite, beryl, garnet, actinolite, corundum), Salkhalas (biotite, orthoclases, corundum, phyllite), Tal (quartzite, microcline, micaceous shale), Panjal trap, Krol, Shali, Blaini series, and Siwaliks. This difference in the parent material of this alluvium itself is responsible for relatively higher orthoclases and plagioclases and less calcite contents of the pedons.

Wadia (1965) reported that unlike Siwalik which are derived entirely from denudation of Himalayan granites and other rocks the Murrees (Sirmurs) have originated from the sediments whose source was the iron bearing Purana formations of Peninsular highlands of the south. Thus coarse fraction mineral

assemblage of Lal Dhang is entirely different, being rich in mica, quartz and kaolinite mineral only. Feldspar contents are very low as compared to other pedons of the Drsadvati-Chautang system. It is believed that ancient rivers draining the northern part of Gondwana land had deposited huge sediments into the Tethyan basin. These highly weathered sediments could have been raised during the upheavals as explained earlier (Pasco, 1959). But it is more important to point out at this stage is that the plagioclase contents of the CSSRI alkali, CSSRI reclaimed alkali and CSSRI normal soils do not differ. This eliminates any possibility of plagioclases being a diffused source of sodium as opined by Gupta and Gupta (1989).

5.9 Source of salts

The Ghaggar alluvium has been contributed by the red and purple silt and clay deposits of Subathu, Dagshai, Kasauli, Sirmur and Murree geological formation. These deposits are enriched with sodium salts due to their long contact with marine and/or salt water lagoon environment.

Soils of the Drsadvati-Chautang basin received contributions from the Jutogh, Krol, Salkhalas, Blaini along with major contribution from lower, middle and upper Siwaliks. Jutogh, Krol, Salkhalas, Blaini and Navkot series had marine contact and are rich in alkali salts. This area represents the zone of contact with siwaliks for not only brackish water Murrees but also the Saline series of the Salt Range (Shali formation). Murree as well as Shali formation are rich sources of salts besides having ample quantities of lime as calcium carbonate concretions nummulites or limestone as described earlier.

While no geological window with outcropping siwaliks has been observed within the Lower Himalayas, the Damudas and/or Eocene Subathus do occur in well outlined tectonic window below older rocks. This window clearly documents the flattish inclination of the thrust. Some Eocene in Shali window is over 35 km

away from the Main Boundary Fault (Gansser, 1964). Shali formation in the Himachal Pradesh Himalayas occur in association with red shale and dolomite of basal Ropri member of the Shali formation. It is pink coloured hard compact marly lithocomplex rich in clay, carbonate mineral, calcite, quartz, plagioclase and orthoclases. Locally this material is known as lokhan. Salt is deposited in the shali epicontinental sea basin marginal to stable land surface salt bed of Shali formation has been correlated with Saline series of the Salt Range of Himalayas (Srikantia and Sharma, 1972). Salt deposits of all ages and occurrence are indicative of dryness of climate as salt deposition always demands a sufficiently dry climate to allow an excess of evaporation over precipitation. Thus, the occurrence of salt bed and red shale in the basal member of Shali formation suggests the prevalence of an arid climate during the initial phase of Shali sedimentation and this is consistent with other evidence like the presence of red beds, worm tracks, mud tracks and also development of Collenia that the climate of the region was warm (Gansser, 1964; Srikantia and Sharma 1972). Though there is no information regarding the limits of evaporite basin because of thick cover of tertiary sediments, it is a distinct possibility that it had extended right upto the saline series of Salt Range during Pre-Cambrian period.

Besides this, numerous brine springs and saline seepages have been noticed in the Shali belt, particularly in the area north of Mandi. In the Megal (district. Mandi, H.P.) area there are several seepages of brine water along the stream beds; and some of these have brine discharge of about 14,550 l/hr during winter months. It is interesting to mention here that thermal spring at Tattapani in Satluj valley occurring within the area of Shali formation contains 2055 mg kg^{-1} of Na and 3243 mg kg^{-1} of chloride (Srikantia and Sharma 1972; Wadia, 1965). Besides these several brine and thermal springs of small magnitude, are encountered in the Solan, Shimla and Sirmur districts of Himachal Pradesh including the Kaleshar Reserve Forest.

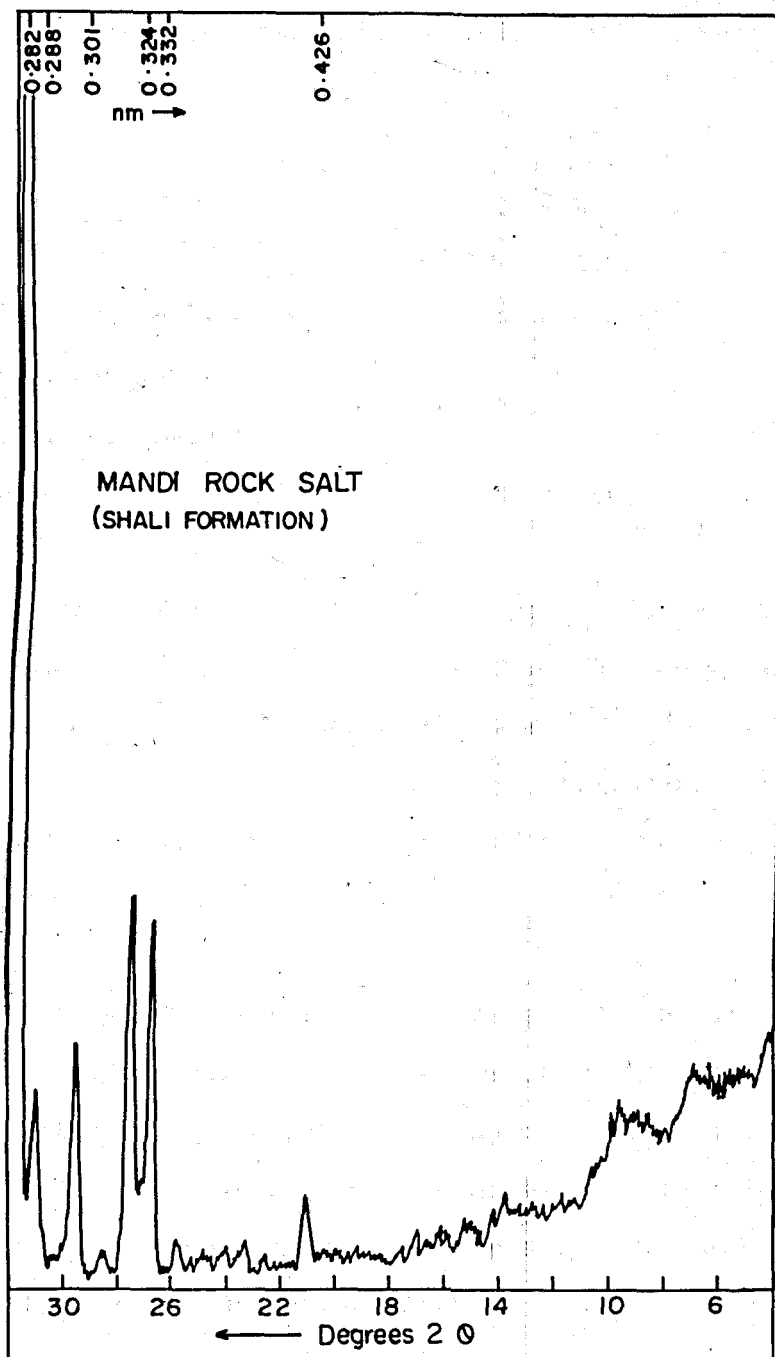


Fig.5.6 X-ray diffractogram of Shali formation

X-ray diffraction analysis (Fig.5.7) of the Rock Salt sample collected from the Shali formation indicated the dominance of halite (0.282 nm) along with other chloride mineral chemical analysis of this sample revealed following elemental composition:

Si = 7.89%	Na = 18.80%	Ca = 3.38%
Al = 0.53%	K = 0.45%	Mg = 1.02%
Fe = 0.53%	Mn = 0.034%	P = 0.018%

Loss on ignition = 3.86%

Important anions were ~~(see/12)~~

Cl = 20.10%	SO ₄ = 4.21%	CO ₃ + HCO ₃ = 0.83%

An archozic coarse sand sample of Kaleshar pedon (Table 4.3.4) in the middle Siwaliks near the Lal Dhang site when analysed for water soluble salts was found to contain sodium and chloride as the dominant cation and anion and in addition contained appreciable quantity of magnesium, sulphate and bicarbonate. This analysis indicates the presence of water soluble minerals of sodium and magnesium in the alluvium of this area.

Although there are plenty of sources of salts and lime in the entire catchment region, the Ghaggar catchment characteristically differs from the Drsadvati-Chautang catchment on account that Ghaggar alluvium has overwhelming contribution from Dagshai and Subathu. These formations are rich in clays that are highly smectitic and are super saturated with salts (Na, cl) because of their marine origin (Gansser, 1964, Wadia, 1965)

On the other hand even though the Jutogh, Tal, Navkot and Saline series (that contributed significantly to the Drsadvati- Chautang alluvium) also had marine or salt lagoon contact, their alluvium is relatively coarser as compared to Subathus and are relatively more permeable. Above differences in the nature

of alluvium has resulted in almost zero internal drainage in the Ghaggar alluvium not only in the hills but also in the piedmont and lower alluvial plains; resulting in very limited movement of salts of even soluble minerals. This is evident from the presence of:

(i) Na and Cl as the dominant cation and anion in the saturation extract of Panchkula, Ramgarh and Kaleshar pedons (Table 4.5.4, 4.6.4); maximum content being:

Na	=	26.7 me/l	pHs	=	8.9
Cl	=	26.0 me/l	EC _e	=	3.49 dSm ⁻¹

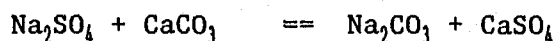
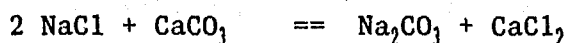
(ii) Large amounts of soluble salts in gently sloping Lalru pedon situated in the piedmont (Table 4.7.4).

pHs	=	9.2 - 10.4	CO ₃	=	7.0 - 214.2 me/l
EC _e	=	1.8 - 21.9 dS/m	HCO ₃	=	6.7 - 28.7 me/l
Na	=	13.0 - 229.6 me/l	Cl	=	8.0 - 40.0 me/l
Mg	=	2.5 - 5.3 me/l	SO ₄	=	1.7 - 7.6 me/l

Thus, while large amounts of water soluble sodium minerals (halite-NaCl; mirabilite-Na₂SO₄.10H₂O, thenardite-Na₂SO₄ etc.) seems to be present in the alluvium, unfortunately their detection by the conventional x-ray diffraction procedures is not possible as these get dissolved during the particle size fractionation itself.

5.10 Mechanism of sodium carbonate formation:

With the presence of chlorides and sulphates of sodium and carbonates of calcium in the parent material of alluvium and increased stability of aluminosilicates in the alkali environment as discussed earlier, the most possible mechanism of Na₂CO₃ formation seems to be the one proposed by the Hilgard (1906):



Strongest criticism of this reaction is that the reaction will proceed in the direction of least soluble component i.e. CaCO_3 . However, this criticism is misconceived in the light of the environmental conditions in which the parent materials of the alluvium of these soils have existed i.e. the low temperature and high pCO_2 conditions in the Himalayas.

Unlike other minerals, the solubility of CaCO_3 increased with decrease in temperature and increase in pCO_2 .

Temperature °C	Solubility of CaCO_3^* (g/l)	pK_s^{**}	pCO_2 %	Solubility of CaCO_3^* (g/l)
0	0.081	8.02	0.00	0.0131
5	0.075	8.09	0.03	0.0634
10	0.070	8.15	0.30	0.0134
15	0.065	8.22	1.00	0.2031
30	0.052	8.40		

*Irrigation, drainage and salinity (1973)

** $\text{pK}_s = -\log K \text{ CaCO}_3$; Garrel and Christ (1965)

Further, it is a common observation that solubility of CaCO_3 increases in the presence of uncommon ions (Garrel and Christ, 1965). In this context Aggarwal and Yadav (1979) reported that in the presence of sodium chloride

(25g/l) solubility of CaCO_3 increases from 0.0131 to 0.1334 g l^{-1} at 0.30 per cent CO_2 .

Earlier, Manchanda (1984) gave considerable weightage to this process of Na_2CO_3 formation in the alkali soils in the Indo- Gangetic alluvium plains on the plea that (i) Himalayan zone is still not stable (ii) deposits of dolomite, calcareous shale, limestone, gypsum and rock salt are abundant in Himalayas (iii) some tectonic movement in catchment zone must have resulted in the release of different salts and their subsequent reaction with each other resulting in the formation of Na_2CO_3 and other salts and subsequently these salts were brought down by the rivers along with alluvium which is parent material of these soils. Once these alkali carbonates or bicarbonates are formed there is very little chance in the Ghaggar alluvium that they will be flushed out, primarily due to the impervious nature of the material, unlike the Drsadvati-Chautang basin alluvium.

5.11 Mineralogical aspects of reclamation

The clay mineral composition of these soils does not suggest the sustenance of smectite in the surface horizon of alkali soils that have been subjected to reclamation, either by natural processes or by the human intervention. Smectite content of surface horizons in Sherpur, Saha, Lalru, Sirsa, CSSRI fenced alkali, CSSRI reclaimed alkali (20 yr), CSSRI normal, Samdhan alkali and Samdhan reclaimed alkali (5 yr) and Narnaund alkali pedons examined in both the river basins were slightly lower than the sub soil clays irrespective of the pedon location or reclamation activity.

It has already been pointed out that chances of clay eluviation in these pedon are infinitesimally small, as neither there has been any observable eluviation of the sesquioxides nor any ferri-argillans were observed in the sub-soil horizons. The reduction in the smectite content of surface horizon,

CHANGES DURING RECLAMATION

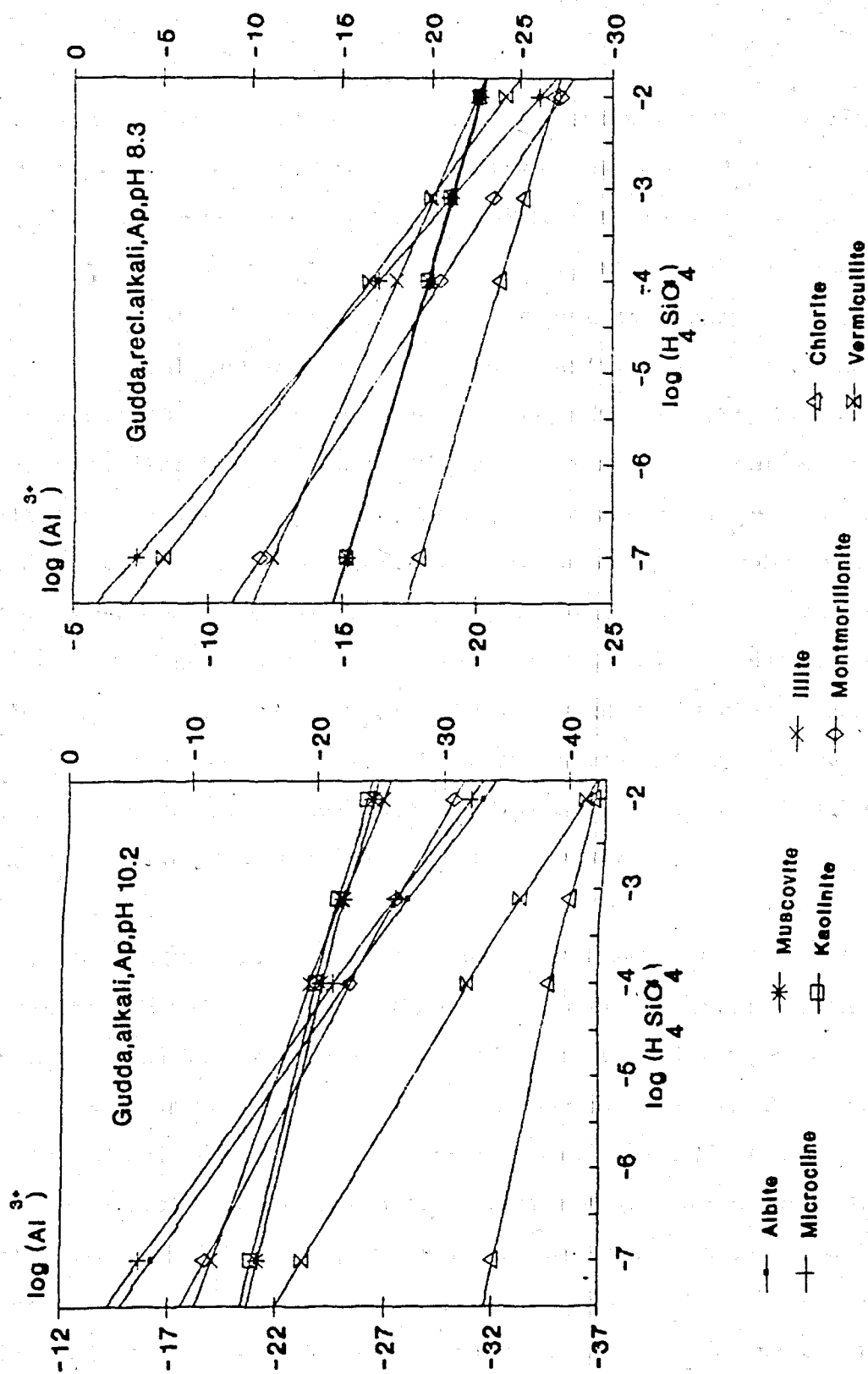


Fig.5.7 Changes in stability of aluminosilicates during reclamation

therefore, needs to be explained in order to clarify the misconception of migration of smectite to lower layers as reported by Kapoor et al. and Abrol et al. (1981) and Sharma (1989).

Equilibrium reaction between the soil minerals and the ambient soil solution is known to control the thermodynamic stability of the alumino-silicates (Corren, 1939, Lindsay, 1979). Accordingly, an attempt was made to study the relation between Al^{3+} and H_4SiO_4 activities as determined in the soil solutions of these soils. Mineral stability diagrams thus obtained (Fig. 5.7) suggested that with improvements in drainage conditions either due to reclamation through gypsum addition or through biotic activity of growing grasses or agricultural crops; thermodynamic environment is not in the favour of stability of the smectites, as a result, these may break down or transform to stabler forms i.e. either a chloritised component in independent phase or as a part of mixed layer component. The clay mineral data on the contents of smectite, chlorite and mixed layer minerals of all these soils clays also support this possibility. Even though the amount of this change in terms of decrease in smectite content along with simultaneous increase in the chlorite or chloritised (1.4 nm) and mixed layer mineral contents of these soil clays is small; these results tend to uphold the above opinion.

There are several reports in literature from India and abroad (Murali et al., 1974; Altschuler et al., 1963; Wilson and Cradwick, 1972; Morgan et al., 1979, Karthansis and Hajetz, 1983) that improvement in leaching and drainage conditions lead to break down of smectite in extreme cases to even kaolinite. Given enough time (3 to 4 yr) and suitably adjusted Si and Al levels the direct route (Smectite - Kaolinite) occurs in the laboratory under room temperature and pressure (Borchardt, 1989). Drastic improvements in soil drainage can increase the weathering rates of smectite so much that even intermediate stable minerals are not formed (Combs et al., 1982). However under moderate stress smectite may

be chloritised completely or partially and thus result in either a 1.4 nm component or as a part of mixed layer minerals (Sakhrov and Drits, 1973).

Both these component have been suggested to be fairly stable in the soils of alluvial plains as well as in the sub-Himalayan zone (Kanwar, 1961, Ghabru and Ghosh, 1980, 1985). Although Kanwar (1961) has suggested chloritisation by aluminium or magnesium hydroxy polymers, it has now been proved that even dominantly iron rich hydroxy inter-layers may precipitate in the expanding layer silicates under natural conditions and result in a either partially or completely chloritised pedogenic 1.4 nm component (Ghabru et al. 1980, 1990).

In the light of effects of reclamation one would expect major improvement in the physical and chemical characteristics of these soils. The pedons studied in this context include CSSRI fenced alkali and CSSRI reclaimed alkali (20 yr); Gudda alkali and Gudda reclaimed alkali (10 yr) and Samdhan alkali and Samdhan reclaimed alkali (5 yr). the reclamation process as a result of gypsum amendment does not seem to have affected the sub-soil in the Samdhan reclaimed alkali and Gudda reclaimed alkali (in 5 years and 10 years time, respectively as compared to the CSSRI reclaimed alkali (20 years). Although there are differences in the physico-chemical characteristics among the reclaimed and non-reclaimed pedons, yet it should be mentioned that even in the so called fenced alkali pedon at CSSRI, Karnal, Gudda alkali and Samdhan alkali pedons; the natural reclamation process is going on in the surface horizon due to agricultural crops or natural grasses. this has resulted in the improvement of water transmission characteristics atleast in the plough layer. Therefore, the trends in the stability of smectite or the contents of chlorite or mixed layer minerals in the surface clay samples are identical to the surface clays of reclaimed pedons.

5.12 Reclamation efforts in Haryana

Most of the efforts to reclaim alkali soils in Haryana have unfortunately been limited to alkali soils lying in Drsadvati- Chautang river basin. Soils of this basin being coarser in texture as compared to the Ghaggar alluvium, allow movement of water both downwards and upwards. As a result during the dry periods the salts show up on the surface. Perhaps it is for this reason that such alkali soils have attracted the attention of researchers long ago and suitable technology developed by CSSRI, Karnal has been use for the last two decades. On the contrary very little has been done to reclaim the alkali soils of Ghaggar basin. The characteristics of Ghaggar alluvium are such that unless land has remained fallow for several years; the salts do not show up on the surface. This is because the Ghaggar alluvium is highly impervious not only to infiltrating water but it possibly also restricts the upwards flux of ground water thereby preventing accumulation of salts on the surface in contrast to alkali soils of Drsadvati-Chautang basin. This possibly is the reason that even the latest salt affected soils map of Haryana (Sharma, 1989) using remote sensing techniques, shows them as normal soils. Consequently very little attention is paid by research workers, engaged in evolving reclamation technology.

Nature of Ghaggar alluvium (high silt, high clay, high smectite, high sodium) will also possibly pose serious problems even if attempt to reclaim these soils is initiated. This is because the reclamation process basically includes incorporation of gypsum and flushing of solublised salts. While it may be possible to add sufficient quantity of gypsum and mix it well with surface soil the flushing operation will be almost impossible because of impervious nature of these soils. Perhaps the best example how effectively this alluvium can prevent seepage of water is the Sukhomajri earthen dam (Grewal et al., 1982; Grewal and Juneja, 1991).

On the other hand the farmers in the Sirsa area have come up with an interesting management practice of mixing of large volumes of aeolian sand from the nearby sand dunes in the plough layer of these soils. Though laborious, technically this is a healthy practice as it improves the water transmission characteristics of Ghaggar alluvium. Such practice of mixing sand along with conventional reclamation procedure may prove effective in correcting the alkalinity of these soils, atleast in the root zone.

CHAPTER 6

SUMMARY AND CONCLUSIONS

In order to understand the genesis of the alkali soils in Haryana a systematic study was undertaken. Using the remote sensing data a geomorphology map of the Haryana state was prepared. Based on this map, twenty one pedon sites were selected to represent different geomorphological units, temperature and moisture regimes, rainfall and alluviums as brought by the various river systems of the study area.

Available reports showed the existence of alkali soils in micro-depressions of plains, in a rainfall zone of 550-900 mm in semi-arid to arid climate only. However, the study of macro-morphology in the field and physico-chemical characterization of these soils reveals their occurrence in diverse geomorphological locations from hilly to lower alluvial plains with rainfall more than 1125 mm to less than 360 mm. Existence of alkali soils well beyond these geomorphological and climatic limits is not ruled out. Occurrence of alkali soils below the lithological discontinuity in normal soils, presence of high pHs and high EC in the gently sloping pedons in a high rainfall zone requires a fresh look on the proposed process of formation of alkali soils by the degradation of alumino-silicates minerals through carbonation yielding bicarbonates and carbonates of alkali, which in turn were deposited in the micro-depression of the alluvial plains. Thus their reported occurrence is restricted to in the micro-depressions only. Near dominance of sodium and chloride though in small amounts, in the soils of undulating hilly terrain of Siwaliks point towards the possible role of easily soluble minerals in the formation of alkali soils.

Sand, silt, clay, soil, calcium carbonate concretions and ferro-magnesian grains were analysed for SiO_2 , Al_2O_3 , Fe_2O_3 , MnO , CaO , MgO , Na_2O , K_2O and P_2O_5 . A comparison of Na_2O content of sand fraction of these soils helped in identification of parent material of alluvium as brought by two different river systems. Total Na_2O content of sand fraction of the Ghaggar alluvium is lower than that of the soils represented by the Drsadvati-Chautang river system. This is due to the less contribution of the plagioclases containing geological formations i.e. Siwaliks to this alluvium. Siwaliks are known to have been formed from the denudation of Himalayan granites and other rocks which are rich in feldspars. Total Na_2O content of sand fraction of the alkali as well as normal soils of the Central Soil Salinity Research Institute, Karnal is almost similar. Thus dispensing any role of the alkali plagioclases as a source of sodium in these soils as reported by earlier workers. Further more the correlation between pHs and Na_2O content is very poor.

Total calcium content of these soils after removal of CaCO_3 is very low. Thus, calcium content of the abundant lime concretions can not be from any source other than calcite or limestone, indicating their primary origin only. Moreover, silica as well P_2O_5 content of these nodules is also high.

Even field observations suggest no differences amongst the CaCO_3 concretions observed in geological formations in the sub-Himalayas as well as in the various pedon irrespective of their geomorphological position. The reason for the commonly held view that, these concretions have formed as a result of pedogenesis is because of their irregular (not rounded) shape. The impact of grinding during transport has probably been minimum because the concretion were collected just before the rivers entered the plains after which the gradient did not allow turbulent flows, besides being suspended along with enough earthy material in the flood waters.

Dark brown ferro-magnesian grains present in these soils, often mistaken for iron-manganese concretions in the field contain very high content of quartz and almost minimum amount of bases. Their sesquioxide content is also low. Such elemental composition indicates their primary nature only. In fact these have been transported along with alluvium from the ferromagnesian minerals rich geological formations.

Study of thermodynamic stability of common alumino-silicates indicates that primary as well as secondary minerals are more stable in these poorly drained alkali soils as compared to the normal environments. Stability of the minerals increases with increase in pH indicating that plagioclase feldspars can not act as diffuse source of sodium in these soils as has been commonly believed till now. Further upon improvement in the drainage conditions due to reclamation by chemical amendments or natural vegetation there could be a change in mineral stability order indicating a possible break-down or transformation of smectites to kaolinite either through a chloritised component or as a part of mixed layer mineral.

Classification of these soils as per Soil Taxonomy shows that most of these soils are still in the Entisol a Inceptisol stage. However, alkali nature of these soils is equally observed in the Udorthents and Ustifluvents. Though, argillans are observed in these soil, yet these seem to be the result of local dispersion of clay in a sodic environment followed by flocculation and deposition at the same place. Thus these are not due to movement of clay from A to B horizon. Such argillans should best be termed as 'salt cutans' only. In order to avoid hazards of misclassification in the event of change in management practices (reclamation etc.) and to make it more meaningful, alkali and saline classes have been proposed at the family level of differentia.

Mineralogical assemblage of the soils of the Ghaggar river basin is entirely different from those of the Drsadvati-Chautang river basin. The former has more smectites while plagioclases are higher in latter. These differences are due to difference in the mineralogical make up of geological formation that contributed to these alluvium. These soils are dominantly illitic. As reported by earlier workers smectite is not pedogenic because nearby geological formation which contributed to this alluvium contain as high as 43% smectite. There is not much change in the smectite content of alluvium even after being transported for 260 km, in fact, it has only been diluted by the mixing of other geologic formations. Kaolinite in these soils also seems to be inherited, as the geological formations contributing to this alluvium contain as high as 34 to 36 per cent kaolinite. Although these formation are alien to this region, as they belong to the Gondwanas. Mineralogical assemblage of the coarse fraction indicates almost identical contents of plagioclases in the alkali as well as normal soils, thus again dispensing the role of albite as a potential source of sodium in these soils.

A study of the mineralogical make-up and salt contents of the geological formations which contributed to alluvium of this area, points to Salt Range in the outer Himalayas as the possible source of salts. Subathus, Murrees and Sirmur series contain lot of salts, smectites as well as lime. Shali formation of nearby Mandi rock salt area in Himachal Pradesh, associated with red shale and dolomite has been co-related with Saline series of Salt Range in the Himalaya. Presence of high sodium and chloride containing brine springs in and around Shali formation are natural expressions of the presence of large amount of soluble salts of sodium in the parent material of alluvium itself. Dominance of sodium and chloride, though in small amount, in the saturation extracts of the pedons located in the hilly areas suggest the sodium chloride (halite) as possible source of sodium and chloride.

Sodium carbonate formation in these soils appears to be the result of a simple chemical reaction between sodium chloride or sodium sulphate and calcium carbonate in the low temperatures of the Himalayas. As generally believed, this reaction will not move in the backward direction owing to increased solubility of calcium carbonate with decrease in temperature.

With improvement in drainage and increased leaching owing to reclamation by chemical amendments or natural vegetation leads to transformation of inherited smectites to a chloritised component or a mixed layer component both of which are fairly stable in the present environment. This is clearly evident from the clay mineralogical data and is in consonance with the thermo-dynamic predictions.

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Appendix - i Climatological data

Monthly rainfall (mm)		Average monthly temperature °C								
Month	Chandigarh (1985-90)	Ambala (1985-89)	Karnal (1985-90)	Sirsa (1985-89)	Hisar (1985-89)	Chandigarh (1985-90)	Ambala (1985-89)	Karnal (1985-90)	Sirsa (1985-89)	Hisar (1985-89)
Jan.	30.3	14.0	14.3	5.4	6.6	12.4	13.4	13.2	12.4	14.7
Feb.	22.2	37.2	26.8	7.6	8.7	16.1	15.1	15.5	14.2	16.3
March	25.0	15.9	16.4	9.7	8.4	20.2	21.2	20.5	21.2	22.5
April	12.0	8.4	9.3	6.0	1.9	25.9	27.3	26.5	28.3	33.7
May	49.0	45.0	28.3	20.1	16.2	30.1	32.3	30.4	32.9	35.0
June	58.5	116.0	101.5	39.9	39.0	31.5	31.5	31.7	31.8	34.2
July	398.2	361.2	180.2	164.5	97.4	28.3	29.2	30.1	31.1	31.8
Aug.	309.9	236.6	200.1	100.6	114.3	27.7	28.5	29.0	29.4	30.7
Sept.	256.6	133.9	90.8	51.5	58.9	26.9	28.3	30.3	28.3	29.9
Oct.	10.7	31.9	11.6	1.1	4.5	24.0	24.5	24.6	24.8	26.0
Nov.	15.0	1.0	16.4	0.0	0.0	19.9	21.8	19.1	19.4	21.2
Dec.	30.0	36.1	29.8	3.2	3.7	14.5	14.7	14.1	14.7	15.3

Source:

Ambala, Sirsa, Hisar: Statistical Abstracts of Haryana.

Karnal: Annual Reports, CSSRI, Karnal

Chandigarh: Annual Reports, CSWCRTI, Dehradun.

Appendix - ii Key to macro-morphology

Boundary: width: a = abrupt, c = clear, g = gradual, d = diffuse

Topography: s = smooth, w = wavy, i = irregular, b = broken

Texture: s = sand, ls = loamy sand, sl = sandy loam, l = loam, sil = silt loam,
cl = clay loam, sicl = silty clay loam,
sic = silty clay

Structure: Grade (distinctness): 0 = structureless, 1 = weak,
2 = moderate, 3 = strong

Class (size): vf = very fine, f = fine, m = medium, c = coarse

Type (shape): pl = platy, pr = prismatic, cr = columnar,
abk = angular blocky, sbk = sub-angular blocky

Consistence (wet): stickiness: wso = non sticky, wss = slightly sticky, wvs =
very sticky,

plasticity: wpo = non plastic, wsp = slightly plastic, wvs = very plastic

Coarse fragments: nature: conca = calcium carbonate

conir = ferro-magnesian grains

size: f = 0.2 - 1 cm, m = 1 - 2.5 cm, c = > 2.5 cm

Cutans: quantity: p = patchy, b = broken, c = continuous

thickness: tn = thin, mtk = moderately thick, tk = thick

Roots: abundance: f = few, c = common, m = many

size: vf = very fine, f = fine, m = medium

Reaction: 0 = no, 1 = weak, 2 = moderate, 3 = strong, 4 = violent

Mottling: abundance: f = few, c = common, m = many

size: fn = fine, md = medium, co = coarse

distinctness: ft = faint, dt = distinct, pt = prominent

Appendix - iii Key to sand and silt mineralogy

++++++ = > 60%
+++++ = 30 - 60%
++++ = 15 - 30%
+++ = 5 - 15%
++ = 1 - 5%
+ = < 1%

