

**CHARACTERIZATION OF MINERALS IN SOME  
SELECTED BENCHMARK SOILS OF WESTERN  
VIDARBHA, MAHARASTRA**

**THESIS**

**157725**

Submitted to

**Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola  
in partial fulfilment of the requirements  
for the Degree of**

**MASTER OF SCIENCE**

**IN**

**AGRICULTURE**

**(SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)**

**(Land Resource Management)**

**By**

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I hereby declare that the experimental work and its interpretation of the thesis entitled "**CHARACTERIZATION OF MINERALS IN SOME SELECTED BENCHMARK SOILS OF WESTERN VIDARBHA, MAHARASHTRA**" or part thereof has not been submitted for any other degree or diploma of any University, nor the data have been derived from any thesis / publication of any University or Scientific Organization. The source of materials used and all assistance received during the course of investigation have been duly acknowledged.

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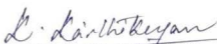
  
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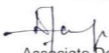
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This is to certify that the thesis entitled " **CHARACTERIZATION OF MINERALS IN SOME SELECTED BENCHMARK SOILS OF WESTERN VIDARBHA, MAHARASHTRA** " submitted in partial fulfillment of the requirements for the degree of "**Master of Science in Agriculture (Soil Science and Agricultural Chemistry - Land Resource Management)**" of the Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola is a record of bonafide research work carried out by Mahale Mahadeo Haridas under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee.

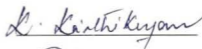


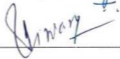

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## ACKNOWLEDGEMENT

It is my proud privilege that I received an opportunity to work under the inspiring guidance of Dr. K. Karthikeyan, Scientist, Division of Soil Resource Studies, National Bureau of Soil Survey and Land Use Planning, Nagpur. I take this opportunity to express my deep sense of gratitude and sincere thanks for suggesting the research topic and also taking keen interest during the course of this investigation, giving valuable suggestion and constant guidance throughout the course of my research work.

I am greatly indebted to Dr. S.K. Ray, Principal Scientist, Division of Soil Resource Studies and Dr. P. Chandran, Principal Scientist, Dr. P. Tiwary, Scientist, Division of Soil Resource Studies and member of my advisory committee for his sharp constructive criticisms in preparation of thesis, open mindedness and for his ever helpful nature during the entire course of study and I am also thankful for his valuable suggestions, during writing, checking and correcting the manuscript.

I am greatly indebted to Dr. T. Bhattacharyya, Head and Principal Scientist, Division of Soil Resource Studies for their sharp, constructive criticisms in preparation of thesis, open mindedness and for their ever helpful nature during the entire course of study. I am highly thankful to Dr. Jagdish Prasad, Principal Scientist and Mr. D. Vasu Scientist for his constant guidance, co-operation and valuable suggestions during this study.

I am highly thankful to Dr. S.K. Singh, Director, NBSS & LUP Nagpur, for providing necessary facilities during the course of this work.

I am sincerely grateful to Dr. T.K. Sen, Principal Scientist, Division of Land Use Planning and Coordinator (Post Graduate Education in LRM)

NBSS & LUP, Nagpur, for his constant encouragement and guidance during entire course of this study.

My sincere thanks to Mr. V. Patil, Technical Officer, NBSS & LUP, Nagpur for providing all necessary academic information and help during the entire course of this study.

I express my deep sense of gratitude to Dr. D.M. Mankar, Associate Dean, PGI, Dr. PDKV, Akola, Shri. D.B. Tamgadge , Head, Department of Soil Science and Agricultural Chemistry, Akola and other faculty members including Dr. V.K. Kharche, Dr. V.V. Gabhane, Dr. S.D. Jadhav, Mr. P.A. Gite, Dr. R.N. Katkar, Dr. N.M. Konde for their kind cooperation during course of this study.

I am highly thankful to Dr. C. Mandal, Principal Scientist Division of Remote Sensing Application Dr. S. Chatterji, Dr. D.K. Mandal, Principal Scientists, Division of Land Use Planning, Dr. M.S.S. Nagaraju, Principle Scientist, Division of Remote Sensing Application, National Bureau of Soil Survey and Land Use Planning, Nagpur for their kind advice and co-operation during the course of study.

I am fortunate enough that I have received advice and help from Mr. V.T. Sahu during field work. I thank Mr. S.V. Bobde, Mr. M. S. Gaikwad, Mr. S.G. Anantwar, Dr. A.M. Nimkar, Ms. S.V. Patil, Mr. R.K Balsagar and Mr. S. Khapekar, for their kind cooperation and also help in my analytical work.

I am sincerely thankful to Dr. Jiji Cyriac, Documentation Officer, and Mr. Pradeep Jadhav for providing library facilities.

My whole hearted thanks to Mr. Atul, Dinesh, Ravi, Sandip for their help in analytical work and their cooperation during entire course of this study.

I affectionately thank my seniors and friends Mr. Deepak Padekar, Kamlesh Kapse, Roshan, Ashish, Baburao patil, Santosh choudhari, Suresh Choudhari, Mohan Choudhari, Vivek, Yogesh, Shiwaji, Dinesh, lopchand, Ishwar, Vitthal, Bhupesh Bawankule, Narayan, Avinash, and Ms. Virushali Deshmukh, Jayshree Kushpure, Dhanshree, Swati Tajane , Varsha, for their help and constant encouragement during this study.

Words are inadequate to express my feelings of love, affection and gratitude to my father Shri Haridas S. Mahale, mother Sau. Venubai H. Mahale, Ranjana Mahale, Brother Mr. Ganesh Mahale, Raj Mr. Balaji Mahale, and Mayuri Mahale, Ashu Mahale, Silpa, Kavita Mahale, whose kind blessings, constant encouragement, patience, and unstinted support to me to complete the thesis. This thesis is affectionately dedicated to my beloved parents, as they are the architect of my past and present.

Place: Nagpur

Date: 05/09/14

  
(Mahadeo Haridas Mahale)  
(EN.no -FF/800)

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**(C)****LIST OF ABBREVIATIONS**

AWC	Available water content
AESR	Agro-ecological sub region
BD	Bulk density
BS	Base saturation
CBD	Citrate bicarbonate dithionite
Cm	Centimeter
COLE	Coefficient of linear extensibility
CEC	Cation exchange capacity
CaCO <sub>3</sub>	Calcium carbonate
Ca/Mg	Calcium: Magnesium ratio
D	Dry
E	East
EC	Electrical conductivity
ECP	Exchangeable calcium percentage
EMP	Exchangeable magnesium percentage
ESP	Exchangeable sodium percentage
EDTA	Ethylene diamine tetra acetic acid
Ext.Ca	Extractable calcium
Ext.Mg	Extractable magnesium
Ext.Na	Extractable sodium
Ext.K	Extractable potassium
Fig	Figure
HCl	Hydrochloric acid
LGP	Length of Growing Period
MAT	Mean Annual Temperature
MSL	Mean Sea Level
Mgm <sup>-3</sup>	Mega gram per metre cube
µm	Micrometre

Mm	Millimeter
Mha	Million Hectare
M	Meter
NaCl	Sodium chloride
N	North
NPC	Non Pedogenic Carbonate
NE	North East
PET	Potential Evapo-Transpiration
PC	Pedogenic Carbonate
PSD	Particle size distribution
Wd	Weight of oven dry soil
°C	Degree Centigrade
%	Per cent
LE	Linear Extensibility
sHC	Saturated Hydraulic Conductivity
Sm/K	Interstratified Smectite Kaolin
SEM	Scanning Electron Microscope
TC	Total clay
XRD	X-ray diffraction
Y	Yellow
YR	Yellowish Red

(D)

THESIS ABSTRACT

- a) Title of thesis : "CHARACTERIZATION OF MINERALS IN SOME SELECTED BENCHMARK SOILS OF WESTERN VIDARBHA, MAHARASHTRA"
- b) Full name of the Student : Mahadeo Haridas Mahale
- c) Name and address of Major Advisor : Dr. K. Karthikeyan Scientist , NBSS&LUP (ICAR), Nagpur.
- d) Degree to be awarded : M.Sc. (Agri) in Soil Science and Agricultural Chemistry (Land Resource Management)
- e) Year of award of degree : 2014
- f) Major subject : Soil Science and Agricultural Chemistry
- g) Total number of pages in the thesis : 77
- h) Number of words in the abstract : 254
- i) Signature of student : 
- j) Signature, name and address of forwarding authority : 

**HEAD,**  
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## ABSTRACT

Three benchmark soils of Western Vidarbha, Maharashtra representing three Agro-ecological sub-regions (AESR) viz., 6.3 (Asra series), 10.2 (Seloo series) and 12.1 (Pahur series) were selected for the present study *i.e.*, "Characterization of minerals in some selected benchmark soils of Western Vidarbha, Maharashtra"

The soils were studied for their Morphological, Physical, Chemical and Mineralogical properties and classified as Typic Haplusterts (Asra series, Seloo series) and Typic Haplusterts (Pahur series).

These soils was moderately alkaline (pH 7.8) to strong alkaline (pH 8.9), medium to high Cation exchange capacity (56.2 to 72.1 cmol(p<sup>+</sup>)kg<sup>-1</sup>) and COLE 0.1 to 0.2 which indicated more smectite mineral in the soils. These soils bulk density (BD) was ranges 1.4 to 1.9 Mgm<sup>-3</sup>. Organic carbon was varies from (0.3 to 0.9%). The saturated hydraulic conductivity (sHC) was impaired in some soils due to increases in ESP (Exchangeable Sodium Percentage) (16.6%). The XRD and subsequent semi-quantitative analysis of total clay fraction shows smectite (75-87%) as the dominant mineral followed by vermiculite and chlorite along with traces of mica, quartz and feldspar. The silt fractions indicated the presence of mica, kaolinite, quartz, smectite, feldspar, chlorite and vermiculite minerals. The submicroscopic study of sand fraction through Scanning Electron Microscope (SEM) shows that coarser fractions of sand are dominated by quartz and plagioclase feldspar whereas the finer fractions are conspicuous by the presence of Mica. It is concluded from this study that the benchmark sites of Western Vidarbha are dominated by smectites in the silt and clay fractions. However, fine clays contain subordinate amounts of vermiculite and feldspars.

## Chapter I

# INTRODUCTION

### 1.1 Background information

A complete knowledge and understanding of the minerals present in the soils is very important to evaluate the problems and potentials of the soils. Study on soil minerals is essential to understand nutrient availability in the soils which is significant for the sustenance of their productivity. Various geomorphic and geochemical processes under different tectonic set up and pedo-environmental conditions lead to physical and chemical changes of the soils. Besides, the studies on sand, silt and clay-sized minerals in the soils they are also useful for understanding the paleoclimatic conditions which prevailed during the formation of these soils (Foucault and Stanley, 1989; Srivastava *et al.*, 1998).

Soils are formed due to the combined effect of various factors and processes. (Jenny, 1941 and Buol *et al.*, 1989) The pedogenic processes and the development of soil profiles are very complex in nature involving many physical, chemical and biological reactions, activated by normal erosion (Milne, 1936) topography (Ruhe, 1956) and regulated over a period of time (Jenny, 1941).

In India the geochemistry and mineralogy of Vertisols are of considerable interest because of their wide distribution (76 mha) (Mandal *et al.*, 2012) and extensive agricultural use. The soils formed from Deccan trap basalt is dominated by smectite clay mineral (Pal and Deshpande, 1987; Bhattacharyya and Ghosh, 1990). However they are more towards montmorillonite of the beidellite- nontronite series (Pal and Deshpande, 1987).

Weathering and clay formation have been considered as the key processes to understand genesis of soils and their classification. It has been demonstrated that the critical evaluation of nature and distribution

of naturally-occurring clay minerals, calcium carbonates, gypsum, gibbsite and zeolites resulting either from inheritance or from the weathering of parent material can yield valuable information to understand the soil forming processes (Pal *et al.*, 2001), so that the soils may be classified in an appropriate manner (Sehgal *et al.*, 1974) for their proper use.

Studies indicate that the benchmark Vertisols of central and Western Peninsular India are of clay and dominated by smectite. The silt fraction contains little or no smectite (Pal and Deshpande, 1987; Kalbande *et al.*, 1992; Balpande, 1993; Bhattacharyya *et al.*, 1993) spatially associated ferruginous and black soils are common in Deccan basalt area. (Basu and Sirur, 1938; Gaikwad *et al.*, 1974) Studies involving soil toposquence with ferruginous soils on the slopes and black soils in depression are many (Gawande *et al.*, 1968, Bhuse *et al.*, 2002) However, reports on close association of these two soils with clear lines of demarcation under almost similar topographical conditions have been rare (Bhattacharyya *et al.*, 1993; Pillai *et al.*, 1996) The ferruginous soils of such association are classified as Ustorthents in the semi-arid climate (Pillai *et al.*, 1996) and Haplustalfs in humid climates (Bhattacharyya *et al.*, 1993). In the former soil type the clay fraction is dominated by smectite minerals whereas in the latter it is dominated by interstratified smectite-kaolinite (Sm/K) minerals.

Black soils were formed from micaceous schists, gneisses and basalts under poor drainage showed the common presence of illite, quartz and feldspar along with smectite, vermiculite and chlorite in the silt fractions whereas the clay fractions were dominated with smectite. Small amount of kaolinite, illite, chlorite, quartz and feldspar were also present. The concentration of smectite was higher in the medium, fine and coarse clay fractions than in the silt fractions (Lotse *et al.*, 1975).

At present, information on weathering and quantification of soil minerals in the BM sites of western Vidarbha are not available in an

organized manner. Therefore, the mineralogical investigations are taken through submicroscopic and XRD techniques for complete understanding of different physical, chemical and mineral weathering processes involved during the soil development. The SEM images and X-Ray diffractograms will be documented. Considerable work has been carried out abroad on the weathering of individual mineral grains using microscopic and submicroscopic techniques (Inskip *et al.*, 1993; Bouabid *et al.*, 1995; Taboada and Garcia, 1999; Mermut *et al.*, 1986; Nugent *et al.*, 1998). In India, few attempts have been made to assess the weathering of individual minerals (Srivastava *et al.* 1998; Niranjane *et al.*, 2001; Pal and Deshpande, 1987). But except the work of Beutelspacher and Van Der Marel in 1968, who had prepared the atlas of electron microscopy of clay minerals and their admixtures, no further documentation is made neither from academic nor from research point of view.

In this pursuit it is observed from the review of literature that in Maharashtra with special reference to Vidarbha, a modest information on soil minerals should be updated. Therefore, a holistic approach will be made in the present study to evolve a comprehensive document of soil minerals and to generate quantified datasets on minerals in the benchmark soils representing the agro-ecological sub-regions of Western Vidarbha.

## **1.2 Importance of study**

This study is important because very few works have been done in this subject of research from the study area especially the mineralogical properties and their characterization. Moreover, the climatic signatures obtained in this study in terms of calcium carbonate, organic carbon, exchangeable bases, cation exchangeable capacity, saturated hydraulic conductivity, characterization of clay minerals etc., are multifaceted and have wide applications.

### **1.3 Objectives of study**

1. To identify major minerals in different soil fractions of Western Vidarbha.
2. To link minerals constituents with soil properties.

### **1.4 Scope and limitations**

- At present, information on weathering and quantification of soil minerals in the BM sites of Western Vidarbha are not available in an organized manner.
- This study could be applied for finding out the presence of minerals in different soil size fractions and their characterization in soils.
- It could be applied to know the age of soils on the basis of mineral make-up and minerals characterization.
- Therefore, the mineralogical investigation are taken through submicroscopic and XRD techniques for complete understanding of different physical, chemical and mineral weathering processes involved during the soil development.

### **Limitation**

- It is required to work further and the M.Sc. program is too short a period.

## Chapter II

# REVIEW OF LITERATURE

The literatures collected for the present study has been revised under the following sub-heads;

### 2.1 Geographical Distribution of Vertisols

### 2.2 Characteristics Features of Vertisols

#### 2.2.1 Morphological properties vertisols

#### 2.2.2 Physical and Chemical properties of vertisols

#### 2.2.3 Mineralogical properties of vertisols

#### 2.2.4 Sub-microscopic Studies (sand mineralogy)

### 2.3 Soil Properties in Relation to Mineralogy

### 2.1 Geographical Distribution of Vertisols

The black soil is known as dark clay soils, the tropical and sub-tropical regions covered about 257 m ha area (Dudal, 1965). They were found in 76 countries, with the largest area occurring in Australia. Ever since the first review, ongoing surveys and preparation of the soil map of the world (FAO, 1974) indicated additional or enlarged extensions of "dark clays" in Canada, China, Egypt, Ethiopia, India, Pakistan, Srilanka, Sudan, Trinidad, USA, USSR and Venezuela.

In India, Vertisols are found in the peninsular region extending from 8°45' to 26°0'N latitudes and 68°0' to 83°45'E longitudes. They are derived from weathering of the Deccan basalt (Pal *et al.*, 2006) and are mainly confined to lower topographical positions, such as the piedmont plains and river valleys. In India the total area covered under the black soil is about 76.4 m ha. (Bhattacharyya *et al.*, 2013) and mostly found in the peninsular Deccan plateau of the country.

## **2.2 Characteristics Features of Vertisols**

Vertisols are clay soils which exhibit impressive volume change due to shrink-swell processes, when soil moisture conditions change. This intrinsic shrink-swell behavior is considered the dominant process involved in Vertisols and results in significantly greater spatial and temporal variability of soil properties than in any other soil order.

### **2.2.1 Morphological properties of Vertisols**

The morphological properties of Vertisols are induced by the soil's mineralogical, physical and chemical properties and specific attributes resulting from cyclical variation of the moisture status. The most critical soil properties are the amount and type of clay. The physical activity of the system increases with the amount of clay, if the clay has shrink-swell characteristics. Dominance of smectites and, specifically of montmorillonite accentuates the volume change characteristics. Other members of smectite family, such as nontronites and saponites, have a lower equivalent coefficient of linear extensibility (COLE). Organic matter also should be low in such soils to increase the effective volume occupied by the clays (Dudal and Eswaran, 1988).

#### *Colour*

In general, Vertisols are dark in colour and commonly lack distinct horizonation. Vertisols with gray, brown or red pigmentation have also been reported in various regions of the world (Soil Survey Staff, 1975).

#### *Texture*

Vertisols are fine-textured soils. According to Soil Taxonomy (Soil Survey Staff, 1975; 1998) Vertisols must have 30 per cent or more clay in the fine earth fraction either between the mineral soil surface and a depth of 18 cm or in an Ap horizon, whichever is thicker, and 30 per cent or more clay in the fine earth fraction of all horizons

between a depth of 18 cm and either a depth of 50 cm, or a dense, lithic or paralithic contact, duripan or petrocalcic horizon whichever is shallower. Clay content of Vertisols can be as high as 90 per cent, particularly for those derived from pyro plastic deposits. If the clay content requirement is not met, but the soil type exhibits considerable shrink-swell activities as measured by coefficient of linear extensibility (COLE), these soils would be considered as vertic intergrades to other soil orders.

#### *Other attributes of Vertisols*

The clay content is not the only requirement to identify a Vertisols, but also exhibit the shrink-swell characteristics to develop unique structures and features in the soil profile. By definition (Soil Survey Staff, 1998), Vertisols must have "a layer of 25 cm or more thick, with an upper boundary within 100 cm of the mineral soil surface that has either slickensides close enough to intersect" or "wedge shaped aggregates which have their long axis tilted 10 to 60 degrees from the horizontal" slickensides are features which exhibit shiny and smooth surfaces at the interface of the peds. The presence of slickensides in a soil horizon is designated in the field as "Bss" and is a diagnostic characteristic common to all Vertisols.

Wedge-shaped aggregates are the structural units that generally result from the intersection of slickensides. The presence of cracks that open and close in response to drying and wetting is also a requirement for Vertisols (Soil Survey Staff, 1975; 1998). Since cracking occur in soils other than Vertisols, criteria for depth and duration when cracks remain open are the basis to discriminate and infer soil moisture regime of Vertisols.

Gilgai and diapir are other features which may be present in Vertisols. Gilgai is an Australian aboriginal term to describe a micro topography that consists of mounds, shelves and/or depressions either in circular, linear or complex patterns. Since gilgai does not occur in all

Vertisols, it was abandoned as a facultative criterion in Soil Taxonomy (Soil Survey Staff, 1998). Diapir, also called Mukhare by the Australians, is another feature which may occur in Vertisols.

### 2.2.2 Physical and Chemical properties of vertisols

Vertisols and their intergrades are fine textured soils with clay content varying from 30 to 70 per cent which sometime may be as high as 88 per cent (Dudal, 1965; Murthy *et al.*, 1982; Kaswala and Deshpande, 1986). The clay content of Vertisols remain uniformly high (>35%) throughout the profile to a depth of 50 cm or more (Kaswala and Deshpande, 1983). On many occasions the clay content increases with increasing depth (Pathak and Patel, 1980).

Coefficient of linear extensibility (COLE) value is a measure of the shrink-swell potential of the soils. It can be measured by the change in length of a ribbon of soil under different soil moisture contents (Schafer and Singer, 1976). Eswaran *et al.*, (1988) reported that the mean COLE values for Vertisols is about 0.13 and the range is from 0.06 to 0.18. According to Coulombe *et al.*, (1996) the mean COLE values in Vertisols range from 0.07 to 0.20  $\text{cm cm}^{-1}$ .

Franzmeier and Ross, (1968) found that COLE depends on the amount of clay, the clay mineralogy and fabric, but not to an appreciable extent on the nature of the adsorbed cations.

Shirsath *et al.*, (2000) showed that the shrinking and swelling is solely due to the amount of smectite mineral in soils and a minimum smectite content of 20% is sufficient to cause enough swelling to have a COLE value of 0.03.

Hydraulic conductivity (K) of Vertisols is an important parameter used to access plant growth, soil aeration, soil water recharge, surface runoff, erosion and evapotranspiration as well as the potential of surface water and ground water pollution by organic and inorganic constituents. Hydraulic conductivity is a very dynamic property. Factor

constituents. Hydraulic conductivity is a very dynamic property. Factor that influences K values are numerous: texture, structure, soil moisture contents, biological activity, electrolyte concentration of the soil solution, soil temperature, depth management practices, place and type of measurement (Coulombe *et al.*, 1997).

In black soils of Jayakwadi and Purna Command area Barambe *et al.*, (1986) reported that the infiltration rate was 40 to 42 mm hr<sup>-1</sup> in shallow soils but only 12-36 mm hr<sup>-1</sup> in deep soils. The saturated hydraulic conductivity also had the same trend as that of infiltration rate with higher values (6 to 39 mm hr<sup>-1</sup>) for shallow soils and lower values (2 to 30 mm hr<sup>-1</sup>) for deep black soils. The values of hydraulic conductivity in Purna Valley were also reported by Kadu *et al.*, (1993) and Balpande *et al.*, (1996).

Vertisols are commonly known as being neutral to alkaline in reaction, since the majority of these soils are derived from calcareous or base rich parent materials (Ahmad, 1985). Acid Vertisols may result from acidic parent materials, a more humid paleoclimate, strong seasonal leaching or ferrolysis. There is generally an increase of pH with depth corresponding to an increase of CaCO<sub>3</sub> and other salts. Acid Vertisols with pH values of 4.5 or less are recognized in Soil Taxonomy as Dystraquerts or Dystrusterts (Ahmad, 1985).

Organic matter is an important constituent of Vertisols as it affects their morphological, physical and chemical properties as well as their management, organic matter content range from 0.5 to 10 per cent (3 to 6 per cent organic C), but are typically from 0.5 to 5 per cent organic C. The differences are due to climatic conditions, cropping history or natural vegetation. The dark colour is not necessarily indicative of high organic matter content in Vertisols as some dark Vertisols contain less than 1 per cent organic matter. This is generally attributed to strong clay organic complexes of smectite and humic substances (Coulombe *et al.*, 1996).

Vertisols are soils which shrink and swell greatly with changes in their water content, the soil movement involved is sufficient to cause vertical mixing of the soil profiles (Soil Conservation Service, 1970). However, most recent studies have nullified the effect of vertical mixing (Satyavathi *et al.*, 2005; Pal *et al.*, 2006). The movement of these soils results from dimensional changes in soil peds. The fractional linear dimension change in a ped or clod which result from a change in water content from oven dryness to the 1/3 atmosphere percentage can be determined from bulk density measurements and has been described by Grossman *et al.*, (1968) as the coefficient of linear extensibility.

Nayak and Chirstensen, (1971) studied the swelling characteristics of compacted expansive soils and concluded that swelling potential was a function of plasticity index, per cent clay and the initial moisture content.

Workentin *et al.*, (1957), studied the smectites and showed that swelling occurs in two stages, the first is the insertion of water between the elementary clay layers; the second is the filling of larger spaces. The relative importance of two mechanisms is different depending on whether the clay is calcic or sodic. Insertion of water between clay layers can occur on a large scale for Na-montmorillonite, but is more limited for Ca-smectite and does not occur for kaolinite (Ben Rhaeim *et al.*, 1987). Furthermore, it is often thought clay swelling is a mechanism which intervenes only between clay layer units. This is largely true for sodic smectites but not for calcic smectites.

According to Soil Taxonomy (Soil Survey Staff, 1975) Vertisols having a udic-ustic moisture regime were considered to be humid and sub-humid, respectively. The criteria in Soil Taxonomy used to subdivide Vertisols according to moisture regime are the duration and pattern of soil cracking. In udic Vertisols cracks do not remain open for more than 90 cumulative days in most of the years, and do not remain open for more than 60 consecutive days during the 90 days, following the summer solstice in more than seven out of ten years. Dominance of

smectite mineral in the clay fraction results in appreciable shrink-swell potential which induces formation of cracks and distinctive structural elements like spheroids and wedge-shaped peds with smoothed surfaces of slickensides (Eswaran *et al.*, 1988); Smith *et al.*, (1985) indicated that usually shrink-swell phenomenon is positively related with the content of expansive mineral as indicated by a high coefficient of linear extensibility (COLE) and clay content dominated by the mineral of the smectitic group.

Dudal and Eswaran, (1988) reported montmorillonitic as the common mineralogy class for most of the shrink-swell soils of the world. Soil Taxonomy (Soil Survey Staff, 1998) proposed a qualitative smectitic mineralogy class for soils that have more smectite by weight than any other single kind of clay mineral. It thus indicates that there is a scope for quantitative estimation of smectite for such soils.

Bhattacharyya *et al.*, (1997) proposed that vertic properties of soils can only be a function of smectite content, even though its content is small. They also stressed on the fact that vertic properties cannot be induced by kaolinite, despite its presence in large amounts.

Borchardt, (1989) reported that soils containing all other clays shrink and swell with changes in moisture content, but changes are particularly extreme in smectites. It has been reported that vertic properties of soils (Soil Survey Staff, 1998; 2003) are primarily regulated by the nature of clay minerals, particularly their surface properties. Weiss *et al.*, (1955) showed that the different swelling properties of clays with identical interlayer cations are mainly due to differences in layer charge densities.

Mooney *et al.*, (1952) demonstrated that smectite hydration is strongly influenced by H<sub>2</sub>O vapour pressure, the extent of crystalline swelling and the nature of exchangeable cations. Although the work of Mooney *et al.*, (1952) was criticized because the samples were H-saturated prior to saturation with the desired cations, the essential

features of their results were reproduced by Ormerod and Newman, (1983) and Chiou and Rutherford, (1997).

Crystalline swelling is a process whereby the basal spacings (d-001-values) of 2:1 phyllosilicates expand or collapse between 10-22 Å in a series of steps corresponding to the intercalation of 0, 1, 2, 3 or 4 discrete layers of H<sub>2</sub>O molecules (Norrish, 1954). The extent of crystalline swelling is controlled by a balance between relatively strong swelling forces, due to the hydration potential of the interlayer cations and charge sites and electrostatic forces of attraction between the negatively charged 2:1 phyllosilicate layers and the positively charged interlayer cations (Kittrick, 1969; Laird, 1996).

Portz, (1967) reported that clay swelling controls permeability and drainage of water through and in soils, and influences the suitability of soils for agricultural purposes.

Chemical reduction of octahedral Fe decreases the swelling of Na smectite (Egashira and Ohtsubo, 1983; Lear and Stucki, 1989) and affects the other physico-chemical properties of smectites, such as surface charge density (Stucki, 1988), specific surface area (Lear and Stucki, 1989), cation fixation (Khaled and Stucki, 1991), hydraulic conductivity (Shen *et al.*, 1992) and structural order (Stucki and Teisser, 1991).

### **2.2.3 Mineralogical properties of vertisols**

Many minerals in Vertisols originate from inheritance, transformation and/or neoformation (Coulombe *et al.*, 1996). The variability in parent materials and environmental conditions leads to the complexity in mineralogy of Vertisols.

Vertisols are dominated by smectitic mineralogy which induces extreme shrink-swell behavior. Kaolinite is a non-swelling accessory clay mineral (phyllosilicate) of secondary importance in Vertisols. However, Vertisols containing abundant kaolinite or a combination of

interstratified clay minerals have been also found in Vertisols regions of the world (Coulombe *et al.*, 1996). But they will not contribute towards shrink-swell activity as observed by the decrease in COLE value with increase in kaolinite content (Bhattacharyya *et al.*, 1997).

Characteristics of smectites in Vertisols, which may also apply to other clay minerals and other soil orders, include (i) a greater thermodynamic stability than reference minerals, (ii) a higher layer charge ( $>0.45$  per half unit cell) which may be as high as vermiculite or illite and in turn impact the structure, particularly when derived from basaltic parent materials containing abundant ferromagnesian minerals (Coulombe *et al.*, 1996).

The black soils of Deccan Trap are rich in plagioclase feldspars and yield dioctahedral smectite as the first weathering product (Pal and Deshpande, 1987; Bhattacharyya *et al.*, 1993). Earlier review on Vertisols of India indicates that black soils of India are dominated by beidellite-nontronite type of minerals (Ghosh and Kapoor, 1982). However, fine clay smectite subjected to Greene-Kelley test (Greene-Kelley, 1953) by heating clays with Li and swelling by glycerol solvation expands to about  $18 \text{ \AA}$  and contracts to  $\sim 0.95 \text{ \AA}$  indicating this to be a mixture of beidellite and montmorillonite in which the amount of the former is more than latter (Pal and Deshpande, 1987). But the Mg saturated fine clay smectite with glycerol vapour (Harward *et al.*, 1969), also expanded to about  $18 \text{ \AA}$  because the solvation energy for the glycerol molecule was greater than the attractive forces of interlayer Mg. It is thus felt that beidellite studied by Harward *et al.*, (1969) had apparently higher tetrahedral charge than the fine clay smectite of Vertisols. In other words, fine clay smectite in Vertisols is nearer to montmorillonite in the montmorillonite beidellite series. Since the nontronite would behave in this test as beidellite does and the studied fine clay smectite is unstable to HCl treatments, releasing considerable iron in the solution, it can be said that this mineral is nearer to montmorillonite of the montmorillonite-nontronite series.

The dominance of beidellite-nontronite type minerals in black soils of India were arrived at from calculations based on smectite formula (Guezal and Wilson, 1981).

The Vertisols of the central and western India (Pal and Deshpande, 1987) contain few biotite and muscovite particles in the sand fractions, in addition to small amounts of silt and clay size micas. As the Deccan basalt does not contain mica and chlorite, their presence in Vertisols has been attributed by the authors of the erosional and depositional episodes experienced by the Deccan basalt areas during the post Plio-Pleistocene transition period.

Black soils of India, Agrawal and Ramamoorthy, (1970) reported the transformation of montmorillonite in to chlorite under alkali conditions was due to the possible formation of brucite layer. However, hydroxy-interlayering has been a very common feature in smectite of these soils. Its extent that can impair the internal surface area as well as the swelling has been more in Vertisols of semi-arid and arid climatic zones (Kalbande *et al.*, 1992).

Pillai *et al.*, (1996) reported dominance of smectite in red ferruginous and black soils of basaltic Malegaon plateau of Nagpur district. Presence of interstratified smectite-kaolin (Sm/K) even though in small amount, in the clay fraction suggests that these soils were formed through a progressive landscape reduction progress. The smectite and Sm/K were formed under humid climate of the geological past and are preserved because of termination of the humid climate. The relatively high soil pH conditions of black soils has caused hydroxy-interlayering in vermiculite, an alteration product of mica. Chlorite in black soils is of pedogenic origin through a hydroxy-interlayering in vermiculite.

Nelson *et al.*, (1960) showed that little change in silicate mineralogy had occurred during pedogenesis of usterts in the Backlands and Grand Prairie of Texas. They concluded that

predominant smectite was inherited from Cretaceous and early Tertiary parent sediments as evidenced by the near intensity of X-ray diffraction of A and C horizon of fine clays. The only detectable mineralogical change taking place as a result of pedogenesis was a decrease in calcite upwards in the profile. Kunze *et al.*, (1963) also reported the similar relationship between late Pleistocene parent sediments and resulting usterts and usterts on the coast Prairie of Texa.

Ahmad and Jones (1969) presented evidence that smectite in Caribbean Vertisols was inherited from the parent Cenozoic marine sediments. In contrast to studies indicating the inheritance of smectite in Vertisols from parent sediments.

Johnson *et al.*, (1962) reported convincing evidence that Vertisols developed in north central and eastern Arizona from basalts (and ejecta or basaltic composition) were dominated by smectite synthesized *in-situ*.

Chatterjee and Rathore, (1976) reported little evidence of significant mineralogical variation among profiles, or within profiles, or usterts developed from basalt in India. They considered smectite as to be the first mineral synthesized as a product of weathering. Although Chatterjee and Rathore, (1976) suggested that smectite weathered to produce the small amount of kaolinite present, they believed the equally small content of illite and quartz to be due to eolian deposition.

Fitzpatrick and Le Roux, (1977) found Fe rich smectites to be the first weathering product of dolerites in the Transvaal, South Africa. The smectite persisted, apparently becoming partially chloritized, during pedogenesis of Vertisols in downslope position of the toposequence studied. However, the smectite was partially altered to kaolinite/halloysite in the more intensively weathered associated upland Mollisol.

Allen *et al.*, (1972) concluded that most of the silicate clay of usterts in West Texas depressions was derived by alleviation from surrounding upland soils.

Majority of the Vertisols of central and western peninsular India occur generally on lower piedmont plains or in valleys. A study was made with five benchmark soils (Nimone series; Kasireddipalli series; Aroli series; Sarol series and Kheri series) to ensure whether the mineralogy of these soils can be fully accounted for petrology of the Deccan trap (Pal and Deshpande, 1987). The sand fractions of these soils were composed of quartz, K-feldspars, anatase and plagioclase, silt fractions contained in addition to the above minerals, amphibole, mica, 1.0-1.4 nm minerals, vermiculite, chlorite, kaolinite and occasionally smectite. Coarse clays (2-0.2 $\mu$ m) were composed of smectite, chlorite, vermiculite, mica, kaolin, 1.0-1.4 nm minerals with small amount of feldspars and quartz. The fine clays (<0.2 $\mu$ m) had dominant amount of well crystallized smectite with little amount of mica, vermiculite and kaolin. The alluvium of weathering Deccan basalt can not account for the presence of all the minerals identified in the sand, silt and clay fractions because basalts are composed dominantly of plagioclase and pyroxene with some accessory minerals like magnetite, ilmenite, volcanic glass and palagonite (Deshmukh, 1980; Chitale and Gueven, 1989). Therefore, the presence of mica, K-feldspars, rutile and zircon in a few Vertisols (Pal and Deshpande, 1987) suggest that they are formed in alluvium of weathering Deccan basalt and other rock formation, transported downstream (Desai, 1942).

In view of the geomorphic and climatic history described above it is suggested that the Deccan basalt must have readily weathered to smectite mineral in an earlier humid tropical climate. A rock, rich in weathereble mineral like plagioclase, can readily give rise to dioctahedral smectite as the first weathering product over an arid to a humid climate range (Tardy *et al.*, 1973). In Deccan basalt, plagioclase

is by far the most dominant mineral that alters to clay mineral of expanding type (Deshmukh, 1980; Chitale and Gueven, 1989). Thus the weathered materials of basalt must have been detached and transported downstream and deposited as alluvium covering the lower piedmont areas or filling the valleys (Pal and Deshpande, 1987). Therefore the dominant smectite mineralogy of these benchmark Vertisols is due to these fluvial deposition in an earlier humid climate. The inherent shrink-swell characteristic of smectite is likely to trigger the typical morphogenetic manifestation of Vertisols induced by the moisture stress during the drier climate.

The weathering of basalt has given rise to fine textured (shrink-swell) soils. This rock yields smectitic clay as its first weathering product as detected in the clay fractions of weathering rinds of spheroidally weathered basalt (Pal and Deshpande, 1987). Measurement of smectite content in the clay fraction of benchmark Vertisols of central and western Peninsular India indicates that the fine clay ( $<0.2\mu\text{m}$ ) is dominated by smectite whereas the coarse clay ( $2-0.2\mu\text{m}$ ) contains 20-50 per cent of smectite. The silt fraction contains little or no smectite (Pal and Deshpande, 1987; Kalbande *et al.*, 1992; Balpande, 1993; Bhattacharyya *et al.*, 1993)

Spatially associated ferruginous and black soils are common in Deccan basalt areas (Basu and Sirur, 1938; Gaikawad *et al.*, 1974). Studies involving soil toposequence with ferruginous soils on the slopes and black soils in depression are many (Biswas and Gawande, 1962; Gawande *et al.*, 1968). However, reports on close association of these two soils with clear lines of demarcation under almost similar topographical conditions have been rare (Bhattacharyya *et al.*, 1993; Pillai *et al.*, 1996). The ferruginous soils of such association are classified as Ustorthents in the semi-arid climate (Pillai *et al.*, 1996) and Haplustalfs in humid climates (Bhattacharyya *et al.*, 1993). In the former soil type the clay fraction is dominated by smectitic minerals

whereas in the latter it is dominated by interstratified smectite-kaolin (Sm/K) mineral.

Black and associated ferruginous soils were reported to occur in the semi-arid regions or in patches in the arid, dry sub-humid and moist sub-humid (Raychaudhuri, 1941; Murthy *et al.*, 1982) and in humid areas (Bhattacharyya *et al.*, 1993). The ferruginous soils (Haplustalfs) have been reportedly considered as having formed in the prevailing humid tropical climate (Bhattacharyya *et al.*, 1993). It is however, difficult to reconcile the relation between these climatic conditions with the associated black soils because smectite, which is mainly responsible for the formation of black soil, ephemeral in such environment. It is equally difficult to understand the formation of black and smectitic red soils (Bhattacharyya *et al.*, 1993; Pillai *et al.*, 1996) in semi arid climate, since it involves the formation of huge amount of smectitic clay.

Salt-affected shrink-swell soils of the Purna Valley of <sup>W</sup>western Vidarbha, Maharashtra developed in the basaltic alluvium under arid/semi-arid climatic conditions were investigated for morphological, physical, chemical and clay mineralogical properties. Taxonomically at great group levels, the soils under study were classified as Aridic Haplusterts, Sodic Haplusterts, Aridic Claciusterts and Sodic Calciusterts. Smectite was the dominant phyllosilicates (>68%) followed by vermiculite (10-17%) with small proportion of chlorite, mica and kaolinite (<8%). The study further established montmorillonite as the member of the smectite group in salt-affected Vertisols of the valley. The weathering mean of clay was 8.61-8.78 which indicates intermediate intensity of weathering (Padole *et al.*, 1998).

Ten soils from a transect in a landscape of basalt and sandstone in different landforms were studied for their physical, chemical and mineralogical properties. Despite the difference in parent material, the mineralogy of soils of both the transects are same. Smectite was found to be dominant in soils of basaltic parent material whereas kaolinite

was for the soils on sandstone. The presence of both smectite and kaolinite in soils on sandstone appears to be the integral part of the sandstone (Chinchmalatpure and Sehgal, 2000). The mineralogical and chemical characteristics of soils developed from quartzite and granite-gneiss parent materials of the Sivagiri micro-watershed in Chittoor district of Andhra Pradesh were studied by Thangasamy *et al.*, (2004). Semi-quantitative estimates of clay fractions based on relative areas under their corresponding peaks indicate that most of the pedons are dominated by smectite followed by kaolinite and mica whereas only a few pedons are dominated by kaolinite followed by considerable amount of smectite and mica. Feldspars and quartz are present in traces. The authors found this information is important for management of these soils for agricultural production.

While characterizing rainfed rice and associated non-rice shrink-swell soils in Nagpur district, Jondhale and Jagdish Prasad, (2006) carried out mineralogical analysis of the soils of the total clay fraction of the soils. Rice soils were reported to contain less smectite in clay fraction compared to non-rice soils. Rice soils also contained more chlorites than non-rice soils. Ghosh, (1973) indicated chloritization may be due to the influence of rice cultivation in soils of Tripura. Recently, Nayak and Sarkar, (2005) however, indicated that chloritization is not so severe to qualify for ferrollysis in some rice-growing soils of West Bengal. Even though there was a higher degree of interstratification in rice growing soils, the smectite content was high (Shirsath *et al.*, 2000). This was confirmed by high COLE values of these soils which were due to more smectite contributed by higher total and fine clay contents.

The alluvium of weathering Deccan basalt can not account for the presence of all kinds of minerals identified in the sand, silt and clay fractions (Deshmukh, 1980). Vertisols are formed in weathered products of basalt and also of metamorphic rocks transported downstream as alluvium (Pal and Deshpande, 1987). The mineralogy of soil clays in the Deccan Plateau of these Vertisols is the result of

several factors interacting with the parent material. In certain combination of circumstances, soil forming processes exhibit their effects on the clay mineralogy viz. Oxisols, Vertisols and Andosols (Newman, 1984). There is ample evidence to show that the amount of clay in a soil has a very important bearing on the genesis, characteristics and physical and chemical properties of soils. However it would be prudent to explain what significance clay mineral type has in soils, especially in terms of their pedology, paleopedology, polygenesis and edaphology (Pal, 2003).

Clay mineralogy and whole-soil major chemistry of an early Quaternary red soil and two late Miocene paleosols between basalt lavas on Penghu Islands (Pescadores), Taiwan, were studied to compare properties of soils from the different periods. The early Quaternary red soil consists of a kaolinite and smectite clay assemblage. The late Miocene paleosols are rich in kaolin minerals. The amounts of Si, Fe and Al in the three profiles are the mineralogical differences. The depth distributions for clay and free Fe oxide contents suggest that the early Quaternary red soil formed in at least two stages. The early Quaternary red soil was classified as fine, mixed, hyperthermic Typic Rhodustalfs. The late Miocene paleosols were classified as fine, kaolinite, hyperthermic, Rhodic Paleustalf. The late Miocene paleosols contain more clay, lower  $\text{SiO}_2/\text{Al}_2\text{O}_3$  and  $\text{SiO}_2/(\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3)$  molar ratios, average of 2.5 and 1.7, respectively and higher chemical indexes of weathering than the early Quaternary paleosol. The  $\text{SiO}_2/\text{Al}_2\text{O}_3$  and  $\text{SiO}_2/(\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3)$  molar ratios and  $\text{Mn}^{2+}$  and  $\text{Mg}^{2+}$  distributions showed zigzag patterns, suggesting that changes in sea level influenced the early Quaternary profile during the soil formation (Wang *et al.*, 2007).

Bhuse *et al.*, (2002) studied the formation of spatially associated red and black soils developed in zeolitic and non-zeolitic Deccan basalt of western and southern India. The presence of well developed kaolinite minerals and smectite kaolinite interstratified minerals in the

red soils have been discussed in the light of presence and absence of zeolites in the basaltic rock in which these soils are developed. They concluded that zeolite, as natural modifier, not only inhibit the process of transformation of minerals but also hinders the formation of sodicity in black soils (Vertisols and its intergrades). The study thus reaffirms the role of natural zeolite as savior against soil degradation (Bhattacharyya *et al.*, 2000).

Pal *et al.*, (2006) studied the pedogenic processes in a shrink-swell soil (Vertic Haplustalf) of Central India. The physical, chemical and mineralogical properties of Vertisols were studied. They suggested that a highly probable pathway for the formation of Vertisols with time from Vertic Alfisols in sub-humid and semi-arid climatic conditions of Central India and also concluded that clay illuviation is more important pedogenetic process in a < 100 year clayey shrink-swell soils than the pedoturbation.

Study of soils from four districts in the Eastern Vidarbha of Maharashtra showed the dominance of smectite along with smectite-kaolinite (Sm/K) interstratified mineral. Smectite is transformed to Sm/K due to the weathering process. Smectite is the first weathering product of plagioclase feldspars in an earlier humid climate the formation of Sm/K interstratifications is a post depositional transformation of clay mineral under high rainfall and temperature conditions. The weathering products are detached and subsequently transported and deposited in the valleys and depressions. These soils continue to exist in the valleys. Due to poor drainage conditions in the valleys and depressions the smectite minerals remained in the pedo-environment and transformed to Sm/K interstratified minerals (Balbuddhe and Bhattacharyya, 2009),

Six non-calcareous pedons from the basaltic terrain of the Western Ghats in Maharashtra, India, were identified for the clay mineralogical investigation (Bhattacharyya *et al.*, 1993). The authors indicated that interstratified smectite-kaolin (Sm/K) is dominant in red

soils whereas smectite is dominant in black soils. The Sm/K is formed by the transformation of smectite, the first weathering product of Deccan basalt in a humid tropical climate. The study suggests that the interstratification of kaolin with chloritized smectite may also be an important ephemeral stage during the transformation of smectite to kaolinite. The presence of zeolites provided sufficient bases to prevent the complete transformation of Sm/K to kaolinite. The presence of smectites and zeolites made the formation of black soils possible in micro-depressions even in a tropical humid climate. The genesis of Sm/K and smectite in red and black soils, respectively, suggests that these soils formed through a progressive landscape reduction process. The presence of both Sm/K and smectite in black soil clays of semi-arid climate suggests that the smectite of these soils was formed in an earlier humid climate.

Deep black soils (> 1 m) developed in the narrow entrenched valley floor in the Jamni/Tamasvada watershed of Wardha district of Maharashtra was studied by Paranjape *et al.*, (1997). Despite their physical, chemical and mineralogical properties being similar to those of Vertisols in the basaltic landscape, the soils lack vertic characters, especially the slickensides. Lack of slickensides is attributed to the young nature of the soils as evidenced by the poor plasma separation. Role of factors that are hitherto known to impair the swelling of smectite is discounted. It appears that the shrinkage and swelling of clay smectite need to continue at least for 550 years after the stabilization of the valley. The study thus point out the importance of time factor in the pedogenesis of Vertisols.

Deshmukh *et al.*, (2012) bulk density of Seloo soils series was higher due high compaction. Hydraulic conductivity of Saikhindi soils series was more in spite of high pedogenic carbonates and slight development of ESP (~5) which may be due to possible presence of zeolites. Physical properties shows high shrink swell activity of these soils due to high smectite content. Mineralogy of silt fraction was

dominated by smectite in both the soils followed by quartz and feldspar in small amount.

Four pedons from the alluvial plain of Northeast Greece were studied for their genesis and found that smectite (montmorillonite) is the dominant clay mineral and was mainly inherited from the parent sediment and neof ormation. High smectite content in combination with alternating wet and dry period results in formation of the morphological characteristics that are typical for Vertisols. The properties of these Vertisols reflect the impact of climate (alternating wet-dry periods), landscape position (alluvial plain; seasonally water saturated). And parent material (clayey, smectite-dominated fluvio-lacustrine, highly calcareous sediments, (Moustakas, 2012).

Vertisolic soils of Canada are associated with fine textured glaciolacustrine plains of the Praire ecozone. For Vertisols soils to occur, the clay content of the parent material has to be more than 60 %. The mineralogy of the clay fractions is also critical swelling 2:1 clay such as smectite must be the dominated (more than 50 per cent) clay mineral fraction of parent material. Climate is the final crucial factor. The soil mass must dry out and rewet several times each year in order for argillipedoturbation (Brierley *et al.*, 2012).

#### **2.2.4 Sub-microscopic Studies (sand mineralogy)**

Karche, (1996) reported that soil (Chethacle-1; Kulasekharam-2) have both weatherable and nonweatherable minerals; the dominant being the opaque minerals (43%) followed by muscovite (25%), biotite (8%), hornblende (2%), pyroxene (7%). The other minerals observed in their order of predominance are tourmaline (5%), zircon (4%), rutile (1.5%) and sphere (1%) which are the ubiquitous minerals. The existence of ferromagnesian minerals such as biotite, hornblende, pyroxene although in low amount (17%) suggest that these soils have not reached the ultimate stage of weathering. A critical study of these minerals however indicates that most of these mineral (almost 70%)

have inclusions of ferruginous material which block site of weathering. Iron oxide coating on grains has been responsible to retard the process of weathering (Eswaran and Sys, 1976). Such minerals should be interpreted as pseudo minerals rather than active minerals for weathering.

Sand fractions are composed of quartz, K-feldspars, anatase and plagioclase; silt fractions contain in addition to the above minerals, amphibole, mica, 10 -14 Å° minerals, vermiculite, chlorite, kaolinite and occasionally smectite (Pal and Deshpande., 1987).

Prasad and Singh, (2000) studied that surface soil characteristics of Ultisols (two), Vertisols (four) and Entisols (four) in Bihar indicate differentiating features like particle size distribution, free CaCO<sub>3</sub>, EC, pH and CEC. Quartz followed by orthoclase feldspar was the dominant light mineral in all the soils whereas heavy minerals varied with soils in their fine sand fractions. Variations in mineralogical make up are mostly associated with nature and composition of parent material and degree of weathering. The CEC of soils and clays in Vertisols was invariably high as compared to Entisols and Ultisols. Kaolinite is the dominant clay mineral in Ultisols whereas smectite in Vertisols, and illite in Entisols.

Soils micas under SEM indicate that biotite particles are generally thick, showing layer separation with bending at edge due to formation of vermiculite around the rim. The Muscovites, on the other hand, were characterized by very miner layer separation at their edges experimental studies of reported Ba-K exchange with specimen biotite and muscovite and their mixtures (Pal *et al.*, 2001).

Mukesh *et al.*, (2011) the petromineralogical characterization of the soil was carried out Siwalik forest division, Dehradun. The quartz was observed as the dominating light mineral fraction (64–80%) in all the profiles studied. Biotite, hornblende, zircon, tourmaline, rutile and opaques comprising of iron minerals constituted the heavy mineral

fraction (20%). The mineralogy of both the sand and clay fractions revealed a mixed mineralogy. The clay minerals in the order of their dominance were vermiculite, illite, kaolinite and mixed layer minerals. The presence of vermiculite and illite in appreciable quantities indicates that these were synthesized from the K-rich soil solution, as orthoclase and micas were present in significant quantities in the sand minerals.

Erasto *et al.*, (2013) studied Vertisols of igneous origin and dark color, and the other of sedimentary origin and pale light color. Soils of igneous origin were classified as Chromic Haplusterts, Typic Haplusterts, and Mollic Ustifluvents. Sedimentary origin soils were classified as Chromic Calcicusterts and Typic Calcicustolls. Dominant mineralogy of the soils of igneous origin in the sand fraction was comprised of volcanic glass (47%), quartz (31%), and feldspars (22%). Amorphous materials, smectites, vermiculites, illites, and cristobalites dominated the clay fraction. In contrast, in the soils of sedimentary origin the sand fraction was composed of calcite (64%), quartz (34%), and feldspars (2%). Smectites, vermiculites, quartzes, and feldspars composed the clay fraction. The parent material of the igneous soils was rhyolite, while the sedimentary soils were derived from limestone and sediments with high calcium carbonate contents.

### **2.3 Soil Properties in Relation to Mineralogy**

Smith *et al.*, (1985) indicated that usually shrink-swell phenomenon is positively related with the content or expansible mineral as indicated by a high coefficient of linear extensibility (COLE) and clay content dominated by the mineral of the smectite group. Shirsath *et al.*, (2000) showed that the shrinking and swelling is solely due to the amount of smectite mineral in soils and a minimum smectite content of 20% is sufficient to cause enough swelling to have a COLE value of 0.06.

Nayak *et al.*, (2006) studied the shrinkage potential of different sates of Indian soils using the Coefficient of Linear Extensibility (COLE) and to examine relationships between soil shrinkage and selected

chemical, physical and mineralogical soil properties. There is a wide range in the shrinkage capacities of different soils; with COLE values between 0.050 and 0.313 soils are found to be dominantly smectitic with minor amounts of kaolinite and illite. The coefficient of linear extensibility (COLE) values of all the soil samples fall in the categories of very high (COLE >0.09) swell-shrink classes.

Bulk density indicates the weight of all the organic and inorganic materials of a given volume of soil. It is an index of workability of soil, availability of soil moisture, aeration and root penetration. It has been reported that Vertisols may have BD values as high as  $2.1 \text{ Mg m}^{-3}$  (Dudal, 1965).

The BD of Vertisols varies greatly because of their swelling and shrinking nature. Since shrink-swell phenomenon depends on soil moisture content, a change in moisture level changes BD values. In general, the Vertisols have higher BD when they are dry and lower BD in a swollen stage. Depending on moisture content, the BD values are reported to vary from, 1 to  $2 \text{ Mg m}^{-3}$  (Jewitt *et al.*, 1979).

The Vertisols generally have a tendency to show higher BD values in subsurface horizons due to compaction. It is due to this reason that the SHC decreases in the subsurface horizons. Nimkar *et al.*, (1990) reported that the bulk density of Vertisols may vary from approximately  $1- 2 \text{ Mg m}^{-3}$  depending upon moisture content. Higher pH values in soils may be due to basalt as parent material, which is alkaline in nature (Cinchmalatpure *et al.*, 2000). Higher values of BD with depth, though there is an increase in clay content is due to compaction (Bhattacharyya *et al.*, 2003) and is common in Vertisols.

The infiltration rate was 40 to  $42 \text{ mm hr}^{-1}$  in shallow soils but only  $12-36 \text{ mm hr}^{-1}$  in deep black soils of Jayakwadi and Purna Command area reported by Bharambe *et al.*, (1986). The saturated hydraulic conductivity also had the same trend as that of infiltration rate with higher values ( $6$  to  $39 \text{ mm hr}^{-1}$ ) for shallow soils and lower values ( $2$  to  $30 \text{ mm hr}^{-1}$ ) for deep black soils. The low values of hydraulic

conductivity in Purna Valley were also reported by Kadu *et al.*, (1993) and Balpande *et al.*, (1996).

Pal *et al.*, (2000) studied the Vertisols of Purna valley and the pedhi watershed in the Vidarbha region Maharashtra and found that soils have almost uniform clay distribution but their hydraulic conductivity (HC) decreasing with depth, their HCs are affected by exchangeable magnesium this has been further impaired by a low level of ESP ( $\geq 5$  >15)

Padole *et al.*, (1998) studied the soils of Purna Valley of Vidarbha region of Maharashtra and reported that the bulk density of these soils ranges from 1.28 to 1.88  $\text{Mgm}^{-3}$ , hydraulic conductivity from low to moderate organic carbon, high CEC [ $> 42.3$  ( $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ )] and high base saturation. The pH, E<sub>ce</sub>, of soil ranged from 7.3 to 9.6, and 0.90 to 5.74  $\text{dS m}^{-1}$ , respectively.

Pal *et al.*, (2004) reported that Purna valley in terms of increase in exchangeable sodium percentage (ESP) with depth has adversely affected the hydraulic conductivity and other properties important for crop growth. The increase in both coefficient of linear extensibility (COLE) and water dispersible clay (WDC) and decrease in hydraulic conductivity with depth were observed in the soils. It is suggested that the swelling of the clay smectite, together with dispersion of clay, have adversely affected the hydraulic properties of these soils.

The presence of exchangeable cations in smectites was first suggested by Marshall, (1935). A significant portion of the fertility of moderately weathered soils can be traced to the presence of smectites. This is due to their ability to hold fertilizer cations such as  $\text{K}^+$  and  $\text{NH}_4^+$  against the effect of leaching by rainfall.

Pal and Deshpande, (1987) studied the genesis of black soil in southern India. They reported that black soils were moderately alkaline, highly calcareous and had low organic carbon, very high CEC (54.0 and 52.9  $\text{meq}/100\text{g}$ ) and high amount of clay.

Cation exchange capacity varies considerably depending on the organic matter content and the amount of smectitic clay (Coulombe et al., 1996). Generally, however, Vertisols have a high CEC ranging from 20 to 45  $\text{cmol}(+)\text{kg}^{-1}$  soil or more. In neutral Vertisols the exchange sites are occupied mainly by calcium and magnesium and to a lesser extent by potassium and sodium. Alkaline Vertisols in which sodium occupies 15 per cent or more of the exchange complex are differentiated as Sodic subgroups in Soil Taxonomy. Aluminum, magnesium and exchangeable acidity replace calcium and magnesium under acid conditions. The bounded out that variation in CEC between the three soils are due to difference in clay content and type of dominant clay.

Bhattacharyya *et al.*, (2013) black soils dominated by smectitic clays and usually to deep to very deep. They are characterized by the presence of either slickensides or wedge-shaped peds,  $\geq 30\%$  clay and cracks that open and close periodically. These soils are grouped as Vertisols. A group of soils belonging to other soil orders possesses the characteristics of black soils showing linear extensibility (LE) of 6.0 cm or more. High LE values are caused by smectitic clays that allocate these soils to vertic sub-group. This fact assumes importance because Vertisols and the vertic intergrades of soils have similar characteristics and require similar land management for agriculture and allied uses. Presence of slickensides is not a must for classifying a soil into vertic intergrades.

The review shows that systematic information on the clay mineralogy of the soils and its relationship with soil properties in Maharashtra, particularly of western Vidarbha region is lacking. Therefore, an attempt has been made to study the soil minerals and to generate quantified datasets on minerals in the benchmark soils representing the agro ecological sub region of western Vidarbha of Maharashtra.

## Chapter III

### MATERIAL AND METHODS

In this chapter, the sampling sites and the analytical methods of soils for physical, chemical and mineralogical properties have been discussed.

**Study Area:** The study area falls in Washim, Buladana, Amravati, Akola (AESR 6.3), Wardha (AESR 10.2) and some part of Yavatmal (AESR 12.1) of (Vidarbha) Maharashtra. The general description of districts is shown below.

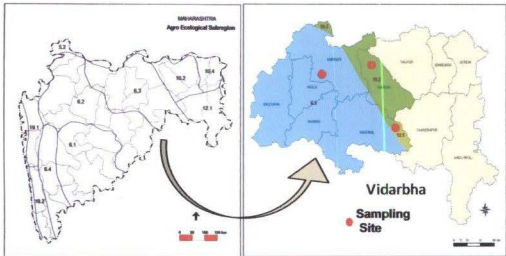


Fig.3.1- Map showing study area and benchmark sites for AESR in Western Vidarbha.

#### 3.1 Eastern Maharashtra Plateau, hot, moist semi-arid eco subregion (AESR 6.3)

The agro-eco subregion constitutes the North Deccan of Central Maharashtra. The subregion covers an area of 5.4 mha representing 17.4% of agro-ecological 6, and 1.6% of the total geographical area of the country. The study area in Washim, Buladana Amravati and Akola comes under (AESR 6.3,) the 6.3 AESR having 5.4 m ha area and brief description are (NW. Maharashtra) plateau, hot, moist semi-arid ecosystem with medium land deep black soil (shallow and medium

black soils as inclusions) and Length Growing Period is 90-120 days. Distribution States and District are Maharashtra Jabalpur (E. Part), Buladana, Akola, Amaravati, some part Yavatmal and major soils group is Ustorthents, Chromusterts, Ustochrepts.

**Agro-Climate:** The agro-climate of the subregion is characterized by hot semiarid moist with summers and mild winters. The mean annual temperature varies from 26 to 27°C rising to maximum of 40°C in the hottest months of December and January. The mean annual precipitation, ranging between 800 and 1100 mm, covers about 50-61 per cent of annual PET demand (1600 and 1800 mm). This results in gross annual deficit of 800 to 1000 mm of water. The monsoon rainfall sets in the second half of June with stormy cloud burst and the area received around 80% of the mean annual rainfall during the monsoon rain months of June to September. The Amravati area shows that experiences dry period from the months of December till May. The moisture index varying from -44 to -49 suggest the semiarid moist condition in the area. The rainfall intensity increasing during the latter part of June through July, August and September, while P excess PET accounting for 75% of the total monsoon rainfall in the area. The moisture regime is Ustic. The MAST in the area is greater than 22°C and the difference between MSST and MWST is 5°C suggesting a hyperthermic soils temperature regime. The mean daily temperature ranging between 27°C and 28°C during the growing period suggests the possibilities of growing climatically adapt able of group 4 with photosynthesis pathway C4, likes millets, sorghum, maize, pulses, cotton, etc.

**Soils:** The soils are represented by moderately to gently sloping Ustorthents and Ustrophepts, grading to level to very gently sloping Chromusterts/ Pellusterts in valleys. They are classified as Pargaon, Sawargaon and Barsi series. The Pargaon soils are shallow, loamy skeletal and highly calcareous in nature. The Sawargaon and Barsi soils, however, are clayey, calcareous and moderately alkaline

showing marked swell-shrink properties. The Jambha series which are very deep, mildly alkaline to moderately alkaline, calcareous soil. They comprise member of very fine, montmorillonitic family of Tropic Chromusters. These are heavy textured soil, clay content ranges from 65 to 70% whereas the content of organic carbon remains more or less uniform throughout the depth. The CEC of the soil is high. These soils have high moisture retentive capacity and the PAWC is about 200 mm/m. The soil is low to very low sub soils hydraulic conductivity. As such, because of poor drainage these soils are prone to waterlogging and salinity problem developed under irrigated farming unless adequate drainage is provided.

**Land Use:** The traditional practice is rain fed agriculture. The sorghum, pigeon pea and pearl millet are major kharif season crops. The drought-prone districts of the region, interestingly, have bimodal rainfall distribution. Therefore, crops are grown during September/October on stored residual soil moisture since there is a significantly long dry period during the first phase of the rains. The post-rainy season crops grown on residual soil moisture are mainly sorghum, safflower and sunflower. Cotton and groundnut are grown under irrigated conditions. The natural vegetation in the region comprises tropical, dry deciduous and thorn forests.

### **3.2 Satpura and Eastern Maharashtra Plateau, hot, dry-subhumid eco-region (AESR 10.2)**

The agro- subregion constitutes the Deccan plateau comprising parts of Madhya Pradesh and Maharashtra states. The subregion covers an area of 2.8 m ha representing 12.5 per cent of agro-ecoregion<sup>10</sup>, and 0.8 % of total geographical area of the country. The study area in Seloo comes under (AESR 10.2,) the 10.2 AESR having 2.8 m ha area and brief description are Deccan (Satpura) plateau, hot dry sub-humid ecosystem with deep black soils (Shallow and medium deep black soils as inclusion) and Length Growing Period is 150-180 days. Distribution States and District are Madhya Pradesh in Betul and

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Maharashtra Wardha, Nagpur, major soils group are Ustorthents, Chromusterts, Ustochrepts, Ustorthents, Rhodustalfs, Haplustalfs.

**Agro-Climate:** The agro-climate of the subregion is characterized by hot dry subhumid with dry summer and mild winters. The mean annual temperature varies from 25 to 26°C. The mean summer (April- May-June) temperature ranges between 30 to 33°C rising to maximum of 42°C in May. The precipitation shows an increasing trend towards east. The mean annual rainfall ranges between 1000 and 1500 mm covering about 80 per cent of the mean annual PET (1300-1600 mm). The region remains fairly dry during the post-rainy period with water 500-700 mm deficit mounting to the winter rains of around 30 per cent probability is commonly observed. The south-western monsoon sets in the second week of June, recharging the dry soils and it extends till September and ending in the first half of October covering 92.7% mean annual rainfall. The intensity of rainfall exceeds PET during the months of July, August and September with moderate water surplus as runoff and accounts for the 94 % of total monsoon rainfall. The moisture index varying between -18 to -22 in the area suggests the prevalence of dry subhumid bioclimatic condition.

**Soils:** The soils are largely medium. The deep black soils are interspersed with patches of Red soils. The soils representing the region are typified by moderately to gently sloping Ustorthents, gently to very gently sloping Ustochrepts and Haplustalfs, and very gently sloping to nearly level Chromusterts. The dominant soil series of region are Marha, Kheri and Linga (Chromusterts) occurring in association with the moderately deep soils of Kamliakheri series (Ustochrepts). They are calcareous, slightly alkaline, montmorillonitic and have high swell-shrink potential. The red soils generally occur on ridges and on pediment surfaces. They are shallow to moderately deep, clayey, neutral to slightly acidic in nature and are represented by Dumra series (Udic Haplustalfs) occurring on gently to very gently sloping pediment surface in Bundelkh and region. The soil pedon, Linga clay typifies

imperfectly drained, very slowly permeable soils of Linga series comprising members of very fine, montmorillonitic, hyperthermic family of Udic Chromosters. These are clayey soils. Clay content varies from 70- 74% with depth. Linga soils crack wide and deep during dry period separating the soils into hard and massive polyhedrons between the cracks, limiting the initial tillage operation. Linga soils are intensively cultivated both for agriculture crops and horticulture crops like oranges, banana, papaya etc. The salient limitations for normal crop husbandry in the Linga soils are their high shrink-swell potentials, narrow ranges of workable moisture, imperfect drainage and very slow sub soils saturated hydraulic conductivity in conjunction with moderately high ESP in sub soils leading to poor air-water relationship.

**Land use:** Rainfed agriculture is the common practice. Rice, sorghum, pigeon pea and soybean are common grown kharif crops. Gram, wheat and vegetables are common rabi season crops. Kharif cropping is totally rainfed, whereas Rabi cropping is partly irrigated at critical stages growth. However, rich farmers grow rice, wheat and gram and, at places, cotton using irrigation facilities. The natural vegetation comprises tropical moist deciduous forest.

### **3.3 Garjat Hills, Dandakarnya and Eastern Ghats, hot, moist subhumid ecoregion (AESR 12.1)**

The agro eco subregion 12.1 constitutes parts of Eastern Ghats highlands of Orissa, Maharashtra and Baster region of Madhya Pradesh. The subregion covers an area of 17.9 m ha representing 66.8% of agro ecoregion 12 and 5.4% of total geographical area of the county. The study area in Wardha comes under (AESR 12.1) the 12.1 AESR having 17.6 m ha area and brief description are Eastern (Gujarat Hills, Dandakaranya) plateau, hot moist sub-humid ecosystem with Red and Lateritic soils and Length Growing Period is 180-210 days. Distribution States and District are Madhya Pradesh in Baster (Jagadapur) Maharashtra Chandrapur Gadachiroli and Wardha, some part of Yavatmal and Orissa in Koraput Kalahandi (Bhiwanipatana),

Phulabani Bolangir, Sambalpur, Sundergarh, Dhenkanal, Mayurbhanj, (Baripada) major soils group are Ustorthents, Chromusterts, Ustochrepts, Ustorthents, Rhodustalfs, Haplustalfs, Haplaquet, Plinthustalfs.

**Agro-Climate:** The sub region is characterized by hot moist subhumid type of the climate with dry summers and cool winters. The mean annual air temperature varies from 26-27°C. The mean summer (April-May-June) temperature is 33°C rising to maximum of 41-42°C in the hottest month of minimum of May. The mean winter (December-January-February) temperature is 21°C. Dropping to a minimum of 12-13°C in the coldest month of December. The climate of the region is characterized by hot summers and cool winters. The area receives an annual rainfall of 1000-1600 mm which covers about 80 per cent of the PET leaving deficit of 500 to 700 mm of water per year. The water balance shows a prolonged dry period from December to May (more than 90 days in a year). As such the area, in general, qualifies for Typic Ustic soil moisture regime. The mean annual soil temperature of more than 22°C qualifies the area for hyperthermic soil temperature regime. The LGP varies from 150 to 180 days and at places it is 180 to 210 days.

**Soils:** The dominant soils of the area are represented by gently to very gently sloping Ustochrepts, Haplustalfs, Plinthustalfs, Paleustalfs, Haplustults and Rhodustalfs. The soils of Pusaro, Bhubaneswar and Chougel series are observed largely in the region. They are fine loamy to clayey, non-calcareous, slightly to moderately acidic and have relatively low cation exchange capacity. The soils are generally shallow on the ridges and plateaus and are under forest cover. The soils in valleys are deep and are generally cultivated. The soils pedon, Chougal sandy clay loam typifies deep soils of Chougal series comprising fine loamy, mixed, hyperthermic family of Typic Plinthustalf. These are brown to dark brown, moderately acidic, well drained soils.

The surface texture varies from sandy clay to clay loam and the clay content increasing with depth.

**Land use:** Rainfed farming is the traditional practice with cultivation of rice, pulses (moong, black gram and pigeon pea) and groundnut in rabi season, rice (at places) and wheat are cultivated mostly under irrigated condition. The natural vegetation comprises tropical dry and moist deciduous forests.

### 3.4 Benchmark soils of Vidarbha region

Murthy *et al.* (1981) reported three benchmark soils in Maharashtra, out of these two benchmark soils are reported from the Vidarbha region. Reported seventeen soil series in Maharashtra, out of these three soil series are reported from Vidarbha. Challa *et al.*, (1999) reported one hundred fifty soil series in Maharashtra, out of these forty four soil series represent Vidarbha region.

The selected soils (Table 3.1) are used for study to carry out physical, chemical and mineralogical properties. Datasets of all the soils have been shown in the Appendix. The locations of soil of different series are shown in figure 3.1.

Table 3.1. Study area and benchmark sites in Western Vidarbha

Sr. No.	Districts	Soils	Cropping System	Bioclimatic Regions**
1.	Amravati	Asra	Soybean – Pigeonpea	SA (h)
2.	Wardha	Seloo	Cotton- Pigeonpea	SH (m)
3.	Yavatmal	Pahur	Soybean – Pigeonpea	SH (m)

\* SH (m) – Sub-humid (moist) (rainfall >1000 mm).\* SA (h) - Semi arid (hot) (rainfall 1000 mm).\*

The benchmark profile sites described above were selected for study after through traversing of area where black soils (Vertisols) are present. Profiles were dug at selected site and detailed morphological examination was carried out as per procedure laid down in Soil Survey

Manual (Soil Survey Division Staff 1995). Soil samples were collected for the estimation of bulk density in the core.

### **3.4.1 Collection and processing of soil samples**

Horizon-wise soil samples were collected from each benchmark site. The soil samples were then dried. They were ground and passed through 2 mm sieve, labeled and stored for subsequent use.

### **3.4.1 Analysis of soil samples**

Brief description of the standard procedure followed for various physical and chemical characteristics of the soil samples are given here. Moisture percentage of the processed samples was determined by heating 105°C to at constant weight to express soil data on oven dry basis.

## **3.5 Physical Properties**

### **3.5.1 Particle-size distribution**

Particle-size distribution was determined as per the International pipette method. The known amount of air-dried soil sample was treated with 1 N NaOAC buffer (pH 5.0) to remove  $\text{CaCO}_3$ . After oxidizing organic matter with 30%  $\text{H}_2\text{O}_2$ , the samples were given citrate-bicarbonate-dithionite (CBD) treatment for removal of free iron and aluminium oxides (Mehra and Jackson, 1960). Deionized water washing was given for removing excess salts. Dispersion and particle-size fractionations were accomplished by standard procedure (Jackson, 1956). Percentage of different soil separates was calculated on the basis of above determination

### **3.5.2 Saturated hydraulic conductivity (sHC)**

The hydraulic conductivity of a soil is a measure of its ability to transmit water. The hydraulic conductivity is defined by Darcy's law, which for one dimensional, vertical flow may be written as:

$$Q = K(\theta) \delta H / \delta z$$

Where,

Q is the volume flux density, Darcy velocity or apparent velocity.

$\delta H/\delta z$  is the gradient of the hydraulic head,

$K(\theta)$  is the hydraulic conductivity.

The driving force is expressed as the negative gradient of the hydraulic head composed of the gravitational head,  $z$  and the pressure head  $h$ , i.e.

$$H = h + z$$

The soil samples (< 2 mm) were fully saturated and then leached with deionized water. The saturated hydraulic conductivity was determined by constant head method described by Richards (1954) and calculated on the basis of Darcy's law as mentioned below :-

$$K = \frac{Q \times \Delta L}{T \times A \times \Delta H}$$

Where,

$K$  = Saturated hydraulic conductivity (cm/hr.)

$Q$  = Water discharge per hr.

$\Delta L$  = Length of soil column (cm)

$\Delta H$  = Hydraulic head drop (cm)

$A$  = Cross section area of soil (sq.cm)

$T$  = Time

### 3.5.3 Coefficient of linear extensibility (COLE)

The determination of COLE was done as per the method of Schaffer and Singer (1976). The COLE has been defined as the ratio of the difference between the moist length and dry length of clod to its dry length.

It is expressed as

$$\text{COLE} = \frac{L_m - L_d}{L_d}$$

Where,

$L_m$  = Length of moist clod

$L_d$  = Length of dry clod

### 3.5.4 Bulk density (BD)

The bulk density of soil was determined by field moist method using core samples. The core samplers of known volume were used to collect the soil core from moist soil. The bulk density was calculated by dividing the oven dry weight of soil by corresponding volume of core samplers (Soil Conservation Service, 1972) and is expressed as  $\text{dSm}^{-1}$ .

## 3.6 Chemical Properties

### 3.6.1 Soil reaction (Soil pH)

pH in soil suspension (1 : 2 soil : water suspension ) was measured by a glass electrode pH meter after equilibrating the soil with water for 30 minutes with occasional stirring (Jackson, 1973).

### 3.6.2 Electrical conductivity (EC)

The clear supernatant extract obtained from the suspension used for pH (soil: water, 1:2 suspension) was utilized for EC measurement by conductivity bridge (Richards, 1954).

### 3.6.3 Calcium carbonate ( $\text{CaCO}_3$ )

For the determination of calcium carbonate, the soils were first treated with a known volume of 0.5 N excess hydrochloric acid solution to neutralize all carbonates and the excess hydrochloric acid was back titrated with standard NaOH solution using phenolphthalein as an indicator (Piper, 1950)

### **3.6.4 Organic carbon (OC)**

Carbon is the chief element present in soil organic matter comprising about 48 to 58 per cent of the total weight. Therefore, organic carbon determinations are often used as the basis for estimating the organic matter by multiplying the organic carbon value by factor 1.724.

Organic carbon was determined by modified Walkley and Black rapid titration procedure (Jackson, 1973). For this 100 mesh soil samples were used.

### **3.6.5 Cation exchange capacity (CEC)**

The fine earth samples (soils) were saturated with 1 N sodium acetate (pH 8.2). After removal of excess sodium acetate washing with alcohol, the absorbed  $\text{Na}^+$  was extracted by washing with 1 N ammonium acetate (pH 7.0) and the leachate was made up to a known volume. The  $\text{Na}^+$  ions present in the leachate were determined with a flame emission spectrophotometer. (Richards, 1954) to determine cation exchange capacity of soils.

### **3.6.6 Extractable bases**

For determination of extractable bases such as  $\text{Na}^+$  and  $\text{K}^+$  ions, the soil samples were pre-washed with ethanol and there after saturated with  $\text{NH}_4\text{OAC}$  (pH 7.0) and measured on atomic absorption spectrophotometer.

Due to presence of  $\text{CaCO}_3$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  ions were determined by saturating soil samples with 1 N  $\text{NaCl}$  solution (Piper, 1950) and then titrating the leachate with standard EDTA solution as per the method of Richards (1954) using Erichrome Black T and Murexide indicator.

### 3.7 Mineralogical analysis by X-ray diffractometer

The sand ( $\geq 50\mu\text{m}$ ), silt ( $50-2\mu\text{m}$ ), total clay ( $<2\mu\text{m}$ ) and fine clay ( $<0.2\mu\text{m}$ ) fractions of each layer of all the pedons were analyzed for qualitative mineralogy by X-ray diffraction techniques. About 40 mg of silt, total clay and fine clay fractions were taken and saturated with Ca and K. Parallel oriented aggregate specimens of clay and silt samples for all the horizons of three pedons were prepared on a glass slide (4.5 x 2.5 cm) taking 1 ml suspension in each case. Slides were dried at room temperature and then subjected to X-ray diffraction analysis (Jackson, 1979).

Identification of each crystalline mineral species present in the sample is the purpose of the qualitative interpretation of a diffraction pattern (Jackson, 1979). The identification of different minerals is accomplished by comparing the d-spacings and intensities with that given in ASTM "X-ray powder data file" published by American Society of testing materials, Philadelphia. For identification of clay minerals, the clay fractions were subjected to x-ray diffraction examination of the parallel oriented samples using a Philips diffractometer with Ni-filtered  $\text{Cu-K}\alpha$  radiation at a scanning speed of  $2^\circ/2\theta/\text{min}$ . The base diffraction spacings vary according to the nature of cation with which the saturation is accomplished and the types of minerals present were identified in the sample. Different thermal pre-treatments as required were given to distinguish and confirm the type of minerals present.

Normally, as a routine method, the following eight treatments were followed

1. Ca: Ca-saturation
2. CaEG: Ca-saturated glycol solvation
3. CaGLV: Ca-saturated glycerol solvation
4. K25°C: K-saturation and heating at 25°C
5. K110°C: K-saturation and heating at 110°C

6. K300°C: K-saturation and heating at 300°C
7. K300°EG: K-saturation and heating at 300°C and then glycol solvation
8. K550°C: K-saturation and heating at 550°C

The semi-quantitative estimates were made by the method of Gjems (1967) and the modified of Ghosh and Dutta (1972).

### **3.7.1 Sand mineralogy**

The soil samples were free from organic matter using standards laboratory procedure. The medium sand fraction chosen for the study was made free from iron oxide coating as per the method given by Jackson (1979). Light and heavy minerals were separated from the sample using bromoform. They were then mounted on the glass slides and polished with carborundum power of 800 and 1000 mesh. The heavy (and light) minerals mounted in thin section were studied under polarizing microscope (Laborlux-12) to study their optical and crystallographic properties for identification of different minerals (Day, 1965).

## Chapter IV

### RESULTS AND DISCUSSION

The study was conducted on three benchmark soil series of Western Vidarbha, Maharashtra P1- Asra (Amravati), P2- Seloo (Wardha) and P3- Pahur (Yavatmal) and the results of the investigation are described in this chapter in following main heads,

- 4.1 Morphological properties of soils
- 4.2 Physical properties of soils
- 4.3 Chemical properties of soils
- 4.4 Mineralogical properties of soils
- 4.5 Sub-microscopic studies of soils
- 4.6 Soil properties in relation to mineralogy

#### 4.1 Morphological properties of soils

Soil morphology can be considered as an index of manifestation of soil forming processes that occur during the soil development. Essentially it shows the interaction of various soil forming factors and management intervention which are important to maintain the health of a soil. Morphological properties and site characteristics of three pedons were from Amravati, Wardha and Yavatmal district of Maharashtra are detailed in Appendix-I, II, III and brief descriptions were also given in (Table 4.1). All the soils represent shrink- swell soils and formed from alluvium of Deccan basalt.

##### 4.1.1 Colour

The colour of Asra soils are very dark brown to very dark grayish brown with hue in 10YR, value and chroma 2. The Seloo soil shows a very dark grayish brown to dark yellowish brown with hue of 10YR, value 3 to 4 and chroma 2 to 4. Similarly for Pahur soils hue value is in

10 YR, value 3 and chroma 2 to 1, the colour is very dark grayish brown in surface and very dark gray colour in down the profile.

#### **4.1.2 Texture**

The soils are developed from the weathered Deccan basalt with high clay content. Thus all the soils are grouped as clayey textured class (Table 4.2).

#### **4.1.3 Coarse Fragments**

The content of coarse fragments in surface horizon Asra soils it is 1-3 per cent, in Seloo soils 5-10 per cent and Pahur soils 2-3 per cent. In the sub surface layer the content of coarse fragment in Asra soils <1 per cent, in Seloo soils it is 5 to 30 per cent (Table 4.1).

#### **4.1.4 Structure**

The surface horizon of all the soils have medium to moderate sub-angular blocky structure. The sub-surface horizon of all soils have medium and coarse, moderate to strong and sub-angular blocky to angular blocky structure (Table 4.1).

#### **4.1.5 Consistence**

The Asra soil was friable when moist and sticky plastic up to 69cm and below very sticky very plastic when wet. The Seloo soils was slightly hard when dry, very friable to friable when moist and sticky plastic to very sticky plastic sticky when wet. The Pahur soil surface was hard when dry, friable to very friable when moist and sticky plastic to very sticky very plastic when wet (Table 4.1).

#### **4.1.6 Roots**

In Asra soils very fine roots are common in the surface layer and which decreased with depth, in Seloo soils is very fine, medium and coarse roots are found in surface layer and decreased with depth and

Pahur soils is very fine roots are present throughout the profile decreasing with depth.

#### **4.1.7 Effervescence**

Strong effervescence was observed throughout the profile In Asra soils while in Seloo soils have strong effervescence at the B<sub>ck</sub> horizon and the above layers shows slight effervescence Pahur soils exhibit strong effervescence up to B<sub>w1</sub> and it has been decreasing down the profile.

#### **4.1.8 Others Features**

##### **a) Pressure faces and Slickensides**

In Asra soils pressure faces are observed in B<sub>w</sub> horizon just below the surface horizon and closely intersecting slickenside after 35 cm onward, but after 69 cm prominent slickenside are visible. Whereas in Seloo and Pahur soils pressure faces and slickenside was observed after 32 cm, 59 cm, and 19 cm, 40 cm, respectively. In Vertisols of India shear displacement and vertical sliding are observed at about 30 to 40 cm below the surface (Murthy *et al.*, 1982). Vadivelu and Challa (1985) has also made a similar report for semi-arid region, in which he further elicited that slickenside occur at depth ranging between 22 and 65 cm (mean 47cm) with a standard deviation of 9.0 cm (Table 4.1).

##### **b) Cracks**

In Pahur soils 10 cm wide cracks in surface and subsequently decrease to 2 cms down the depth in B<sub>ss3</sub> (Table 4.1). While in other pedons no such prominent cracks are visible.

**Table 4.1 Morphological properties of soils**

Horizon	Depth (cm)	Boundary		Matrix Colour	Texture	Coarse fragments (%)	Structure			Consistence			Roots		Effervescence	Other Features	Cracks (cm)
		D	T				S	G	Ty	D	M	W	S	Q			
<b>Pedon 1 - Asra series (Typic Haplusterts) District – Amaravati</b>																	
Ap	0 – 14	c	s	10 YR 2/2	c	1-3	M	2	Sbk	--	fr	sp	vf, f	c, f	es	-	
Bw1	14 – 35	c	s	10 YR 2/2	c	1-3	M	3	Sbk	--	fr	sp	vf, f	c, f	es	pf-	
Bw2	35 – 69	g	s	10 YR 2/2	c	1-3	M	3	Abk	--	fr	sp	vf,	c	es	weak ss	
Bss1	69 – 107	g	s	10 YR 2/2	c	<1	M	3	Abk	--	fr	vsvp	vf,	f	es	ss	
Bss2	107–150			10 YR 2/2	c	<1	M	3	Abk	-	fr	vsvp	vf,	f	es	ss	
<b>Pedon 2 - Seloo series (Typic Haplusterts) District – Wardha</b>																	
Ap	0 – 13	c	s	10 YR 3/2	c	5-10	M	2	Sbk	sh	vfr	sp	vfm	f, c	e	-	-
Bw1	13 – 32	c	s	10 YR 3/2	c	<5	M	2	Sbk	sh	vfr	sp	vfm	f, c	e	-	-
Bw2	32 – 59	g	s	10 YR 3/2	c	<5	M	2	Abk	sh	fr	vsps	F	c	e	pf	-
Bss1	59 – 81			10 YR 3/2	c	<5	M	2	Abk	sh	fr	vsps	F	f	e	ss	-
Bss2	81–115			10 YR 3/2	c	<2	M	2	Abk	sh	fr	vsps	F	f	e	ss	-
BCK	115-145			10 YR 4/4	c	25-30	M	2	Sbk	l	fr	vsps	F	f	e	ss	-
<b>Pedon 3 - Pahur series (Typic Haplusterts) District – Yavatmal</b>																	
Ap	0-19	c	s	10YR 3/2	c	2-3	M	2	Sbk	h	fr	sp	vf, f	fc	es	--	10
Bw1	19-40	g	s	10YR 3/2	c	2-3	M	2	Sbk	--	fr	vsvp	fm	f	es	pf	5
Bss1	40-78	g	s	10YR 3/2	c	2-3	M	3	Abk	--	fi	vsvp	fm	f	e	ss	5
Bss2	78-122	g	s	10YR 3/1	c	2-3	m/c	3	Abk	--	vfi	vsvp	F	f	e	ss	5
Bss3	122-150			10YR 3/1	c	3-5	m/c	3	Abk	--	vfi	vsvp	F	f	e	ss	2

\* Abbreviations are according to Soil Survey Manual (Soil Survey Division Staff, 1995)

1. Boundary: D – Distinctness; c – clear; g – gradual; T – topography; s – smooth; w = wavy

2. Texture: c- clay; sic-silty clay; cl- clay loam

3. Coarse fragments: fg-fine gravel; cg-coarse gravel; st- stony, b-boulders

4. Structure: S = size; m = medium, c = coarse; G = grade; 2 = moderate; 3 – strong; T=Type, sbk = sub angular blocky, abk =angular blocky

5. Consistence: D = dry; h = hard, sh = slightly hard, l=loose; M = moist; fr = friable; vfr = very friable; W = wet; s-sticky, vs- very sticky, p-plastic, vp- very plastic.

6. Porosity: S-size, f-fine, vf- very fine, f-fine; Q=Quantity, f-few, c-common, m-many.

7. Nodules (calcium carbonate): S-size = vf- very fine, f-fine; Q=Quantity, f-few, c-

common, m-many. 8. S=Size; f-fine, vf-very fine; Q= Quantity, f-few, c-common, m-many.

9. e= slightly effervescence, es= strongly effervescence.

10 Roots: quantity; f- few (<1 per area), c- common, m- many ; size- vf- very fine, f- fine, m- medium , c=- coarse, vc- very coarse. 11. pf =Pressure faces, ss=Slickenside

## 4.2 Physical Properties of Soils

### 4.2.1 Particle-size distribution

The sand content of Pahur soil (Table 4.2) was higher (1.5 to 4.0%) compared to Asra soil (2.1 to 2.8%) and Seloo soil (0.4 to 1.4%). This indicated that the Pahur soil may not have solely formed from the alluvium of deccan basalt (Pal and Deshpande, 1987) that provide the fine textured material (Balpande *et al.*, 1996) as in Asra soil and Seloo soil.

The silt content of Asra, Seloo and Pahur soils ranged from 34.6 to 36.1%, 40.9 to 48% and 32.2 to 43.8 per cent, respectively, whereas, clay content varied from 61 to 62.7%, 51.5 to 58.2% and 54.8 to 65.9% for the Asra, Seloo and Pahur soils (Fig. 4.1).

The clay content was more in Asra soil as compared to Seloo and Pahur soils and clay content was found to increase from surface to down the profile in Pahur soils. The increase trend of fine clay with depth may be due to illuviation of fine material from surface horizon to subsurface horizons (Satyavathi *et al.*, 2005).

### 4.2.2 Bulk density (BD)

Bulk density (BD) indicates the weight of all the organic and inorganic materials of a given volume of soil. It is an index of workability of soil, availability of soil moisture, aeration and root penetration.

There is variation in bulk density in these soils Table 4.2 (Fig. 4.2). It is highest in Seloo soil (1.7 to 1.9  $\text{Mgm}^{-3}$ ) followed by Asra (1.5 to 1.6  $\text{Mgm}^{-3}$ ) and Pahur (1.4 to 1.6  $\text{Mgm}^{-3}$ ). The higher values of BD with depth may be due to compaction (Balpande, 1993; Kadu, 1997; Bhattacharyya *et al.*, 2003) which is common in Vertisols.

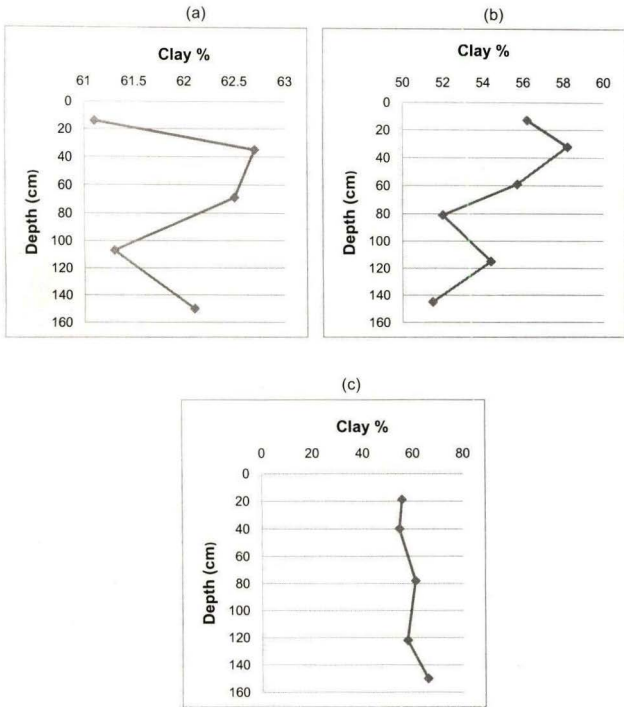
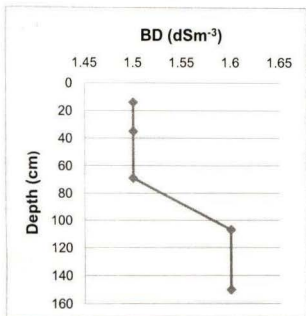
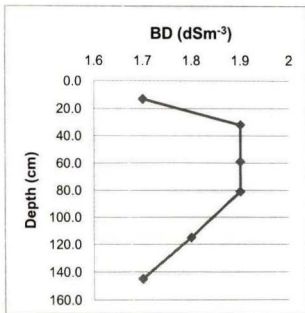


Fig.4.1 Variation in clay with depth (a) Asra soil (b) Seloo soil (c) Pahur soils

(a)



(b)



(c)

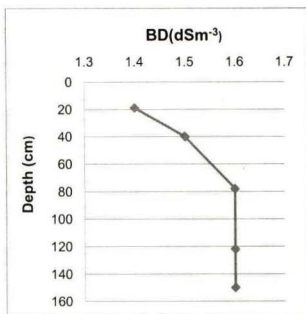


Fig.4.2 Variation in BD with depth (a) Asra soil (b) Seloo soil (c) Pahur soils

### 4.2.3 Coefficient of Linear Extensibility (COLE)

The COLE (Coefficient of Linear Extensibility) value helps to predict the potential of a soil to shrink and swell. Many workers observed that higher COLE values are due to very fine texture and high smectite content (Eswaran *et al.*, 1988; Gabhane, 1996, Shirsath *et al.*, 2000). Though relationship between COLE and BD could not be obtained, but it is clear that with higher COLE values, there is possibility of variation in moisture retained and thus the BD values.

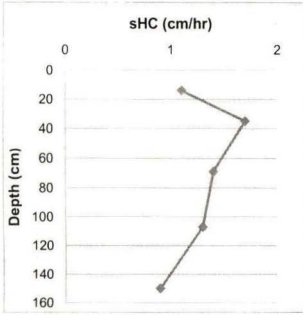
The COLE values of Asra, Seloo and Pahur ranges from (0.20 to 0.25), (0.18 to 0.24) and (0.10 to 0.20), respectively. The higher values of COLE for pedons indicated the high shrink-swell potentials of these soils. Eswaran *et al.* (1988) reported that the mean COLE value for Vertisols is about 0.13 and it is due to their very fine texture and high smectite content.

### 4.2.4 Saturated Hydraulic Conductivity

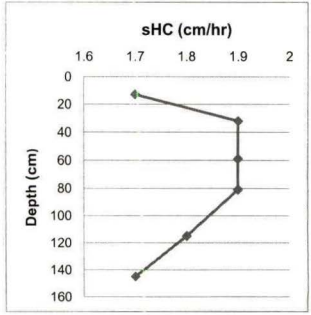
Flux of soil water through a profile is governed by the saturated hydraulic conductivity of soil which is influenced by texture, structure, moisture content, exchangeable sodium, other parameters, cropping system *etc.*, of soils and thus affects crop growth as well.

The values of hydraulic conductivity of Seloo soils were more or less uniform through the profile, but in case of Asra soil the sHC decreases gradually after 35cm depth *i.e.* from 1.7 to 0.9 cm hr<sup>-1</sup>, (Table 4.2). Whereas Pahur soil the saturated hydraulic conductivity decrease from 1.0 to 0.3 cm hr<sup>-1</sup>, from surface to down the profile (Fig.4.3).

(a)



(b)



(c)

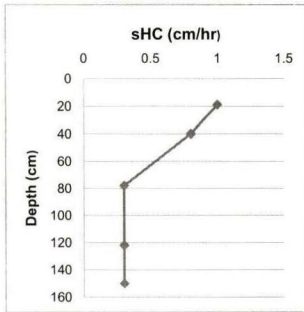


Fig.4.3 Variation in sHC with depth (a) Asra soil (b) Seloo soil (c) Pahur soils

The decrease in sHC down the profile of P1 and P3 may be due to the increase level of  $\text{Na}^+$  and  $\text{Mg}^{++}$  in the exchangeable complex and increases in ESP *i.e.* 0.74 to 4.21 in Seloo and 1.38 to 16.6 in Pahur soils. Similar result was reported by (Balpande *et al.*, 1996; Pal, 2002). Considerable reduction in hydraulic conductivity with increase depth was also observed in deep black soil by Bharambe *et al.*, (1986) and Kadu, (1991; 2003).

**Table 4.2 Physical properties of soils**

Horizon	Depth (cm)	Particle size analysis (%)			Bulk Density (Mg m <sup>-3</sup> )	sHC (cmh <sup>-1</sup> )	COLE
		Sand	Silt	Total Clay			
<b>Pedon 1 - Asra series (Typic Haplusterts) District – Amaravati</b>							
Ap	0 – 14	2.8	36.1	61.1	1.5	1.1	0.2
Bw1	14 – 35	2.7	34.6	62.7	1.5	1.7	0.2
Bw2	35 – 69	2.7	34.8	62.5	1.5	1.4	0.2
Bss1	69 – 107	2.6	36.1	61.3	1.6	1.3	0.2
Bss2	107–150	2.1	35.8	62.1	1.6	0.9	0.2
<b>Pedon 2 - Seloo series (Typic Haplusterts) District – Wardha</b>							
Ap	0-13	1.4	42.5	56.2	1.7	0.5	0.2
Bw1	13-32	0.9	40.9	58.2	1.9	0.5	0.2
Bw2	32-59	0.4	43.9	55.7	1.9	0.6	0.2
Bss1	59-81	0.5	47.5	52.0	1.9	0.5	0.2
Bss2	81-115	0.5	45.1	54.4	1.8	0.6	0.2
BCK	115-145	0.5	48.0	51.5	1.7	0.7	0.1
<b>Pedon 3 - Pahur series (Typic Haplusterts) District – Yavatmal</b>							
Ap	0-19	3.2	41.2	55.6	1.4	1.0	0.2
Bw1	19-40	1.5	43.8	54.8	1.5	0.8	0.1
Bss1	40-78	1.5	38.2	60.9	1.6	0.3	0.1
Bss2	78-122	4.0	38.3	57.7	1.6	0.3	0.1
Bss3	122-150	1.7	32.2	65.9	1.6	0.3	0.2

## **4.3 Chemical properties of soils**

### **4.3.1 Soil reaction**

Soil reaction reflects the nature of parent material and climate, which determine soils composition. It affects availability of various nutrient, activities of micro-organisms and control many physical and chemical properties of soils. Higher pH in these soils are attributed their genesis and aridity.

The pH values indicated moderately alkaline to strong alkaline reaction of the soils which increasing with depth. The pH of soils (1:2 soil: water suspension) ranged between 7.8 to 8.1 in P1, 8.0 to 8.4 in P2 and 8.3 to 8.9 in P3 (Table 4.3). Increases pH in P2 and P3 down the profile may be due to high amount of exchangeable sodium in lower horizon (Fig.4.4). A similar relationship with pH and sodicity was observed for natural alkali soil conditions in shrink-swell soils of central India (Kadu, 1991, Nimkar *et al.*, 1992; Balpande, 1993). The higher pH is also related to the pedogenic development of  $\text{CaCO}_3$  (Pal *et al.*, 2000).

### **4.3.2 Electrical conductivity**

The values of electrical conductivity (1:2 soil: water suspension) for P1, P2 and P3 soils ranged from (0.10 to 0.32 ds/m), (0.16 to 0.26 ds/m), and (0.19 to 0.33 ds/m), respectively at 25°C (Table 4.3). The electrical conductivity values increased with depth. Low values of EC suggest that these soils are not saline. However, for Pahur soil, higher ESP values with lower EC enables the soils to remain in a more dispersed state (Wilding and Tessier, 1998) which decreases the permeability of soils.

### **4.3.3 Calcium carbonate equivalent ( $\text{CaCO}_3$ )**

Calcium carbonate equivalent in soils, also known as inorganic carbon is an important component in soils of the arid and semi-arid region and a measure of the degree of degradations in soils (Pal *et*

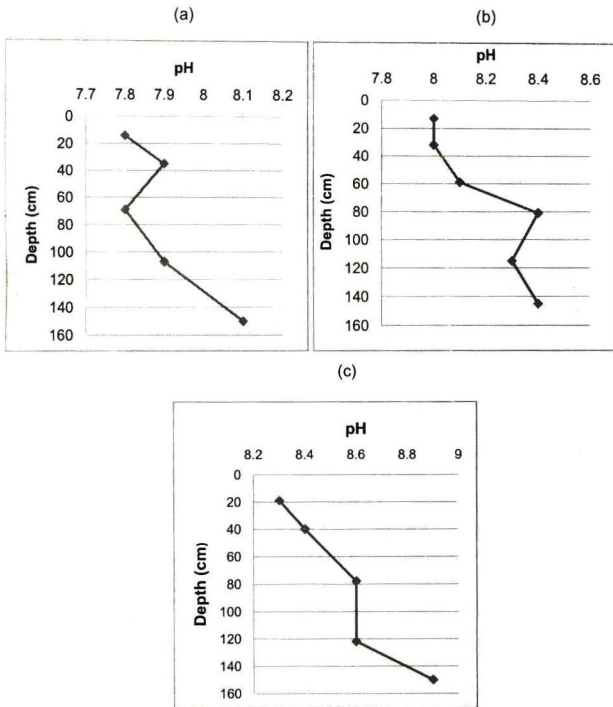


Fig.4.4 Variation in pH with depth (a) Asra soil (b) Seloo soil (c) Pahur soils

*al.*, 1999). Higher amount of these may either increase (increase of pedogenic  $\text{CaCO}_3$ ) or decrease (increase in non-pedogenic  $\text{CaCO}_3$ ) the BD.

The free calcium carbonate percentage for P1, P2 and P3 soils ranges from (8.1 to 10.6%), (3.4 to 4.4%) and (8.2 to 9.8%), respectively. The calcareous nature of vertisols is due to the presence of both pedogenic and non- pedogenic  $\text{CaCO}_3$ , and both form react with HCl and therefore cannot be distinguished from each other by chemical method. However, physical removal of carbonate clay can provide as idea about pedogenic carbonates (Pal *et al.*, 2010). In general, the distribution of calcium carbonate content was somewhat uniform and slight increase with depth. A similar observation was also reported by (Murthy *et al.*, 1982; NBSS and LUP staff, 1996). The trend has been mainly due to leaching of bi-carbonate during the rainy season from the upper layer and subsequent precipitation during the hot and dry periods prevailing in the area which result in increase of pH, decrease in partial pressure of  $\text{CO}_2$  ( $p\text{CO}_2$ ) and loss of water through evapotranspiration (Pal *et al.*, 2000; Chadwick and Graham, 2000).

#### **4.3.4 Organic carbon**

Vertisols generally have low organic matter due to low prevailing rainfall or aridity, which results in higher degree of ions in organic matter, absence of luxuriant vegetation further decrease level of organic matter in the soils. The significant of nature and content of clay as substrate has been stressed as the most important factors influencing organic carbon dynamic.

The organic carbon content for P1, P2 and P3 soils, ranged from (0.5 to 0.8%), (0.3 to 0.9%) and (0.5 to 0.9%) respectively. These values are moderate to high in general, decreasing with depth in all three pedons. The higher values of organic carbon in surface

layers may be due to the intercropping system with legume (Bhattacharyya *et al.*, 2007) replenishment from crop residues.

#### 4.3.5 Extractable bases (cations)

Calcium is dominant cation in all the three soils, which ranged from 36.2 to 40.1, 18.2 to 49.0 and 31.1 to 43.0  $\text{cmol}(\text{p}^+)\text{kg}^{-1}$  for Asra, Seloo and Pahur soils, respectively. (Table 4.3) The exchangeable magnesium values are 12 to 22.2, 4.4 to 14.8 and 13.9 to 22.3  $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ , respectively, in the P1, P2 and P3 soils. The calcium and magnesium ratio (Ca/Mg) decreases with depth indicating decrease in calcium and simultaneous increase in magnesium, which is generally observed in Vertisols of this region (Balpande *et al.*, 1996). The increase in extractable  $\text{Mg}^{++}$  with depth is more in P1 and P3 compared to P2 soils, which may be the probable reason of decrease in sHC in P1 and P3 compared to P2 (Table 4.2).

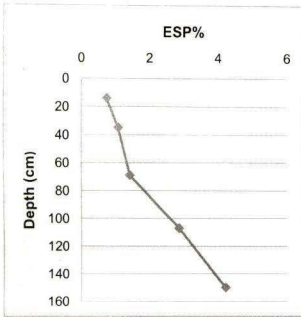
The exchangeable sodium values for P1, P2 and P3 soils varied from 0.4 to 2.6, 0.4 to 0.5 and 0.8 to 10.7  $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ , respectively (Fig.4.5). Exchangeable sodium percentage (ESP) has not have any deleterious impact on P3, which increases down the profile the values of  $\text{K}^+$  for P1, P2 and P3 soils varies from 0.8 to 1.1, 0.4 to 0.9 and 0.4 to 1.0  $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ , respectively. The exchangeable potassium values for all the three pedons decreased with depth.

#### 4.3.6 Cation exchangeable capacity

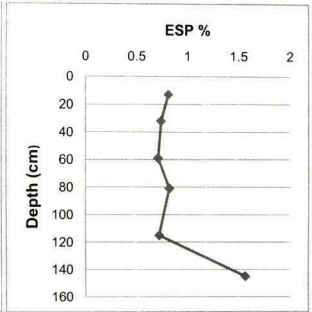
The CEC is the most important parameter for charge behavior of the soils. The CEC values provide important information regarding soils ability to supply certain nutrients to the plants and thus have a strong influence over agriculture productivity.

All the three soil registered high CEC values, which ranged from (56.5 to 63.0)  $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ , (64.8 to 71.1)  $\text{cmol}(\text{p}^+)\text{kg}^{-1}$  and (55.5 to 72.1)  $\text{cmol}(\text{p}^+)\text{kg}^{-1}$  P1, P2 and P3 soils respectively. The higher values of CEC mainly depend on the amount and nature of clay,

(a)



(b)



(c)

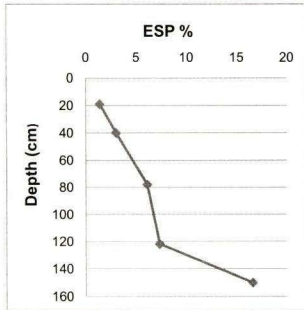


Fig.4.5 Variation in ESP with depth (a) Asra soil (b) Seloo soil (c) Pahur soils

organic matter content and pH (Brady, 1984). The high values of CEC as related to the presence of smectite in black soils were reported by Kaswala and Deshpande (1986) and (Balpande *et al.*, 1996) the values of CEC increasing in the sub-surface horizons due to increase in clay and smectite content (Table 4.3).

#### 4.3.7 Correlation study

Simple correlation through bi-variate relation was studied between different soil properties of three sites (Asra, Seloo and Pahur) (Table 4.5) to know the relationship between the soil properties. The relevant relationship has been explained here under.

Significantly and positively correlated was observed between  $\text{CaCO}_3$  % ( $r=0.764^{**}$ ),  $\text{Mg}^{++}$  ( $r=0.662^{**}$ ),  $\text{Na}^+$  ( $r=0.554^*$ ), ESP ( $r=0.535^*$ ) with clay, respectively, whereas, bulk density had a significance negative correlation with sHC ( $r=-0.524^*$ ), OC ( $r=-0.504^*$ )  $\text{CaCO}_3$  ( $r=-0.795^*$ ) and many other relationship between soils properties of the study area is shown in the (Table 4.5).

Clay was significantly and positively correlated with  $\text{CaCO}_3$  which may indicated that most of the  $\text{CaCO}_3$  was of clay size fractions and partially physically behaved – like clay. Similarly bulk density actually decreased with non-pedogenic  $\text{CaCO}_3$  as the density of  $\text{CaCO}_3$  is less than the density of shrink-swell type clay, and hence the significant and negative relationship between them. Use of heavy machineries in the field results in compression of soil, and increased bulk density in shrink-swell soils resulted in low sHC, so that there exist a negative correlation between BD and sHC. Increase in bulk density indicates that there is less amount of organic matter in the soils which in turn results in less organic carbon.

**Table 4.3 Chemical properties of soils**

Horizon	Depth (cm)	pH	EC	Organic Carbon	CaCO <sub>3</sub> eq.	Extractable bases				Sum	CEC	Ca/Mg ratio	ESP (%)
						Ca <sup>++</sup>	Mg <sup>++</sup>	Na <sup>+</sup>	K <sup>+</sup>				
						←-----cmol (p <sup>+</sup> ) kg <sup>-1</sup> ----->							
			dS m <sup>-1</sup>	(%)									
<b>Pedon 1 - Asra series (Typic Haplusterts) District – Amaravati</b>													
Ap	0 – 14	7.8	0.10	0.8	8.1	40.1	12.2	0.4	1.1	53.8	60.9	3.28	0.74
Bw1	14 – 35	7.9	0.15	0.7	9.4	39.0	14.9	0.6	0.8	55.3	56.5	2.61	1.08
Bw2	35 – 69	7.8	0.14	0.6	9.6	38.0	16.9	0.8	0.8	56.5	59.8	2.24	1.42
Bss1	69 – 107	7.9	0.32	0.6	9.7	37.8	19.0	1.7	0.8	59.3	63.0	1.98	2.87
Bss2	107–150	8.1	0.23	0.5	10.6	36.2	22.2	2.6	0.8	61.8	61.9	1.63	4.21
<b>Pedon 2 - Seloo series (Typic Haplusterts) District – Wardha</b>													
Ap	0-13	8.0	0.26	0.97	3.8	44.0	4.4	0.4	0.9	49.6	64.8	10.0	0.81
Bw1	13-32	8.0	0.21	0.65	4.4	38.4	14.8	0.4	0.8	54.3	66.4	2.59	0.74
Bw2	32-59	8.1	0.17	0.50	3.4	45.8	9.4	0.4	0.6	56.1	70.3	4.87	0.71
Bss1	59-81	8.4	0.19	0.41	3.3	49.0	11.0	0.5	0.6	61.0	70.3	4.45	0.82
Bss2	81-115	8.3	0.16	0.47	3.8	43.2	11.6	0.4	0.6	55.7	71.1	3.72	0.72
BCK	115-145	8.4	0.24	0.32	3.4	18.2	13.0	0.5	0.4	32.0	70.3	1.40	1.56
<b>Pedon 3 - Pahur series (Typic Haplusterts) District – Yavatmal</b>													
Ap	0-19	8.3	0.23	0.94	8.2	42.4	13.9	0.8	1.0	58.0	55.5	3.05	1.38
Bw1	19-40	8.4	0.19	0.64	8.2	43.0	15.2	1.8	0.4	60.0	60.8	2.82	3.00
Bss1	40-78	8.6	0.27	0.56	8.8	42.3	16.1	3.8	0.3	62.4	68.7	2.62	6.09
Bss2	78-122	8.6	0.31	0.51	8.8	36.5	15.0	4.1	0.5	56.1	56.2	2.43	7.31
Bss3	122-150	8.9	0.33	0.54	9.8	31.1	22.3	10.7	0.4	64.4	72.1	1.39	16.6

**Table 4.4 Descriptive statistics of the parameters taken for correlation studies**

Soil Properties	Minimum	Maximum	Mean	Std. Deviation
Sand %	0.4	4.0	1.81	1.10
Silt%	32.2	48.0	39.93	4.87
Clay %	51.5	65.9	58.28	4.20
BD ( $\text{Mg m}^{-3}$ )	1.4	1.9	1.64	0.15
sHC (cm/hr)	0.3	1.7	0.78	0.42
COLE	0.1	0.2	0.17	0.04
pH	7.8	8.9	8.21	0.32
EC dS/m	0.1	0.3	0.21	0.06
OC (%)	0.3	0.9	0.58	0.17
CaCO <sub>3</sub> (%)	3.3	10.6	7.08	2.80
Ca <sup>++</sup>	18.2	49.0	39.06	7.02
Mg <sup>++</sup>	4.4	22.3	14.49	4.51
Na <sup>+</sup>	0.4	10.7	1.86	2.65
K <sup>+</sup>	0.3	1.1	0.67	0.23
Sum	32.0	64.4	56.01	7.42
CEC	55.5	72.1	64.28	5.74
ESP	0.71	16.60	3.128	4.12

**Table 4.5 Simple correlation coefficient (r) between soil properties**

	Sand	Silt	Clay	BD	sHC	COLE	pH	EC	OC	CaCO <sub>3</sub>	Ca <sup>++</sup>	Mg <sup>++</sup>	Na <sup>+</sup>	K <sup>+</sup>
Sand	1.00													
Silt	-0.668**	1.00												
Clay	0.504*	-0.979**	1.00											
BD	-0.777**	0.571*	-0.46	1.00										
sHC	0.42	-0.37	0.32	-0.524**	1.00									
COLE	-0.03	-0.26	0.29	0.16	0.36	1.00								
pH	-0.15	0.14	-0.13	0.06	-0.727**	-0.523*	1.00							
EC	0.02	-0.07	0.09	0.11	-0.518*	-0.28	0.553*	1.00						
OC	0.502*	-0.32	0.24	-0.504*	0.37	0.37	-0.46	-0.08	1.00					
CaCO <sub>3</sub>	0.765**	-0.859**	0.794**	-0.795**	0.42	-0.05	0.01	0.07	0.24	1.00				
Ca <sup>++</sup>	-0.05	0.13	-0.12	0.18	-0.03	0.34	-0.20	-0.05	0.36	-0.14	1.00			
Mg <sup>++</sup>	0.35	-0.655**	0.662**	-0.39	0.17	-0.04	0.24	0.10	-0.27	0.778**	-0.40	1.00		
Na <sup>+</sup>	0.18	-0.524*	0.554*	-0.20	-0.41	-0.15	0.715**	0.533*	-0.21	0.48	-0.30	0.622*	1.00	
K <sup>+</sup>	0.39	-0.25	0.17	-0.24	0.567*	0.697**	-0.779**	-0.44	0.745**	0.09	0.26	-0.21	-0.48	1.00
CEC	-0.865**	0.41	-0.24	0.725**	-0.584*	0.03	0.38	0.20	-0.613*	-0.580*	-0.09	-0.12	0.21	-0.514*
ESP	0.20	-0.512*	0.535*	-0.21	-0.42	-0.20	0.729**	0.546*	-0.23	0.48	-0.33	0.619	0.998**	-0.502*

\*\* Significant at 1% level

\* Significant at 5% level

#### 4.4 Mineralogical properties of soils

The XRD analysis of the total clay and silt sample of a representative horizon of pedons P1, P2 and P3 were carried out. The mineralogical compositions of all the size fractions of soils are similar. Therefore, only representative XRD patterns are discussed below.

##### 4.4.1 Mineralogy of the silt fractions

XRD analysis of the silt fractions (50-2  $\mu\text{m}$ ) of all the three soil indicated the presence of mica, kaolinite, quartz, feldspar, smectite, chlorite and vermiculite. A representative X-ray diffractograms each for P1, P2 and P3 of silt fractions are presented in figure 4.6, 4.7 and 4.8. Smectite was identified in all samples by the appearance of 1.4 nm peak in Ca- saturated samples which shifted to 1.7 nm on glycolation. The presence of kaolin was ascertained by the appearance of 0.70 nm peak in Ca-saturated and glycolated sample and in K-saturation when heated up to 300°C and disappearance of this peak after subsequent heating to 550°C. The persistence of 1.38 nm peak after heating to 550°C for 1 h indicates the presence of pedogenic chlorite. Silt mica peaks were identified in all samples by the appearance of 1.0 nm peak in Ca and CaEG samples. On K-saturation this 1.0 nm peak was broader after K-300°C treatments. The 002 reflection of 1.0 nm peak was also identified in CaEG silt samples of all the horizons. The peak at 0.42 nm indicates the presence of quartz in all samples. The feldspar peaks were detected between 0.318 to 0.319 nm for Ca-feldspar and 0.325 nm for K-feldspar. Pahur soils have higher amount of kaolin and quartz. Close to them are chlorite, feldspars and mica in sub-dominant amounts followed by smectite and vermiculite. Smectite was the dominant mineral in the silt fraction. Similar results were reported by Kapse, 2007; Deshmukh, 2012; Kuspure, 2013.

#### 4.4.2 Mineralogy of total clay fractions (<2µm)

A representative X-ray diffractograms of total clays of P1, P2 and P3 soils are shown in figures 4.9, 4.10 and 4.11. The total clay fractions (<2 µm) are composed dominantly of smectite followed by small amounts of vermiculite, kaolinite, mica, 1.0-1.4 nm minerals, small amount of pedogenic chlorite, quartz and feldspars are present in traces. The Ca saturated samples gave peak at 1.4 nm and expanded to about 1.7 nm after ethylene glycol solvation indicating the presence of smectite which is the dominant mineral. This smectite was found to be a little chloritized as evidenced by broadening toward lower angle side of 1.0 nm peak after heating the K-saturated sample at 550°C (Pal and Deshpande, 1987; Bhattacharyya *et al.*, 1993; Pillai *et al.*, 1996). However, on K-saturation and subsequent heating at 110°C the 1.0 nm peak of mica was reinforced indicating the presence of small amounts of vermiculite. At 300°C heating 1.4 nm peak persisted but disappeared at 550°C heating with a tailing at low angle side of 1.0 nm indicating the chloritization in the vermiculite interlayers. The smectite is low charge one as confirmed by the expansion of smectite beyond 1.4 nm after glycolation of K-saturated and heated at 300°C sample (Ross and Kodama, 1984). All the three soils have similar amounts of smectite whereas vermiculite is slightly higher in Pahur soils.

The 0.72nm peaks in a Ca-saturated and glycolated and K-saturated samples and heated up to 300°C indicated the presence of kaolin. This peak was disappeared after heating to 550°C, with the subsequent reinforcement of the 1.0 nm peak (Bhattacharyya *et al.*, 1993; 1997).

#### 4.4.3 Semi-quantitative analysis of total clay

The semi-quantitative analysis of total clay (Table 4.6) gives the overall estimates of mineral in the soils fractions. All the three soils shows smectite (75-87%) as the dominant mineral followed by

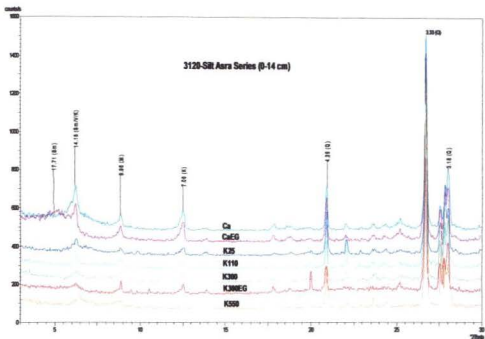


Fig.4.6 Representative X-ray diffractograms of silt fraction (50-2µm) of Asra soils Sm=smectite, M=mica, K=Kaolinite, Q=quartz, F=Feldspar, Ca=calcium saturated; CaEG=saturated and ethylene glycolated; K25 /K110 /K300 /K550 / = K saturated and heated at 25, 110, 300, and 550°C.

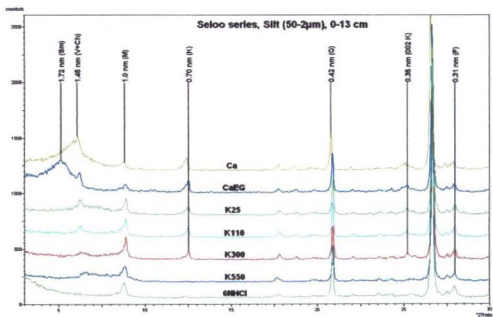


Fig. 4.7 Representative X-ray diffractograms of silt fractions (50-2 µm) of Seloos series; Ca = Ca saturated; Ca-EG = Ca saturated plus ethylene glycol vapour treated; K-saturated and heated to 25, 110, 300, 550°C. 6NHCl = 6N HCl treated fine clays; Sm = Smectite, V + Ch = vermiculite plus chlorite; K = Kaolinite; F = Feldspars; Q = Quartz;

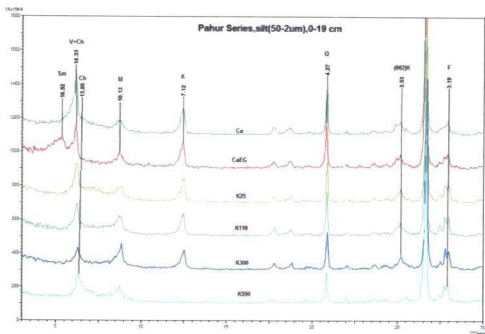


Fig.4.8 Representative X-ray diffractograms of silt fractions (50-2µm) of Pahur soils; Ca=Ca saturated; Ca-EG=Ca saturated plus ethylene glycol vapour; K-saturated and heated to 25, 110, 300, 550°C. Sm=Smectite, V+Ch = vermiculite plus chlorite; Ch = Chlorite; M = mica; K = Kaolinite; F = Feldspars; Q = Quartz; (002) K = (002) Kaolinite.

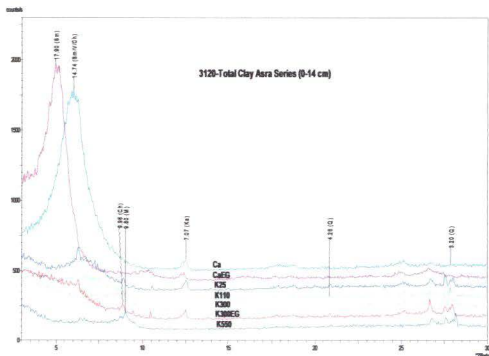


Fig. 4.9 Representative X-ray diffractograms of total clay fraction (<2 µm) of Asra soils; Sm=smectite, M=mica, K=Kaolinite, Q=quartz, F=Feldspar, Ca=calcium saturated; CaEG=saturated and ethylene glycolated; K25/K110/K300/K550 = K saturated and heated at 25, 110, 300, and 550°C.

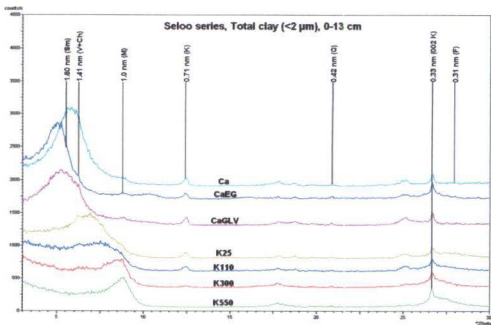


Fig. 4.10 Representative X-ray diffractograms of total clay fractions (<2  $\mu\text{m}$ ) of Selloo soils; Ca = Ca saturated; Ca-EG = Ca saturated plus ethylene glycol vapour treated; K-saturated and heated to 25, 110, 300, 550°C. K300°EG = K-saturated and heated to 300°C plus ethylene glycol vapour treated; V + Ch = vermiculite plus chlorite; Ch = Chlorite; K = Kaolinite; F = Feldspars.

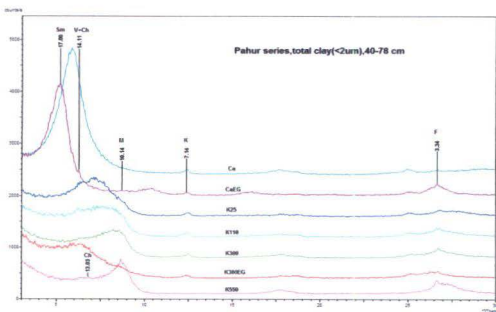


Fig. 4.11 Representative X-ray diffractograms of total clay fractions (<2  $\mu\text{m}$ ) of Pahur soils; Ca=Ca saturated; Ca-EG=Ca saturated plus ethylene glycol vapour; K-saturated and heated to 25, 110, 300, 550°C. K300°EG= K-saturated plus ethylene glycol vapour and heated to 300°C; Sm=Smectite, V+Ch = vermiculite plus chlorite; Ch = Chlorite; M = mica; K = Kaolinite; F = Feldspars.

vermiculite, chlorite, there are some traces of mica, quartz and feldspar in the total clay fraction.

Table 4.6. Semi-quantitative estimates of minerals in total clay fraction clays of the soils.

Horizon	Depth (cm)	Clay minerals (%)						
		Smectite	Vermiculite	Chlorite	Kaolin	Mica	Quartz	Feldspar
<b>Asra series</b>								
Ap	0-14	84	11	1	Tr	Tr	Tr	Tr
Bw1	16-35	84	6	3	Tr	Tr	Tr	6
Bw2	44-69	76	12	2	Tr	Tr	Tr	8
Bss1	69-107	87	5	2	Tr	Tr	Tr	Tr
Bss2	102-150	76	6	6	Tr	Tr	Tr	9
<b>Seloo series</b>								
Ap	0-13	79	5	Tr	Tr	Tr	Tr	6
Bw1	13-32	75	5	6	Tr	Tr	Tr	6
Bw2	32-59	84	Tr	Tr	Tr	Tr	-	7
Bss1	59-81	81	8	Tr	Tr	-	-	7
Bss2	81-115	81	7	Tr	Tr	Tr	Tr	6
BCK	115-145	83	6	Tr	5	-	-	Tr
<b>Pahur series</b>								
Ap	0-19	87	9	1.0	1.0	1.0	<1	Tr
Bw1	19-40	86	10	1.0	1.0	1.0	<1	Tr
Bss1	40-78	86	9	2.0	1.0	1.0	<1	Tr
Bss2	78-122	87	6	3.0	2.0	1.0	<1	Tr
Bss3	122-150	86	9	1.0	2.0	2.0	<1	Tr

#### 4.5 Sub-microscopic Studies of Soils

Particle-size analysis was done by International pipette method, sand (200-50 $\mu$ m), silt (50-2 $\mu$ m) and total clay (<2  $\mu$ m) fractions were separated from all the three pedons (P1, P2 and P3) after dispersion

according to the size segregations procedure of Jackson (1979). Total sand was passed through sieve and different size fractions were separated following the procedure outlined by Day, (1965) fine and very fine sand of the selected horizons were separated and fractionated these fractions were then mounted on stubs and mineral species were identified using Scanning Electron Microscope (SEM).

Quartz is found to be the most dominant mineral in all the sand fractions and is polycrystalline in nature (Fig 4.12). This may be due to its abundance, hardness and crumbing into smaller pieces (Fig 4.13).

After quartz, feldspar was the next major mineral identified by its morphological features (Fig.4.14, 4.15 and 4.16) but at different stages of weathering along with mica in the finer fractions of sands (Fig. 4.17).

#### **4.6 Soil properties in relation to mineralogy**

The soils minerals from the study area derived from the alluvium developed from the weathering Deccan trap and from the exhumed metamorphic rocks during the multicycle erosion since the Pliocene-Pleistocene as explained by Pal and Deshpande, (1987). The semi-quantitative estimates of XRD analysis showed that total clay fraction constitutes the major portion (75-87%) of the dominant mineral *i.e.* smectite so the correlation studies of soils properties and total clay will imply their relationship of both and smectite in specific. As smectite is solely responsible for the vertic properties of soils (Shirsath *et al.*, 2000), smectite appears to be the exclusive parent material of Vertisols.

The linear correlation co-efficient worked out between various soil properties (Table 4.5) showed that the clay was significantly and positively correlated with  $\text{CaCO}_3$  % ( $r=0.764^{**}$ ),  $\text{Mg}^{++}$  ( $r=0.662^{**}$ ),  $\text{Na}^+$  ( $r=0.554^*$ ) and ESP ( $r=0.535^*$ ). Soils of the study area have  $\text{pH} > 7$  indicating that there is a dearth of  $\text{H}^+$  in the soil solution, which allows others cations to take part in the exchange reaction. As a results, the measured values of CEC increases as the pH increases (Biswas and

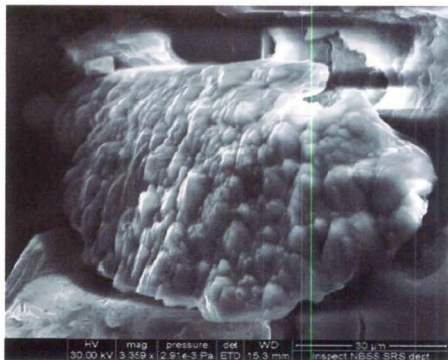


Fig.4.12 Quartz- (cryptocrystalline variety) from coarse sand of Asra  $50 \times 10^3$

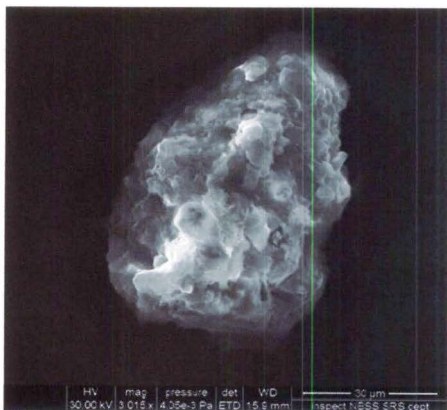


Fig.4.13 Quartz from the sand fractions of Pahur  $50 \times 10^3$

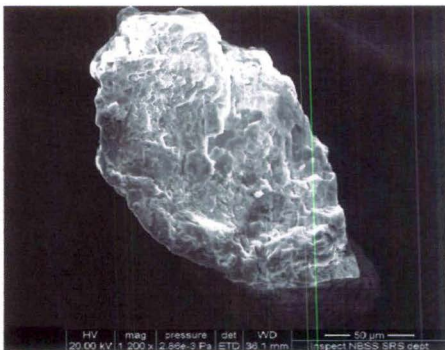


Fig.4.14 Feldspar from sand fraction of Asra soil

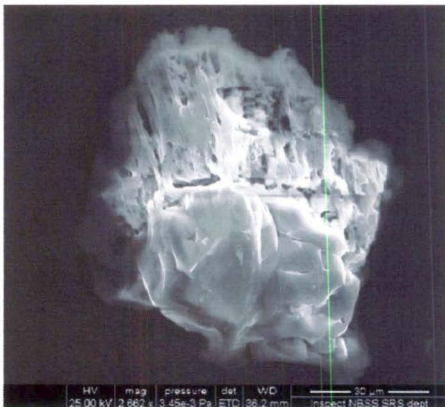


Fig.4.15 Weathered Feldspar from sand fraction of Selo soil



Fig.4.16 Feldspar from sand fraction of Asra 50A

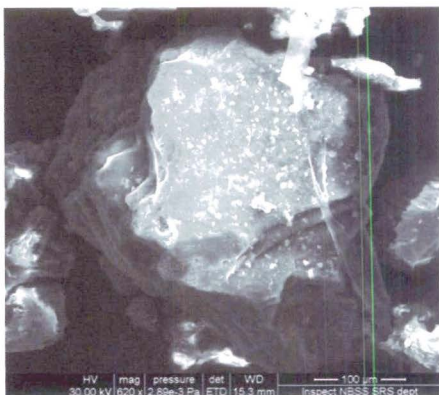


Fig.4.17 Mica weathering in sand fraction of Seloo 50A

Mukherjee, 1997). In all the three pedons (P1, P2 and P3) there is an increasing trend of CEC with increase in pH. In P1 pH increases from 7.8 to 8.1 whereas CEC increase from 60.9 to 61.9. Similarly in P2, a pH variation from 8.0 to 8.4 resulted in increases in CEC from 64.8 to 70.3 and in P3 a pH increase from 8.3 to 8.9 resulted in increases CEC from 55.5 to 72.1. The clay CEC values of all the pedons is  $>60$ , which indicated the dominance of smectite group ( $> 45 \text{ cmol(p}^+) \text{kg}^{-1}$  clay) of minerals (Kaswala and Deshpande, 1986; Smith, 1986; Balpande *et al.*, 1996; Soil Survey Staff, 2006).

Co-efficient of linear extensibility (COLE) values  $>0.03$  indicate that significant amount of smectite is present (Boul *et al.*, 1980). Table 4.2 indicates that COLE values of all the pedons are 0.03. Higher COLE indicates more smectite in the soils. In fact COLE values are one of the important diagnostics criteria for shrink-swell soils (Soil Survey Staff, 1999). The shrink-swell behavior is primarily governed by the nature of the clay minerals, particularly their surface properties. Other minerals such as kaolin, mica, chlorites, palygorskite and vermiculite do not expand on solvation (Borchardt, 1989). Similar relationship has been observed by (Shirsath *et al.*, 2000).

Smectite clays have a variable net negative charge, which is balanced by Na, Ca, Mg and H adsorbed externally on inter-lamellar surface. In most of the natural smectites of Indians the charge is distributed over both tetrahedral and octahedral sheets (Kapse, 2007, Kapse *et al.*, 2010; Ray *et al.*, 2008). These authors have elaborated that the soils of the study area are dominated by clays of montmorillonite beidellite type (Pal and Deshpande, 1987). However, the beidellite/nontronite species dominated over the montmorillonite species.



## Chapter V

### SUMMARY AND CONCLUSIONS

The study on characterization of minerals in some selected benchmark soils of Western Vidarbha, Maharashtra were taken up with two objectives viz., 1) To identify major minerals in different soil fractions of Western Vidarbha. 2) To link mineral constituents with soil properties.

Keeping this in view of three benchmark Vertisols profile sites Asra series (P1), Seloo series (P2) and Pahur series (P3) were selected for the study. The Asra soils are classified as very fine, smectitic, hyperthermic, Typic Haplusterts located at 20°52'41"N latitude and 77°29'16"E longitude in village Asra of Batkuli tehsil, Amravati district, Maharashtra. The Seloo soils are classified as fine, smectitic, isohyperthermic, Typic Haplusterts located at 20°53'3.2"N latitude and 78°41'48.5"E longitude in village Bhramani of Seloo tehsil, Wardha District of Maharashtra and Pahur soils are classified as very fine, smectitic, hyperthermic, Typic Haplusterts located at the cross section of 29°8'15" N latitude and 78°5'59"E longitude in village Pahur, Arni tehsil, Yavatmal district, Maharashtra.

The soil profiles were studied; samples were collected and analyzed in the laboratory by standard methods. The summary of the results and conclusions drawn are enumerated below.

- The Asra (P1) soils are very dark brown to very dark grayish brown colour (10 YR 2/2), moderate sub angular blocky structure with clayed texture. Whereas Seloo (P2) soils are very dark grayish brown colour (10YR 3/2), moderate sub angular blocky structure to moderate angular blocky structure with clayed texture and Pahur (P3) soils are very dark grey to dark gray colour (10 YR 3/2), moderate to strong, sub angular blocky to angular blocky structure with clayed texture. Pressure faces are seen all in the Bw horizon and thereafter in all the three

pedons. Slickensides are found in all the three pedons in Bss horizons.

- Bulk density values vary from 1.4 to 1.9 Mg/m<sup>3</sup>.
- Hydraulic conductivity values of P1, P2 and P3 ranges from 0.9 to 1.7cm/hr, 0.5 to 0.7 cm/hr and 0.3 to 1.0 cm/hr, respectively. That's indicating soil related drainage problems in Pahur (P3) soils as compared to Asra (P1) and Seloo (P2) soils.
- Coefficient of linear extensibility (COLE) values varies from 0.10 to 0.26. Higher the COLE value indicates more smectite mineral in the soils. Organic carbon varies from 0.3 to 0.9 per cent.
- pH (1:2) of the soils ranges from 7.8 to 8.9 and the Electrical conductivity from 0.10 to 0.33 dSm<sup>-1</sup>.
- Calcium carbonate equivalent of P1, P2 and P3, varies from 8.1 to 10.6%, 3.3 to 4.4% and 8.2 to 9.8%, respectively.
- CEC of the soils are high for P1, P2 and P3 soils, It ranges from 56.5 to 63.0 cmol(p<sup>+</sup>)kg<sup>-1</sup>, 64.8 to 70.3 cmol(p<sup>+</sup>)kg<sup>-1</sup> and 55.5 to 68.7cmol(p<sup>+</sup>)kg<sup>-1</sup>, respectively.
- Extractable bases were found in the order Ca<sup>++</sup> >Mg<sup>++</sup> >K<sup>+</sup> >Na<sup>+</sup>.
- The XRD study indicated that smectite is the dominant minerals in total clay fraction along with small amount of vermiculite, kaolinite, and mica etc. The silt fractions indicated the presence of mica, kaolinite, quartz, feldspar, smectite, chlorite and vermiculite minerals.
- Semi-quantitative analysis of total clay shows smectite as dominant (75-87%) Followed by vermiculite and chlorite.
- The sub-microscopic study of sand fractions through Scanning Electron Microscope (SEM) shows, coarse sand comprise of quartz, feldspar and mica in majority and mica in the finer fractions.

## Conclusions

1. The benchmark sites of Western Vidarbha are dominated by smectites in the silt and clay fractions. However, fine clays contain subordinate of vermiculite and feldspars.
2. Coarser fractions of sand are dominated by quartz feldspars. Whereas the finer fractions are conspicuous by the presence of mica which may have implications in the potassium management of these soils.

## Chapter VI

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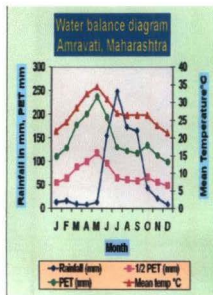
Date: 05/09/2014

  
Signature of Student

**Pedon1- ASRA (Amravati):Semi-arid  
(Soybean+Pigeonpea)**

- Classification** : Very-fine, smectitic,  
hyperthermic,  
TypicHaplustert
- Location** : Village- Asra, Bhatkuli,  
District- Amravati.  
Latitude 20°52'41"N,  
Longitude 77° 29'16"E
- Physiographic position** : Lower Maharashtra Deccan  
Plateau
- Topography and slope** : Very gently sloping to slightly  
undulating, (1-3%) at a slope  
length of 50-150 m.

- Vegetation** : Ber (*Zizipus zuzuba*),  
Babul (*Acecia nilotica*),  
Neem(*Azadirachtaindica*),
- Land Use** : Soybean+Pigeonpea  
intercropping
- Parent material** : Basaltic Alluvium



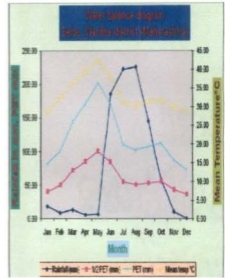
**Water balance diagram of  
Amravati**

Horizon	Depth	Descriptions
Ap	0-14 cm	Very dark brown to very dark grayish (10 YR 2/2) clay; moderate medium sub angular blocky structure; friable, sticky and plastic; common very fine, few fine roots; many very fine, few fine lime nodules ; many very fine and fine pores; slightly alkaline (pH 7.8) strongly effervescent; clear smooth boundary.
Bw1	14-35 cm	Very dark brown to very dark grayish (10 YR 2/2) clay; strong medium sub angular blocky structure with pressure faces on peds surface; friable, very sticky and very plastic; common very fine, few fine roots; many very fine, few fine

		lime nodules; many very fine and fine pores; slightly alkaline (pH7.9); strongly effervescent; gradual smooth boundary.
Bw2	35-69 cm	Very dark brown (10 YR 2/2) clay;strong medium, sub angular blocky structure with well-developed pressure faces on peds surface;very sticky and very plastic; common very fine roots; many very fine, few fine lime nodules; slightly alkaline(pH 7.8) strongly effervescent; clear smooth boundary.
Bss1	69-107 cm	Very dark brown to very greyish brown (10 YR 2/2) clay;strong medium angular blocky structure with well-developed wedges shaped aggregate and slickenside that breaks into small angular peds; slightly firm, very sticky and very plastic;few very fine roots; common very fine, few fine lime nodules; slightly alkaline (pH 7.9); strongly effervescent; gradual smooth boundary.
Bss2	107-150 cm	Very dark brown to very greyish brown (10 YR 2/2) clay;strong coarse angular blocky structure with well-developed wedges shaped aggregate and slicken side that break into small angular peds; slightly firm, very sticky and very plastic; few very fine roots; common very fine lime nodules; moderately alkaline (pH 8.1); strongly effervescent; gradual smooth boundary.

**Pedon 2- SELOO (Wardha):Sub-Humid  
(Cotton+Pigeonpea)**

- Classification** : Fine, smectitic,  
isohyperthermic, Typic  
Haplusterts
- Location** : Vill. Bhramni-Seloo, Wardha,  
Maharashtra;  
Lat. 20°53'3.2"N,  
Long. 78°41'48.5"E
- Physiographic position** : Maharashtra Deccan Plateau
- Topography and slope** : Flat to undulating 1-3% slope
- Vegetation** : Banana,  
Neem(*Azadirachta indica*),  
Mango (*Mangifera indica*).
- Land Use** : Cotton+ Pigeonpea, Wheat,  
Chilli, Cauliflower, Banana
- Parent material** : Basaltic Alluvium



**Water balance diagram of  
Seloo Wardha**

Horizon	Depth	Descriptions
Ap	0-13 cm	Very dark grayish brown colour(10YR 3/2) Clay, medium moderate to sub-angular blocky structure, slightly hard, very friable, slightly sticky and plastic, very fine, medium and coarse roots, fine many pores, coarse lime nodules, slight effervescence, moderately alkaline (pH 8.0), clear smooth boundary.
Bw1	13-32cm	Very dark grayish brown colour(10YR 3/2) Clay, medium moderate subangular blocky structure, very friable, slightly sticky and plastic, very fine, few roots; fine many pores, fine lime nodules, slight effervescence, moderately alkaline (pH 8.0), clear smooth boundary

Bw2	32-59cm	Very dark grayish brown colour (10YR 3/2) Clay, medium to moderate sub-angular blocky structure, slightly hard, friable, very sticky to very plastic, many medium roots; fine many pores, fine lime nodules, slight effervescence, moderately alkaline (pH 8.1); gradually smooth boundary, pressure faces.
Bss1	59-81cm	Very dark grayish brown colour (10YR 3/2) Clay, slickensides forming parallelepipeds that breaks into moderate medium angular blocky structure, friable, very sticky and very plastic, fine few roots; fine lime nodules, slight effervescent, moderately alkaline (pH 8.4).
Bss2	81-115cm	Brown colour (10YR 3/2), slickensides forming parallelepipeds that breaks into moderate medium, angular blocky structure, friable, very sticky and very plastic, few fine roots, fine lime nodules, slight effervescent, moderately alkaline (pH 8.3); smooth boundary.
Bck	115-145cm	Very dark grayish brown to dark yellowish brown (10 YR 3/1) Clay, medium, moderate sub-angular blocky structure, loose, friable, very sticky to sticky plastic, consistent, common few roots, coarse lime nodules, < 25-30% strong effervescence, moderately alkaline (pH 8.4).

## Annexure-III

### Pedon3 - PAHUR (Yavatmal):Sub-Humid (Soybean+Pigeonpea)

- Classification** : Very-fine, smectitic,  
hyperthermic,  
TypicHaplustert
- Location** : Village- : About ½ km. West of  
Pahur village on  
PahurMohsole Road, Pahur,  
Arni, Yavatmal, M.S.  
Latitude 20°08'15"N,;  
Longitude 78°05'59"E

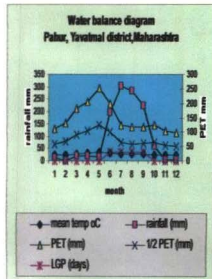
**Physiographic position** : Lower Maharashtra Deccan Plateau

**Topography and slope** : Very gently sloping, 1-3%  
(0-50 m)

**Vegetation** : Ber (*Zizipus zuzuba*),  
Babul (*Acecia nilotica*),  
Neem(*Azadirachta indica*),

**Land Use** : Soybean+Pigeonpea  
intercropping

**Parent material** : Basaltic Alluvium



**Water balance diagram of Yavatmal**

Horizon	Depth	Descriptions
Ap	0-19 cm	Very dark to dark grayish brown (10YR 3/2) clay; moderate medium sub angular blocky structure; hard, friable, very sticky and very plastic; few very fine and medium common fine roots; common fine lime nodules; common very fine pores; moderately alkaline (pH 8.3); strongly effervescent; clear smooth boundary.
Bw1	19-40 cm	Very dark grayish brown (10YR3/2) clay; moderate medium sub angular blocky structure with pressure faces on surface of peds; friable, very sticky and very plastic; common fine, few medium roots; many fine and medium

lime nodules; common fine pores; moderately alkaline (pH 8.4); strongly effervescent; gradual smooth boundary.

- |      |               |   |
|------|---------------|---|
| Bss1 | 40-78cm       | Very dark grayish brown (10YR3/2) clay; strong, medium to coarse angular blocky structure with wedge shaped aggregates and slickensides that breaks into small angular peds; friable, very sticky and very plastic; common fine, few medium roots; common fine and medium lime nodules; strongly alkaline (pH 8.6); slightly effervescent; gradual smooth boundary                      |
| Bss2 | 78 -122<br>cm | Very dark gray to very dark grayish brown (10YR 3/1) clay; strong, medium to coarse angular blocky structure with well-developed wedge shaped aggregates and slickensides that breaks into strong angular peds; friable, very sticky and very plastic; few fine roots; common fine and medium lime nodules; strongly alkaline (pH 8.6); slightly effervescent; gradual smooth boundary. |
| Bss3 | 122-150<br>cm | Very dark gray to very dark grayish brown (10YR3/1) clay; strong, medium to coarse angular blocky structure with well-developed wedge shaped aggregates and slickensides that breaks into strong angular peds; friable, very sticky and very plastic; few fine roots; common fine and medium lime nodules; strongly alkaline (pH 8.9); slightly effervescent.                           |

