CHAPTER - 1

INTRODUCTION

1.1. Weathering: A Prologue

Weathering, the primary process in the formation of soils, refers to the disintegration and alteration of minerals at or near the Earth's surface, through a combination of physical, chemical and to a lesser extent biological and, sometimes, anthropogenic processes. Weathering is a pivotal process in the formation of soils, as this provides its inorganic components.

Polynov (1937) defined weathering "as the change of rocks to the clastic state". This addresses only the physical processes of weathering. Later, Reiche (1950) considered weathering "as the response of materials which were in equilibrium within the lithosphere to conditions at or near its contact within the atmosphere, hydrosphere and perhaps still more importantly the biosphere". However, in the recent past based on the geochemical transformation of constituent rock minerals at or near surface conditions, Nesbitt and Young (1989) applied the term weathering to interactions between waters derived directly from precipitation and rocks, and their weathering residues.

Broadly speaking, classically, two types of weathering are recognized, viz., physical and chemical weathering. Physical weathering (a.k.a. mechanical weathering) refers to rock disintegration without any chemical change to the constituent rock minerals, and results in residuum of unaltered rock material.

Chemical weathering is brought out by meteoric water with the dissolved gases and/or salts. Here, organic activity also plays a vital role. Out of the source rocks, chemical weathering produces unaltered minerals (e.g. quartz), insoluble residuum (e.g. clay minerals) and soluble ions through simple chemical reactions viz., oxidation, reduction, hydrolysis, hydration, carbonation and chelation (Reiche, 1950; Loughnan, 1969; Ollier, 1979). These processes operate simultaneously, and in unison, and hence the overall system becomes complex.

1.2. Weathering: A Review

Studies on weathering phenomena came as an off-shoot of soil studies (a.k.a. Pedology) particularly from Russia and Germany in the mid of 18th century onwards. Fallou, in 1862, introduced the term 'Pedologie' (in *German* for pedology) to define soil science. In continuation to his work, the concept of soil profile was perceived by pioneer pedologists in the 1870s. Following this, the term 'soil profile' ('bodenprofil' in *German*) was first put forwarded by Orth in 1873, as a vital basis for geological–agronomic mapping. However, the model of A-B-C profile was first published by Dokuchaev in 1879, which was an extension of the concepts evolved out of Fallou's and Orth's contribution.

Later, Shaler (1891) did pioneering work in USA to describe a soil profile scheme without A-B-C connotation in forest soils and in 1924, Smith published the A-B-C designation system in USA at a meeting of the American Soil Survey Association in 1923.

The phenomena of weathering vis-à-vis soil formation have been a topic of discussion among geologists, geochemists, pedologists, agricultural scientists and civil engineers due to multiple reasons. Firstly, many finer aspects of weathering, like the processes and products under specific conditions of weathering are not yet fully understood. Secondly, weathering profiles provide the best natural laboratory to study the geochemical behavior of elements under sub-aerial conditions. Thirdly, the whole picture of interdependence of factors controlling weathering under various environmental conditions is still elusive.

The literature amply vouches for the variety and complexity of these problems (Nahon, 1991). Any investigation on weathering should address the following aspects, a). Intricate geochemical processes involved in weathering, b). Behavior of various rock minerals during weathering and c). Influence of factors like topography, bed rock, slope, time and climate on the rate, processes and products of weathering.

Hence, research is currently aimed at understanding the precise working of weathering mechanism, the degree to which these processes can be theoretically modeled, the effects of a variety of climatic conditions on weathering rates, the influence of climate on processes or products of weathering, the degree to which natural weathering systems approach equilibrium, and the effects of non-equilibrium conditions on weathering kinetics (Colman and Dethier, 1986).

In this backdrop, various facets of weathering like, rate of weathering, processes and products of weathering, mineral specific and rock specific alterations, chemical changes in weathering profiles, weathering-sediment relationships and lateritization. In the following pages, significant markers of study of weathering are examined.

1.2.1. Rate of Weathering

An important pursuit in studies of rock-to-soil transition is the estimation of rate of weathering of minerals and/or rocks in a soil profile. The rate of weathering is controlled by factors like topography, nature of bed rock, time, climate and organic activity (Jenny, 1941). In addition to this, chemical composition of weathering fluids, type of chemical reactions on mineral surfaces, structural relations between parent mineral and its alteration products also control rate of weathering. It is faster at sites of excess free energy, boundaries, or micro-fractures and slower at locations where path ways of diffusion are blocked by alteration products (Berner, 1978).

When other soil forming factors remain the same, climate (essentially temperature and rainfall) should exert a strong influence on rate of weathering. An excellent contribution in this respect is that of Singer (1980) and Nesbitt and Young (1984), who drew attention to the role of climate on weathering profiles and concluded that the extent of weathering is primarily determined by amount of acids introduced into the profile by rainwater propelled solutions. Other contributions in tune with this are Carroll (1970); Hay and Johns (1972); Chadwick *et al.* (1994); White and Blum (1995); Nesbitt *et al.* (1996); Kelly *et al.* (1998); Brady *et al.* (1999); and Stewart *et al.* (2001). Yet, studies on basaltic (Chadwick *et al.*, 1999) and granitic (Bullen et al., 1997) parent rocks demonstrate longer time frames for weathering rates (i.e., 100 ka).

Chief determinants of weathering rate are the differences in lithology and precipitation. Jenny and Leonard (1934), Jenny (1941) and Bryan (1967) related the soil generated by weathering of rocks to rainfall. Brady *et al.* (1999) also underscored the roles of lichen, rainfall and temperature on silicate weathering and concluded that abiotic weathering rates increase with rainfall and dissolution of plagioclase and olivine becomes more sensitive to rainfall underneath lichen. Higher the rainfall, higher the rate of weathering, opined Ramirez (1990). Kump *et al.* (1990) included geographical features as an additional factor controlling chemical weathering.

Lerman (1990) estimated net rate of chemical denudation of continents by taking dissolved load of rivers as a measure of rate of weathering, while Meirding (1981, 1993) reported data on the impact of air pollution on rate of chemical weathering in surface environment. White *et al.* (1998) reported the long term vs. short term weathering fluxes in a tropical watershed, in Luquillo Mountains, Puerto Rico. Again, in 2001, White *et al.* documented the rate of feldspar weathering in a granitic regolith and concluded that kinetic rate constants for plagioclase are higher by a factor of 2-3 than K-feldspar, and corroborated by experimental results. Bellbel (1999) related bond strength of orthosilicates to their susceptibility to weathering. He suggested a weathering series for orthosilicates.

1.2.2. Mineral Specific Changes

The effect of chemical weathering is mineral specific, and is ultimately controlled by the composition and structure of mineral. Hence, in order to probe the nature of alterations, several investigations have been made on specific minerals. A notable contribution by Loughnan (1962) documents weathering of silicate minerals and its relationship with mobilities of essential cations and mineral structure. Leaching potential is considered as an important factor affecting the mobility of cations in the p^H range of 4-10. The parent mineral's structure controls accessibility of percolating waters to the bonding cations. Garrels and Christ (1965) portrayed a detailed picture of the thermodynamic and kinematic reasoning of certain selected weathering reactions. Again, Loughnan (1969) discussed the role played by crystal structure in the rate of decay of specific minerals.

SEM has been used by many workers to examine the fine scale changes in respect of altered mineral grains, like feldspars (Wilson, 1975; Eswaran and Bin, 1978), and augite. Lee and Parsons, (1995) combinedly used SEM and TEM to decipher the micro-textural controls on weathering of perthitic alkali feldspars.

A plethora of publications deals with the weathering of feldspar grains. For example, Berner and Holdren (1977, 1979) using SEM images demonstrated similarity of features of naturally altered feldspar grains well as grains treated in reactors. Weathering of feldspar grains under natural condition may be strongly influenced by formation of Al-rich precipitates, filling of reaction sites, or by loosely bound residues (Paces, 1973; Colman, 1982). Later, Nesbitt *et al.* (1997) examined the feldspar stability, weathering and petrogenesis of siliciclastic sands and muds. They proposed that the kinetic and thermodynamic properties of quartz and feldspar can provide a tool for prediction of mineralogical and chemical change involved in the production of siliciclastic sediments.

Others like Dong *et al.* (1998) used TEM to characterize the progressive alteration of biotite to kaolinite in a soil profile. The rate and mechanism of biotite weathering in a tropical watershed was reported by Murphy, *et al.*, (1998). Schulz and White (1999) studied the dissolution rates of quartz and inferred that the calculated weathering rates of quartz is different from that of alumino-silicates, and in fact fall below the previously reported rate constants.

1.2.3. Chemical Processes in Weathering

Several documentations of the chemical weathering is related to base exchange, chelation reactions etc. For example, processes like cation exchange between root systems and minerals to bring about chemical weathering of augite, hornblende and olivine is very well charted out by Keller and Frederickson (1952). Schnitzer and Skinner (1963) illustrated stability of organo-metallic compounds co-formed during podzolic weathering (i.e., in cool, humid environment) in the presence of decaying humus.

The influence of cation exchange, chelation and dissolution by organic acids in mineral alteration is best explained by Marshall (1964) and Kononova (1966), who independently proposed that the ability of organic matter to attach cations to organic molecules is related to the level of decomposition of organic matter and formation of humic acid.

Further, Davies (1971) discussed the influence of polyphenols produced during decomposition of organic matter in the weathering of augite, hornblende and olivine. The attack of bacteria and fungi and their products on rocks and minerals causing chemical breakdown was the focus of a study by Henderson and Duff (1962) and Duff *et al.* (1963).

A number of publications are available documenting the chemistry of weathering of quartz, ferromagnesians and feldspar. Doornkamp and Krinsley (1971) refer to the "differential swelling" of quartz grains from Uganda due to entry of moisture between "cleavage plate" and some form of reaction with the surface material. Mechanical and chemical processes may both operate in the weathering of quartz.

Although the equilibrium solubility of quartz under earth surface conditions is very low, there is considerable observational evidence that chemical attack may be significant if suitable geochemical conditions persist (Cleary and Conolly, 1971; Eswaran and Stoops, 1979). Theoretical and experimental work suggests that solubility of quartz is highest at pH of >9.0 (Krauskopf, 1956).

In humid climates, especially the humid tropics, chemical dissolution appear to be a major mechanism of size reduction in quartz and hence quartz silt is abundant in many tropical weathering profiles. Eswaran and Stoops (1979) stated that in north eastern Australia, in tropical humid conditions, virtually pure quartz of dune sand breaks to generate considerable amount of silt.

Compared to quartz, the ferromagnesian minerals are easily susceptible to weathering. In general, weathering products of these minerals are Mg-rich, trioctahedral-expandable-clays, often interstratified. Amphiboles are relatively more resistant to weathering compared to olivine and pyroxene. Stephen (1952b) and Kato (1965) reported that hornblende initially alters to chlorite and subsequently to interstratified chlorite-vermiculite in a soil developed on ultrabasic rocks.

Ferromagnesians (viz., olivine, amphibole, pyroxenes) possess composition and structure suited for chemical weathering to progress in almost all environments (Berner et. al., (1980) and Birkeland (1984) suggest that alteration manifests in hornblende and biotite as etching, disaggregation and total depletion of the grains in weathering profile. The degree of etching may be gauged qualitatively or quantitatively (Hay, 1959; Locke, 1979).

Cleary and Conolly (1971) and Huang and Keller (1970) proposed that organic acids have a major role in breakdown and dissolution of minerals in soil horizons and organic acids enhance, several fold, dissolution of silica, iron and alumina.

Weathering of feldspars ultimately results in clay minerals. Potash feldspars weather slower than plagioclase and illite is one alteration product (Busenberg and Clemency, 1976; Nesbit and Young, 1989). Weathering of potash feldspar in granite yields illite (Wahlstrom, 1948., Sand and Bates, 1953., Grant, 1963., Nestbitt *et al.* 1980).

In highly leached tropical soils feldspars may get altered to gibbsite either through an intermediate halloysite stage (Bates, 1962) or directly (Stephen, 1963). However, feldspar to gibbsite transition may occur in cooler-temperate-environment (Wilson, 1969) or even in alpine conditions (Reynolds, 1971). Yet, weathering of this mineral in a confined environment - as in a saprolite - results in the formation of "mica" (Kato, 1965) owing to the retention of K essential for "mica" in closed environments. But, alteration of feldspar in humid environs yield kaolinite and in semi-arid regions gives smectite.

Several hypotheses explain the hydrolysis/dissolution of feldspars, which are a). Armoring precipitate hypothesis (Correns, 1961 and Helgeson, 1971), b). surface reaction hypothesis Berner and Holdren (1977, 1979) and c). leached layer hypothesis (Garrels and Christ, 1965; Loughnan, 1969; Birkeland, 1974).

Todd (1968) suggested that a combination of low relief, high non-seasonal rainfall and subtropical temperatures would result in "orthoclase-more-weathered-than-plagioclase" scenario and kaolinite will be the product of weathering. On the contrary, higher relief (i.e., lower soil water levels), lower temperatures and seasonal rainfall lead to "plagioclase-more-weathered-than-orthoclase" situation, and the end product is K-hydro mica rather than kaolinite. Todd (1968) also linked the higher susceptibility of orthoclase to weathering in a warm, humid climate to the high Na^+/ H^+ ratio relative to K^+/H^+ ratio that exist in such an environment. Luxuriant vegetation in a warm, humid set up will favor organic complexing of K^+ released from orthoclase, thereby reducing the K^+ activity in soil waters. The resulting higher Na^+ activity will inhibit release of sodium from plagioclase decelerating its breakdown.

James *et al.* (1980) studied the degree of alteration of Holocene detrital potash and plagioclase feldspars from first order streams under contrasting wet and dry climates. Results indicated a broad overlap in the amount of alteration of these feldspars irrespective of climate. Plagioclase feldspars were found to be 20-30% more altered than K-feldspars. So they questioned the validity of using the amount of alteration of feldspar as an indicator of palaeoclimate. According to James *et al.* (1980) the palaeoclimatic significance of "orthoclase-more-weathered-than-andesine" scenario as observed by Todd (1968) needs re-evaluation.

The study of James *et al* (1980) suggested that composition of the alteration product is sensitive to climate. However, the amount of alteration product of feldspar from different environments show considerable overlap and hence is of little use in palaeoclimatic studies as under humid as well as semi-arid climate, plagioclase weathers faster than orthoclase- feature noticed in modern soils also.

Garrels and Christ (1965), Loughnan, (1969), Wilson (1970) and Birkeland (1974) reported that in semi-arid or arid climate higher rate of evaporation and rapid run-off favor concentration of alkali ions in the soil enabling formation of phyllosilicates like illite or smectite.

Again, studies related to the weathering of mica are quite interesting. Depending on the composition and structure of parent mineral and various environmental factors, weathering of micas results in a variety of secondary minerals. Muscovite resists alteration in the initial stages of weathering but gets altered at advanced stages of weathering. Accordingly, micas may get altered to vermiculite, smectite, vermiculite-chlorite and kaolinite (Wilson, 1970). Vermiculite is the common weathering product of biotite and chlorite Wahlstrom, (1948) and Clauer *et al.* (1982) reported that kaolinite and smectite are the weathering products of biotite and chlorite respectively.

Nesbitt and Young (1984) used mineralogical and chemical data together with thermodynamic and kinetic concepts to predict the trend of weathering in weathering profiles. The models were tested on recent weathering profiles developed over a variety of plutonic and volcanic rocks under different climatic regimes. The predicted bulk compositional trends observed in recent profiles were used by them as a "norm" to which ancient weathering profiles were compared to isolate imprints of diagenesis.

1.2.4. Rock weathering

Rock weathering is another essential chemical process leading to the formation of soil. Mineral transformations associated with rock weathering are relatively well documented. Colman and Pierce (1981) studied the development of weathering rinds in basalt and andesite clasts in United States to assess the rate of formation which stood as high as 20.0 μm/kyr (av.= 5.0 μm/kyr; during past 500,000 yr).

Noack et al. (1990) studied the chemical weathering of basalts in North Parana basin (Brazil) to discover that Mg, Ca, and K are released at higher rates due to weathering and trace elements also followed suit.

In humid climate, the intense chemical weathering practically transforms almost all primary rock forming silicates, which are replaced by hydrated oxides of Fe and Al together with halloysite and kaolinite in deep soil profiles (Curtis, 1990).

The degree and direction of weathering can be quantified by assessing pedogenic strain (i.e. volume change) and mass transfer (Brimhall and Dietrich, 1987; Brimhall *et al*, 1988; Chadwick *et al*, 1990; Bestland, 2002). Both of which are estimated from geochemical data of parent material and weathered product.

The contributions of Sharma and Rajamani (2000a) in a study of the weathering of gneisses in the upper reaches of Cauvery River in South India, reported its implications to neotectonics of the region. Schroeder *et al.* (2000) studied the weathering of meta-gabbro in Georgia Piedmont in USA and stressed the implications of global weathering of silicates and their rate of weathering.

1.2.5. Chemical Element Mobility

Rainbird *et al.* (1990); Braun *et al.* (1993); Mathieu *et al.* (1995); Kurtz et al. (2000) examined the mobility /immobility of elements during weathering and inferred that no element /mineral phase is absolutely immobile in a weathering milieu; the exceptions being Ti, Zr, Cr, V, Y, and Nb - far less mobile than others. Ti is an immobile element because of its relative uniform behaviour in a range of weathering environments (Ashely and Driese, 2000; Driese et al. 2000; Hill et al. 2000). Al, another immobile element, is also frequently used in weathering calculations (Nesbitt and young, 1982).

Young and Nesbitt (1998) reported the distribution of Ti and Al in weathering profiles and its controlling processes and concluded that the trends in TiO_2 vs. Al_2O_3

plots useful to decipher more knowledge on the weathering and depositional history, in addition to their use as provenance indicators.

Sharma and Rajamani (2000b) based on their study of soil and sediment of amphibolite of parentage, Cauvery catchment, reported on the trends of major element, REE and trace elements during weathering under semi-arid conditions. Sajinkumar et al. (2011) studied the relation of landslides to weathering process in Ernakulam and Idukki districts, Kerala.

In a subsequent, Viers *et al.* (2000) report the constraints on chemical weathering processes and element transport mechanisms in humid tropical environment based on abundances of major and trace elements and strontium isotopes. Further, they inferred that in small unit-watersheds chemical weathering mainly concentrates in swamp zones and mineral dissolution is increased by humic substances.

Later, Bestland (2002) proposed a parameter called PS (pedogenic strain) as a measure of the relative depletion or enrichment of immobile element with respect to the parent material and when PS is positive (= dilation) or negative (= collapse).

Sheldon, *et al.* (2002) quantified the relationship between mean annual precipitation and mean annual temperature using major element chemical analysis of 126 soil samples from North America. The relative abundances of rare earth elements in sediments can be used as a tool for determining their lithological parentage (Morey and Setterholm, 1997).

1.2.6. Biological Weathering

It is an area that attracted relatively lower attention of researchers. However, Drever (1994) characterized the effect of land plants on weathering rates of silicate minerals, in that the land plants and the associated microbiota directly involve in mineral weathering by way of generating chelating ligands, modifying pH by the production of CO_2 or organic acids and by altering the physical properties of a soil.

Electron Microprobe and petrographic microscope were used by Cochran and Berner (1996) to study the biota-rock interface beneath higher plant communities and lichens on basalt flows of Hawaii and inferred that chemical weathering of older flows with higher plants are at minimum.

1.2.7. Climate and Soil

Strakhov (1967) made a novel study on the relationship between relative depth of weathering, products of weathering and climate along transect from the equator to the North Pole, which (i.e., variation in pedogenic processes and soil properties with change in climate later) was designated as pedogenic gradient by Tedrow (1977). McFadden and Tinsley (1985) and McFadden (1988) applied the concept of pedogenic gradient along a climatic gradient from aridic to xeric.

Data on climate-soil relations had been collected extensively by Jenny and Leonard (1934). The relationship between climate and soil classification units is very complex (Birkeland and Gerson, 1991).

Karlstrom (1991) attempted palaeoclimatic reconstruction based on variation in soil morphology. Jenny (1941, 1961 and 1980) checked the climatic transects to determine trends of organic matter in soil. Jenny (1950 and 1961) also gave the organic matter – climate trends and related the same to yearly gains or losses in the organic content. Jenny (1935) demonstrated a linear relation between soil-clay-content and moisture inferring an exponential relation between soil clay content and temperature.

Folkoff and Meentemeyer (1987) examined the relation between A–horizon clay mineralogy and climate. The difference in pathways of weathering between humid and semi-arid terrains across the Western Ghats has been established by the variance in clay mineralogy (Deepthy and Balakrishnan, 2005).

Schwertmann et al. (1982), Kampf and Schwertmann (1983), and Schwertmann (1993) focused on soil redness and pedogenic iron minerals vis-à-vis climatic factors. Soils in relatively humid climate are enriched in Fe and Al but depleted in phosphorous - an aspect related to precipitation (Birkeland, 1999). Change in soil properties vs. altitude is charted to depict the combined effect of climate and vegetation on soils (Amundson *et al.* 1989).

The morphologic and various other soil properties can be used to reconstruct palaeoclimate (Pawluk, 1978; McFadden and Weldon, 1987; Bussacca, 1989 and McFadden, 1988). Foscolas *et al.* (1977) related depth of pedogenic clay mineral alteration to palaeoclimate. Mineral etching, another surface feature, has been used to decipher past climate (Locke, 1979). Palaeoclimatological interpretations using stable isotopes of carbon and oxygen present in soil and clay have become an area of active research since 1980's (Cerling, 1984; Cerling and Hay, 1986; Goodfriend and Magaritz, 1988; Quade *et al.*, 1989, 1995; Cerling and Quade, 1992)

1.2.8. Lateritization Process

Credit for the name Laterite goes to Buchanan (1807), who coined the term to describe a 'red rock with a capability to harden on exposure' that he saw at Angadippuram in Malappuram district, - type area of Laterite. In a later monograph, McFarlane (1976) defines laterite as "highly weathered material (1) rich in secondary forms of iron, aluminium or both; (2) poor in humus; (3) depleted of bases and combined silica; (4) with or without non-diagnostic substances such as quartz, limited amounts of weatherable primary minerals or silicate clays; and (5) either hard or subject to hardening upon exposure to alternate wetting and drying."

But, Schellmann (1978) defined laterite as 'products of intense subaerial rock weathering whose Fe and /or Al content are higher and Si content lower than in merely kaoilinised parent rocks and consisting of kaolinite, goethite, hematite, gibbsite and quartz'. This definition has no genetic implications.

Lateritization involves sub-aerial, residual, physicochemical weathering of rocks under tropical to subtropical climate under the influence of a variety of factors viz., climate, topography, groundwater quality and movement, type and amount of vegetation and nature of bedrock (Subramanian, 1978). Chemically, lateritization of rock leaches off alkalis, alkaline earths and silica with simultaneous and complimentary enrichment of Al, Fe and certain trace elements. Alternate wet and dry seasons as well as low relief are an ideal climato-geomorphic environment conducive to the formation of laterite.

The rather lengthy bibliography, spanning over two centuries of research relating to origin, distribution, morphology, mineralogy and geochemistry and petrography of laterite, is the best testimony to the continuing interest of geomorphologists, geochemists and pedologists. This theme has therefore become controversial to a great extent as vouched by contributions of McFarlane (1976) and Widdowson and Gunnel (2001). So far, three international conferences on lateritization have been held, (i) Thiruvananthapuram, India; 1979; (ii) Sao Paulo, Brazil; 1982 and (iii) Tokyo, Japan; 1985.

Laterite occurs extensively in Kerala especially most visibly in the midland as longitudinal tract straddling between the high land and coastal land. Morphologic expression in the field is very visible. It always forms a cap on the hills and ridges. For e.g., the Calicut airport is built on a table-top like laterite capped hill. Laterite forms low, flat or nearly flat-topped table lands, (table-tops) or rectilinear flat topped ridges, and isolated flat topped hills covering the crystalline basement. It is the ferricrete that enables the flat-tops. A younger laterite of Warkalli age caps the coastal Tertiary sediments exposed in the hilly coastal land (e.g., Karichal, south of Vizhinjam, Varkala, and Kannur).

Previous studies on laterite are many and chiefly the credited to Sinha Roy (1979), Karunakaran and Sinha Roy (1980), Nair and Mathai (1980), Nambiar et al (1981), Sambandham and Prasad (1980), Ghosh (1983), Soman (1982), Narayanaswamy and Ghosh (1987), Banerji (1990) and Narayanaswamy (1992).

Nair and Mathai (1980) studied the textural, mineralogical and geochemical trends in laterite profiles developed on rocks of different compositions from north Kerala. The variation and correlation between major elements are linked to the abundance of different trace elements.

Nambiar *et al.* (1981) in a case study of lateritization of charnockite, gabbro, granophyre and anorthosite from Kerala reported that laterite developed on the first three rock types were relatively more siliceous whereas that from anorthosite was more aluminous.

In a study of laterite profile development in relation to geomorphic surfaces in South Kerala, Karunakaran and Sinha Roy (1980) proposed the existence of two laterite profiles viz., detrital and residual. The residual components are compatible with leaching and concentration of constituents at different levels of the profile. A brief review of important works in this field are given in Appendix-I.

1.3. Objectives of this Research

This study is formatted to cover the aspects of weathering profile development under two contrasting climates from similar parent source viz., in the Neyyar basin of tropical humid (Kerala) and Tambraparni semi-arid (southern Tamil Nadu). Specifically the following aspects are addressed.

1. Development of weathering profiles and soil horizons in under different physiographic and lithologic domains under contrasting climates
2. Gain a better knowledge of mineral transformations due to chemical weathering
3. Comparison of mineral phases either created or destroyed due to chemical weathering.
4. To sketch the geochemical portrait of profiles from bed rock to soil.

1.4. Plan of Treatment

This thesis is presented in seven chapters. Ch.1 gives introduction, review of literature, objectives of the study, description of study area, summary of materials and methods used as well as a survey of previous work. Ch.2 covers specifics of climate, physiography and geological setting of the study areas. Ch.3 examines the role of physiography (altitude, slope and relative relief), lithology and climate on development of weathering profiles. Ch.4 addresses textural features of soil /weathered material in different horizons of weathering profiles. Ch.5 deals with mineralogy (petrography of parent rocks) in the horizons of select weathering profiles. Ch.6 covers results of analysis of chemical composition. Then, finally the Ch.7 summarizes the significant findings of the study.

1.5. Study Area

The Neyyar basin (NB, Thiruvananthapuram Dist., Kerala) and Tambraparni River basin (TB, Tirunelveli and Thoothukudi Dist., southern Tamil Nadu) are selected for this study. Neyyar basin (NB) to the west and Tambraparni basin (TB) are set back to back on either side of the southern Western Ghats. The contrasting climates, viz., tropical humid in NB and semi-arid in TB, qualified these basins for this study. What follows is a brief description of the vital aspects of these basins.

1.5.1. Neyyar Basin (NB)

Neyyar basin (Length = 73 km.; Area = 492 km^2) is the southernmost river basin in Kerala (Fig. 1.1). It is confined between N. Lat. 8°15' to 8°40' and E. Long. 77°00' to 77°20' (covered by SOI toposheet no. 58H/2, H/3 & H/6). Neyyar river originates from Agasthyamalai (elev. = 1866 m.) in Western Ghats and flows westerly through the three physiographic domains (high-, mid- and low lands), to debouch into the Lakshadweep sea at Poovar (E. Long. 77°3'55"; N. Lat. 8°19'6").

Neyyar and its tributaries drain through Thiruvananthapuram district. There are 8 tributaries on the right bank and 11 on the left bank. Among these, the major ones are *Chittar* and *Aruviode thodu*, both on the left bank.

A straight gravity masonry dam at Kallikkad (i.e., Neyyar Dam; E. Long. 77°8'43"; N. Lat. 8°31'43") for purposes of irrigation was commissioned in 1959. A comparative study of SOI toposheets of 1914 and 1969 reveal that the previously 7th order mainstream, now reverted to 6th order obviously due to the subsequent human intervention in the river system (Thrivikramaji, 1986).

1.5.2. Tambraparni Basin (TB)

Tambraparni basin (Length = 126 km.; Area = 5969 km^2 and N. Lat.8°06' to 9°12' and E. Long. 77°09' to 78°08' E), is covered in the SOI toposheets 58G/4, 8, 12, 16; 58H/1, 2, 5, 6, 7, 9, 10, 11, 13, 14 and 58 L/2 & 3 (Fig. 1.2). The mainstream is a 7th order stream which originating in the Papanasam reserved forest, on the eastern side of the WG, where the highest peak along the drainage divide is Agasthyamalai (E. Long. 77°14'48"; N. Lat. 8°36'50" elev.= 1866 m.). The river flows through districts of Tirunelveli and Thoothukudi and joins the Gulf of Mannar at Punnaikkayal (E. Long. 77°07'06"; N. Lat. 8°37'58").

Major tributaries of the river are Manimuttar, Chittar and Pachaiyar. Manimuttar originates within the ranges of the Kalakkad reserved forest (elev. = 1553 m). A dam across and at Manimuttar (E. Long: 77°24'52"; N. Lat: 8°39'07") is meant for irrigation. Chittar originates in the Kuttalam hills - famous for Kuttalam water falls. Uppodai is a tributary of Chittar. Pachaiyar originates in the Kalakkad forest. Minor tributaries include Gatananadi, Pambar and Serval Ar. The mainstream is dammed near Karaiar (forming

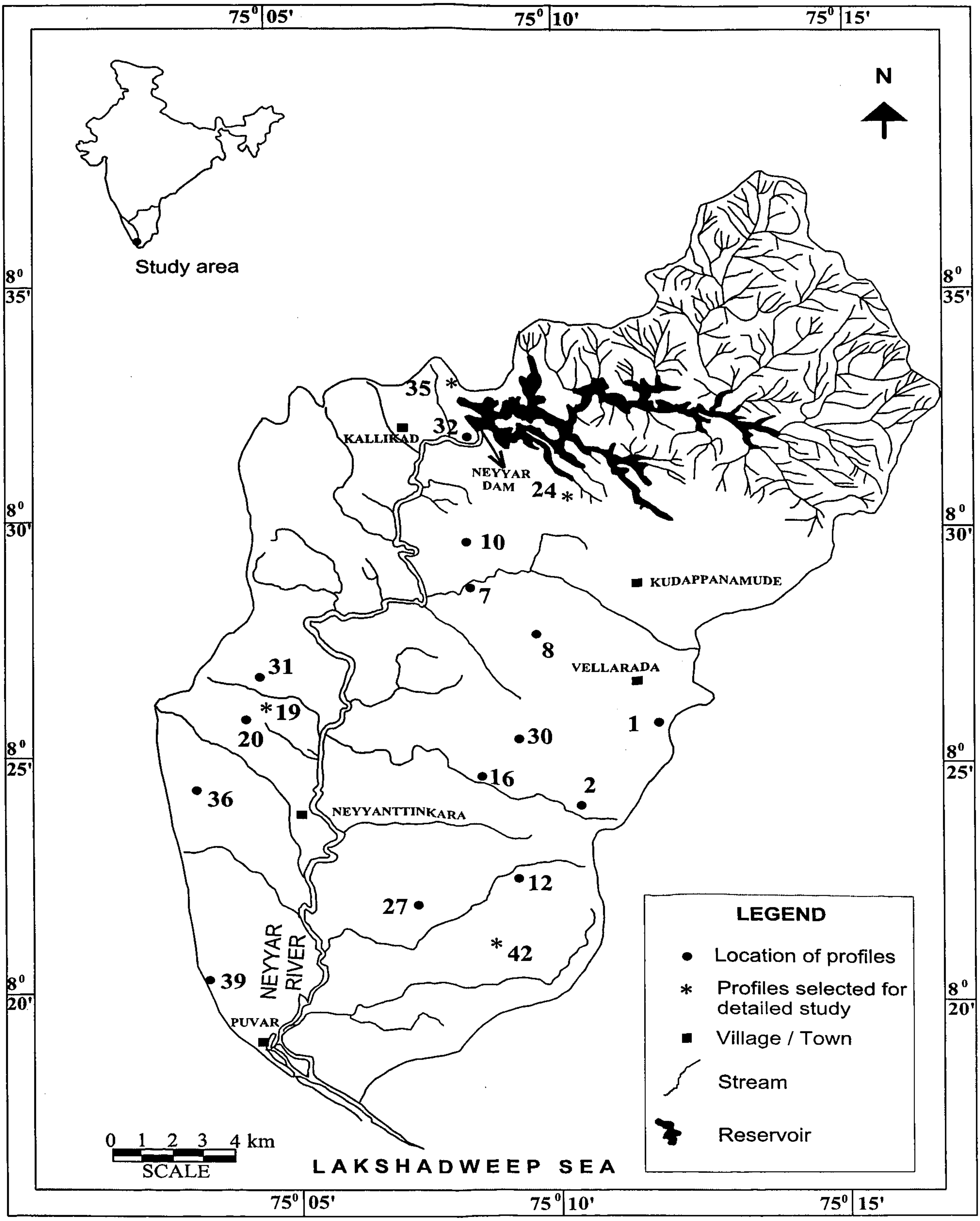

Fig.1.1: Neyyar river basin showing location of selected weathering profiles

Table 1.1: Location of soil profiles selected for study in Neyyar Basin (NB)

Sl. No.	Profile	Location	Toposheet No.	Latitude[#]	Longitude[#]
1.	NB 1	Panachamudu	58 H/3	8°25'35"	77°11'34"
2.	NB 2	Aruviode	58 H/3	8°23'59"	77°10'11"
3.	NB 7	Chempur	58 H/3	8°28'36"	77°08'36"
4.	NB 8	Muttilammudu	58 H/3	8°27'28"	77°09'40"
5.	NB 10	Chettikkunnu	58 H/3	8°29'39"	77°08'31"
6.	NB 12	Peruvila	58 H/3	8°22'28"	77°09'04"
7.	NB 16	Tattiyur	58 H/3	8°24'37"	77°08'31"
8.	***NB 19**	**Perumbazhuttur**	58 H/3	8°26'03"	77°04'45"
9.	NB 20	Perumbazhuttur	58 H/3	8°25'57"	77°04'17"
10.	***NB 24**	**Pantha**	58 H/2	8°30'37"	77°10'16"
11.	NB 27	Mariyapuram	58 H/3	8°21'55"	77°07'10"
12.	NB 30	Kottakkal	58 H/3	8°25'22"	77°09'17"
13.	NB 31	Valiyavila	58 H/3	8°26'12"	77°04'41"
14.	NB 32	Neyyar Dam	58 H/2	8°31'51"	77°08'36"
15.	***NB 35**	**Mlavetti**	58 H/2	8°32'58"	77°08'38"
16.	NB 36	Choliakonam	58 H/3	8°24'31"	77°03'18"
17.	NB 39	Karumkulam	58 H/3	8°20'26"	77°03'20"
18.	***NB 42**	**Idichakkaplamudu**	58 H/3	8°21'07"	77°03'34"

* Profiles selected for textural, petrographic, mineralogic and chemical studies in addition to study of profile characteristics.

[#]-Latitude represents N. Lat. and Longitude denotes E. Long.

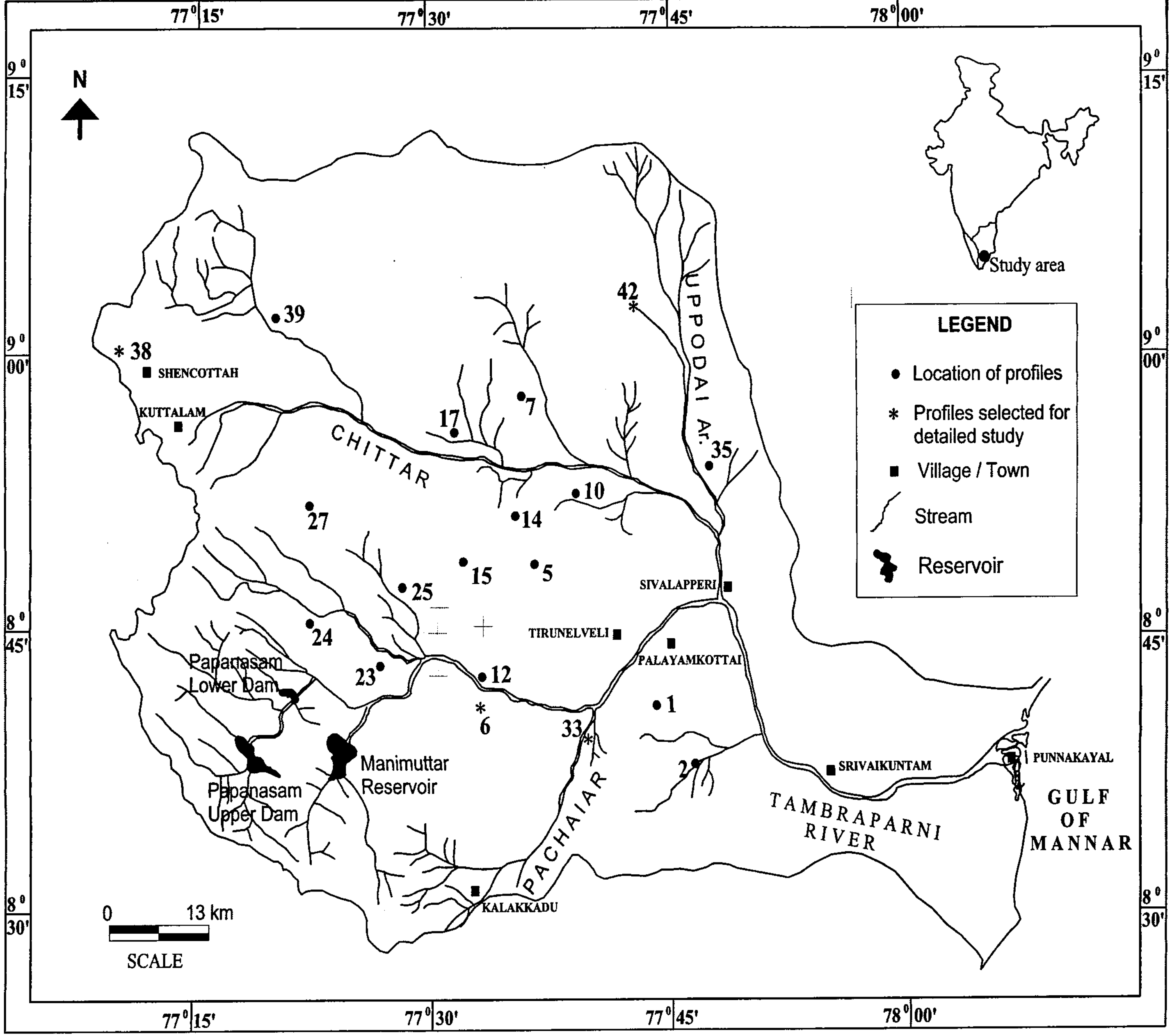

Fig. 1.2: Tambraparni river basin showing location of selected weathering profiles

Table 1.2: Location of soil profiles selected for study in Tambraparni Basin (TB)

Sl. No.	Profile	Location	Toposheet No.	Latitude	Longitude
1.	TB 1	NGO Colony	58 H/10	8°41' 02"	77°44'30"
2.	TB 2	Sivandipatti	58 H/14	8°38'09"	77°46'22"
3.	TB 5	Ugandanpatti	58 H/9	8°48"43"	77°36'45"
4.	***TB6**	**Cheranmahadevi**	58 H/10	8°41' 26"	77°33'36"
5.	TB 7	Devarkulam	58 H/9	8°58'17"	77°35'43"
6.	TB 10	Kallampuli	58 H/9	8°52'16"	77°39'25"
7.	TB 12	Vadakku- Ariyanayakipuram	58 H/10	8°42'40"	77°33'41"
8.	TB 14	Marandai	58 H/9	8°51'10"	77°35'27"
9.	TB 15	Marudamputtur	58 H/9	8°49'13"	77°32'11"
10.	TB 17	Nachiapuram	58 H/9	8°55'57"	77°31'36"
11.	TB 23	Pallakudi	58 H/6	8°43'13"	77°27'23"
12.	TB 24	Mel Ambur	58 H/5	8°45'32"	77°22'17"
13.	TB 25	Anjanadanarpatti	58 H/5	8°47'31"	77°28'21"
14.	TB 27	Pulavanur	58 H/5	8°51'45"	77°22'22"
15.	***TB 33**	**Kil Omanallur**	58 H/10	8°39'27"	77°40'20"
16.	TB 35	Rajapudukkudi	58 H/13	8°54'16"	77°47'38"
17.	***TB 38**	**Shencottah**	58 G/4	9°00'00"	77°10'11"
18.	TB 39	Idaikkal	58 G/8	9°01'53"	77°20'35"
19.	***TB 42**	**Vadakku- Konarkottai**	58 G/12	9°02'41"	77°43'15"

* Profiles selected for textural, mineralogic, petrographic, and chemical studies in addition to study of profile characteristics

[#]-Latitude represents N. Lat. and Longitude denotes E. Long.

Hope Lake; E. Long. 77°18'38"; N. Lat. 8°39'00") and at Papanasam (E. Long: 77°21'29"; N. Lat: 8°41'42") to store water for irrigation.

Isolated hillocks (monadnocks), for example Vallanadmalai (elev. = 314 m; E. Long. 77°53'56"; N. Lat. 8°42'45"), Kottaimalai (elev. = 205 m; E. Long. 77°33'14"; N. Lat. 8°52'17"), and Kolundumalai (elev. = 695 m; E. Long. 77°33'30"; N. Lat. 8°33'30") stand out in an otherwise peneplained basin. The region adjoining the mouth of the Tambraparni exhibits deltaic/tidal flat morphology where a number of salt pans operate.

1.6. Previous Work

No serious studies have so far been made to document the weathering profiles in the different physiographic provinces of NB in Kerala and TB in Tamil Nadu, and also to relate the characteristics of these profiles to climate.

i. Neyyar River Basin

The previous studies on Neyyar river basin are mostly confined to the water quality, geomorphology, land use etc. For example, Nair and Prabhoo (1977) examined the hydrography of Neyyar reservoir. A quantitative geomorphological study of this basin was conducted by Samsuddin in 1980. Subsequently, Thriviramajii (1986) conducted a thorough examination of the topography of the basin which covers the aspects like land use, geomorphology, surficial geology and slope studies.

A terrain evaluation of Neyyar wild life sanctuary using Remote Sensing and GIS was conducted by Suresh Babu *et al.* (2000). Temporal change in the drainage network over a period of four decades as well as the extent of loss in the perennial status of tributaries have been recorded in this study to evaluate the landform changes. A catchment treatment plan has also been suggested. Again, a study on siltation analysis in the Neyyar reservoir and forest degradation in its catchment was conducted by Suresh Babu *et al.* (2000). Recently, Sheeja (2010) studied the drainage basin characteristics and hydrochemical portrayal of Neyyar basin using remote sensing and GIS method.

ii. Tambraparni Basin

In the case of Tambraparni basin, Southern Tamil Nadu, Foote (1883) has given details of lithology of Madurai and Tirunelveli districts in which sands of Tamraparni river is described. He attributes the occurrence of calcareous tufa to the induration of Tambraparni river sediments, particularly in the Tirunelveli segment. Foote also provides a picture of distribution of Teris, coastal dunes and doubly plunging synclinal charnockite occurrences in a map. An account of the physiography of Tirunelveli District can be seen in Iyer (1940). In the meantime, Dowie (1940) grouped biotite gneisses, crystalline limestone and quartz-granular gneisses to Vedic Era, and gritty sandstone and laterite of Tertiary, marine calcareous grits, alluvial and aeolian sediments are of younger age.

Narayanaswamy and Purnalakshmi (1967) provide a description of the geological setting, structure, petrography, metamorphic grade and origin of charnockitic rocks in Tirunelveli district. But, recently, based on several lines of evidence, gathered from southwestern part of the basin (and including radiochronology), Manimaran (1995) placed the Charnockite group above the Khondalite group.

Later, Joseph *et al.*, (1998, 1999, 2002) studied the textural, mineralogical, geochemical aspects of red dune sands (a.k.a. Teris) covering the Tirunelveli district of southern Tamil Nadu. They also highlighted the origin and paleoclimatic implications these red sands. Radhakrishnan (2002) studied the channel morphology and texture and mineralogy of bed sediments of Tambraparni river system.

1.7. Relevance of the study

Among the factors controlling the development of soil profile in a weathering domain, climate and parent rock come first, and ultimately determine the nature of soil profile, i.e., texture, mineralogy and chemistry.

Hence, for a proper understanding of the development of soil profile vis-à-vis weathering, is essential for long term soil budgeting- a domain of soil scientist. Bulk of sediment in a tropical humid environment is derived from soil solum (i.e., A + B horizon) and tectonically “stable terrains” such as southern India, and from parts which is under a tropical climate and generally tending to develop deep weathering profiles.

Although, the mineralogical and geochemical aspects of weathering profile have been amply documented, studies related to the development of weathering profiles, particularly in terms of thickness of soil profiles / horizons, are lacking. In addition, gross textural features of weathered material (in terms of gravel, sand and mud) and its relation to climate have not been well documented so far.

1.8. Materials and Methods

1.8.1. Delineation of Horizons /Profiles

Both NB and TB have representation of three physiographic divisions viz., lowland, LL (<7.5m), midland, ML (7.5-75m) and highland, HL (>75m). Newly dug wells, road cuts and abandoned quarries offered sites to study soil profiles in NB and TB. A reconnaissance survey was conducted to locate typical profiles, natural and otherwise, in well walls, quarries and road cuts. Among these, sections exposed in newer well walls in the midland (ML) and highland (HL) were ideal for sampling of both basins as these provided fresh samples. In the low land of NB and TB crystalline parent rocks are not exposed and hence no soil profiles qualifying for the study in this context.

The field program included inspection of weathering profiles in 45 locations in NB and 36 in TB (Appendix- II and III), identification of horizons/sub-horizons (Soil Survey Staff (1975), and description and sampling of 18 sites in NB and 19 TB (Table 1.1 & 1.2).

Selection for sampling was based on a fulfillment of a set of criteria, like physiographic domain, spatial setting, nature of bed rock and state of profile. Thickness of the horizons was measured in the field. Elevation and nature of slope at sampling locations estimated from SOI toposheet (Wentworth, 1930). The detailed characteristics of the select profiles are documented and detailed in Chapter 3.

1.8.2. Sampling Scheme

Soil samples (~2.0kg each) were collected from various horizons exposed vertically down the weathering profiles. From these, soil samples of four select profiles from each basin, were chosen for detailed textural, mineralogical, and geochemical studies. The sampling rationale was to select complete profiles (i.e., typical horizons/sub-horizons) developed over different bedrocks.

The profiles are NB19, NB24, NB35 and NB42 in NB, and TB6, TB33, TB38 and TB42 in TB (Table 1.1 & 1.2 and Fig. 1.1 & 1.2). The total number of samples covering the horizons selected from 4 profiles in NB are A (2), B (7), C (3), and bed rock, R (4). Correspondingly number of samples from TB are A (4), B (3), C (5) and R (4).

1.8.3. Analysis Scheme

The above select samples covering the profiles of NB and TB (4 each) were subjected to detailed textural, mineralogical, petrographical and geochemical studies by following the standard methods and are briefed in the respective chapters (Section 4.2, 5.2, and 6.2 respectively) and detailed in Appendix-IV.

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