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Modelling Highly Weathered Ferruginous Soils of Tropical India

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Introduction

President of the Indian Society of Soil Survey and Land Use Planning, distinghished members of the Society, Ladies and Gentlemen. I feel honoured by the invitation of the Society to deliver the 2nd Dr. S.V. Govindarajan Memorial Lecture during the Annual Convention of the Indian Society of Soil Survey and Land Use Planning (ISSALUP). I profusely thank the Council of the ISSALUP for this invitation. Through this lecture I get the opportunity to pay my humble tribute to Late Dr. S.V. Govindarajan whom I admired most as an able research manager. Dr. Govindarajan led the Soil Researchers of the country in a magnificient way. With this homage paid to him I start presenting the lecture on modelling highly weathered ferruginous soils of tropical India, the soil type area that was close to Dr. Govindarajan.

Soils are very complex dynamic systems which can be discussed in terms of fundamental laws of the basic sciences. Thus in order to study such a complex systems, simpler framework is to be devised to guide investigations and also assimilate information. Denbigh (1951) stated that the idea of equilibrium is one of the most simplifying concepts that is employed in chemistry and this way systems can be made more amenable to analysis. However, unfortunately such equilibrium is not applicable to open systems such as soils. Present pedogenetic models attempt to organize, simplify and enumerate the factors that affect soil systems or processes in soil systems. All models should ultimately destroy themselves in whole or in part as models simply present a series of approximation towards the truth. However, a good model will instill in the scientist a probing attitude toward the system of concern in order to improve, redefine and expand the model to gain a complete understanding of the system (Smeck *et al.* 1983).

Modelling soilsystems

Dijkerman (1974) listed four types of conceptual models, (1) mental, (2) verbal, (3) structural and (4) mathematical. Whereas most of our working models have been of a verbal nature, more emphasis is now being shown in mathematical models due to availability of computers (Smeck *et al.* 1983)

The presentation through this lecture has examined the pros and cons of the most popular models employed in pedogenetic studies for tropical soils. It is hoped that applicability of models on the formation of tropical soils of the country will help us in a better understanding of factors and processes operative in tropical soil systems. Among the models known to us are (1) state-factor analysis (Jenny 1941), (2) energy model-factorial model (Runge 1973), (3) residua and haplosoil models (Chesworth 1973a,b 1980), (4) generalized process model (Simonson 1959) and (5) soil-landscape model (uggett 1975). Out of these models the most challenging ones are residua and haplosoil models of Chesworth (1973a, b 1980) and have enormous relevance in highly weathered ferruginous soils of humid tropical climate. These two models are the further simplification of the five factors of soil formation (Jenny 1941). Chesworth (1973a,b) viewed soils as a system spontaneously moving toward a state of equilibrium. Chesworth contends that the soil forming factors are not undependent variables and thus can not be expressed in differential forms. In addressing the influence of parent materials in soil genesis he states that

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time has the result of modifying and ultimately of nullifying the effect of parent material.Thus he envisaged that only in young and relatively immature soils parent material will exert is strongest influence on the soil forming process and such on the soil forming process and such an influence will be an inverse functions of time. To illustrate this he indicates that soils derived fromas dissimilar parent materials as granite and basalt will become indistinguishable given sufficient time to attain equilibrium. Thus it is speculated that time is the only independent variable of soil formation or any other process occurring spontaneouslyin nature.

Chesworth (1973b) suggested that 4-component system consisting of SiO_2-Al_2O_3-H_2O constitutes a chemical sink or residua system toward which mineral composition trends during weathering. He supports his theory by suggesting that as soils approach the residua system which most closely correlated with soils of the Oxisol order, the degree of horizon differentiation increases. However, most pedologists would not agree to his as horizonation is not at all well expressed in Oxisol like in less weathered soils. Although Chesworth (1973b) indicated that the intensity factors such as temperature, water status and landform simply control the rate at which soil composition moves toward the residua system, however, he realized the limitation of the residua system. It does not provide means to evaluate soil systems and mineral stabilities at points during the evolutionary pathway. Instead it emphasizes at the ultimate end point and thus it lacks general usefulness. Consequently Chesworth (1980) proposed a haplosoil system that contains a 6-component system (SiO_2-Al_2O_3-Fe_2O_3-MgO-K_2O-H_2O) by including the activities of mobile components like Mgo and K_2O to the residua system. By doing this Chesworth (1980) further suggested that the humid tropics due to a combination of high temperature, adequate moisture and long term stability of many landforms, provide the best opportunity for attaining equilibrium. This way it would contain minerals of common assemblages found in the humid tropics and will be consistent with the haplsoil system. Yaalon (1975) was however of the opinion that a terminal state consisting of SiO_2-Al_2O-Fe_2O_3 Would tend to mask desilication of soil system during weathering. Furthermore, since the models only insists on the terminal state toward which soil system are moved by weathering, they contribute little to our knowledge of the actual weathering processes operative in soil systems. Despite this general understanding, Chesworth (1980) opines that the real value of the residua and haplosoil systems is that they indicate the states natural soil systems will attain if given sufficient time.

Formation of highly weathered ferruginous soils and validation of residua and haplosoil models

Formation of highly weathered ferruginous soils in humid tropical climate of India provides us an opportunity to validate the existence of both residua and haplosoil systems. To do this three areas of India are chosen,

(1) Western Ghats, Maharashtra,

(2) Meghalaya Plateau, and

(3) Kerala

The ferruginous soils (FS) of the Western Ghats (Bhattacharyya *et al.* 1993; 1999) are developed on zeolitic Deccan basalt during tropical humid climate since the Tertiary period. They are acidic Alfisols and their clays are dominated by kaolin (Kaolin-hydroxy interlayered smectite, Kl-HIS) with a moderate amount of HIS and mica and are non-gibbsitic (Bhattacharyya *et al.* 1993).

The FS of the Meghalaya Plateau (Bhattacharyya *et al.* 2000) are developed on granite-gneiss during tropical humid climate since the Tertiary period. They are acidic Ultisols and their clays are dominated by kaolin (kaolin-hydroxy-interlayered vermiculite, HIV), with moderate amount of HIV, gibbsite and mica (Fig. 2). Their sand fractions contain gibbsite (Fig. 2a,b).

The FS of Kerala (Chandran *et al.* 2005) are developed on granite-gneiss during the tropical humid climate since the Tertiary period. They are acidic Ultisols and their clays are dominated by Kl-HIV with moderate amount of HIV, gibbsite and mica (Fig. 1). Their sand fractions contain gibbsite (Fig. 2a,b).

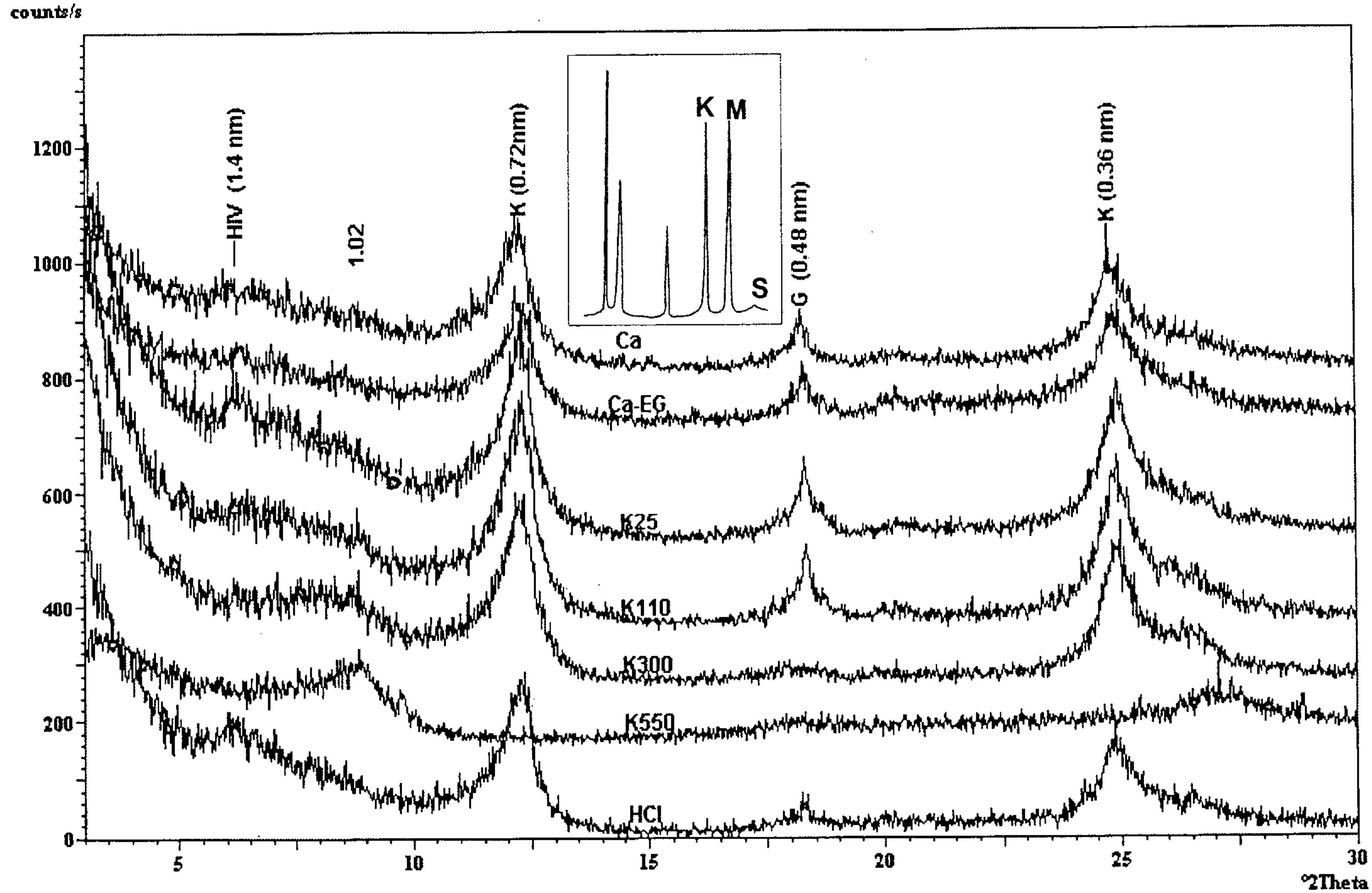
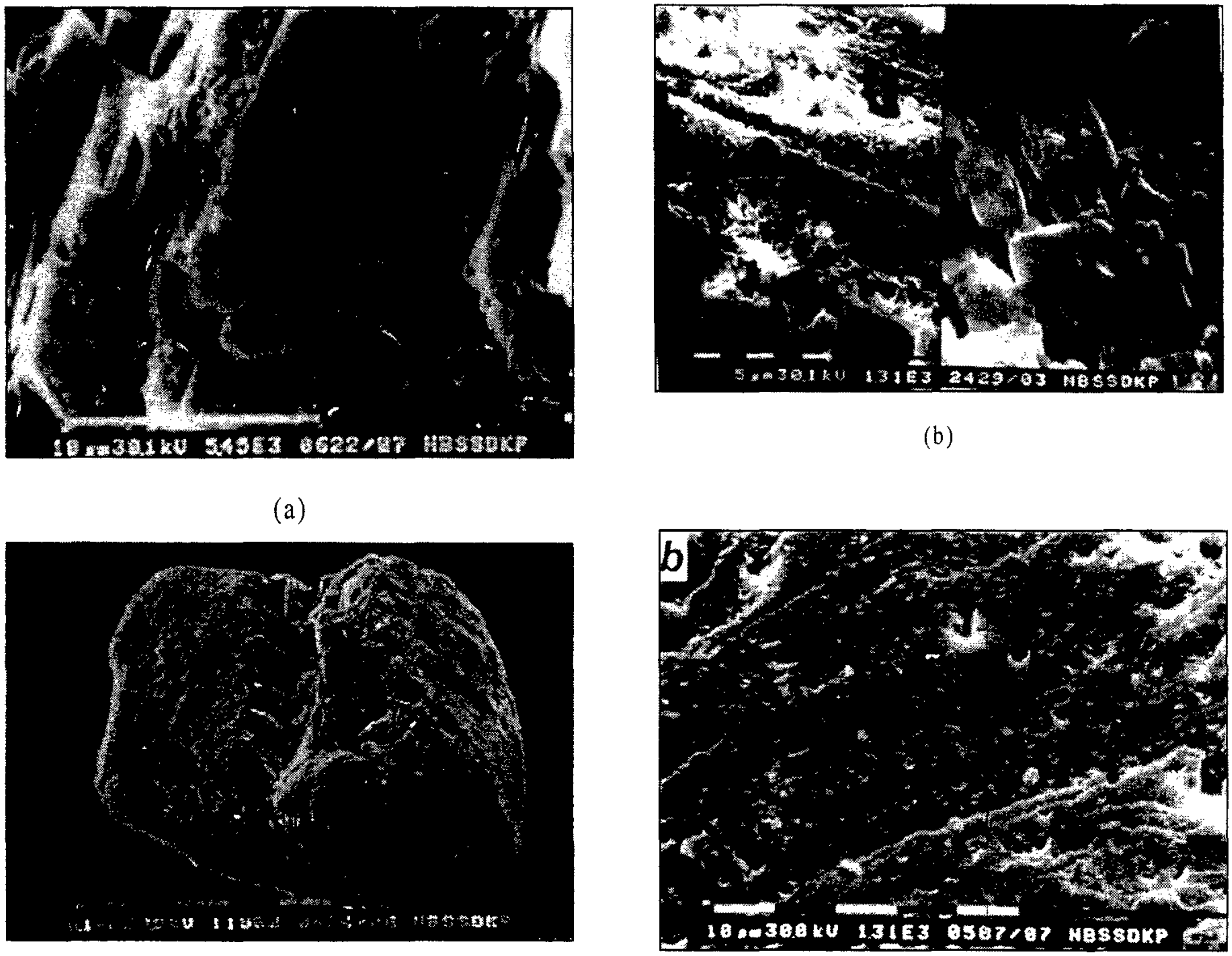


Fig. 1: Representative X-ray diffractograms of fine clay fractions of Ultisols: Ca, Ca-saturated; Ca-EG=Ca-saturated and ethylene glycolated; K25, K110, K300, K550, K-saturated and heated at $25^0/110^0/300^0/550^0$C, respectively; HCl, treated with 6N HCl, HIV, hydroxy-interlayered vermiculite, K; kaolin; G, gibbsite, (Inset : an x-ray diffractogram showing highly crystalline kaolinite of an acidic ferruginous soil in comparison to kaolin of Ultisols) (Source : Division of Soil Resource Studies, NBSS & LUP, Nagpur).



(a) (b) (c) (d)

Fig. 2: Representative SEM photographs of rod shaped gibbsite pseudomorphed after feldspars (a) and sillimanite (b) and slightly altered zeolites (c) and feldspars (d). (Source : Division of Soil Resource Studies, NBSS & LUP, Nagpur).

With a combination of high temperature and adequate moisture, the tropical humid climate of the Western Ghats, Meghalaya and Kerala provided a weathering environment that should have nullified the effect of parent rock composition. This should have resulted in kaolinitic and/or oxidic mineral assemblages consistent with either residua (Chesworth 1973a,b) and haplosoil (Chesworth 1980) models of soil formation. But, the presence of Kl-HIS/Kl-HIV indicates that in spite of a prolonged weathering since the Tertiary, the weathered products of Deccan basalt and granite-gneiss have not yet reached the kaolinitic and/or oxidic mineralogy stage.

Review of the results of three case studies indicates that the formation of gibbsite is possible even in presence of 2:1 minerals that were considered to prevent the formation of gibbsite (Jackson 1963, 1964). Studies have proved that the weathering sequence hitherto considered for the formation of gibbsite at the expense of kaolinite appears to be in error. The Ultisols are siliceous and desilication in acidic soil condition is highly improbable. The presence of gibbsite is not an index of advanced stage of mineral weathering as it needs to be considered to have formed from primary minerals in an earlier alkaline pedo-environment (Bhattacharyya *et al.* 2000; Chandran *et al.* 2005).

Formation of Alfisols and Ultisols and their pedogenic threshold at this time supports that steady state may exist in soils developed over long periods of time not only spanning a few hundreds to thousands of years (Yaalon 1971; Smeck *et al.* 1983) but also millions of years (Bhattacharyya *et al.* 1993, 1999; Chandran *et al.* 2005). Thus the hypothesis of Chesworth for soil formation in humid tropics can not explain the persistence of Alfisols and Ultisols developed on zeolitic Deccan basalt and granite-gneiss because stability of zeolites and feldspar (Fig. 2c,d) was not considered in his models. Thus the formation and persistence of Alfisols and Ultisols for millions of years provides a unique example that in an open system such as soil, the existence of a steady state appears to be a more meaningful concept than equilibrium in a rigorous thermodynamic sense (Bhattacharyya *et al.* 1993, 1999; Chandran *et al.* 2005). In view of the contemporary pedogenesis of Ultisols that do not include desilication and transformation of kaolinite to gibbsite, it is thus difficult to reconcile that Ultisols would ever be weathered to reach the stage of Oxisols with time (Chandran *et al.* 2005) as envisaged by Chesworth (1973a) and Smeck *et al.* (1983).

Conclusion

This review presents a state-of-art information that provides a deductive check on the inductive reasoning so far made on the formation of soil in tropical humid climate.

Acknowledgement

The state-of-art information presented through this review has evolved over a period of years in research among the author and his esteemed colleagues namely Drs. T. Bhattacharyya, P. Chandran, S.K. Ray and P. Srivastava in the Division of Soil Resource Studies of the National Bureau of Soil Survey and Land Use Planning (ICAR), Nagpur.

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