Chapter 5
Conceptual Models on Tropical Soil Formation

Abstract Use of models to explain adequately the formation of tropical soils indicates that although among the most popular models applicable in soil formation, the residua and haplosoil models have relevance to formation and persistence of Indian tropical soils, they cannot explain the existence of million years old Vertisols, Alfisols and Mollisols under humid tropical climate because these models did not consider the stability of base rich primary minerals over time. This novel understanding provides a deductive check on the inductive reasoning so far made on the formation of soils in tropical humid climate and also establishes the validity of Jenny's state factor equation in the formation of the Indian tropical soils in the intense weathering environments under HT climate.

Keywords Validation of models · Acidic Alfisols · Acidic Vertisols · Acidic Mollisols · Ultisols

5.1 Introduction

Dijkerman (1974) listed four types of conceptual models. They are (1) mental, (2) verbal, (3) structural and (4) mathematical. Whereas most of the working models are of a verbal nature, more emphasis is now being laid in mathematical models due to availability of computers (Smeck et al. 1983). It would be worthwhile exercise to examine the pros and cons of the most popular model employed in pedogenetic studies of Indian tropical soils (spatially associated Mollisols-Alfisols-Vertisols) in order to gain a better understanding of factors and processes operative in tropical soil system. 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, 1980), (4) generalized process model (Simonson 1959) and (5) soil-landscape model (Huggett 1975). Out of these models the most challenging ones are residua and haplosoil models (Chesworth 1973a, 1980) and have strong relevance to the formation of Vertisols, Alfisols, Mollisols and Ultisols in humid tropical climate of India. Formation and persistence of such

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soil orders under prolonged HT climate provides an opportunity to validate both residua and haplosoil system, and in this exercise soils developed on zeolitic Deccan basalts, gneissic and sedimentary rock systems are discussed in the following.

5.2 Vertisols Spatially Associated with Alfisols and Mollisols on Zeolitic Deccan Basalts

Vertisols, Alfisols, and Mollisols are the members of Mollisol-Alfisol-Vertisol association (Bhattacharyya et al. 2005, 2006) on the zeolitic Deccan basalt areas. The associated Alfisols were formed in HT climate and are persisting since the early Tertiary (Bhattacharyya et al. 1999). The transformation of smectite (the first weathering product of the Deccan basalt) (Pal and Deshpande 1987) to kaolin (Sm-K) during HT weathering began at the end of the Cretaceous and continued during the Tertiary (Kumar 1986), and thus Alfisols date back to the Tertiary and the Cretaceous (Idnurm and Schmidt 1986). With a combination of high temperature and adequate moisture, the HT climate of the Western Ghats and Satpura Range of central India provided a weathering environment that should have nullified the effect of parent rock composition in millions of years, resulting in kaolinitic and/or oxidic mineral assemblages consistent with either residua (Chesworth 1973a) or haplosoil (Chesworth 1980) models of tropical soil formation like in Ultisols and Oxisols (Soil Survey Staff 1999). Instead, the soils of the zeolitic Deccan basalt have Sm-K and represent Vertisols, Alfisols and Mollisols. The knowledge gained on the role of zeolites in the persistence of soils not only provides a deductive check on the inductive reasoning on the formation of soil in the HT climate, but also throws light on the role of these minerals in preventing loss of soil productivity even in an intense leaching environment. This indeed may be the reason why crops do not show response to liming in acid soils of the tropical Western Ghats (Kadrekar 1979).

5.3 Acidic Alfisols, Mollisols and Ultisols on Gneissic and Sedimentary Rock Systems

Under Indian HT climate, soils formed do not belong to the same soil order; they belong to Ultisols, Alfisols and Mollisols. Mollisols are prevalent under thick forest vegetation, whereas Alfisols are under sparse forest vegetation and/or in agricultural soils and Ultisols are in general under agriculture (Pal et al. 2014). However, there are strongly acidic Ultisols and mildly acidic to neutral Alfisols and Mollisols.

In Goa on gneissic rock, strongly acidic Ultisols are associated with moderately acidic Alfisols (Chandran et al. 2004; Harindranath et al. 1999). In Karnataka, on gneissic rock in the Western Ghats area, moderately acidic Ultisols, Alfisols and Mollisols are spatially associated (Shiva Prasad et al. 1998). In the Nilgiri Hills areas of Tamil Nadu on gneissic rock, strongly acidic Ultisols are spatially associated with mildly acidic Alfisols and Mollisols (Natarajan et al. 1997). In Nilgiri hills areas in Kerala on calc-gneiss, near the north of the Palghat Gap strongly acidic Ultisols are associated with mildly acidic to neutral Mollisols, whereas one of the major soil orders in the Palghat Gap is mildly acidic Alfisols (Krishnan et al. 1996).

In NEH areas on sedimentary and gneissic rock, strongly acidic Ultisols are associated with moderately acidic Alfisols (Bhattacharyya et al. 2000; Maji et al. 2000, 2001; Nayak et al. 1996b; Sen et al. 1996, 1999; Singh et al. 1999). In the Andaman and Nicobar Islands on calcareous/micaceous sandstones and lime stones, neutral to slightly alkaline Mollisols are associated with slightly acidic pH Alfisols (Das et al. 1996).

5.4 Critique on the Validation of the Conceptual Models

The soils of the zeolitic Deccan basalt, gneiss/calc-gneiss, sedimentary deposits, lime stones have kaolin and other hydroxy-interlayered clay minerals in abundance (details are available in Chaps. 2 and 3) and represent Ultisols, Alfisols and Mollisols, suggesting that the presence of Ca-bearing weatherable minerals in the soil parent materials under forest vegetation have influenced the weathering rate and exerted a decisive influence on the nature of the soil silicate clay minerals and the formation of soils with various soil orders (Pal et al. 1989). It follows from these results that factors and processes of formation and persistence of these three soil orders in adverse HT climate during the Cenozoic time (Pal et al. 2014) need a further analysis in the light of the existing conceptual models for tropical soil formation.

In either residual (Chesworth 1973a) or haplosoil model of soil formation (Chesworth 1980) in tropical climate, it was envisaged that with a combination of high temperature and adequate moisture, the HT climate of India provided a weathering environment that should have nullified the effects of parent material composition by resulting kaolinitic and/or oxidic mineral assemblages (Chesworth 1973b). The models of Chesworth were based on the hypothesis that (a) the effect of parent rock will be overshadowed and nullified with time; (b) its effect will be evident only in younger or relatively immature soils, and (c) the time is the only independent variable of soil formation or any other processes occurring spontaneously in nature.

In soils of HT climate of India, the dominance of kaolin indicates that in spite of prolonged weathering for millions of years since the early Tertiary, the weathered products of Ca-rich minerals of the parent materials have not reached even the pure kaolinitic mineral stage. The formation of kaolin clay mineral suggests that the formation of Vertisols, Ultisols, Alfisols and Mollisols and their pedogenic threshold at this time supports the supposition that steady state may exist in soils developed over long periods of time spanning not just thousands of years (Smeck et al. 1983; Yaalon 1971, 1975) but also millions of years (Bhattacharyya et al. 1993, 1999; Chandran et al. 2005). The hypothesis of Chesworth for soil formation in HT climate of India cannot explain the persistence of Vertisols, Ultisols, Alfisols and Mollisols, because of the stability of feldspar, zeolites and other Ca-rich minerals/rock (i.e. limestone, and calc-gneiss) over time was not considered in his model. Therefore, the formation and persistence of these soils provide an example that in an open system such as the soil, the existence of a steady state seems a more useful concept than based on equilibrium in a rigorous thermodynamic sense (Smeck et al. 1983; Bhattacharyya et al. 1999, 2006; Chandran et al. 2005), and Jenny's state factor equation is also essentially valid. This contention finds support from the current pedogenetic processes in Ultisols in NEH areas. The OC rich Ultisols have less Al-saturation in surface horizons due to the downward movement of Al as organo-metal complexes or chelates, but have higher base saturation than the sub-surface horizons due to addition of alkaline and alkaline metal cations (please refer to Table 3.2) through litter fall (Nayak et al. 1996a), and there is no desilication and transformation of kaolin to gibbsite (Pal et al. 2014).

In view of contemporary pedogenesis, it is difficult to reconcile that Ultisols (especially of Kerala hitherto considered to be of international reference for laterite) would ever be weathered to reach the Oxisols stage with time frame as envisaged by Smeck et al. (1983), Lin (2011) (please refer to Fig. 2.12a). The knowledge gained on the role of Ca-rich parent materials and Ca-zeolites in the persistence of soils for millions of years provide a deductive check on the inductive reasoning on the formation of Vertisols, Alfisols, Mollisols and Ultisols in the HT climate.

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