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Podzolisation and soil organic matter dynamics

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Abstract

Present models of podzolisation emphasize the mobilization and precipitation of dissolved organic matter, together with Al(-silicates) and Fe. Such models cannot explain the dominance of pellet-like organic matter in most boreal podzols and in well-drained podzols outside the boreal zone, and the discrepancy between the chemistry of percolating organic matter (DOC) and the organic matter accumulated in well-drained podzol-B horizons.

The present paper offers an amended podzolisation theory, in which relative contribution of illuviated organic matter and root litter together with organic matter dynamics provide an explanation for the large variation in podzol morphology. It is suggested that fast organic matter dynamics as occurs on nutrient-rich parent materials in the boreal zone causes small accumulation of organic matter, mainly derived from roots. In such soils, the colors of Fe components dominate in the B horizon. Slow organic matter dynamics, as occurs on nutrient-poor parent materials and under hydromorphic circumstances, favors large organic matter accumulations in the B horizon, and a larger abundance of DOC-derived organic matter coatings. The latter group includes tropical podzols.

Keywords: Soil organic matter; Podzols; B horizon

1. Introduction: conflicts between theory and observation

Current theories about the podzolisation process, i.e. the mobilization of humus and sesquioxides in the topsoil of acidic soils, and their precipitation in a B horizon, are built up of three non-exclusive processes (e.g. Browne, 1995; Courchesne and Hendershot, 1997; Lundström et al., 2000):

– mobilization of unsaturated metal–organic complexes in the forest floor and the A and E horizons, followed by precipitation in the B horizon upon saturation of organic molecules through metal complexation: the *fulvate theory* (e.g. McKeague et al., 1978); with a variant by Browne (1995).
– transport of sols of (proto-)imogolite allophane, precipitation of these sols in the B horizon and

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subsequent adsorption of mobile humus: the *proto-imogolite theory* (e.g. Anderson et al., 1982).

– two stages of profile development which occur sequentially or simultaneously: (a) in situ formation of imogolite/allophane in the Bs horizon by a carbonic acid weathering process, and (b) precipitation of fulvic acid on the Al-rich precipitates in the Bs horizon. This is known as the *fulvate-bicarbonate theory* (Ugolini and Dahlgren, 1987).

A variation upon the first model suggests that transport of metals is effected by complexation to low-molecular weight (LMW) organic acids, and that upon breakdown of these carriers, the metals are transferred to larger organic molecules, which causes their precipitation (Lundström et al., 1995; Van Breemen and Buurman, 2002). Skjemstad et al. (1992) propose the additional influence of reduction on the mobility of iron compounds.

Recent research on Swedish podzols clearly indicated that high-molecular weight OM may precipitate on allophanic material, while LMW-OM plays a significant role in movement of sesquioxides (Riise et al., 2000; Van Hees et al., 2000). Farmer and Lumsdon (2001) proved that fulvates could be precipitated by proto-imogolite in the laboratory.

In all these theories, the mobilization–transport–precipitation model dominates.

Although partial proof of all the above processes appears to exist, they do not explain the major variations in podzol chemistry and morphology. Macromorphology and classification, micromorphology and organic matter chemistry all indicate discrepancies between theory and observation that have been overlooked in theoretical models. These discrepancies will be discussed in the following. We will use the term *boreal podzols* for the podzols occurring in cold climates at high latitudes and altitudes. For both well-drained and poorly drained podzols on poor parent materials, which occur outside the boreal zone, we will use the term *non-boreal podzols*. Although tropical podzols should be included in this second group, we have awarded them a separate category in the following.

1.1. Macromorphology and classification

Some of the conceptual problems are apparent in the various parts of the definition of the spodic horizon in FAO, USDA, and World Reference Base (WRB) publications. Table 1 gives a compilation of the criteria currently used in these three systems. The classification criteria address the quality and accumulation of organic matter and sesquioxides. Two criteria of Table 1 indicate that horizons with essentially different properties are grouped together in the spodic horizon. Firstly, the organic matter can occur either as cracked coatings (and eventually strongly cement a horizon), or as silt- and sand-size pellets. Secondly, the color can either be black or have a strong chroma.

Table 1
Criteria for the spodic horizon[a]

Criterion	SSS, 1999 (USDA) ‘spodic materials’	FAO-Unesco, 1997 ‘spodic B horizon’	WRB, 1998 ‘spodic horizon’
Color	5YR or redder, *or* 7.5YR and ≤5/4, *or* 10YR and ≤2/2, *or* 10YR3/1		7.5YR or redder; *or* 10YR, dark
Cementation	Yes	Yes	Yes
Organic pellets		Yes	Yes
Cracked coatings	Yes		
Org C content	>0.6		>0.6%
and pH-water	<5.9		<5.9
Al_o+0.5Fe_o	>0.5		>0.5%
ODOE	>0.25		>0.25
Additional	Movement of OM	(Fe+Al)p/(Fe+Al)d>0.5; (Fe+Al)p/clay>0.2 d* (CEC8.2–0.5*clay)>65	

[a] Some criteria are used independently, others in combination; see primary publications.