Micromorphology of a welded paleosol in the Dillondale loess, Charwell Basin, South Island, New Zealand

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Abstract

Micromorphological evidence and soil phosphorus chemical data supporting the presence of a welded paleosol from the Dillondale loess are presented. Since both topdown and upbuilding pedogenesis can occur in loess deposits, welding of paleosols will occur when topdown pedogenesis overprints an existing paleosol. Intact soil samples were collected and their micromorphology described, and soil P fractions were determined. The micromorphology and soil P fractions provide strong evidence for a welded soil between 3.0 and 4.0 m depth (L3b basal unit). Throughout this unit the b-fabric is both porostriated and granostriated; amorphous concentration features are moderately to strongly impregnated, postdating clay cutans. We interpret this to reflect greater mechanical stress on the clay domains and hence a longer period of topdown pedogenesis. Low levels of P_{Ca} and a high proportion of P_{Occ} in the L3b basal unit imply these are highly weathered horizons. This suggests two phases of topdown pedogenesis during a hiatus in loess accretion. We propose that an extended period of illuvial clay deposition in the underlying b2Btg1 and b2Btg2 horizons occurred, reducing macropore continuity in the horizons above. Intense anaerobic conditions would have resulted, with the onset of gleying and the formation of the amorphous concentration pedofeatures.

Key Words

Micromorphology, welded paleosol, loess, pedogenesis, pedofeatures

Introduction

Fragmentary terrestrial records such as loess deposits constitute important archives of Quaternary environmental change. In New Zealand, loess is an extensive deposit commonly occurring on Pleistocene and Holocene river terraces. Loess-paleosol stratigraphic studies supported by luminescence and radiocarbon dating and tephrochronology suggest that the majority of loess deposits are less than 300 ka old (Schmidt *et al.* 2005). Pedogenic alteration within the loess deposits is driven by temporal variation of both the rate of loess accretion and external climatic factors. Pedogenesis within the loess accretionary column occurs in two phases: during active accretion, known as upbuilding (weak pedogenesis); and during hiatuses in loess accretion, known as topdown (strong pedogenesis in warmer and wetter periods when no new sediment accumulates) (Almond and Tonkin 1999; Lowe *et al.* 2008). Ruhe and Olson (1980) defined welded soils as those formed when pedogenesis from an overlying soil extends down into and overprints a lower soil. Loess accretionary columns can contain paleosols comprised of both accretionary and welded components – named pedocomplexes by Kemp *et al.* (1994). Welded soils can thus obscure details of the loess stratigraphy and hence events associated with Quaternary climatic change can be missed. To tease apart the phases of pedogenesis obscured in the morphology, chemical and micromorphological analysis can be used. In this paper we focus on the micromorphology of a striking buried paleosol in the third (basal) loess sheet of a 3-loess sheet sequence found in north-eastern South Island, New Zealand. The paleosol is thick, very clay rich, when compared to surface soils, and shows spectacular reductimorphic features including large Mn nodules and a network of horizontal and vertical gley veins. Our results refine the present loess stratigraphy and contribute to a better understanding of paleoenvironment in this part of NZ in the Late Quaternary.

Methods

Samples were taken from a loess section exposed in a cliff face cut in the Dillondale terrace. The buried soil developed in L3 was sampled at 287 mm (b2Bt(g)); 330 mm (b2Btgc1) and at 399 mm (b2Btg2). Samples were also taken from the L1 and L2 sheets higher up in the section for comparison (sampled at 138 mm, 169 mm (Bx(g); 189 mm (bBw(g)), 205 mm (bBcg) and 240 mm (bBt(g)). Soil blocks were prepared according to standard procedures (Lee and Kemp, 1992) and thin sections were described according to Bullock *et al.* (1985). Fabric features described included b-fabric, excremental infillings, clay lamellae, laminated and non-laminated cutans, fragmented cutans and amorphous crystalline segregations. Phosphorus fractions for the Dillondale interfluve section were determined at each 10 cm interval for the first 1 m, and then at every 20 cm for the remainder of the loess column. Detailed methods are reported in Hughes *et al.* (in prep). Total soil P (P_T) was determined using the sodium hydroxide fusion method of Smith and Bain (1982) while organic phosphorus (P_{Org}) was determined using a method adapted from Bowman (1989) Total inorganic P (acid+base) subtracted from estimated total P (acid+base) gives P_{Org}. Organic P (P_{Org}) subtracted from P_T determined by the Smith and Bain (1982) method gave inorganic P. The non-occluded phosphorus fractions of this (P_{Ca} and $P_{Fe/Al}$) were determined using an acid and base extraction method adapted from Murphy and Riley (1962). All P fraction extracts were analysed on a Varian Cary 50 ultraviolet/visible spectrophotometer set at 880 nm wavelength. The occluded fraction was calculated as the difference between total inorganic P and P_{Ca}+$P_{Fe/Al}$. (Hughes *et al.* in prep).

Results and Discussion

Phosphorus fractions

Total P: From the top of L3 downwards, there was a slight increase in P_T before subsequent decreases in the b2Btgc1 and b2Btgc1 horizons. Total P peaked at the top of the b2Btg horizon at ~3.8 m, before decreasing to 221 µg/g at 4.1 m, then increased to 292 µg/g at the base of L3 (Figure 1.). P fractions: P_{Occ} dominated, peaking at 70% of P_T at 3.7 m, while $P_{Fe/Al}$ comprised the second dominant fraction peaking at 55% at 3.1 m. These two peaks in absolute concentrations coincided with two distinct peaks in relative abundance of P_{Org}. Apatite P (P_{Ca}) comprised a relatively low percentage of P_T in the upper half of L3, but increased to 19% at the base of L3. P_{Ca} makes up a significant component of the least weathered, lower subsoil peaks in each loess sheet. P_{Occ} reaches maxima in horizons persisting at the surface for long periods and in deep subsoils (e.g. Bwg, Bxg), and minima in gleyed upper subsoil horizons (e.g. Btg, Bcg). P_T and P_{Ca} are lower in L2 and L3 suggesting they are more weathered than L1, and the very low P_{Ca} and high proportion of P_{Occ} in the upper part of L3 suggests these are the most weathered horizons of all. Organic P makes up a high proportion of P_T in the A horizon of the surface soil, but persists as in the upper parts of buried soils as well. Organic P showed a broad peak centred at the L2/L3 boundary that overlapped with relatively high levels in the base of L2. A secondary peak occurred at 3.5 m in the b2Btgc2 horizon (Figure 1).

Micromorphology

The micromorphology of the L3a (b2Bt(g)) is noticeably different when compared to the L3b unit. The b-fabric in the L3a is granostriated only, and there are few amorphous concentration pedofeatures. In the b2Bt(g) horizon, excremental fabric is readily apparent, postdating the amorphous concentration pedofeatures therein. Cutans are extensive and postdate or are contemporaneous with the excremental fabric. We interpret this to reflect one period of topdown pedogenesis only, since there are fewer amorphous concentration pedofeatures and the b-fabric is granostriated, suggesting that less intense physical stresses were involved in realigning the clay domains.

Towards the base of the L3b (b2Btg2) there is a prominent macro vein and prism structure, but excremental fabric is absent. The veins contain clay and silt cutans while the b-fabric therein is both porostriated and granostriated. The prisms contain some redox segregations adjacent to the prism faces. At the top of the L3b (b2Btgc1), the b-fabric is also porostriated and granostriated. In the b2Btgc1, there are noticeably more amorphous concentration pedofeatures compared to the b2Btg1 below, and these postdate the majority of clay cutans. We propose that an extended period of illuvial clay deposition in the underlying b2Bt1 and b2Btg2 horizons occurred – reducing macropore continuity in the overlying b2Btgc1 and b2Btgc2 horizons. Intense anaerobic conditions would have resulted in these horizons, (more so in the b2Btgc1) with the onset of gleying and the formation of the amorphous concentration pedofeatures.

Porostriated b-fabric is indicative of considerable shrink/swell activity; the stress induced by alternating cycles of wetting and drying causing the realignment of clay domains. This fabric is to be expected in the veins of the b2Btg2 horizon, due to the considerable shrink-swell processes associated with vein and prism morphology. We infer this to reflect an intense and long-lived phase of pedogenesis. We propose that the welded soil in b2Btgc1 resulted from two separate phases of intense pedogenesis; phase one (long and intense) and phase two (shorter, and less intense), separated by a loess accretion phase. Micromorphological evidence for a welded horizon in this situation would include the overprinting of the existing subsurface morphology in b2Btgc1 with further subsurface features. If the overlying loess sheet is thin enough, the second phase of pedogenesis would drive both the morphology of the L3a (b2Bt(g)) and the underlying L3b (b2Btgc1).

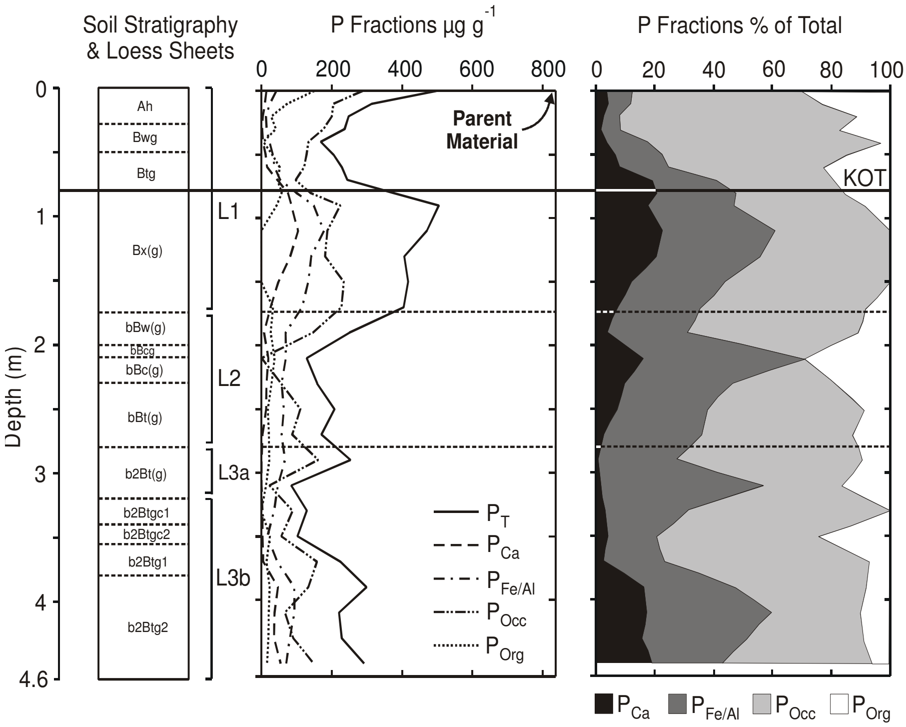

Figure 1. Phosphorus fractions presented as absolute values (centre) and percentages of total values (right). Soil stratigraphy and loess sheet delineations are presented on the left. P_T = total P, P_{Ca} = apatite P, $P_{Fe/Al}$ = Fe- and Al-bound P, P_{Occ} = occluded P, P_{Org} = occluded P. Also shown is the value (P_T) of river silt parent material, and the stratigraphic location of the ca. 27 ka Kawakawa/Oruanui Tephra (KOT; solid line). Figure reproduced from Hughes *et al.* (2010) (in prep.).

Thus subsurface processes will overprint on existing subsoil morphology. We infer overprinting from the intensity of the micromorphological features developed therein, in the top of the L3b (b2Btgc1): porostriated b-fabric and the moderately-strongly impregnated amorphous concentration features postdating the majority of clay cutans. This overprinting is supported by the phosphorus chemical data: (very low P_{Ca} and high proportion of P_{Occ} in the upper part of L3) implying a highly weathered horizon.

Conclusion

Both the micromorphology and the soil P chemistry strongly suggest that a welded soil can be distinguished in the L3b, between 3.0 and 4.0 m depth. We conclude that welding occurred as a result of two phases of topdown pedogenesis, punctuated by a short period of loess accumulation of ~0.5 m and associated pedogenic upbuilding. This would have resulted in two separate periods of clay illuviation and associated gleying conditions. Topdown pedogenesis in L3a affected both the more recently aggraded loess and also the top of the underlying L3b unit (b2Btgc1 horizon).

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