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Soil morphology of a debris flow chronosequence in a coniferous forest, southern California, USA

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ABSTRACT

Soils on a series of debris flow deposits, ranging from <1 to 244 years old, were described and sampled in order to investigate the early stages of soil development. The parent material at the site is debris flow regolith, composed mainly of gneiss, the soil moisture regime is xeric, and the vegetation is mixed coniferous forest. Ages of the deposits were assessed using dendrochronology. Morphologic trends in the organic horizons included a thickening of the humus form over time, along with the development of Fm and Hr horizons. The humus forms underwent a progression from Mormodors (20 years old), to Hemimors (26–101 years old), and finally Lignomors (163 years old) and Resimors (184–244 years old). Changes in physical properties of the uppermost mineral horizons as a function of increasing age included a decrease in the volume of coarse fragments, a linear decrease in bulk density, and a darkening and reddening of the soil color. No significant soil development took place in the subsoil during the time span of this chronosequence. The soils described were classified as Typic Xerofluvents and Typic Xerorthents (Regosols and Leptosols). Buried A horizons were observed in many of the soils. Where the A horizons could be linked to dendrochronology to assess the age of the buried surface, we found that the properties of the buried A horizons do not serve as a good indicator of the age of the surface. This study suggests rapid development of the humus form profile (organic horizons and A horizon) following debris flow deposition and rapid degradation of these horizons when the debris flow surface is buried.

1. Introduction

A chronosequence is defined as a group of soils that are similar with respect to all soil forming factors except for time (Jenny, 1941). The chronosequence approach has been used in pedology research for over half a century to study the development of soil properties such as texture, structure, color, and chemical composition. On the basis of these studies, soil properties can be divided into "rapidly-adjusting" properties (reaching a steady state in <1000 years) and "slowly-adjusting" properties (reaching a steady state in >1000 years) (Yaalon, 1970). Typical slowly-adjusting properties include accumulation of clay or $CaCO_3$ in the B horizon, while rapidly-adjusting properties include accumulation of organic matter and nitrogen in the A horizon.

Short-term chronosequences, spanning <1000 years, are most useful when high temporal resolution is desired. High temporal resolution is necessary for describing chronofunctions for rapidly-adjusting properties. Short-term chronosequences have been studied on 0 to 220-year-old alluvial terraces (Adair et al., 2004), 10 to 240+-year-old glacial moraines (Alexander and Burt, 1996), 27 to 1200+-year-old mudflows (Dickson and Crocker, 1953a,b, 1954), 0 to 178-year-old colliery waste tips (Down, 1975), and 50 to 350-year-old windthrow mounds (Bormann et al., 1995). These studies illustrate the rapid accumulation of organic carbon during the early stages of soil development, as well as the development of properties that are influenced by soil organic matter (e.g., bulk density, color, organic horizon and A horizon thickness).

A well-studied short-term chronosequence in northern California consists of a series of mudflow deposits at Mt. Shasta, which ranged in age from 27 to 1200+ years (Dickson and Crocker, 1953a). This chronosequence has been useful for describing trends in organic carbon accumulation (Dickson and Crocker, 1953b, Sollins et al., 1983, Lilienfein et al., 2003); however, no significant changes in soil texture took place over the course of the chronosequence (Dickson and Crocker, 1954). In a slightly longer-term chronosequence in Michigan, spanning 5200 years of soil development, changes were detected in surface texture and extractable Fe and Al (Barrett, 2001). However, trends in organic carbon accumulation were not significant because the resolution of early soil development was too coarse.

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Although debris flows occur in mountainous regions around the world (Coussot and Meunier, 1996), few studies have been made of soil formation in their deposits. In this study, we investigated the development of soil morphologic and physical characteristics in a forested debris flow chronosequence in southern California. The chronosequence, which spans the first 244 years of soil development, is considered to be a high-resolution chronosequence because soil age intervals are less than 65 years, but mostly less than 25 years. The objectives of this study were to assess (1) trends in development of the forest ecosystem relevant to soil formation, (2) trends in morphologic and physical properties of the soils, and (3) the application of those trends in determining the age of buried deposits. To our knowledge, no other short-term chronosequence studies have been conducted in southern California. The current study thus provides chronofunctions that are most applicable for rapidly-adjusting soil properties in the region. These chronofunctions could be useful for understanding the carbon sink in young, coniferous forests in the region, as well as for interpreting the age of soils that experience similar soil forming factors.

2. Methods and materials

2.1. Study area

The study site is on the Rattlesnake Creek alluvial fan, near the town of Forest Falls, at about 1675 m elevation, in the San Bernardino Mountains of southern California. Yucaipa Ridge, south of Forest Falls, is the source of debris flows. Debris flows are highly concentrated slurries of rock, soil, and water that form, develop, and flow along a streambed (Coussot and Meunier, 1996). Yucaipa Ridge, composed mainly of highly-fractured gneiss, rises approximately 500 m above Forest Falls. Debris flows on Yucaipa Ridge are triggered by brief, high-intensity rainfall events, associated with summer convective thunderstorms and winter polar jet stream cyclones.

The debris flows on the Rattlesnake Creek fan are slow moving (<16 km h^{-1}) and most flows are confined to a channel, though some material overshoots the banks (Morton and Hauser, 2001). Outside of the channel, the debris flows leave short, discontinuous levee deposits or lobate deposits with steep-fronted, rocky snouts. Eleven debris flows were recorded at Forest Falls between 1955 and 1998; suggesting a debris flow frequency of approximately 5 years (Morton and Hauser, 2001). Numerous debris flow chutes coalesce at the base of Yucaipa Ridge, forming an approximately 30 ha debris flow fan.

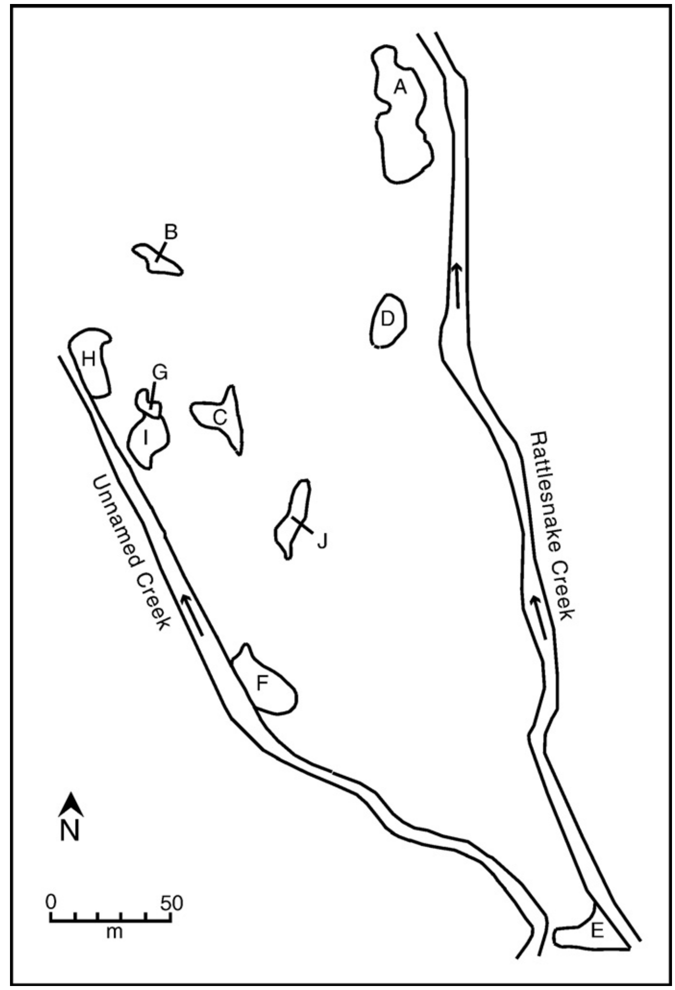

Fig. 1. Map of the study area displaying the spatial arrangement of the debris flow deposits used for this study (A–J), the active debris flow channel (Rattlesnake Creek), and a large remnant channel which probably conducted of many of the older deposits (Unnamed Creek).

The section of the fan that was studied is on the western flank of the Rattlesnake Creek fan (N 34.1°W 116.9°, Datum WGS84). Soil pits were excavated on the levees and lobate deposits formed where debris flows overflowed from the channel. Surfaces of the deposits slope downward to the north (poleward-facing aspect), with a 9 to 22% gradient and a convex/convex slope shape. Depositional areas range from 70 to 900 m^2 and thickness of the deposits range from 0.3 to 2 m. The deposits are composed of unsorted clasts and fine-grained material. The clasts mostly range from gravel-sized (0.2–7.6 cm) to stone-sized (25–60 cm) and compose 45 to 85% of the deposit material by volume; the fine-grained material has a loamy coarse sand texture. A total of 10 debris flow deposits were used in the study, which ranged in age from <1 to 244 years old (Table 1). Most of the deposits were lobes formed by debris flows that overshot the banks of the debris flow channel, but three levee deposits formed along the debris flow channel were sampled as well (sites E, F, and H) (Fig. 1).

The study site is forested with incense cedar (*Calocedrus decurrens* Torr.) and interspersed ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), Coulter pine (*Pinus coulteri* D. Don), California black oak (*Quercus kelloggii* Newb.), white fir (*Abies concolor* [Gord. and Glend.] Lindl. ex Hildebr.), and canyon live oak (*Quercus chrysolepis* Liebm.). Debris flow surfaces were often associated with a cohort of trees, which were presumed to represent

Table 1
Surface age assessment by dendrochronology

Site[a]	Growth past tree ring features[b]	Tree ring feature	Deposition (years)	Sampling (years)	Age[c] (years)
A			2003	2003 and 2006	<1 and 3
B	19(6×IC),20(1×IC) 20&28(1×IC)	Pith Scar	1985	2005	20
C	24(3×IC),25(10×IC)	Pith	1977	2003	26
D	47(1×IC), 49(1×IC), 51 (2×IC)	Eccentric growth	1954	2005	51
Db	77(1×IC),88(1×IC),89 (1×IC)	Pith	1915	2005	90
E	70(1×PP),73(1×PP),74 (1×IC)	Pith	1930	2005	75
F	80(1×WF),81(1×WF)	Pith	1923	2005	82
Fb	123(1×IC),127(1×IC),129 (1×IC)	Pith	1875	2005	130
G	99(1×IC),100(1×IC)	Pith	1902	2003	101
H	160(1×IC),162(1×PP)	Pith	1843	2006	163
I	171(1×PP),183(1×PP)	Pith	1822	2006	184
J	238(1×IC),243(1×IC)	Pith	1759	2003	244

[a] At sites with buried soils, "b" indicates the buried deposit.
[b] Values in parentheses indicate the number of observations and the species (IC = incense cedar, PP = ponderosa pine, WF = white fir).
[c] Age is tree age plus one.