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Features of some paleosols on the flanks of Etna volcano (Italy) and their origin

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Abstract

Volcano flanks are usually covered by deposits of fine materials (tephra) with variable thickness originated by the explosive activity. The deposits form bedded sequences of tephra layers often alternated with paleosols. Pyroclastic successions on Etna volcano (Italy) are composed of scoria or pumice lapilli and ash deposits, representing separate eruptions, and volcanogenic sediments developed between eruptions. The origin of paleosols cropping out in three pyroclastic successions on Mt Etna is here discussed on the basis of stratigraphic, pedological, chemical and mineralogical data. The results suggest that the sequences originated from the accumulation of primary volcanic materials produced by explosive events, together with material of secondary origin derived from wind-transported materials originated by the alteration of the pyroclastic deposits formed at higher elevations. The vegetation present at the surface at any time would have favoured the aggrading of the soil by exerting a trapping effect on the wind-blown materials. At the same time, the presence of plants would have favoured enrichment in organic C and mineral alteration. In the studied paleosols, the pedogenetic processes were not sufficiently intense or did not act for a sufficient time to favour neogenesis of mineralogical phases, either crystalline or "amorphous".
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1. Introduction

Volcanic soils are often classified as Andisols (Soil Survey Staff, 2003) or Andosols (IUSS Working Group WRB, 2006). In both classification systems, the central concept in the designation of these soils is the presence of considerable amounts of short-range order minerals (allophane, imogolite and ferrihydrite) or Al-humus complexes. Following these rules, Andisols/Andosols may develop from not volcanic-derived parent material (García-Rodeja et al., 1987), while some soils on volcanic ejecta may not enter in these orders because of a scarce weathering. In these cases, most of the soils are classified as Entisols (Soil Survey Staff, 2003) or Regosols or Leptosols (IUSS Working Group WRB, 2006). These latter soils are considered as transitional to Inceptisols/Cambisols or Andisols/Andosols but, in some environmental conditions, they may be preserved as such over long periods.

Volcanic soils are widely dispersed on the Earth's surface, following the distribution of active and dormant volcanoes (Ugolini and Zasoski, 1979). However, most of these soils occur in areas with active volcanoes such as the Circum-Pacific Ring of Fire, in particular in central Andes (Zehetner et al., 2003), Hawaii (Loganathan, 1967; Hassan et al., 1975), Fiji (Naidu et al., 1986), New Zealand (Kirkman, 1980; Bakker et al., 1996), and New Guinea (Chartres and Pain, 1984). Other areas with active volcanism are in Africa along the Rift Valley and in Southern Italy. Where there is an active volcanism, the soils are fated to be buried by pyroclastic deposits, so becoming paleosols (Bäumler and Zech, 2000; Zehetner et al., 2003). The deposits (which general term is *tephra*) can be produced by fall or flow deposition

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from an eruptive plume. In a volcanic area, pyroclastic fall deposits are widely diffused and their distribution is conditioned by wind direction and eruptive intensity.

Mt Etna, in Southern Italy (Fig. 1), has a history of explosive eruptions in Late Quaternary that are recorded in the pyroclastic successions that blanket, with variable thickness, the slopes of the volcanic edifice (Coltelli et al., 2000). Earlier, these successions were interpreted as due to a phreatomagmatic activity and, hence, produced by a unique eruption (Guest et al., 1984; Chester et al., 1987) or distinct eruptive events (Kieffer, 1985). Then, Cortesi et al. (1988) recognized that paleosols were interbedded with layers of scoria or pumice lapilli and ash. Afterward, the sedimentary origin of these deposits was discussed by Coltelli et al. (2000). However, the presence of paleosols intercalated with pyroclastic layers slightly or not pedogenised indicates that the explosive events were alternated with phases favourable to the establishment of the pedogenesis. Since little is known on the development of volcanic paleosols (Zehetner et al., 2003) and similar situations to those of Mt Etna are common for the areas with active volcanoes, to study features of some etnean pyroclastic successions might allow assessing their origin and helping in reconstructing volcanoes activity.

In this paper we present stratigraphic, pedological, chemical and mineralogical features in order to reconstruct the events that originated the paleosols occurring in the pyroclastic successions on the flanks of the Etna volcano.

2. Studied sites

Mt Etna (Italy) is characterised by a quasi-persistent basaltic effusive and explosive activity, mainly concentrated at the summit craters. Because of the dominant winds direction, pyroclastic fall deposits occur mostly on the northeast, east and southeast flanks of the volcano and they have been grouped into five stratigraphic units: A, B, C, D and E; these latter run from about 100 kyr B.P. (before present) to the present, corresponding to five main periods of explosive activity (Coltelli et al., 2000). Three sites were selected for this study (Fig. 1). Two of them, Cubania and Mt Salto del Cane, belong to unit E, which is made of layers formed during the explosive activity of the last 12 kyr. The third site, Piano delle Concazze, was used for collecting observation and unaltered pyroclastic materials.

1) Cubania (37°45′08″ N, 15°04′13″ E) is a pine forest located in the municipal district of Zafferana Etnea, at an elevation of 1550 m. The mean annual precipitation is 1560 mm and the mean annual air temperature is 11.9 °C. The area hosts a vegetation made of *Pinus laricio* Poiret, *Quercus cerris* L., *Quercus robur* L., *Betula aetnensis* Rafin., *Populus tremula* L., with an understory of grasses and shrubs. The soil at the surface is an Andic Eutrudept (Soil Survey Staff, 2003). The stratigraphic section exposed at this site, the section n. 156 of Coltelli et al. (2000) and Del Carlo et al. (2004), is about 15 m deep and 20 m wide (Fig. 2) and shows depositions starting from about 10 kyr ago (Del Carlo et al., 2004). Within the section, two sequences were considered: the sub-sequence 1, with the upper layer at about 3 m below the soil surface in 2001, and the sub-sequence 2, with the upper layer at about 6 m below the same soil surface.
   The sub-sequence 1 (Fig. 3) has a thickness of about 1 m and is comprised between a tuff layer resting on a bed dated 2880 ± 60 years B.P. and an upper stratum lying 45 cm below the base of the deposits belonging to the marker eruption of the 122 B.C. (2128 years B.P. in Figs. 2 and 3) (Coltelli et al., 1998). From the top, the sub-sequence consists of a 3 cm thick tuff layer, a 7 cm thick layer of ash, an 18 cm thick lapilli layer with the uppermost 10 cm made of reddened material, a horizon 29 cm thick made of dark and light parts interpreted as A and Bw soil materials, a tuff layer 1 cm thick, and an apparently reworked A horizon 24 cm thick.
   The sub-sequence 2 (Fig. 4) is about 1 m thick and rests between two layers dating back 7110 ± 80 and 5640 ± 50 years (Del Carlo et al., 2004). This sub-sequence is characterised by three A horizons intercalated by tuff and scoria fall deposits interpreted as C horizons.
2) Mt Salto del Cane (37° 40’ 10’’ N, 15° 02’ 11’’ E) is a scoria cone located in a chestnut wood in the municipal district of Zafferana Etnea, at 1350 m above sea level. The mean annual precipitation is 1300 mm and the mean annual air temperature is 11.0 °C. Vegetation consists of *Castanea sativa* Miller, *Quercus robur* L., *Quercus cerris* L., with an understory of grasses and shrubs. The soil at the surface is an Andic Eutrudept (Soil Survey Staff, 2003). The outcrop is about 6 m deep and 10 m wide (Fig. 5). Within this exposure, the section n. 26 of Coltelli et al. (2000) and Del Carlo et al. (2004), a sequence of about 1 m was considered (Fig. 6). The upper layer of this sequence is 3 m below the soil surface in 2001 and dates back 5740 ± 240 years; the lower layer rests on a stratum of weathered cinders collapsing under fingers pressure. The sequence appears to be made of buried soils consisting of A and Bw horizons, with at the base an A/Bw horizon.
3) Piano delle Concazze is an almost-barren flat area at 2800 m above sea level. Climatic information on this site is scarce. In winter, the soil surface is frozen and covered by snow, while in July, at 2–3 cm below the surface, the soil may reach the temperature of 50 °C at noon, and 7–10 °C during night. During the explosive activity of the summit craters, the area accumulates large amounts of pyroclastites. In summer 1999, the surface was mantled by a thickness of 210 cm of black pyroclastic materials ejected during the 23/12/1995 lava fountain episode. Within this layer, from 15 to 150 cm of depth, the larger clasts hosted sand caps with a grey-yellowish colour. These sand caps are analogous to the silt caps reported by Washburn (1956, 1980) and Van Vliet-Lanöe (1988) but, at Piano delle Concazze, rather than by accretion of ice lenses, they were likely produced by illuviation of fine-to-medium sandy particles. Underneath the clasts with sand caps there were small silica pendents, whitish to pinkish in colour. The surface of the area is subjected to strong morphological transformations. Indeed, as a function of explosive energy, the area accumulates from few decimetres to meters of pyroclastites of various size, but with time this material is eliminated. For example, the layer

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