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Short communication

# Paleosols and pedostratigraphy

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A B S T R A C T

Paleopedology and pedostratigraphy are devoted to the use of buried and relict soils in interpreting the record of environmental conditions that are different from the current ones. As such, paleosols may be used in models that aim at predicting future earth system reactions to changing environmental conditions. Dated paleosols are an important part of the natural heritage and should be protected.

## 1. Paleosols

Paleosols are soils that formed, or started to form, in times earlier than recent and often under environmental conditions that were different from the current ones. They show horizons and features diverse from those of younger soils, formed in analogous present settings, because of a change of at least one soil forming factor, lasting enough time and acting so strong to affect the kind or rate of pedogenesis. Actually, many paleosols began to develop long periods ago and have little relationship in their chemical and physical characteristics to the present-day climate, vegetation, or topographic position.

We distinguish relict and buried paleosols (Retallack, 1998). Relict paleosols remain at the surface today and continue to develop, while buried paleosols have been buried by younger sediments such as loess, glacial till, colluvium or alluvium, and can be more or less modified from the burial and even diagenesed or petrified (Olson and Nettleton, 1998). Burial can cause modification of soil properties and features, especially in the uppermost horizons. An intermediate possibility is that of welded paleosols. Welded paleosols show sediments that have been pedogenetically incorporated in the soil profile, since the covering layer (e.g. aeolian, fluvial, colluvial) is not thick enough to isolate the underlying soil profile from pedogenesis. Such profiles can be called "Polygenetic".

Paleosols are a fundamental source of evidence for environmental processes that took place in the past and, as such, they may be used in models that aim at predicting future earth system reactions to changing environmental conditions. Large numbers of papers on paleopedology are continuously being published. We observe a progressive increase in the number of papers during the last 30 years (Fig. 1), especially in the last years, driven by the concern about climate change and the interest on the reaction of the earth system during analogue past climate changes (Sauer et al., 2008a,b, but also by the need to steer their management. In fact, paleosols frequently have low fertility and some limiting condition to agricultural use, because of long and deep weathering and leaching of nutrient (Retallack, 1978). However, moderate fertility of paleosols with low-grade plinthite has been found functional to produce high quality wine (Costantini and Priori, 2007) and some of the best terroir correspond to paleosols (Costantini et al., 2012; Retallack and Burns, 2016). In addition, where paleosols do not dominate the soilscape, likewise in countries without a tropical climate, they can host endemisms, which increase the biodiversity of a land. Actually, an empirical correlation between paleosol diffusion, pedodiversity, and biodiversity, has been demonstrated (Ibañez et al., 1995; Costantini and L'Abate,2016a,b).

Along with paleosols genesis, the focuses of paleopedological research are:

i) the reconstruction of paleo environmental characteristics and development, in particularly climate. That is, the use of soil characteristics as proxies of palaeo-environmental conditions and time

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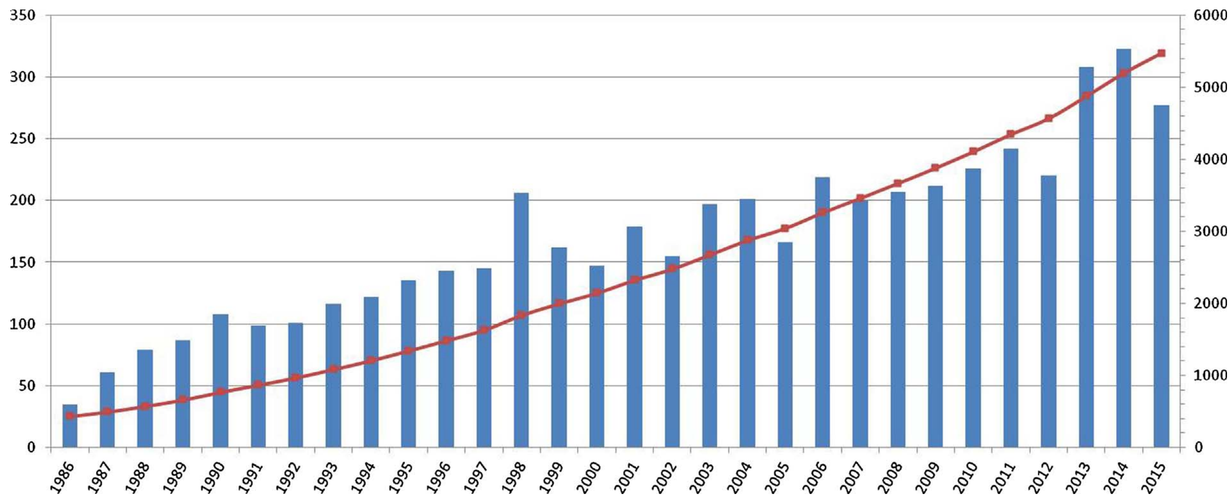


**Fig. 1.** Papers dealing with paleosols during the years 1986–2015 (Scopus database). Published works and cumulative curve.

of surface formation (a.o. Costantini and Damiani, 2004; Sauer, 2010; Carnicelli and Costantini, 2013);

ii) the quantification of pedogenic processes, studied in soil chronosequences established on sequences of river terraces (a.o. Torrent, 1976; Arduino et al., 1984; Ajmone Marsan et al., 1988; Bain et al., 1993; Tsai et al., 2006), marine terraces (a.o.Muhs, 1982; Scarciglia et al., 2006; Tsai et al., 2007; Wagner et al., 2007; Sauer et al., 2010), beach ridges (a.o. Sauer et al., 2007; Sauer et al., 2008a,b), moraines (a.o.Egli et al., 2001), dunes of different ages (a.o.Lichter, 1998), volcanic (a.o., Dazzi, 2007; Jahn et al., 1987; Solleiro-Rebolledo et al., 2015), colluvial (a.o.Costantini et al., 2006), or loess depositions (a.o. Bronger, 2003; Costantini et al., 2009; Sauer et al., 2015);

iii) Heritage soil documentation and protection. Paleosols store information about the environmental conditions during their genesis and thus reflect the natural and cultural heritage of the landscape. This particular nature of paleosols, referred to as "soil memory" (Targulian and Goryachkin, 2004; Costantini et al., 2007a), makes them particularly valuable among the various earth soil bodies.

## 2. Pedostratigraphy

Adding soil and paleosol information to geological mapping has always been a challenge for both paleopedologists and geologists (Morrison, 1993). The North American Commission on Stratigraphic Nomenclature (1983) has defined the concept and application of pedostratigraphic unit as "a buried, traceable, three-dimensional body of rock that consists of one or more differentiated pedologic horizons" (*UBSU*. Unconformity-bounded Stratigraphic Units). The upper and lower boundaries of a pedostratigraphic unit correspond to the soil horizons formed by pedogenesis in a buried soil profile. A pedostratigraphic unit is characterized by the range of physical and chemical properties in the type area, rather than by "typical" properties exhibited in a type section. A pedostratigraphic unit has a consistent stratigraphic position and is defined at a type locality where the horizons are buried by younger deposits, but may be traced to sites where it crops out on the present land surface. The term "pedostratigraphic unit" is frequently considered a synonym of "Geosol" (WG on Definitions used in Paleopedology, 1997). Using the Geosol concept, inter-regional or even global correlation of buried paleosols, and loess-paleosol sequences, were proposed by Rutter et al. (1991), Benvenuti et al. (2002), Bronger (2003), Jacobs et al. (2009), Marković et al. (2015), Sycheva and Khokhlova (2016).

Costantini et al. (2007b) worked out the concept of "pedostratigraphic level", which differentiates from that of "pedostratigraphic unit" or "Geosol" since it can be applied to non-buried paleosols. The rationale is that the whole soil body, from the soil surface downwards, can be classified in levels according to genetic characteristics and degree of weathering. Therefore, a pedostratigraphic level (PL) is considered as a characteristic assemblage of similar genetic soil horizons, formed by materials having the same degree of weathering, and an estimated age through correlation to benchmark soils. Thus a PL is a three-dimensional soil layer with:

1. traceable upper and lower boundaries
2. showing a characteristic assemblage of similar soil genetic horizons (e.g., Bt1, Bt2, etc.)
3. formed in materials having a certain degree of weathering (e.g., clay minerals assemblage, free crystalline iron content) and
4. having an age that is estimated by means of direct dating or correlation with dated horizons.

This approach needs the characterization of soil profile horizons according to two criteria: i) the expression of pedofeatures, leading to the identification of a class of genetic horizon, and ii) the degree of weathering of the parent material. Both criteria are related to the five soil forming factors, but the second one provides better clues on the duration of pedogenesis. In addition, the decoupling of the two criteria allows to clearly separate pedofeatures formed either in fresh or pre-weathered materials. This can be useful to distinguish, for instance, soils formed from unweathered sediments deposited in-situ and not reworked, from those developed in colluvia, where already weathered soil sediments accumulated.

Similar to mapping Geosols in buried paleosols, tracing pedostratigraphic levels (PLs) in relict paleosols is a four-dimensional approach in the study of soils and associated sediments, integrating field and laboratory analyses. It takes into account both horizontal as well as vertical field soil variations and time pegs determined in the laboratory.

The methodology can be summarized in the following 8 steps:

1. soils are placed in their geomorphological context,
2. sedimentological processes are recognized on natural or artificial sections,
3. soil profiles are described and analysed, in order to identify genetic processes characterizing each soil horizon and to highlight discontinuities,
4. the degree of weathering of the parent material of each soil horizon is assessed, by means of selected aging indicators,
5. time pegs are fitted by means of laboratory datings and proxies,
6. horizons with same genetic processes and degree of weathering of