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COMPARISON OF PRE-AD 79 ROMAN PALEOSOLS IN TWO CONTRASTING PALEO-TOPOGRAPHICAL SITUATIONS AROUND POMPEII (ITALY)

ABSTRACT: VOGEL S. & MÄRKER M., *Comparison of pre-AD 79 Roman paleosols in two contrasting paleo-topographical situations around Pompeii (Italy)*. (IT ISSN 0391-9838, 2012).

Two transects of 13 stratigraphical cross-sections were studied and 7 pre-AD 79 Roman paleosols were analysed in two contrasting paleo-topographical situations northwest (Boscoreale) and south (Moreggine) of ancient Pompeii. The pre-AD 79 paleosol properties were characterised and compared identifying individual paleocatenary relationships between soil parameter values and the paleo-landscape position along the two transects.

Furthermore, between the two study areas, pronounced differences in the paleosol characteristics were revealed. Most notably, they seem to be related to the presence or absence of post-burial groundwater influence in the originally terrestrial pre-AD 79 paleosols. Under the recent influence of groundwater dynamics the paleosols are characterised by: (i) higher amounts of organic carbon and nitrogen, (ii) a darker Munsell color of the top soil, (iii) lower amounts of calcium carbonate, (iv) increased sulphate concentrations together with a decreased pH value and (v) redoximorphic features in the overlying AD 79 pumice layer.

Moreover, the different thickness of the AD 79 pyroclastic deposits that buried the pre-AD 79 paleosols reflects the volcanogenic processes that took place during the explosive eruption of Somma-Vesuvius in AD 79.

KEY WORDS: Somma-Vesuvius; AD 79; Pompeii; Paleo catena; Paleosol; Paleo-topography.

RIASSUNTO: VOGEL S. & MÄRKER M., *Confronto fra paleosuoli romani pre-AD 79 dei dintorni di Pompei (Italia) in due differenti ambienti paleo-topografici.*. (IT ISSN 0391-9838, 2012).

In questo lavoro presentiamo lo studio di 13 sezioni stratigrafiche e di 7 paleosuoli anteriori all'eruzione del Somma-Vesuvio dell'anno 79 AD, articolato in due transetti ubicati in due situazioni paleo topografiche differenti, a Nord Ovest (Boscorele) e a Sud (Moreggine) degli scavi di Pompei. Le proprietà di tali paleosuoli pre-AD 79 sono state caratterizzate e comparate identificando le relazioni fra i parametri pedologici di ciascuno di essi e la rispettiva posizione paleo-topografica lungo i transetti.

Sono state individuate differenze significative nelle caratteristiche dei paleosuoli fra le due aree di studio. È risultata evidente l'influenza della presenza o assenza di acqua di falda dopo la sepoltura dei suoli originalmente terrestri del 79 AD. I paleosuoli che dopo del 79 AD hanno risentito dell'influenza di acqua di falda sono caratterizzati da: i) un contenuto maggiore di carbonio organico e azoto, ii) un colore (Munsell) più scuro del primo orizzonte, iii) valori più bassi di carbonato di calcio, iv) aumento della concentrazione di solfati, insieme con un decremento del pH, v) caratteristiche figure pedologiche da ossido-riduzione nello strato di pomici sovrastanti il paleosuolo.

È stato infine confermato che i differenti spessori dei depositi piroclastici che hanno sepolto i suoli studiati riflettono la natura dei processi vulcanici che hanno caratterizzato la eruzione esplosiva del Somma-Vesuvio dell'anno 79 AD.

TERMINI CHIAVE: Somma-Vesuvius; AD 79; Pompei; Paleo-catena; Paleosuolo; Paleo-topografia.

INTRODUCTION

Between buried paleosols that are attributed to the same buried landsurface, complex paleocatenary relationships can exist. This soil characteristic is mainly assigned to lateral variations in paleosol properties as a result of differing paleo-landscape positions and drainage regimes and

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cannot be produced by sedimentation and diagenesis (Dalrymple & *alii*, 1968; Valentine & Dalrymple, 1975). In practice such paleocatenary relationships are often difficult to establish (Fenwick, 1985), e.g. due to:

(i) an insufficient spatial extent of burial to cover an extensive soil landscape (e.g. in case of alluvial sedimentation),
(ii) a rate of sedimentation being too slow to immediately and effectively isolate the buried soils from recent surface processes and thus to preserve paleocatenary relationships over time (e.g. in case of aeolian sedimentation),
(iii) a lack of finds or only isolated, discontinuous finds of buried paleosols,
(iv) difficulties to laterally trace buried paleosols, date and clearly assign them to the same paleo-landsurface.

Due to the formation of pyroclastic fallout and the high intensity emission of large amounts of pyroclastic material explosive volcanic eruptions are spatially extensive and, depending on stratospheric wind direction and wind speed, can almost instantly mantle a large area with thick volcanic deposits (Self, 2006). Consequently, explosive volcanic eruptions can create a good preservation environment for landsurfaces and hence are particularly suitable for soil geomorphologic studies of buried soil sequences.

In the history of Somma-Vesuvius volcanic complex (Campania, Italy) the peri-volcanic territory was repeatedly buried by volcanic deposition. Important protohistoric and historic explosive eruptions of Somma-Vesuvius are Mercato/Ottaviano (7,070-6,770 BC), Avellino (1,890-1,630 BC) and Pompeii (AD 79) (e.g. Delibrias & *alii*, 1979; Santacroce, 1987; Rolandi & *alii*, 1993a,b; Andronico & *alii*, 1995; Civetta & *alii*, 1998; Sigurdsson, 2002). Due to the characteristic stratigraphy associated to explosive volcanic eruptions their deposits can be used as chronostratigraphic markers to identify the pre-eruption landsurfaces (Druitt & *alii*, 2002).

The explosive eruption of Somma-Vesuvius in AD 79, one of the most well-known volcanic eruptions in the antiquity, caused the burial of its south-eastern territory and destroyed the Roman settlements of Pompeii and Herculaneum (Lirer & *alii*, 1973; Sigurdsson & Carey, 2002). In a very short time of only 19 hours the entire ancient landscape of the Sarno River plain was covered by pyroclastic deposits of approximately 3.4 m (mean and median, determined from 1,236 stratigraphical drillings distributed in the Sarno River plain; for further explanations see Vogel & *alii*, 2011). The burial in AD 79 caused an excellent conservation of the pre-AD 79 landsurface and the pre-AD 79 paleosols of this ancient landscape (Foss & *alii*, 2002). Thus, it allows for the study of both stratigraphical and paleo-pedological characteristics and their correlation with the particular paleo-topographic situation of the research area.

First paleo-pedological analyses around Pompeii were carried out by Foss (1988), Scudder & *alii* (1996) and Foss & *alii* (2002). They investigated paleosols from isolated, discontinuous finds taking samples in quarries and archaeological excavations and analysed the morphological, physical and chemical soil properties. Topographic reconstructions of the pre-AD 79 landscape features such as the ancient coastline, the ancient fluvial network and floodplain using litho-stratigraphical data from core drillings and archaeological sections were presented by several authors such as Cinque & Russo (1986), Livadie & *alii*, (1990), Furnari (1994), Pescatore & *alii*, (1999), Di Maio & Pagano (2003), Stefani & Di Maio (2003), Vogel & Märker (2010) and Vogel & *alii*, (2011).

A first soil geomorphologic study in the Sarno River plain using the paleocatena concept (Dalrymple & *alii*, 1968; Valentine & Dalrymple, 1975) was carried out by Vogel & Märker (2011). They characterized the pre-AD 79 Roman paleosols in their associated paleo-topographic situation along two transects south of Pompeii (Moreggine). Through comparison of paleosol properties with its paleo-landscape position along the transects a correlation between soil parameter values and paleo-topography was revealed. At Moreggine, the spatial distribution of paleosol characteristics is mainly a function of soil development in relation to elevation and distance from the paleo-floodplain of the paleo-Sarno River network (Vogel & Märker, 2011).

In the present study, the litho-stratigraphical and pedological data of Moreggine is partly utilized and combined with newly obtained data from northwest of Pompeii (Boscoreale). The objectives are twofold: (i) the characterization of the pre-AD 79 paleosols in their paleo-topographic situation to identify paleocatenary relationships and (ii) the comparison of the pre-AD 79 Roman paleosols developed in two contrasting paleo-topographies and thus under differing pedogenetic constraints.

RESEARCH AREA

The Sarno River plain is situated in the south of Italy and is embedded between the volcanic complex of Somma-Vesuvius (1,281 m a.s.l.) in the north and the Apennine mountain range in the south (Lattari Mountains, Monte Faito: 1,131 m a.s.l.) and in the east (Sarno Mountains). It is drained by the Sarno River fluvial network into the Tyrrhenian Sea (Gulf of Naples) in the west. The Sarno River plain covers an area of approximately 210 km^2 and can be subdevided into the following geomorphological landscape units: (i) Tyrrhenian coast, (ii) alluvial plain, (iii) footslopes of the volcanic edifice of Mount Somma-Vesuvius, and (iv) footslopes of the carbonatic rocks of the Lattari and Sarno Mountains (fig. 1).

The research area is characterized by a Mediterranean climate with almost 70% of the mean annual precipitation falling between October and March and a pronounced dry summer season. The soils of the Sarno River plain are particularly influenced by the volcanic activity of Somma-Vesuvius. They develop on ash, pumice lapilli fallout, scoria, pyroclastic surges and lava flows whereas pedogenesis especially depends on the characteristics of these different volcanic materials as well as the pedoclimatic conditions, anthropogenic activity and time (Lulli, 2007). Three sub-

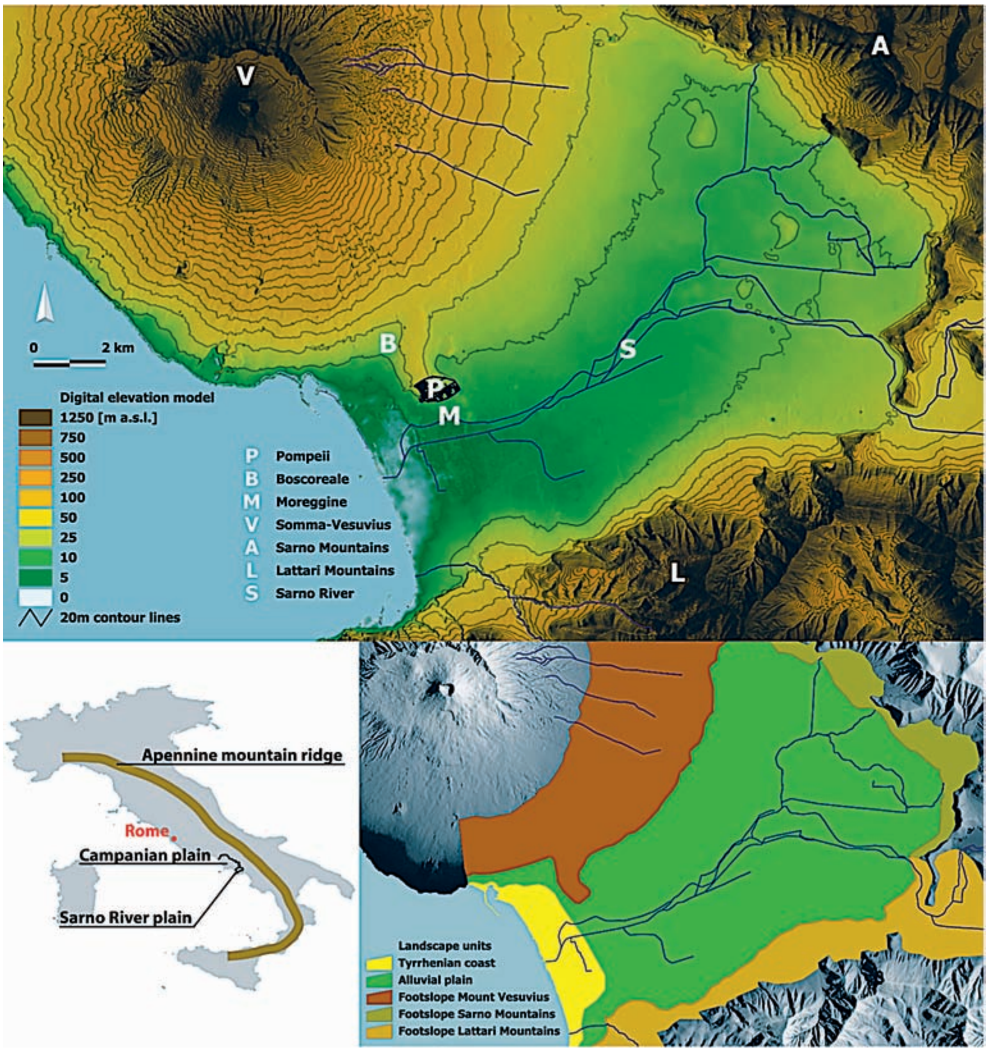

FIG. 1 - Digital elevation model of the Sarno River plain with the location of the study areas (top) and the different landscape units (bottom right). The small scale map (bottom left) shows Italy with the location of the research area and the Apennine mountain ridge.

groups of soil formation can be distinguished for the Sarno River plain (Di Gennaro & Terribile, 1999, modified):

(i) soils on old pyroclastic deposits showing weak to moderate profile differentiation and vitric, vitrandic or andic properties,

(ii) calcareous volcanic soils with mollic features developing on pyroclastic deposits containing calcium carbonate (Lattari and Sarno Mountains) and

(iii) weakly developed soils (Regosols) on lapilli and ash from the 1944 eruption of Mount Vesuvius.

The vegetation and landuse of the Sarno River plain can be subdivided into three different zones. The slopes of Somma-Vesuvius in the north are characterized by deciduous, coniferous and mixed forests as well as mediterranean scrubland (macchia). The Apennine Mountains (Lattari and Sarno Mountains) in the south and in the east are dominated by deciduous forests and mediterranean scrubland whereas the river plain is highly urbanized and intensively agronomically utilized (CORINE land cover 2000, Italian National Institute for Environmental Protection and Research, ISPRA).

The volcanic stratigraphy of the AD 79 eruption of Somma-Vesuvius can be divided into two main depositional units reflecting the main eruptive phases (Cioni & *alii*, 1992). It begins with the Plinian fallout phase in which a high eruption column and an eruption cloud was generated. The associated fallout deposits consist of a layer of white phonolitic pumice lapilli which is followed by a layer of grey tephritic phonolitic pumice lapilli. At times the white and grey pumice layer is separated by a thin layer of grey volcanic ash announcing the transition to the second eruptive phase of pyroclastic density currents (PDCs). The PDCs are the results of several cycles of collapse and recovering of the eruption column due to the progressive evacuation of the magma chamber. They consist of thin layers of grey, poorly-sorted ash exhibiting cross bedding and dune structures (see Sigurdsson & *alii*, 1985; Cioni & *alii*, 1992; Lirer & *alii*, 1993).

In the present study pre-AD 79 Roman paleosols are characterized along transects in two topographically contrasting locations, i.e. in the area of Moreggine and Boscoreale. The Moreggine transect is situated in the river plain, south of the archaeological excavation of Pompeii. Its runs approximately 950 m from the north to the south and shows an elevation between 11 and 5 m a.s.l.. The Boscoreale transect, on the other hand, is situated northwest of ancient Pompeii at the transition between the alluvial plain and the footslopes of Somma-Vesuvius volcanic complex. It has a northwest-southeast extent of approximately 1,500 m and crosses the longitudinal depression between the slopes of the Pompeiian hill and Somma-Vesuvius (fig. 1, 2). The absolute elevation ranges from 24 to 50 m a.s.l..

METHODS

To provide a detailed characterization of the pre-AD 79 Roman paleosols in their associated paleo-topographical situation two transects comprising 13 stratigraphical core drillings were conducted in the area of Moreggine and Boscoreale. The drillings were carried out mechanically extracting a core of approximately 15 cm in diameter. The drill cores were cut into segments of 1 m, packed into storage cassettes and finally labeled. In the field the stratigraphies were photo documented and the individual strata were identified, measured and macroscopically described. The stratigraphical cross-sections of the study areas were modelled by interpolation of the drilling points using:

(i) x-y-location coordinates of the drilling points (using a differential GPS),
(ii) the absolute elevation of the present-day surface (using a differential GPS),
(iii) the depths and thicknesses of the individual strata and
(iv) their classification in terms of lithofacies from the lithostratigraphical description.

From those stratigraphies containing pre-AD 79 Roman paleosols underneath the pyroclastic deposits of AD 79, the paleosol substrate was sampled for further laboratory analysis. The following soil physical and chemical analyses were carried out:

(i) soil pH measured in 1 M $CaCl_2$ (DIN ISO 10390),
(ii) soil texture of the fine earth fraction by wet sieving and sedimentation following Stokes' law (1845) after dispersing the sample with 0.2 N Na-pyrophosphate (DIN ISO 11277). Due to the presence of poorly-ordered aluminium silicates in volcanic soils and the arising difficulties to disperse the sample the particle size was only used in classes and on a relative scale (Mizota and Van Reeuwijk, 1989; Meijer & *alii*, 2007),
(iii) total organic carbon (TOC) and total inorganic carbon (TIC) by elementary analysis using the dry combustion reference method (DIN EN 13137),
(iv) total nitrogen using the modified method of Kjeldahl (DIN ISO 11261),
(v) sulfate ions (SO_4^{2-}) by complexometric titration with barium chloride (BaCl2) (DIN 38405 D5, 1985).

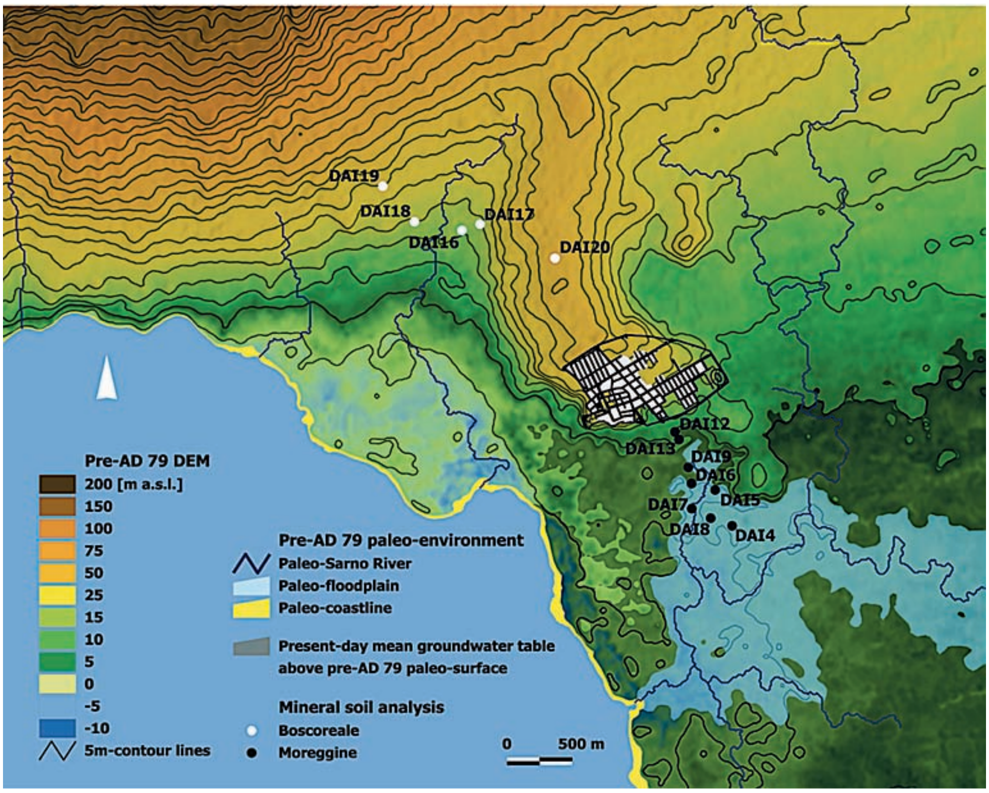

FIG. 2 - Location of the litho-stratigraphical and pedological investigations (Boscoreale, northwest of Pompeii and Moreggine, south of Pompeii) illustrated on the pre-AD 79 topography of Vogel & *alii* (2011) The shaded area represents the zone where the pre-AD 79 paleosol is recently influenced by a fluctuating groundwater table.

(vi) effective cation exchange capacity (CEC_{eff}) and the amount of exchangeable base cations by sequential extraction with unbuffered ammonium chloride,

(vii) ammonium-oxalate extractable Fe, Al and Si by flame atomic absorption spectrometry (AAS) and inductively coupled plasma atomic emission spectrometry (ICP-AES).

By comparing the stratigraphical sequences and the paleosol's mineral soil properties with the paleo-landscape position along the transects paleocatenary interrelations can be revealed. Finally, specific paleosol characteristics of Boscoreale and Moreggine allow for the comparison of the paleosols in two contrasting paleo-topographical situations.

RESULTS AND DISCUSSION

Figure 2 shows the location of Boscoreale and Moreggine in relation to the pre-AD 79 topography reconstructed by Vogel & *alii* (2011). In figure 3 a cross-sectional slice through the stratigraphy of the two transects can be seen. table 1 characterises the main litho-stratigraphical units of the core drillings whereas in tables 2 and 3 soil physical and chemical properties of the pre-AD 79 paleosols are summarised. In this section, at first, the paleo-topography, stratigraphy and paleosols of Boscoreale and Moreggine are characterized separately which is followed by a comparison of the two topographic locations.

Boscoreale

At the location of Boscoreale the pre-AD 79 paleo-surface runs nearly parallel to the present-day surface in a depth between 7.4 and 9.3 m (fig. 3). The overlying volcanic deposits of the AD 79 eruption of Somma-Vesuvius are approximately 5.4 m in thickness whereupon the pumice layer is 2.6 m and the PDC layer is 2.8 m thick.

Comparing the thickness of the AD 79 volcanic products with the paleo-topography of the Boscoreale transect it is striking that the PDC deposits are thinner at the slopes of Somma-Vesuvius (DAI 19) and the Pompeiian hill (DAI 20) and thicker in the depression in between (DAI 17, DAI 18). In contrast, the pumice fallout seems to be thicker at the slopes and thinner in the depression. These antithetic deposition features can be explained by the geomorphic processes that occurred during the eruption of Somma-Vesuvius in AD 79. The initial Plinian phase causing the pumice fallout from the eruption cloud had a coating effect on the pre-AD 79 topography. Then, with the gravitational collapse of the eruption column several PDCs were generated. Especially the movement of the

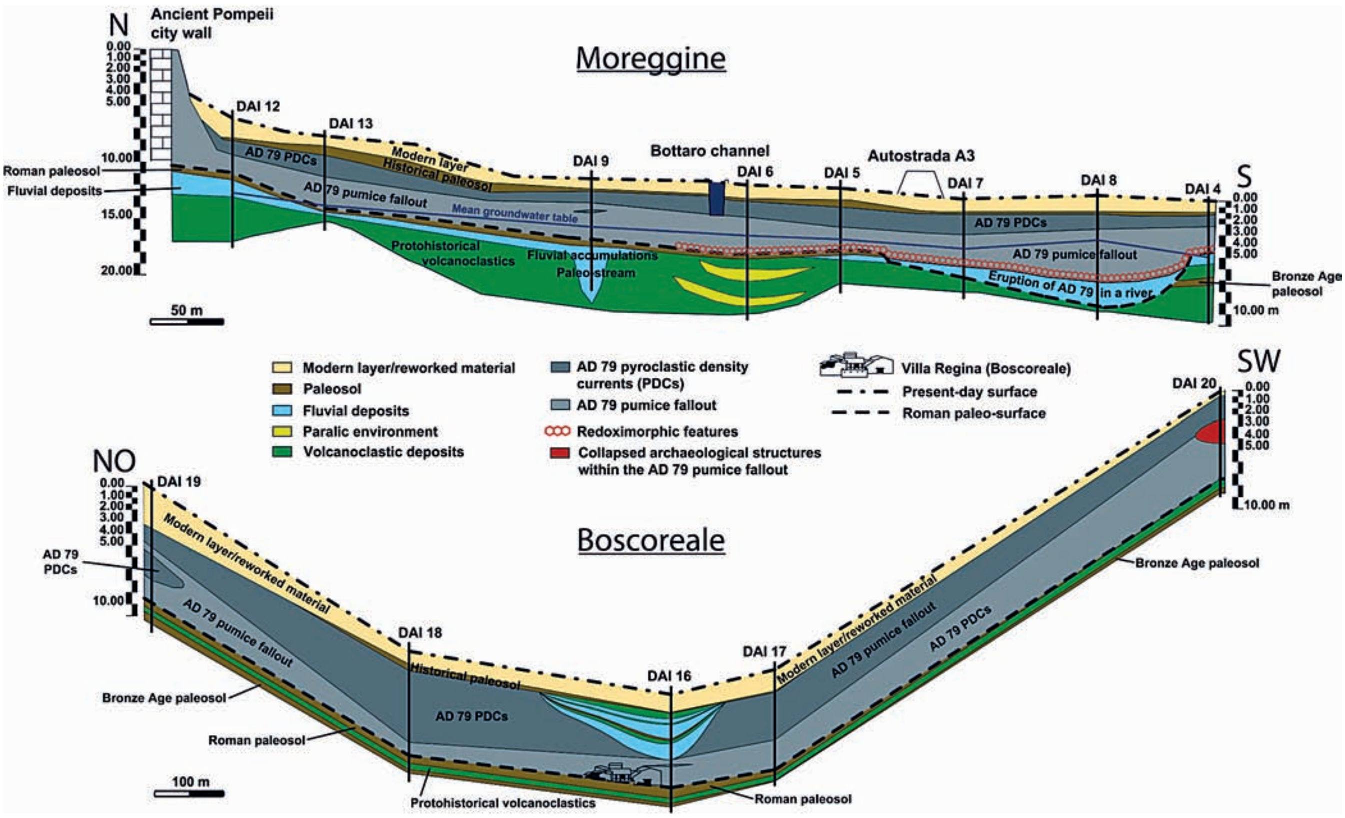

FIG. 3 - Stratigraphic cross-sections of the north-south transect at Moreggine and the northeast-southwest transect at Boscoreale as interpolated from the drilling data. Note the different horizontal scales.

lower, dense part of a PDC is strongly controlled by topographic irregularities as it follows valleys and river channels (Barberi & *alii*, 1978; Sparks & *alii*, 1978; Thouret, 2010). Therefore, in Boscoreale the PDC deposits are accumulated in the longitudinal depression between Somma-Vesuvius and the Pompeiian hill. Channeling of the PDCs controlled by the topography is also the reason why the pumice fallout deposits are thinnest in the depression, i.e. the PDCs eroded the initially deposited pumice layer and carried it away. Vogel & Märker (ongoing research) observed the high erosive power of the AD 79 PDCs at the southern slopes of Somma-Vesuvius resulting in a very thin or even missing layer of AD 79 pumice fallout deposits underneath. Calder & *alii* (2000) explained this by the incorporation of the freshly deposited material into the PDC due to interactions between the particles during PDC movement.

Subsequent to the eruption of AD 79, at DAI 16, which is the deepest point on the Boscoreale transect, the AD 79 PDC deposits seem to be eroded by fluvial processes as the AD 79 volcanic material is truncated and overlain by fluvial sediments (fig. 3). They are characterized by accumulations of bedded grey to black gravel within a sandy or loamy matrix containing reworked, rounded and mostly sorted pumice and lithic clasts. On top of that follow thin layers of volcanoclastics and pedogenized substrate and again thick layers of fluvial deposits. The volcanoclastic deposits consist of grey volcanic ash and scattered clasts of small-sized pumice and scoria whereas the intercalated paleosol contains greyish brown loamy sand of volcanic origin that shows signs of humus accumulation and weathering. This succession reflects different cycles of volcanic activity and volcanic quiescence in terms of pedogenesis or water-induced erosion and redeposition.

The water erosion can be explained by a convergence of the main water discharge in the depression between the Pompeiian hill and Somma-Vesuvius volcano. This is reflected by a pre-AD 79 paleo-channel near DAI 16 (fig. 2) as well as a high topographic wetness index deduced from the pre-AD 79 digital elevation model of the Sarno River plain (Vogel & Märker, 2010; Vogel & *alii*, 2011). The increased occurrence of fluvial deposits after AD 79 may be related to the fact that after burial by volcanic deposition, the Sarno River plain, and especially the slopes of Somma-Vesuvius, have been a bare landscape free of vegetation and covered with loose, unconsolidated volcanic material. This may have created very unstable conditions leaving the slopes vulnerable to severe soil erosion processes especially during intense rainfall events. Soil erosion and the destruction of the vegetation cover cause a reduction of the water retention capacity which results in increased surface runoff and increased soil erosion of the mountain slopes, a self-reinforcing process. Cinque & *alii* (2000) and Cinque & Robustelli (2009) state for the southern Lattari Mountains that directly after the eruption of AD 79 catastrophic syn-eruptive erosion events in terms of debris flows and landslides occurred for a period of several decades.

Underneath the volcanic deposits of AD 79 the pre-AD 79 paleosol can be found. It is composed of fine

TABLE 1 - Characterization of the main litho-stratigraphical units found at Moreggine and Boscoreale

Litho-stratigraphical unit	Description
Modern layer	For the sake of clarity the following three litho-stratigraphical units were combined under the term «modern layer»: (i) present-day soil substrate with clear evidence of humus accumulation and soil weathering, (ii) modern reworked material or anthropogenic disturbed substrate showing no signs of pedogenesis, (iii) thin layers of buried soil substrates and intercalated volcanoclastic deposits from modern eruptions of Mount Vesuvius.
Historical paleosol	Paleosols of volcanic parent material with signs of humus accumulation and weathering. They are overlain by pyroclastic deposits of a historical eruption of Mount Vesuvius.
AD 79 PDCs	The AD 79 pyroclastic density currents (PDCs) consist of several thin layers of grey poorly-sorted ash exhibiting cross bedding and dune structures. They can contain pisolites (concretionary ash grains) of approximately 1 cm in diameter.
AD 79 pumice fallout	The AD 79 pumice fallout is divided into two different pumiceous materials reflecting variations in the density and chemical composition of the magma: (i) a layer of well-sorted phonolitic white pumice lapilli that is overlain by (ii) a layer of phono-tephritic grey pumice lapilli. At times the lower section of the pumice layer can contain red Fe(III)-oxide concretions indicating the influence of modern groundwater fluctuations.
Roman paleosol	The pre-AD 79 Roman paleosol is situated underneath the AD 79 volcanic deposits of Somma-Vesuvius. It consists of sandy loam, is compacted and colored dark brown to grey. It is characterized by the formation of a dark humus A horizon and sometimes by an initial Bw weathering horizon. It is composed of fine weathered ash, pumice lapilli and lithic clasts. Sometimes traces of agricultural use and former vegetation as well as charcoal and fragments of ceramics can be found.
Fluvial deposits	Fluvial deposits consist of accumulations of black fluvial gravel within a sandy or loamy matrix. They contain rounded pumice and lithic clasts mostly sorted in thin layers of different deposition cycles. Sometimes also fragments of travertine can be found.
Paralic deposits	Successions of heterogeneous, stratified blackish sands and gravels of volcanic origin, sorted and strongly reworked. It can contain fenocristals of augite and leucite and rounded/flattened pebbles of reworked pumice and calcium carbonate.
Protohistorical volcanoclastics	Grey volcanic ash of sandy to gravelly texture. It can contain intercalated bands of small-sized lapilli and scoria.
Bronze Age paleosol	The Bronze age paleosol consists of reworked pyroclastic ash, has a brown to black color, is compacted and shows signs of humus accumulation and weathering.

weathered ash, pumice lapilli and lithic clasts from the protohistorical activity of Somma-Vesuvius. From the stratigraphic sequence and by comparison with the volcanic history of Somma-Vesuvius, at Boscoreale, this protohistoric volcanic activity can most likely be narrowed down to the Avellino eruption or the following AP1/AP2 eruption which are composed of tephritic phonolites to phonolites. At DAI 16 AP2 pyroclastic products could be clearly detected. This implies an approximate time span between 3,450 BP and 3,000 BP (Andronico & Cioni, 2002 and references therein).

The pre-AD 79 paleosol mainly consists of sandy loam, is compacted and colored dark brown to grey. It is characterized by the formation of a dark humus A horizon and sometimes by an initial Bw weathering horizon. Sometimes traces of agricultural use and former vegetation as well as charcoal and fragments of ceramics can be found.

Some differences in the soil properties of the pre-AD 79 paleosols can be explained by their specific paleo-topographical location along the Boscoreale transect. The paleosols are between 0.5 m (DAI 17) and 1.0 m (DAI 16) thick showing a gradient of increasing soil thickness from the slopes of the Pompeiian hill and Somma-Vesuvius towards the bottom of the depression. This is due to the fact that the hillslopes are predominantly subject to erosion processes whereas the eroded material is accumulated in the depression on top of the existing soil and finally incorporated into the profile.

The soil texture class of DAI 17 and DAI 18 is consistently sandy loam. However, at DAI 16 the soil texture alternates within the entire soil profile between loam and sand. This layering may reflect the influence of hydrological processes in the longitudinal depression in terms of different deposition and erosion cycles being active during the development of the soil profile. This is due to a much larger hydrological catchment area at DAI 16 compared to the soils at the hillslopes and is again supported by the pre-AD 79 paleo-channel which runs only 120 m away from DAI 16 (fig. 2). Consequently, the pH value and the effective cation exchange capacity (CEC_{eff}) at DAI 16 are lower compared to the hillslope paleosols which may refer to a more pronounced leaching especially affecting the amount of exchangeable calcium.

MOREGGINE

At the location of Moreggine, south of ancient Pompeii, the post-AD 79 deposits are much thinner compared to Boscoreale hence the pre-AD 79 paleo-surface is located in a depth of only 5.5 to 6.4 m (fig. 3). Like in Boscoreale, the paleo-surface runs more or less parallel to the present-day surface. The overlying volcanic deposits of AD 79 are thinner (4.5 m) in Moreggine even though the AD 79 pumice fallout is slightly thicker (2.8 m) compared to Boscoreale. However, the PDC layer is considerably thinner showing a thickness of only 1.6 m. Above all this is due to the greater distance of Moreggine to the vent of Somma-Vesuvius, the source of the AD 79 eruption. For Moreggine it amounts to approximately 10 km linear distance compared to only 8 km for Boscoreale. Following Sigurdsson & Carey (2002) the first three PDCs (S-1, S-2, S-3) did not reach further than to the footslopes of Somma-Vesuvius. S-4 and S-5 overwhelmed Pompeii and the last PDC S-6 even reached further south to the foot of the Lattari Mountains. Consequently, whereas Boscoreale, northwest of Pompeii, was probably hit by all six PDCs,

TABLE 2 - Soil properties of the Roman paleosols of Boscoreale

												Exchangeable cations [cmolc/kg]								
		Depth [m]	Soil texture class	Munsell soil color	pH ($CaCl_2$)	$CaCO_3$ [%]	TOC [%]	N [%]	C/N	CEC_{eff} [$cmol_c$/kg][a]	eff. base saturation [%]	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al_{ox} [%]	Fe_{ox} [%]	Si_{ox} [%]	Al_{ox}+0.5Fe_{ox} [%]	SO_4^{2-} [mg/l]
Boscoreale	DAI 16	8.0-8.1	sL	10YR4/2	7.13	0.79	0.89	0.08	11.25	13.96	100	2.03	1.32	9.47	1.17	1.09	0.41	0.72	1.30	0.6
		8.1-8.2	sL	10YR3/2	7.06	0.70	0.85	0.08	11.23	13.92	100	1.96	1.30	9.53	1.16	1.44	0.50	0.97	1.69	0.6
		8.2-8.3	L	10YR3/2	7.08	0.64	0.95	0.08	11.26	13.48	100	2.01	1.32	9.02	1.17	1.46	0.56	1.03	1.74	0.6
		8.3-8.4	L	10YR3/2	7.09	0.63	0.95	0.08	11.49	13.41	100	2.06	1.37	8.79	1.22	1.53	0.56	1.02	1.81	0.6
		8.4-8.5	sL	10YR3/2	6.96	0.49	0.06	0.01	12.67	18.42	100	2.80	0.99	13.24	1.43	0.24	0.31	0.10	0.40	0.2
		8.5-8.6	S	10YR4/2	6.97	0.56	0.06	0.01	9.25	22.05	100	3.44	0.62	16.51	1.53	0.22	0.36	0.09	0.40	0.2
		8.6-8.7	lS	10YR4/2	6.86	0.68	0.33	0.02	21.16	20.88	100	3.38	0.71	15.43	1.41	0.31	0.42	0.16	0.52	0.2
		8.7-9.0	sL	10YR3/2	7.20	0.80	0.97	0.08	12.46	20.27	100	3.34	0.75	14.90	1.33	1.28	0.59	0.83	1.58	0.3
	DAI 17	9.0-9.1	sL	10YR4/2	7.44	0.76	0.80	0.07	11.92	19.82	100	3.17	0.70	14.67	1.33	1.23	0.46	0.82	1.46	0.3
		9.1-9.2	sL	10YR3/2	7.30	0.69	0.84	0.07	12.06	19.98	100	3.19	0.74	14.73	1.36	1.28	0.52	0.86	1.54	0.3
		9.2-9.3	sL	10YR3/2	7.32	0.55	0.72	0.06	11.84	15.07	100	3.34	1.02	9.77	0.97	1.14	0.46	0.74	1.37	0.3
		9.3-9.4	sL	10YR4/2	7.32	0.71	0.84	0.07	11.77	10.35	100	3.49	1.26	5.02	0.58	1.24	0.45	0.79	1.46	0.3
		9.4-9.5	sL	10YR3/2	7.36	0.54	0.49	0.04	12.57	8.43	100	2.68	1.15	4.15	0.46	0.87	0.51	0.57	1.12	0.2
	DAI 18	9.3-9.4	sL	10YR4/2	7.53	1.62	0.34	0.01	25.65	17.16	100	1.63	0.66	13.85	1.07	0.35	0.29	0.14	0.50	0.7
		9.4-9.5	sL	10YR4/2	7.53	1.07	0.29	0.02	15.61	19.56	100	1.61	0.64	16.11	1.25	0.31	0.28	0.14	0.46	0.6
		9.5-9.6	sL	10YR3/2	7.53	1.97	0.61	0.04	17.10	21.00	100	1.56	0.63	17.48	1.38	0.58	0.37	0.26	0.77	0.6
		9.6-9.7	sL	10YR3/2	7.23	0.62	0.67	0.06	10.39	19.23	100	2.24	0.74	14.78	1.52	0.64	0.35	0.35	0.81	0.6
		9.7-9.8	sL	10YR3/2	7.17	0.46	0.44	0.04	11.55	18.43	100	2.95	0.89	12.93	1.71	0.50	0.37	0.26	0.68	0.5
		9.8-9.9	sL	10YR4/2	7.35	1.19	0.52	0.04	13.32	18.88	100	2.99	0.90	13.25	1.78	0.55	0.38	0.27	0.74	0.5
		9.9-10.0	sL	10YR4/2	7.55	1.26	0.39	0.02	20.41	18.76	100	3.00	0.88	13.12	1.81	0.41	0.37	0.18	0.60	0.4

ND-not detectable; soil texture classes: sL-sandy loam, L-loam, S-sand, lS-loamy sand, uL-silt loam

[a] In soil samples containing >1% $CaCO_3$ (calcite) the analysis of CEC_{eff} can cause a dissolution of $CaCO_3$ which may result in increased values of CEC_{eff} and exchangeable Ca^{2+} (Dohrmann & Kaufhold, 2009)

Moreggine, south of Pompeii, was only influenced by the last three PDCs. Hence they have created much thicker deposits in the area of Boscoreale compared to Moreggine. From a total of 739 stratigraphical drillings that are distributed in the Sarno River plain Vogel & Märker (ongoing research) determined that the PDC thickness decreases exponentially with increasing distance from the vent of Somma-Vesuvius.

The volcanic deposits of AD 79 are underlain by the pre-AD 79 paleosol. Similarly to Boscoreale the pre-AD 79 paleosol at Moreggine developed from pyroclastic material such as ash and lapilli from the protohistoric activity of Somma-Vesuvius. However, at Moreggine the exact age of this parent material is less clear compared to Boscoreale, as especially between DAI 9 and DAI 12 these deposits seemed to be strongly reworked by the influence of water-induced erosion and redeposition (fig. 3).

At Moreggine the spatial distribution of paleosol characteristics is mainly a function of soil development in relation to elevation and distance from the paleo-floodplain of the paleo-Sarno River network (Vogel & Märker, 2011). Near the paleo-Sarno River and its floodplain the Roman paleosols are 30 cm (DAI 5, DAI 6) thick and mainly show an initial soil horizonation (A-C profile). Furthermore, they are characterized by lower amounts of soil organic matter (SOM) and phosphates. In contrast, at higher elevation and distance from the paleo-Sarno River the paleosols are thicker (DAI 13: 60 cm) and have a more pronounced soil horizonation due to the formation of a weathered B-horizon (A-Bw-C profile). They also show higher contents of SOM and phosphate. Moreover, a partly finer particle size distribution and higher amounts of ammonium oxalate extractable silicium infer to a higher weathering rate of the soil substrate. Irrespective of these inherent differences, with respect to their degree of soil development, all four Roman paleosols south of Pompeii can be considered relatively young and immature soils. This may result from the direct vicinity of Moreggine to the active floodplain of the paleo-Sarno River and its seasonal influence in terms of riverborne erosion and deposition processes. This is supported by the drillings DAI 7 and DAI 8 where the AD 79 pumice fallout was slightly rounded and surrounded by a matrix of mud (Vogel & Märker, 2011). This indicates that the pumice fallout of AD 79 was directly deposited into a flowing water body. In this case the litho-stratigraphical data perfectly correspond to the paleo-topographical reconstruction of Vogel & *alii* (2011) who have modelled a tributary of the paleo-Sarno River directly between the drillings DAI 7 and DAI 8 (fig. 2).

Boscoreale versus Moreggine

The Boscoreale transect, northwest of Pompeii, stretches between the southern slope of Somma-Vesuvius and the western slope of the Pompeiian hill. It is situated at the transition between two landscape units: the alluvial plain and the footslopes of Somma-Vesuvius volcanic complex (fig. 1). The Moreggine transect, south of Pompeii, on the other hand, is situated in the alluvial plain. Consequently, Boscoreale shows a higher relief energy compared to Moreggine. This is characterized by higher elevations (24 to 50 m a.s.l.) and a slightly sloping to gently inclined topography (fig. 2, 3). In contrast, Moreggine shows lower elevations (5 to 11 m a.s.l.), a flat to slightly sloping relief and a direct vicinity to the present-day Bottaro channel

TABLE 3 - Soil properties of the Roman paleosols of Moreggine (modified from Vogel & Märker, 2011)

												Exchangeable cations [cmolc/kg]								
		Depth [m]	Soil texture class	Munsell soil color	pH ($CaCl_2$)	$CaCO_3$ [%]	TOC [%]	N [%]	C/N	CEC_{eff} [$cmol_c$/kg][a]	eff. base saturation [%]	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al_{ox} [%]	Fe_{ox} [%]	Si_{ox} [%]	Al_{ox}+0.5Fe_{ox} [%]	SO_4^{2-} [mg/l]
Moreggine	DAI 5	5.6 - 5.7	sL	10YR3/1	7.79	0.05	2.19	0.11	19.90	13.20	99.8	4.38	1.97	5.55	1.27	0.38	0.56	0.20	0.66	51.0
		5.7 - 5.8	sL	10YR3/1	7.84	0.4	1.89	0.1	18.90	12.30	100	3.97	1.85	5.50	1.20	0.33	0.22	0.12	0.44	137.0
		5.8 - 5.9	sL	10YR3/1	7.81	0.00	1.94	0.1	19.40	11.70	100	4.36	1.79	4.38	1.19	0.34	0.19	0.11	0.44	79.0
	DAI 6	6.4 - 6.5	sL	10YR2/1	7.46	0.28	2.50	0.1	25.00	8.34	100	2.62	1.14	4.07	0.51	0.44	0.72	0.27	0.81	125.0
		6.5 - 6.6	sL	10YR3/1	4.73	0.26	1.71	0.1	17.10	7.60	98.9	2.39	1.82	2.93	0.38	0.43	0.42	0.16	0.64	298.0
		6.6 - 6.7	sL	10YR3/1	6.06	0.1	0.83	0.06	13.80	5.19	100	1.93	1.49	1.53	0.24	0.38	0.22	0.14	0.49	24.0
	DAI 9	5.5 - 5.6	sL	10YR2/2	6.77	0.23	1.21	0.06	20.20	10.30	99.6	2.54	1.27	5.90	0.55	0.27	0.25	0.12	0.40	ND
		5.6 - 5.7	sL	10YR3/1	7.12	0.01	1.08	0.06	18.00	9.50	100	2.36	1.38	5.30	0.46	0.27	0.25	0.12	0.40	ND
		5.7 - 5.8	sL	10YR3/1	7.29	0.4	0.93	0.06	15.50	10.60	99.8	2.47	1.10	6.55	0.46	0.27	0.26	0.12	0.40	ND
		5.8 - 5.9	sL	10YR2/2	7.40	0.17	1.12	0.06	18.70	9.19	100	2.62	1.02	5.10	0.45	0.31	0.25	0.14	0.43	ND
		5.9 - 6.0	S	10YR3/1	7.47	0.17	0.21	0.02	10.60	7.03	100	2.26	1.41	3.06	0.30	0.23	0.36	0.10	0.41	ND
	DAI 13	6.1 - 6.2	uL	10YR3/1	7.46	0.00	4.10	0.14	29.3	15.30	100	4.66	1.22	8.45	0.93	0.48	0.16	0.17	0.57	10.0
		6.2 - 6.3	uL	10YR3/1	7.46	0.27	4.08	0.13	31.4	15.60	100	4.48	1.28	9.10	0.69	0.39	0.08	0.13	0.43	10.0
		6.3 - 6.4	uL	10YR3/1	7.48	0.12	3.89	0.09	43.30	13.40	100	4.27	1.12	7.50	0.51	0.35	0.09	0.12	0.40	7.0
		6.4 - 6.5	uL	10YR3/1	7.50	0.09	3.28	0.08	41	13.10	100	3.60	0.85	8.20	0.44	0.34	0.11	0.12	0.39	7.0
		6.5 - 6.6	uL	10YR3/1	7.49	0.32	3.12	0.07	44.60	13.80	100	3.79	1.30	8.30	0.40	0.37	0.14	0.12	0.44	8.0
		6.6 - 6.7	uL	10YR3/1	7.54	0.08	3.33	0.08	41.60	15.60	100	4.79	1.21	9.15	0.40	0.38	0.14	0.15	0.45	14.0

ND-not detectable; soil texture classes: sL-sandy loam, L-loam, S-sand, lS-loamy sand, uL-silt loam and the Sarno River (fig. 3). Corresponding to the pre-AD 79 paleo-environmental reconstruction of Vogel & *alii* (2011), Moreggine is also influenced by the paleo-Sarno River and its floodplain (fig. 2).

Generally, the paleosols of Boscoreale and Moreggine are compacted, have mainly a sandy loam soil texture and show a neutral to slightly alkaline soil reaction. Furthermore, they are assumed to have developed under the same paleo-climatic conditions and from similar protohistoric volcanic deposits of Somma-Vesuvius even though in Moreggine considerable rework by water-induced erosion and redeposition took place. With respect to the approximate age of the parent material the pre-AD 79 paleosols can be subdivided into a pre-burial age, i.e. the time that it developed upon the ancient land surface, of a maximum of 1,050 to 1,500 years and a post-burial age of approximately 1,900 years. Hence, it must be emphasised that the pre-AD 79 paleosol developed for a much longer period of time under buried than under unburied conditions.

Irrespective of these similarities and even though there is an only 2,500 m linear distance between Boscoreale and Moreggine there is a main difference between the two study areas. It is connected with the above mentioned absolute elevation and the distance to the river network and in this context with the recent presence or absence of groundwater dynamics in the Roman paleosols.

According to present-day groundwater data of the Autorità di Bacino del Sarno the lower and central areas of the plain are influenced by a high mean groundwater table (fig. 3). By modelling this groundwater table and comparing it with the pre-AD 79 DEM of Vogel & *alii* (2011) an increase of the groundwater table since AD 79 by approximately 1.8 m was determined. This comprises an area of approximately 37% of the Sarno River plain. At lower elevations near the Sarno River network this results in a temporarily influence of originally terrestrial and unsaturated pre-AD 79 paleosols by groundwater dynamics. Moreggine is situated within this zone of post-AD 79 groundwater influence whereas Boscoreale is not (fig. 2, 3). In contrast, in Boscoreale, the Roman paleosol is still part of the vadose zone and rather influenced by vertical or lateral soil water flow.

It is plausible that, to some extent, this groundwater rise may be an indirect result of the AD 79 eruption of Somma-Vesuvius. As earlier described, after the eruption, the steep mountain slopes were vulnerable to severe soil erosion processes that reduced their water retention capacity and led to increased runoff. Finally, this may have caused a rise of the groundwater table in the adjacent river plain.

This post-burial rise of the groundwater table is expected to have a distinct influence on the paleosol's mineral soil properties at Moreggine especially when considering the post-burial age of the paleosols of about 1,900 years. Some of these post-burial effects become particularly evident by comparison with the paleosols at Boscoreale which is not influenced by groundwater.

At Moreggine the AD 79 pumice layer contains evident redoximorphic features in terms of red Fe(III)-oxide accumulations towards the transition to the pre-AD 79 paleosol (DAI 4, DAI 5, DAI 6, DAI 7 and DAI 8). They result from the alternation between reducing and oxidizing condition due to a fluctuating groundwater table (table 1; fig. 3) (Vogel & Märker, 2011). Accordingly, the pre-AD 79 paleosols at Moreggine show increased sulphate concentrations that lead to decreased pH values due to the formation of sulphuric acid and resulting soil acidification (Vogel & Märker, 2011). In soils that are subject to an oscillating water table increased amounts of sulfate can be caused under aerobic conditions by an oxidation of organic sulfur or inorganic sulfide to sulfate (Ahmad and Wilson, 1992; Nemeth & *alii*, 1970). Moreggine is furthermore characterised by more than three times higher amounts of organic carbon and two times higher amounts of nitrogen than Boscoreale. This may be due to reduced decomposition rates of SOM as a result of air exclusion during periods of groundwater saturation. Higher amounts of SOM in Moreggine coincide with darker top soils being very dark brown (10YR2/2) or very dark gray (10YR3/1) compared to dark grayish brown (10YR4/2) in Boscoreale. Moreover, Moreggine has lower amounts of calcium carbonate of below 0.5% whereas it can rise to a maximum of 2% in Boscoreale (DAI 18). Hypothesizing a similar original $CaCO_3$ concentration in the parent material it can be assumed that, in Moreggine, $CaCO_3$ was dissolved and washed out of the profile as a result of seasonal groundwater saturation.

In Boscoreale, on the other hand, the Roman paleosol is still part of the vadose zone and not influenced by post-burial groundwater dynamics. Water movement within the soil profile rather derives vertically from infiltration or laterally from interflow. Consequently, redoximorphic features within the AD 79 pumice layer are absent or only sporadic. Furthermore, compared to Moreggine, the paleosols of Boscoreale show lower amounts of organic carbon and nitrogen and negligible amounts of sulphate. In Boscoreale higher carbonate contents result in a higher effective cation exchange capacity which is above all caused by increased amounts of exchangeable calcium. Thus the effective base saturation of the upper soil is slightly higher in Boscoreale being constantly at 100%.

With respect to higher amounts of ammonium oxalate extractable Fe and Al the paleosols of Boscoreale seem to be stronger weathered in comparison to Moreggine. Moreover, the paleosols of Boscoreale show a greater soil thickness and a more distinct soil horizonation in terms of a weathered B-horizon resulting in an A-Bw-C profile. Hence the soils at Boscoreale appear to be pedogenetically more mature compared to Moreggine which lies near the active floodplain of the paleo-Sarno River and its erosional or depositional influence.

Concluding, it must be emphasized that every single difference in the character of the pre-AD 79 paleosols between Boscoreale and Moreggine may also have additional explanations than described above. However, it is the sum of litho-stratigraphical and soil chemical evidence together with the paleo-topographical findings that suggests that the post-burial influence of a fluctuating groundwater table may have caused the described differences between Boscoreale and Moreggine.

CONCLUSIONS

Stratigraphical cross-sections and the pre-AD 79 Roman paleosols were studied south (Moreggine) and northwest (Boscoreale) of ancient Pompeii to provide a characterization and comparison of the paleosols in two contrasting paleo-topographical situations. Paleocatenary relationships were identified between paleosol properties and paleo-topographic location along the two transects. Furthermore, pronounced differences in paleosol characteristic between the two study areas were revealed. The results suggest that the differences are mainly related to the presence (Moreggine) or absence (Boscoreale) of post-burial groundwater influence in the former terrestrial paleosols. Finally, the thickness of AD 79 pyroclastic deposits that buried the pre-AD 79 paleosols reflects the volcanogenic processes that took place during the eruption of Somma-Vesuvius in AD 79.

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