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THE LONG SEDIMENTARY SUCCESSION OF THE VALLE GIUMENTINA BASIN (ABRUZZO, CENTRAL ITALY): NEW EVIDENCE FROM STRATIGRAPHIC STUDIES AND ELECTRICAL RESISTIVITY TOMOGRAPHY (ERT)

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ABSTRACT: We carried out a multidisciplinary study on the sedimentary succession of Valle Giumentina, a small intermountain basin located in the Central Apennine. Studied in the 1950s, this 70 m-thick succession, including nine Palaeolithic occupation layers, was considered to be of Rissian and Würmian age. However, recent $^{40}Ar/^{39}Ar$ geochronological and tephrochronological investigations constrained the sedimentary history of the whole succession to the MIS 15-MIS 12 interval (Villa et al. 2016). Geophysical investigations (Electrical Resistivity Tomography) allow detecting the contact between bedrock and Quaternary infilling of the basin. No master fault was identified along the flank of the basin, suggesting that tectonics played a marginal role in the formation and evolution of the basin. Indeed, the basin sedimentary processes appear to be mainly climate-driven, with the deposition of glacio-fluvial sediments during colder glacial periods of MIS 14 and MIS 12 and alluvial sedimentation and/or pedogenesis processes active during warmer interglacial (MIS 15 and MIS 13) and interstadial phases (during MIS 12). Based on the available chronological data, the capture of the basin by a tributary stream of the San Bartolomeo canyon and its definitive extinction, occurred in MIS 12 glacial; i.e., when the uplift of the Apennine chain induced the reorganisation of the regional drainage system and the capture of almost all the lakes hosted in the intermountain basins.

Keywords: Middle Pleistocene; Central Apennine; intermountain basin; electrical resistivity tomography

1. INTRODUCTION

Valle Giumentina is a small hanging valley located at 740 m a.s.l on the Adriatic side of the Central Apennine, on the north-western slope of the Majella massif (Fig. 1a and 1b). The valley spreads over 1 km2 with a NE-SW axis and it is bordered by two perpendicular gorges to the North and to the South, San Bartolomeo and Orfento, respectively (Fig. 1c). During the Quaternary this small karstic-alluvial basin was filled by a succession (70 m-thick) of alluvial and lacustrine/palustrine deposits, then deeply incised by a SW-NE tributary stream of the San Bartolomeo, which exposed in its northern portion the uppermost 25 m- thick section (Fig. 1c). The 1953-54 archaeological excavations carried out by A.M. Radmilli and J. Demangeot revealed nine Lower Palaeolithic occupation layers attributed to Clactonian, Acheulian and Levalloisian (Demangeot & Radmilli, 1953). On the basis of the typological characteristics of the lithic assemblages and of the stratigraphic study of the basin infilling, Demangeot & Radmilli (1953; 1966) suggested to attribute the archaeological layers to the period between the Riss and Würm glacials. Since then, the site is considered a key reference for the definition of the Italian Lower Palaeolithic cultural evolution. Valle Giumentina thus represents an exceptional archive documenting the Middle Pleistocene evolutionary history of both palaeoenvironment and Palaeolithic human groups. Archaeological excavations funded by the École française de Rome started in 2012 (Nicoud et al., 2016 and references therein). At the same time a multidisciplinary study of the basin infilling (sedimentology, geochemistry, biomarkers, geochronology) was carried out to reconstruct the palaeoenvironmental and climatic evolution of the site during the Quaternary and to determine the chronology of the Palaeolithic settlements (Villa et al., 2016). In this paper we present the results of geophysics surveys we performed in the valley with the aim

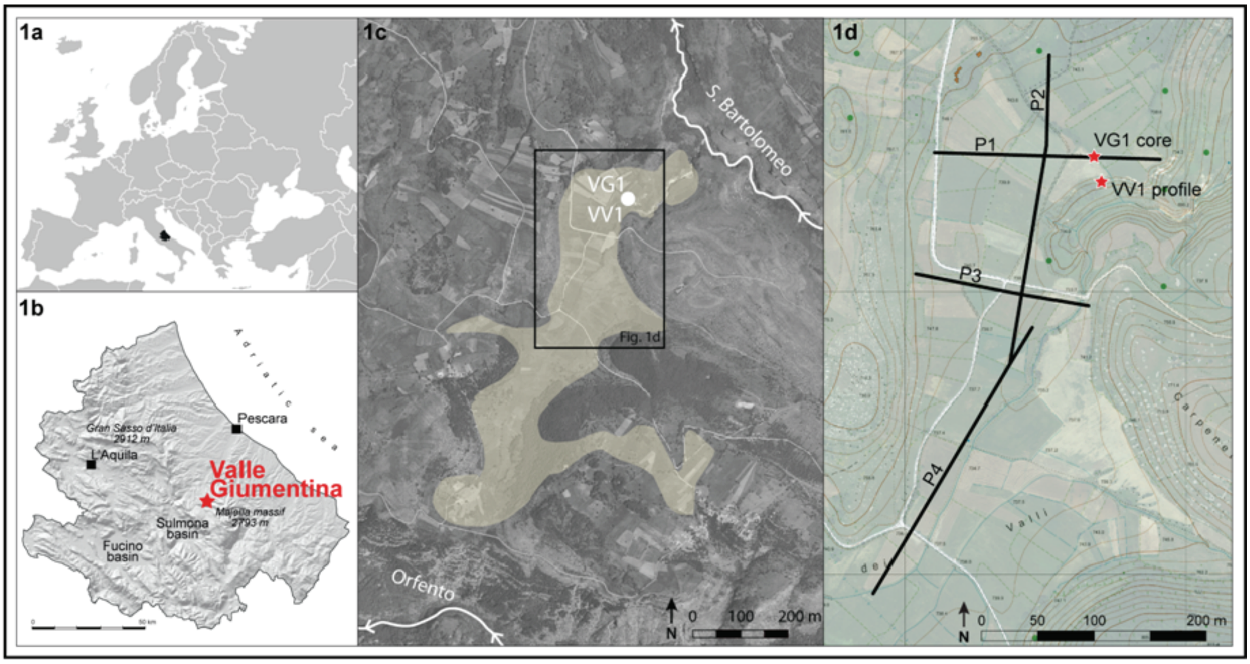

Fig. 1 - Reference map and view of Valle Giumentina. (a): location of the Abruzzo region (in black). (b) location of the Valle Giumentina basin. (c) aerial view of the basin and location of the stratigraphic records studied; the Quaternary infilling of the basin is highlighted in yellow. (d) aerial view of the basin and location of the ERT profiles, of the VV1 profile and of the VG1 core.

of defining the global geological setting of the site, the geometry of the basin and of its infilling. We provide for the first time an electrical image of the deep structure of Valle Giumentina and describe the distribution and depositional architecture of the lithostratigraphic units in the subsurface. These results allow a better comprehension of the site formation for environmental reconstructions.

2. GEOLOGICAL AND GEOMORPHOLOGICAL CONTEXT

The Apennines are a NW-SE Neogene fold and thrust belt, characterised by Mesozoic-Cenozoic calcareous ridges alternating with valleys and/or wide intermountain basins (Doglioni et al., 1994; Patacca et al., 1990; Patacca and Scandone, 1989). The formation of these basins was led by normal faulting, which affected the chain since the Upper Pliocene, at the same time of its uplift (Bosi et al., 2003; Galadini & Galli, 2000). During the Quaternary, some of these basins hosted large lakes and were filled by long and complex sedimentary successions (e.g. Amato et al., 2014; Giaccio et al., 2015; Russo Ermolli, 1994). As a consequence of the regional uplift, during the late Middle Pleistocene, regressive fluvial incision, from the coast toward the axial zone of the Apennines, determined the progressive capture of the basins. Hence, the infilling of most of them was partially eroded by fluvial incisions, which in turn were partially filled by fluvial deposits, leading to a system of terraced deposits (Bartolini et al., 2003; D'Alessandro et al., 2003; Miccadei et al., 1998). These well preserved stratigraphic successions thus represent precious records of the past environmental and climatic changes.

3. METHODS

3.1. Field surveys and stratigraphic analyses

Field investigations were carried out in the northern sector of the Valle Giumentina basin, where the stream incision allows the direct observation of the uppermost ~25 m-thick interval of the sedimentary infilling. A 17 m-long stratigraphic profile named VV1 was established on the left side of the valley, in connection with the archaeological excavation area (Fig. 1c and 1d). A borehole (VG1) was drilled 30 m north of the VV1 profile (Fig. 1d). It reached the base of the Quaternary infilling at a depth of 45 m. The VV1 profile and the VG1 core were sampled for sedimentological and geochemical analyses, biomarkers studies (pollen and molluscs) and geochronology ($^{40}Ar/^{39}Ar$ dating) (Villa et al., 2016).

3.2. Geophysics

Geophysical investigations were realised to complete the stratigraphic analyses. The Electrical Resistivity Tomography - (ERT) was used to image the contact between the limestone substratum and the basin infilling and characterize the sedimentary architecture of the latter. The pole-dipole protocol was used to allow an adequate depth of investigation while keeping a good resolution. A 64 electrodes Terrameter Abem LS system was used for field data acquisition with an inter-electrode spacing of 5 meters. Electrical resistivity measurements were realised along two NE-SW longitudinal profiles (P2 and P4) and two NW-SE cross-section profiles (P1 and P3) (Fig. 1d). Profiles length range between 315 and 555 m. The acquired ERT data were processed using the Res2Dinv software (Loke & Barker, 1996).

4. RESULTS

4.1. Stratigraphy

The stratigraphic study of both the VG1 and the VV1 profile allowed the identification of 5 main sedimentary units (SU), named SU1 to SU5, which were further subdivided into 40 stratigraphic sub-units (Fig.2). Correlations between the VG1 and VV1 profiles were established thanks to the presence of some lithostratigraphic markers, such as coarse detrital layers (CGB2 and CGB1), palaeosols and tephra layers (Fig. 2).

The lower unit, SU5, is formed by a thick fluvial gravel deposit, which overlies the Miocene limestone bedrock.

Unit SU4, consisting of lacustrine and palustrine calcareous sediments, attests the formation of a shallow lake. Oxidation, bioturbation and pedogenic processes characterise these deposits, testifying repeated oscillations of the water table, subaerial exposure and alteration of the sediments. Detrital input from the basin catchment is progressively weaker towards the top of the unit, where the sediments show almost no traces of alteration or desiccation.

Unit SU3 is formed by clayey organic deposits, which attest the evolution from lacustrine to marshy environments. The upper part of the unit (layer AO2-AO1; Fig. 2) shows an abrupt transition to coarser sediments, rich in CaCO3. Three grey sandy layers of volcanoclastic material (named SG3, SG2 and SG1) are interbedded with the organic deposits of the SU3 unit.

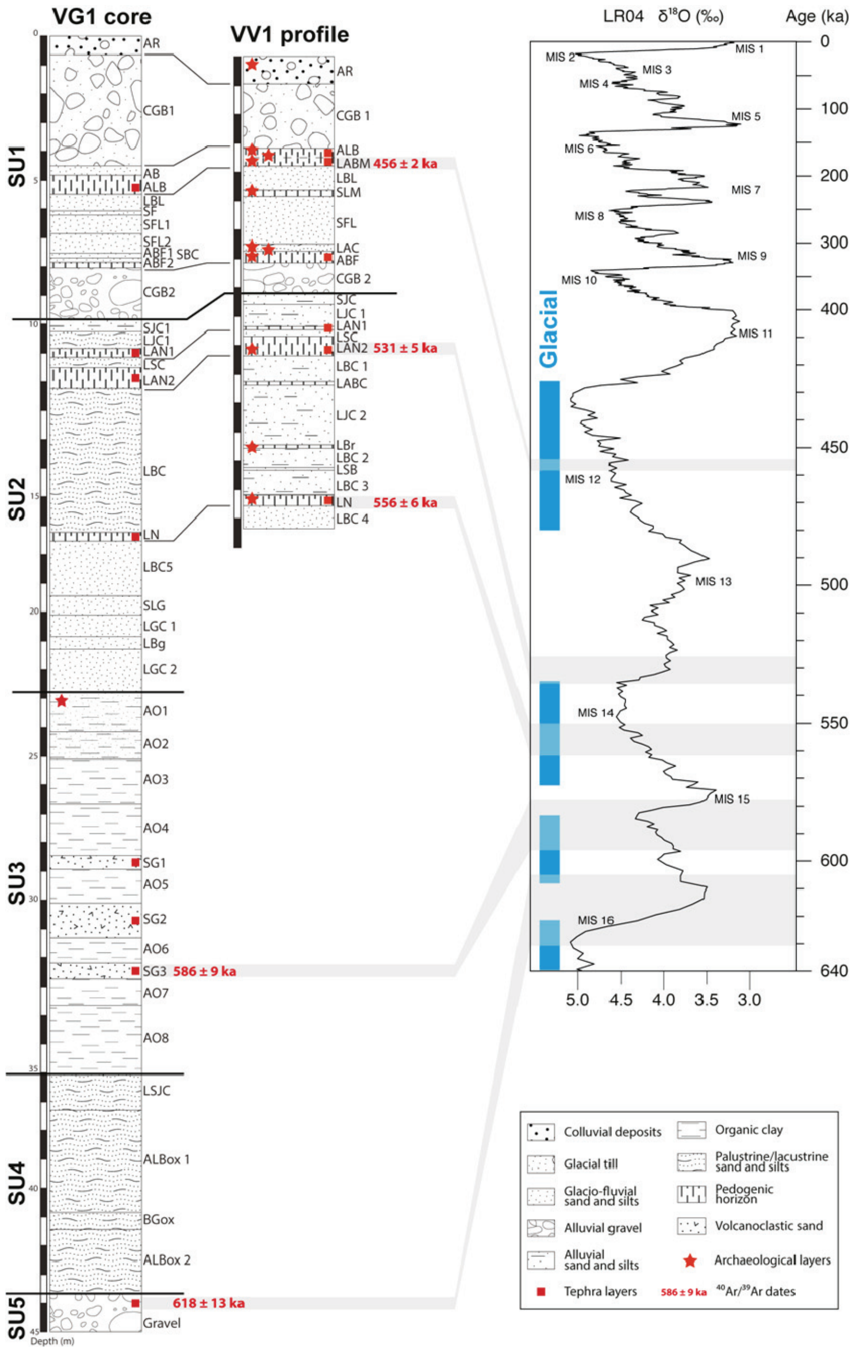

Fig. 2 - VG1 core and VV1 profile successions and position of key layers (archaeological levels and tephra layers). The possible correlations with the palaeoclimatic marine record from LR04 stack (Lisiecki and Raimo, 2005) are also shown. Note that the temporal scale between 400 ka and present is contracted.

Unit EN2 mainly consists of fine detrital calcareous deposits characterised by planar bed laminations. Mottled carbonates are frequent at the base of the unit, but they are progressively replaced by calcareous silts and clay showing no traces of alteration and comprising some pyrite framboids and fragments of molluscs. Three additional tephra layers (LN, LAN2 and LAN1; Fig. 2) were identified in this unit.

The transition to unit SU1 is marked by an abrupt lithological change represented by coarse alluvial layer (CGB2). The overlying deposits are mainly formed of sandy/silty sediments, characterised by planar and/or crossed lamination. These fine detrital deposits are interbedded with four palaeosols. The succession ends

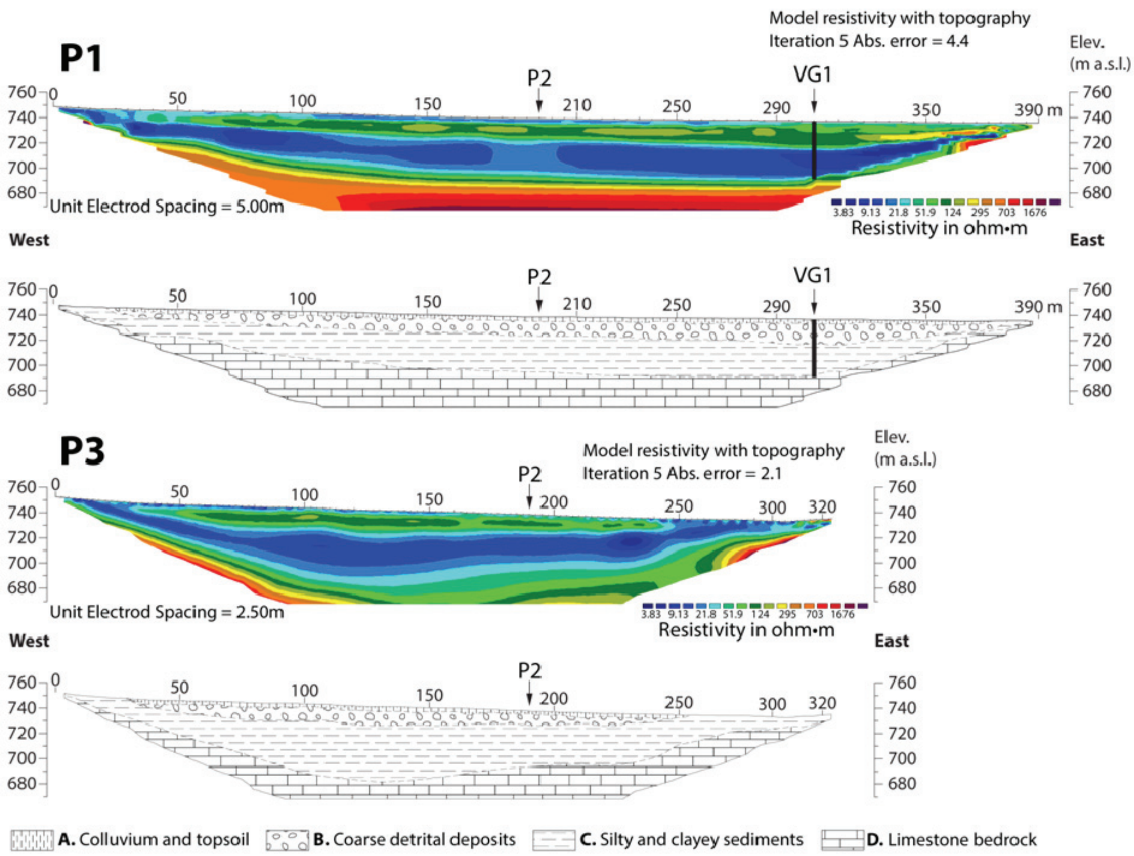

Fig. 3 - Electrical resistivity tomographies carried out across the Valle Giumentina basin, transverse profiles P1 and P3. Locations in Fig. 1b.

with one thick layer of heterometric limestone boulders (CGB1) and a red clayey-sandy colluvium deposit (AR; Fig. 2).

4.2. Geophysics

The Electrical Resistivity Tomography (ERT) results were calibrated using the stratigraphic succession of the VG1 core, which reached the limestone bedrock at 43.68 m-depth. The 2D ERT pseudosections show five main units (Fig. 3 and 4). The first thin unit (A), observed in the P1, P2 and P3 profile, has resistivity values ranging between 15 and 40 Ω·m. Its thickness is irregular, comprised between <1 and 2 - meters. Unit A corresponds to the topsoil and the colluvium layer AR, which were identified in both the VG1 core and the VV1 profile (Fig. 2). It is visible along the whole left bank of Valle Giumentina, where it actually shows an abrupt wavy contact with the underlying layers.

The second unit (B), in green, has resistivity values ranging between 50 and 200 Ω·m. It is visible in all the profiles (Fig. 3 and 4). In P1 its thickness varies between 4 and 20 m, being thicker in the centre of the basin and progressively thinner toward its margin. In P2, it is disconnected from the northern limit of the basin and becomes progressively thinner southward. In P3, it appears to be disconnected from the western basin slopes and show an almost vertically cut at 70 m from the eastern margin of the basin, corresponding to the bed of a tributary stream of the San Bartolomeo canyon. In P4 it is visible in the northern part of the profile, where it is 5 m-thick and gradually becomes thinner, stopping at ~80 m from the northern limit of the profile. This unit corresponds to the coarse detrital calcareous layers CGB1 and CGB2 (Fig. 2). The ERT does not distinguish considerable lithological differences in the deposits at depths between 4.5 and 8 m, but the stratigraphic succession of the VG1 core clearly shows three lithologically different segments at this location, with fine-grained deposits comprised between the two units CGB1 and CGB2 (Fig. 2). Furthermore, the whole thickness of these two coarse-grained layers appears to be overestimated (15 m instead of 10 m in the VG1 core location). This is probably due to a combination of factors, such as (i) the low resolution of the electrical resistivity measures, (ii) the compression of the deposits during the extraction of the core and (iii) the gradual transition between these coarse units and the overlying layer (AR), which is rich in detrital blocs and gravels.

The third unit (C), in blue, is more conductive, with values of resistivity ranging from 1 to 20 Ω·m (Fig. 3 and 4). It corresponds to the fine sediments forming the lower portion of the Quaternary infilling of the basin (lithostratigraphic units EN3 and EN4; Fig. 2). Its thickness varies from a few meters in the external sector of

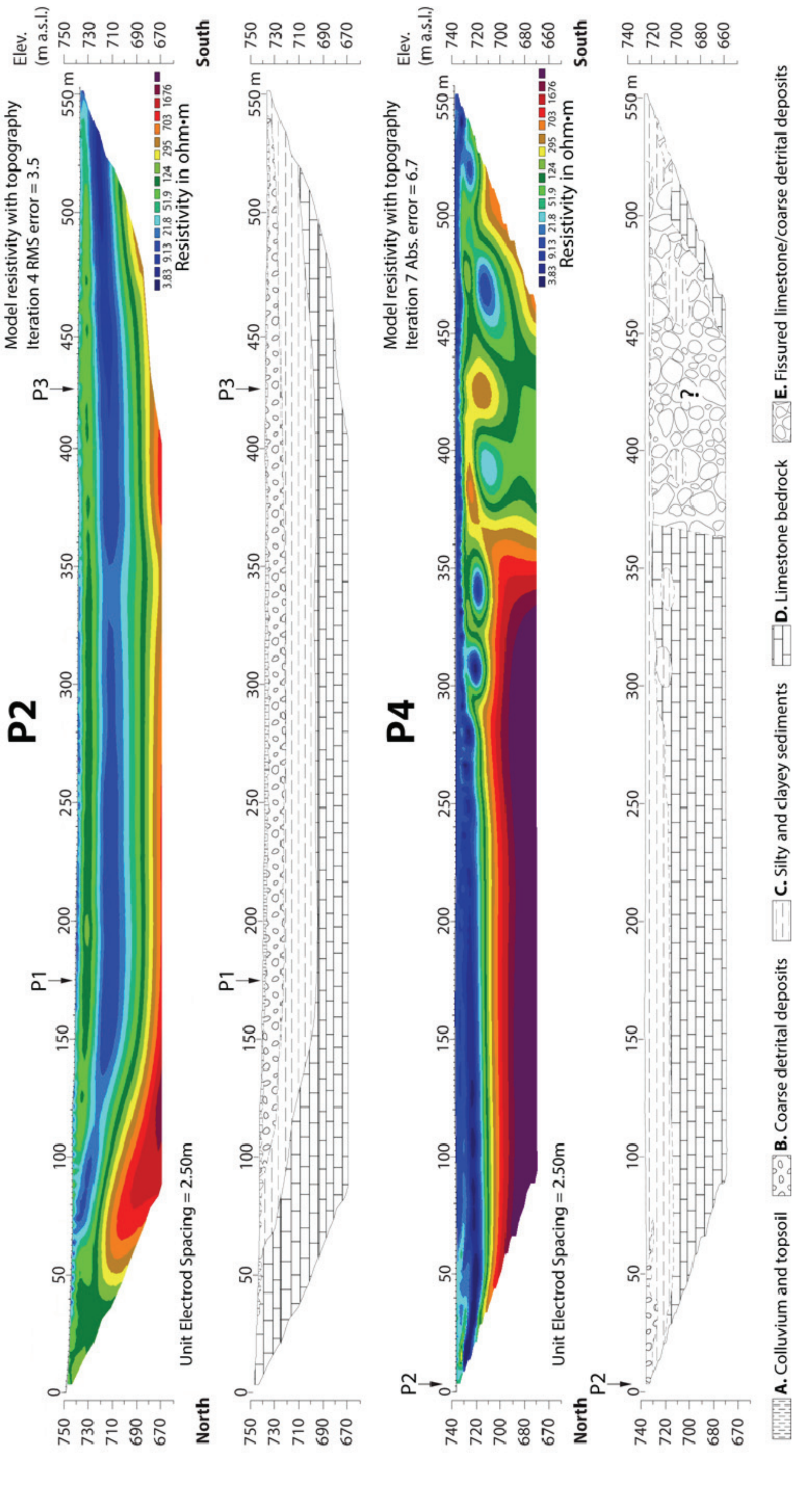

Fig. 4 - Electrical resistivity tomographies carried out across the Valle Giumentina basin, longitudinal profiles P2 and P4. Locations in Fig. 1b.

the basin to >20 m in its centre, reaching maximum values, >40 m, in the depocentre of P3, located at 130 m from the western limit of the profile.

The fourth unit (D), corresponding to the limestone bedrock, has resistivity values comprised between 2500 and >10000 Ω·m (Fig. 3 and 4). In the cross-section profiles the bedrock rises to the surface in both the western and eastern area and is characterised by steep margins. The bottom of the basin appears to be slightly asymmetric in P3, where the depocentre is located in the western sector (Fig. 3). The longitudinal profiles P2 and P4 show a flat bottom and the progressive gentle raising of the limestone both in the northern and southern sector. In P4, at ~320 m, an abrupt discontinuity of the bedrock is visible (Fig. 4). It is filled by a less resistant unit (E), characterised by resistivity values ranging between 50 and 200 Ω·m (Fig. 4). This could correspond to a fault dissecting the bedrock or to a karstic depression, i.e., a sinkhole, filled by coarse detrital deposits and surrounded by strongly fissured limestone. Further investigations are needed to understand the geological mean of this abrupt discontinuity.

On the whole, the ERT pseudosections provide a good expression of the overall geometry of the basin and of its infilling, up to a depth of 80 m. The geophysical signature of the contact between the Quaternary clastic sediments and the bedrock is marked by a shift of resistivity from 20 Ω·m to around 2500 Ω·m. The basin is 800 m long and between 330 m and 380 m large. The shape of the basin is slightly asymmetric and the maximum sediment thickness (~70 m) occurs along the north-western margin. The presence of extremely conductive horizons (units A and C) is related with fine-grained sediments, whilst the high-resistivity zones can be associated to coarser deposits (unit B and E) and to the limestone bedrock (unit D).

5. CONCLUSION

The results of the integrated geological study performed on the Valle Giumentina sedimentary sequence allow to reconstruct the environmental evolution of the basin during the Quaternary (see detail in Villa et al., 2016). The sedimentary sequence covers a time span of about 150 ka, from 618 ±13 ka to 456 ±2 ka and includes two complete interglacial-glacial cycles, between MIS 15 and MIS 12. After the deposition of a thick fluvial conglomerate (SU5) occurred between the end of the MIS 16 and the beginning of MIS 15 (after 618 ±13 ka and before 586 ±9 ka), the basin hosted a shallow lake (SU4). Then, during MIS 15 the lacustrine sedimentation was replaced by the development of marshy environments, indicated by SU3. This thick sedimentary unit, consisting of organic sediments, records the evolution towards a strong cooling, corresponding to the transition from MIS 15 to MIS 14. Another ephemeral lacustrine phase is attested by SU2, characterised by several phases of drying and concurrent development of pedogenic horizons. Two $^{40}Ar/^{39}Ar$ dates (556 ±6 ka and 531 ±5 ka) correlate this phase to MIS 14 and MIS 13. The definitive transition to exclusively sub-aerial depositional environments is attested by the topmost unit SU1, which correspond to MIS 12. Particularly relevant is the occurrence of a till deposit (CGB1), as it indicates a significant expansion of glaciers during the MIS 12 glacial, possibly reaching the relatively low altitude of the site. The ERT pseudosections show that this deposit (corresponding to the resistivity unit B) is present in the whole northern sector of the basin and its geometry suggests a deposition from the eastern slope.

Our results highlighted that the sedimentary dynamic in the Valle Giumentina basin was strongly conditioned by climatic changes. The Valle Giumentina succession records glaciofluvial-lacustrine sedimentation during glacial periods and alluvial sedimentation or pedogenic processes during interglacials. We excluded any major role of local tectonics in the evolution of the basin during the Middle Pleistocene. These conclusions are confirmed by the ERT data. No master faults have been identified along the flanks of the basin and the Quaternary infilling doesn't show any dissection or perturbations which could suggest the existence of synsedimentary faults. One fault is possibly present in the southern part of the basin, but we suggest excluding any major role of local tectonics in the formation and evolution of the basin, which seems to be rather of karstic origin. However, tectonic processes were responsible for the basin capture resulting from the general regional uplift which affected the whole Apennine chain since the second half of the Middle Pleistocene. Indeed, the majority of the Apennine intermountain basins record almost simultaneously a transition from lacustrine to fluvial environments and are definitively captured during MIS 12 (e.g. Giaccio et al., 2014; Petrosino et al., 2014; Robustelli et al., 2014; Russo Ermolli et al., 2010, 2015). Based on the available data (Villa et al., 2016), the Valle Giumentina basin was captured almost at the same time and thus, the till deposit of layer CGB1 could be correlated to the MIS 12 glacial. After the capture of the basin, the tributary stream of the San Bartolomeo canyon progressively migrated northward and deeply incised the Quaternary deposits until the limestone bedrock.

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