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Quaternary evolution of the intermontane Val d'Agri Basin, Southern Apennines

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ABSTRACT

Optically Stimulated Luminescence (OSL) enables the chronology of the late Pleistocene evolution for the Val d'Agri intermontane basin of Southern Apennines to be defined in the frame of Mediterranean geodynamic and climate changes. Quartz sand from braided floodplain and alluvial fan depositional systems was analyzed using the coarse-grained, single-aliquot regenerative-dose (SAR) technique. The obtained optical ages are mostly consistent with other assessments (radiocarbon, tephrochronology) and stratigraphic constraints. OSL allows for the dating to 56–43 ka of an asymmetric subsidence stage that forced alluvial fan progradation, filling of a former lacustrine area, and development of an axial alluvial plain. A short period of Mediterranean-type pedogenesis, recorded at the top of the prograding-aggrading fans (OSL age bracket 43–32 ka), corresponds with MIS 3. During the subsequent stage of decline of vegetation cover, possibly corresponding to MIS 2, the latest progradation of alluvial fans occurred. The subsequent uplift and breakthrough of the basin threshold during the latest Pleistocene and Holocene induced entrenchment of the drainage network. The results presented here provide an example of the usefulness of OSL dating in intermontane continental settings where other geochronological constraints are scarce.

Introduction

In the Southern Apennines, intermontane basins occur in regions of active faulting that dissect the mountain range. The chain is an east-verging fold-and-thrust belt, accreted at the collisional boundary between the European and Ionian/Adria plates, since the Late Oligocene (Doglioni et al., 1996). Tectonic accretion came to an end by the middle Pleistocene, even at the external front of the thrust belt (Cinque et al., 1993). During the Quaternary, the whole chain was affected by orogen-parallel extension that led to regional volcanism, fast uplift of the accretionary prism and opening of several lacustrine–alluvial intermontane basins (Isernia, Vallo di Diano, Tanagro, Pergola-Melandro, Noce, Mercure, Castrovillari, Vittoria and Val d'Agri basins; Schiattarella et al., 2003 and references therein). The continental sedimentary record of these basins documents the Quaternary tectonic and volcanic evolution of the Southern Apennines, as well as the climate dynamics of the Mediterranean region. Specifically, the Val d'Agri Basin (hereafter VAB) offers a chance to delineate the middle–late Pleistocene history through the study of its well-exposed alluvial units that host evidence of syn-sedimentary tectonic activity, regional volcanism (documented by well-preserved tephra; Zembo et al., 2008) and climate changes (Zembo, 2007, 2008).

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The new dates that we obtained from the Optically Stimulated Luminescence (OSL) technique contribute to determining the tectonic and climatic controls on sedimentation and relating the newly available stratigraphic and evolutionary framework of the VAB with the Quaternary climate changes and isotope stratigraphy of the Mediterranean area, based on a continental sedimentary record. Moreover, calibration of OSL data by independent chronological data and stratigraphy testifies to the reliability of this technique in the case of late Pleistocene continental intermontane sediments.

Regional framework. The Quaternary of Val d'Agri Basin (VAB)

The high valley of the Agri River is a large tectonic intermontane basin, NW–SE trending, which originated in the axial zone of the Campania-Lucania Apennines (Fig. 1A). The basin developed after strike-slip faulting and extensional deformation affected the fold-and-thrust belt since the early Pleistocene along two branching fault systems: the N 120°-trending, SW-dipping Val d'Agri fault system to the NE (VAFS; Cello, 2000; Cello et al., 2000a, 2000b) (Fig. 1B) and the eastern branch of the N 150°-trending, NE-dipping Monti della Maddalena fault system to the SW (MMFS; Maschio et al., 2005) (Fig. 1B). The VAB consists of three tectonically controlled and diachronous depocenters bounded by the aforementioned fault systems and by NE–SW faults, kinematically linked to the VAFS (Fig. 1C). The Quaternary continental basin fill crops out only in the south-eastern “Pertusillo depocenter” (Colella et al., 2004; Fig. 1C).

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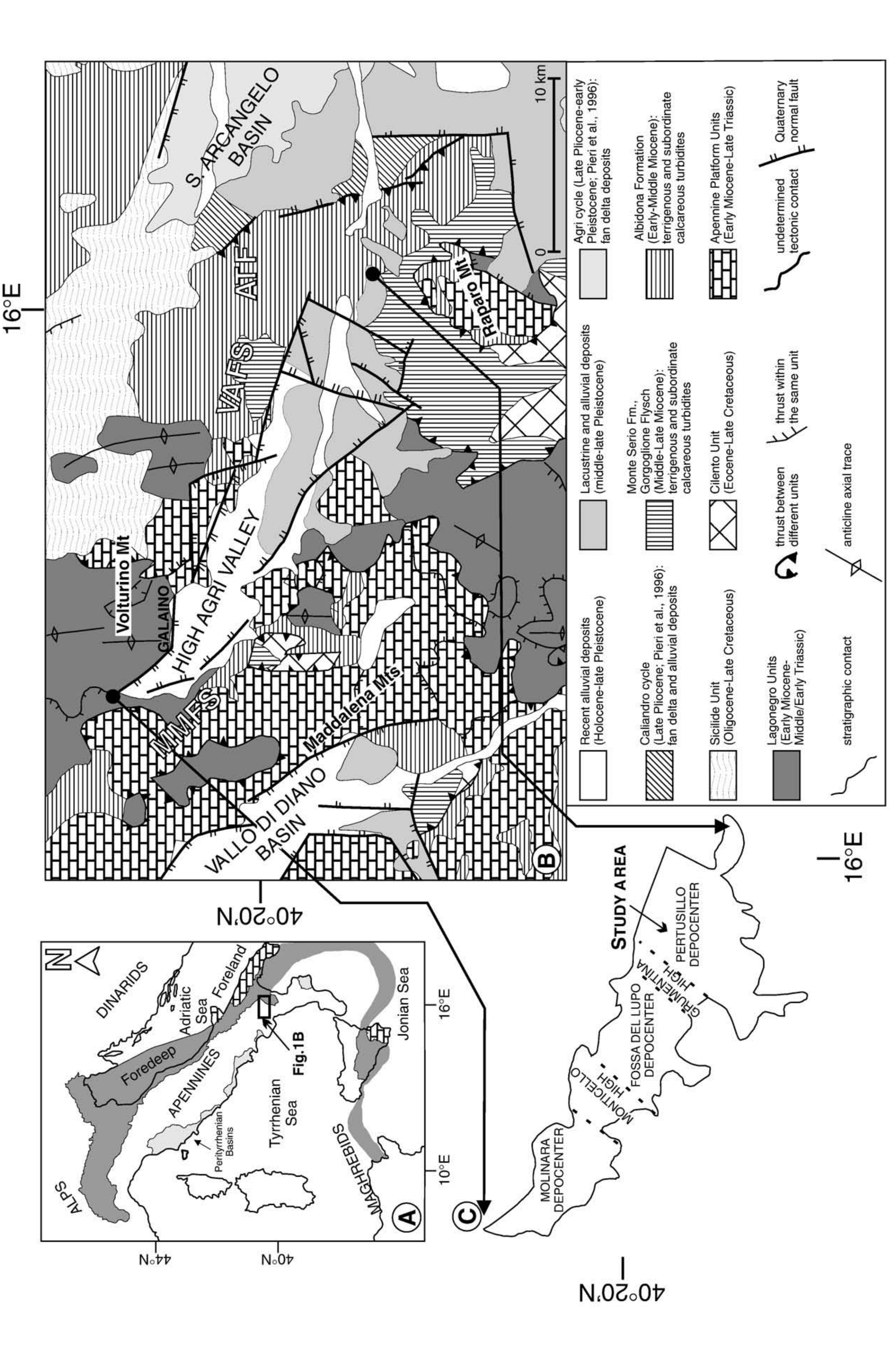

Figure 1. (A) Sketch map of the central Mediterranean area and location of the Val d'Agri basin within the Apennine range (modified from Bosi, 2004). (B) Geological sketch map of the Val d'Agri basin (modified from Bigi et al., 1990). Faults: Val d'Agri Fault System (VAFS); Monti della Maddalena Fault System (MMFS); Armento Thrust Fault (ATF). (C) Depocentres of the Val d'Agri basin and position of the study area. The basin is formed by a mosaic of fault-bounded blocks that, along the basin axis, consist of three main depocentres separated by two structural highs (modified from Colella et al., 2004). Pre-Quaternary bedrock is not shown (See Pieri et al., 1996).

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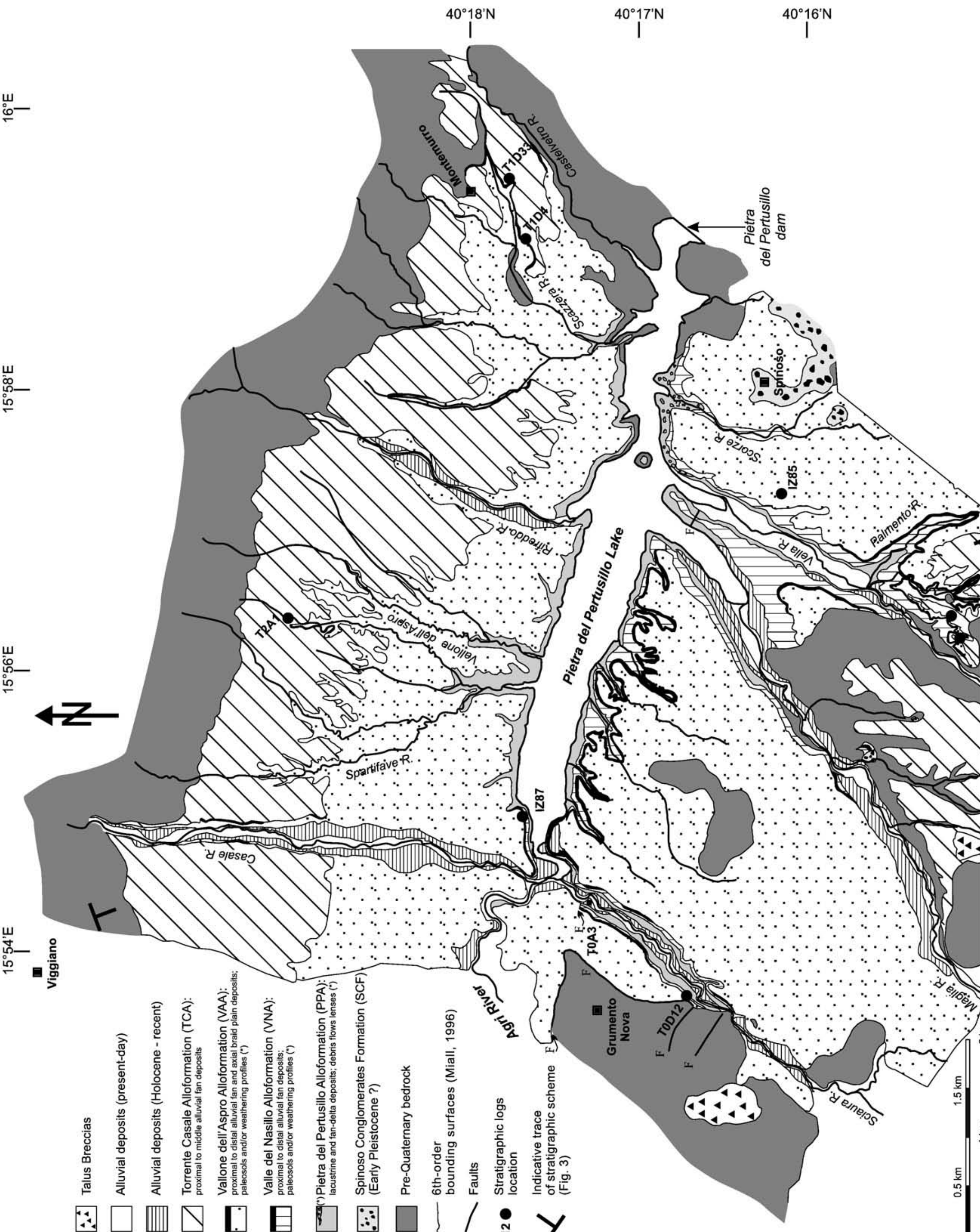

Figure 2. Simplified geological map of the Pertusillo depocentre (study area) and sedimentological log locations (see Fig. 4; partially modified from Zembo, 2007).

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The sedimentary fill was deeply dissected during the latest Pleistocene–Holocene, as a consequence of deepening of the drainage network. The deepening is due to uplift and breakthrough of the VAB threshold that was located close to the Pliocene WSW-dipping Armento thrust fault (Fig. 1B). The maximum thickness of the basin fill occurs in the Molinara buried depocenter and the minimum occurs in the Pertusillo depocenter (Fig. 1C).

Basin geometry is characterized by seismic and ERGI images (Morandi and Ceragioli, 2002; La Penna and Rizzo, 2003; Colella et al., 2004; Rizzo et al., 2004) that show: 1) the asymmetric basin shape, with the deepest depocenters aligned along the northern basin margin; these presumably developed during the first opening tectonic stage relates to left-lateral strike-slip along the VAFS, in association with transpression and local uplift, originated by restraining bends of the master faults (early–middle Pleistocene (?); Di Niro and Giano, 1995; Giano et al., 1997, 2000; Schiattarella, 1998); 2) the steep profile of the northern faulted basin margin; 3) the southwestward-tilted depositional surfaces and the related displacement of alluvial sedimentation that follow the SW displacement of the Agri river course, plausibly due to the shift of active extensional faulting from the northern to the southern basin margin (MMFS; Maschio et al., 2005) during the latest Pleistocene; 4) the stacking pattern of several alluvial units, some hundreds of meters thick on the whole within the Molinara depocenter, with the youngest three units, more than 250 m thick, presumably corresponding to the exposed “Complesso Val d'Agri” (Di Niro et al., 1992; Bersezio et al., 2003; 2007).

The basin fill exposed in the southeastern sector of the Agri valley (study area, Pertusillo depocenter, Fig. 1C) consists of up to 200 m of thick succession that rest unconformably above the Apenninic bedrock (locally the Tertiary Gorgoglione and Albidona Flysch units, the Apennine Platform-derived Mesozoic–Paleogene carbonate units and the coeval Lagonegro basinal successions; Carbone et al., 1991; Fig. 1B). The exposed part of the Quaternary succession is represented by lower–middle Pleistocene slope breccia bodies (“Brecce di Galaino and Marsicovetere”, Di Niro and Giano, 1995; Giano et al., 1997) and by a middle–upper Pleistocene group of clastic units (“Complesso Val d'Agri”; Di Niro et al., 1992) that were deposited in scree, alluvial and lacustrine environments. In the literature, the ages of the Quaternary basin fill have been inferred by correlation of the polygenetic landsurfaces of the VAB with post-Sicilian morphostratigraphic features from the nearby Sant'Arcangelo Pliocene–Pleistocene basin (Fig. 1B; Di Niro et al., 1992). Only a few radiocarbon ages of slope deposits and paleosols involved in faulting on the valley flanks are available (with ages between 39 and 18 ^{14}C ka BP; Giano et al., 2000).

Turning points in the evolution of the Val d'Agri Basin at the Pertusillo depocenter

In the Pertusillo depocenter, a new stratigraphic framework has been developed after geological, sedimentological, (paleo-)pedological and paleontological studies. Four unconformity-bounded alloformations have been defined and grouped to form the Agri Valley Allogroup (Zembo, 2007, 2008; Figs. 2 and 3). Each alloformation consists of an axial depositional system (lacustrine to alluvial) that interfingers with transverse units (fan deltas to alluvial fans) asymmetrically fed by the opposite basin margins. Their boundaries correspond to 6th-order erosion–aggradation surfaces (ranking after Miall, 1996; labeled with Arabic numbers in Figs. 3 and 4). Truncated weathering profiles and/or paleosols developed during geomorphological stability stages generally mark these stratigraphic contacts. Therefore, the individual alloformations represent different increments of basin evolution, which occurred under control of both syn-sedimentary faulting and climate changes.

The Pleistocene tectono-sedimentary and palaeoclimate history recorded by the VAB Pertusillo depocenter can be briefly sketched in six stages (Table 1) that are time-constrained by OSL dating.

Asymmetrical basin opening

Sediments deposited during the earliest stages of basin evolution are mostly buried. In outcrops, the remnants of uplifted and faulted breccias directly overlay the Apenninic basement by an erosion surface (S1). The remnants are aligned along the northern VAFS (Fig. 1B), documenting its early activity (Brecce di Galaino and Marsico Vetere, early Pleistocene(?); Di Niro and Giano, 1995; Giano et al., 1997; Giano et al., 2000). The remnants probably interfinger with fine-grained sediments in the subsurface (Colella et al., 2004; Rizzo et al., 2004). The deformed remnants of the Spinoso Conglomerate Formation are restricted to the southern basin margin (Figs. 2 and 3), suggesting moderate uplift and inactivity of the southern MMFS (Fig. 1B).

Tectonic subsidence close to the northern margin

The Pietra del Pertusillo alloformation (PPA, Figs. 2 and 3) developed above erosion surface S2. It documents endhoreic drainage, development of a lacustrine area close to the northern basin margin and progradation of fan deltas from the southern and western basin flanks (Bersezio et al., 2003; Zembo 2008). At the end of stage 2, the lacustrine area was almost filled and a caliche paleosol developed documenting low aggradation and transition to semi-arid climate, with seasonal contrasts (Zembo, 2008); uplift and erosion of the Spinoso Conglomerates were on the way. Vertebrate fossils were found in the fine-grained sediments of the Pietra del Pertusillo alloformation (De Lorenzo, 1898), suggesting an age not younger than the middle Pleistocene for the topmost lacustrine layers. Recent findings of *Cervus elaphus* remnants (Zembo, 2007, 2008; determinations after courtesy of M.R. Palombo, 2005) confirm these data.

Basin widening and progradation of alluvial systems

Stage 3 is represented by the Valle del Nasillo alloformation (VNA, Figs. 2 and 3) that developed above erosion surface S3. The VNA documents i) basin widening due to renewed faulting along the southern MMFS, ii) complete filling of the lacustrine area, iii) rearrangement of the drainage network, iv) progradation of alluvial fans from the southern basin margin, and v) final development of a highly mature fersiallitic paleosol (Duchaufour, 1995) during prolonged warm–humid “Mediterranean-like” climate (Zembo et al., 2007; Zembo, 2008). Published paleontological or geochronological data do not provide any age constraint for this unit and the correlative evolutionary stage 3.

Southward tilting, development of an axial alluvial system and symmetrical progradation of alluvial fans

Both sides of the Pertusillo depocenter contributed to development of alluvial fans in the Valle dell'Aspro alloformation (VAA, Figs. 2 and 3), sitting above erosion surface S4. The fan systems prograded above the first well-developed axial alluvial system of the VAB. Hydromorphic and vertic paleosols are present within this succession and a well-developed and mature brunified-fersiallitic (*sensu* Duchaufour, 1995) pedocomplex marks its top surface. The last paleosol shows polycyclic relict features consistent with paleoclimates of typical interglacial conditions, spanning from semi-arid to warm and moderately wet with clear seasonality of the water deficit. All the pedological bodies are incomplete due to the absence of topsoil. These observations suggest climate changes, plausibly related to transition from a humid/warm to a dry/cold period. The only available age constraint that is known so far

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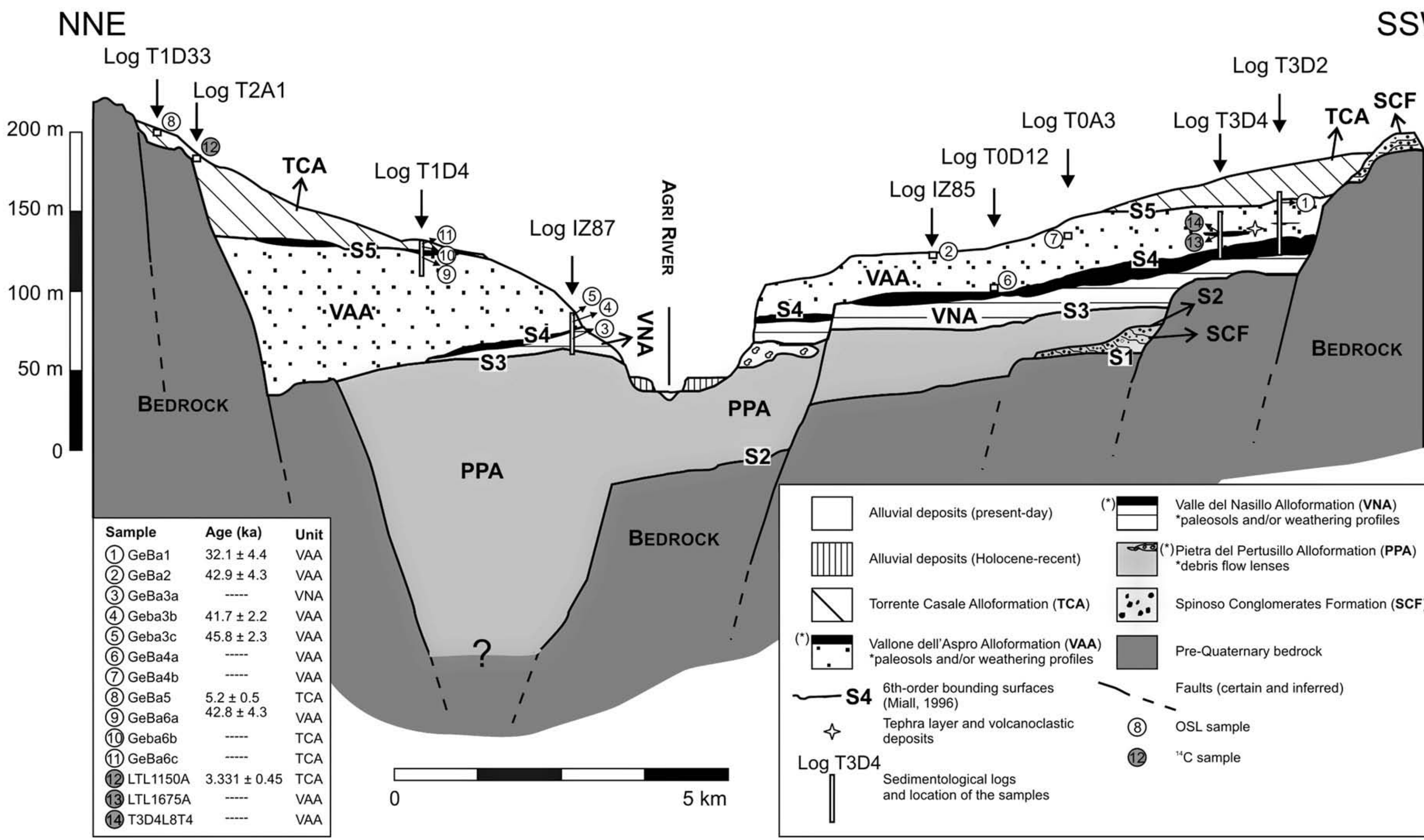

Figure 3. Schematic stratigraphic scheme of the south-eastern part of the Val d'Agri Basin (Pertusillo depocenter; Zembo, 2007 and 2008) showing the relations between the units defined in this study (location in Fig. 2). The sample locations are representative.

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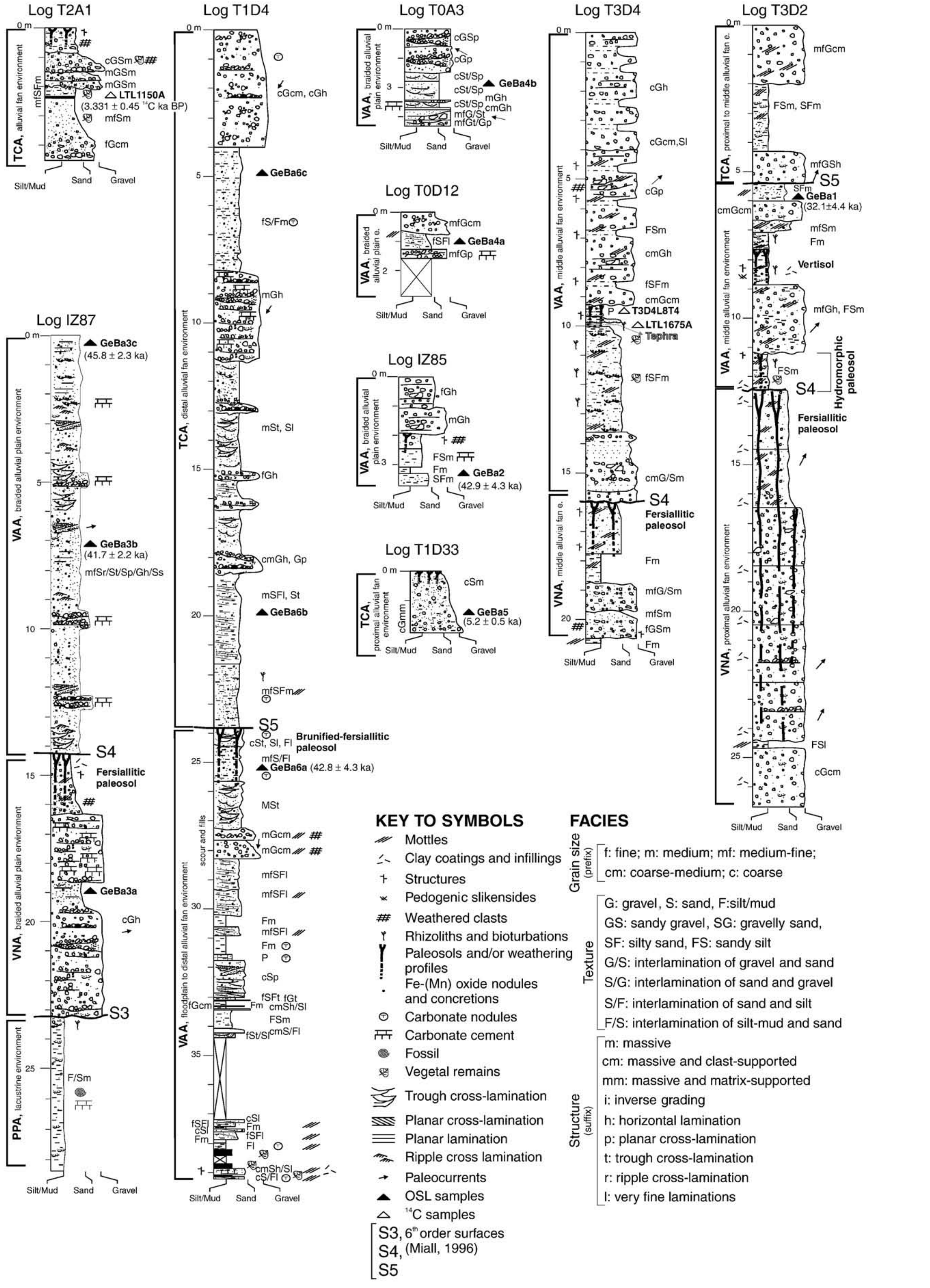

Figure 4. Sedimentological log sections of sample site locations (see map in Fig. 2 and stratigraphic scheme in Fig. 3). Logs illustrate the vertical facies variability, the sample horizons and the overall context of the depositional environment sampled.

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Table 1
Synopsis of tectonic stages and climate periods, as determined by the sedimentary signature (deposits and soils) of the VAB basin fill.

Tectonics	Climate	Sedimentary signature
1 — Asymmetrical basin opening.	Presumably semi-arid, rhexistasy.	Spinoso, Galaino, Marsico Vetere breccia bodies, above an erosion surface (S1).
2 — Tectonic subsidence close to the northern margin.	Initially wet, followed by transition to semi-arid with seasonal contrast.	Erosion surface S2, covered by lacustrine to palustrine deposits (Pietra del Pertusillo alloformation) capped by caliche paleosol.
3 — Basin widening due to fault activity along the southern margin.	Transition to humid-warm "Mediterranean-like".	Erosion surface S3. Progradation of alluvial fans (Valle del Nasillo alloformation), capped by highly mature fersiallitic paleosols.
4 — Southward tilting.	Transition from humid – warm to dry – cold (interglacial vs. glacial?).	Erosion surface S4. Development of an axial alluvial system, progradation of lateral alluvial fans with hydromorphic and vertic paleosols (Valle dell'Aspro alloformation). Mature brunified-fersiallitic pedocomplex at the top.
5 — Lowering of subsidence rates.	Dry – cold (?).	Erosion surface S5. Slow aggradation of alluvial fans (Torrente Casale alloformation).
6 — Breakthrough of the basin threshold.	Humid – warm.	Entrenchment of the drainage network and development of the lowermost alluvial terraces.

OSL dates, calibrated to independent stratigraphy, radiocarbon age determinations and tephrostratigraphy, allow to discuss this evolution in the frame of the Quaternary climate changes, marine isotope stages and Apenninic geodynamics.

is the indirect and relative timing of the terrace that developed at the surface of the Valle dell'Aspro alloformation that has been attributed to the middle–late Pleistocene (Di Niro et al., 1992; Bianca and Caputo, 2003). Traces of activity from far-away volcanic centers are represented by an ash layer and the overlying re-worked volcanogenic sedimentary deposits (Zembo, 2008; Zembo et al., 2008; Fig. 3). These deposits can be used in the calibration for OSL datings of the Valle dell'Aspro alloformation. Chemical composition and mineral assemblage of the volcanic fraction suggest correlation with the Tufo Verde Epomeo of Ischia and the pyroclastic fall deposit Y-7 recognized in the Ionian Sea cores. The latter has been dated by laser $^{40}Ar/^{39}Ar$ on sanidine at 56 ± 4 ka (Allen et al., 1999).

Slow aggradation of alluvial fans during reduction of subsidence rates

Coalescent alluvial fans form the Torrente Casale alloformation (TCA) above erosion surface S5 (TCA, Figs. 2 and 3). This unit records a new progradation and aggradation episode at low rates, due to reduction of the regional subsidence rate, presumably during a period of rhexistasy (presumably arid and cold, prone to promote erosion and deposition of gravel). This evolution slightly predates and then accompanies the entrenchment of the entire drainage system. The top boundary of this unit, an aggradational surface (Bersezio et al., 2003; Zembo, 2007, 2008), has been considered a part of the middle–late Pleistocene terrace by Bianca and Caputo (2003).

Breakthrough of the basin threshold, entrenchment of the drainage network and development of the lowermost alluvial terraces

The fast recession of the last prograding alluvial fans was followed by erosion along the river network that transformed the basin landscape. River deposition occurred during and after breakthrough of the basin threshold and entrenchment. The most recent alluvial deposits are preserved in at least four orders of terraces that step down to the present-day alluvial surface, trying to keep grade with lowering of the relative base level (late Pleistocene to Holocene terraces of Bianca and Caputo, 2003).

OSL dating

Tectonic and climatic events are recorded by the continental fill of the VAB; however, the age constraints for this evolution are very poor. In the next sections, we will present the new OSL data and calibration with radiocarbon ages, tephra correlation and stratigraphic evolution.

Sample collection and preparation

Although the Agri Valley Allogroup is dominated by coarse gravels and fine-grained sediments, it was possible to sample some sand layers suitable for OSL analyses. Three facies were sampled from different environments: i) moderately sorted coarse and medium sands at the top of alluvial sand bars and bedforms; ii) fine to coarse sands and silty sands forming multistory channel fills; and iii) sandy silt and silty sands of crevasse splays and sheetflood deposits. A schematic overview of the whole of sampling in the Pertusillo depocenter is given in Figure 3.

Eleven samples in total were taken by hammering steel tubes (5 cm diameter and 30–50 cm long) into freshly cleaned exposures. The tubes were capped with aluminum sheets and sealed using black plastic bags. Samples GeBa5, GeBa6b and GeBa6c (hereafter samples 5, 6b and 6c) can be ascribed to the younger Torrente Casale alloformation, while samples GeBa1, GeBa2, GeBa3b, GeBa3c, GeBa4a, GeBa4c and GeBa6a (hereafter samples 1, 2, 3b, 3c, 4a, 4c and 6a) belong to the Vallone dell'Aspro alloformation. Sample 3a was taken from the braid plain deposits underlying the fersiallitic paleosol at the top of the Valle del Nasillo alloformation. Nine representative log sections show the vertical facies variability, the depositional environments sampled and the overall stratigraphical context (Fig. 4).

The quartz extraction was made following the conventional procedure (Stokes, 1992; Mejdahl and Christiansen, 1994; Lang et al., 1996; Mauz et al., 2002) under dim red light. All the luminescence measurements were conducted on coarse quartz grains (75–120 μm).

The samples were first extracted from the sampling tubes. The outer material was exposed to sunlight during sampling, and a slice of about 1 cm was removed and retained for dosimetric evaluation. The sediments were wet sieved to extract the 80–180 μm sand fraction. To remove colloidal hydrated Fe–Mn-oxides, a 20% NaH solution was used; to remove organic material, the sediment was treated with H_2O_2 (36 vol) for at least 2 h on a magnetic stirrer. In some cases, a 12-h treatment was necessary. Carbonates were removed with HCl attack (32%) for 40 min.

The resulting fraction was a mixture of quartz, feldspars and heavy minerals. They have small differences in density and can be isolated by suspension in heavy liquids ($Na_6[H_2W_{12}O_{40}]\cdot xH_2O$; Mejdahl and Winther-Nielsen, 1982; Mejdahl, 1985). The polymineral sample was suspended in a solution of 2.73 g/cm^3 and then left to spin in a centrifuge for 3 min at 2500 rpm. A ratio of sample weight to volume of heavy liquid not greater than 1:30 was used, to minimize negative grain interactions during separation (Galli et al., 2007).

After this first density separation, the mixture of quartz and feldspars was etched for 40 min in 40% HF. The feldspars, being chemically less resistant than quartz to HF, are partially or completely dissolved after this step. In some cases, it was necessary to repeat this process one or two times to obtain a good separation. This treatment also removed the outer rind of the quartz grains and reduced the external alpha particle contribution to the OSL signal. Finally, the extract was sieved to get the 75–120 μm fraction. During this stage, two samples (4a and 4b) were rejected because the quartz fraction was too small.

For measurement, the grains of quartz were deposited on aluminum discs (0.5 mm thick and 10 mm in diameter) coated with

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Table 2
Dose rate calculations of the Val d'Agri Basin samples.

Sample	Sampling depth (m)	Altitude (m a.s.l.)	U (ppm; ±5%)	Th (ppm; ±5%)	^{40}K (ppm; ±3%)	Water content (%)	Dose rate (mGy/y)	Aliquots (#)	D_e (Gy)	Age (ka)	Unit
GeBa1	5.5	611	4.01	12.03	3.07	20±10	3.77±0.15	20	121±14	32.1±4.4	VAA
GeBa2	3	590	2.69	8.07	2.31	20±10	2.75±0.16	21	118±8	42.9±4.3	VAA
GeBa3b	12	543	2.95	8.85	1.86	20±10	2.54±0.16	19	106±2	41.7±2.2	VAA
GeBa3c	5	550	2.54	7.62	2.04	20±10	2.51±0.16	22	115±3	45.8±2.3	VAA
GeBa5	1.5	690	2.49	7.47	2.25	20±10	2.63±0.17	18	13.8±1.0	5.2±0.5	TCA
GeBa6a	25.5	624.5	2.39	7.17	2.80	20±10	2.99±0.17	20	128±9	42.8±4.3	VAA

a non-luminescent heat-resistant resin. A typical aliquot consisted of a few thousand of grains.

Optically luminescence measurements

The OSL measurements were made using an automated luminescence system (Risø TL/OSL-DA-15), equipped with a ^{90}Sr/^{90}Y beta source delivering 0.10 Gy/s (±3%) to the sample position. The quartz OSL was stimulated by an array of blue LEDs (470±30 nm) for 100 s at 125°C with a constant stimulation power of 54 mW/cm^2. The absence of feldspars was checked using an IR diode array (830±10 nm) with a stimulation power of 360 mW/cm^2. The preheat was at 260°C for 10 s and the cutheat was at 160°C for 10 s. Photons were detected by a bialkali photomultiplier tube (EMI 9235QB15) coupled to a 7.5 mm Hoya U-340 filter.

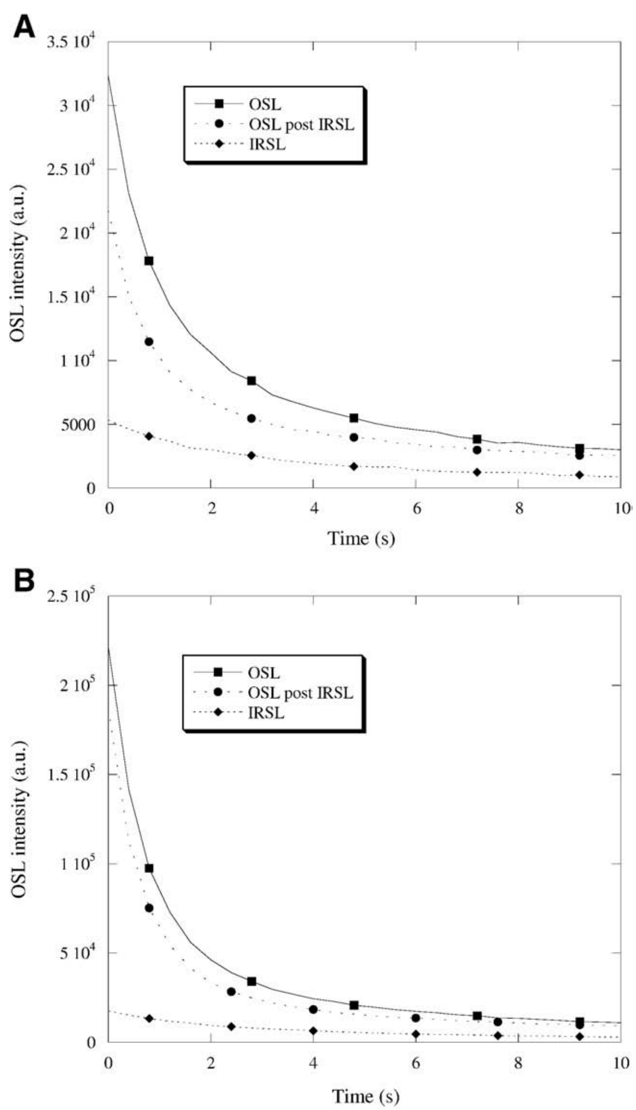

Figure 5. OSL-IR-depletion ratio test for a) sample GeBa3a and b) sample GeBa2. Solid line refers to an irradiated aliquot (100 Gy beta) obtained under blue light stimulation, dashed line to the same aliquot irradiated with the same dose obtained under blue light stimulation after IR light stimulation (dotted line).

Radioactivity measurements

In order to calculate the annual dose, the Th and U concentrations of the sediments were measured with total alpha counting using ZnS scintillator discs (Aitken, 1985), assuming a concentration ratio Th/U equal to 3. ^{40}K content was deduced from the total concentration of K and the concentration of K was measured with flame photometry. Attenuation of the beta dose was taken into account (Bell, 1979). The contribution of cosmic radiation, usually a few percent of the annual dose rate, was taken as 0.15 mGy/y at depths of about 1 m. For greater depths attenuation factors were used (Aitken, 1985). The results of radioactivity measurements together with the corresponding dose-rates are reported in Table 2.

In calculating the dose-rates, water content was estimated on the basis of present moisture and sediment type, presuming discontinuous water saturation of the sediments. It was assumed that the average water content over the entire burial period was about 20% (Table 2).

Age determination

To control the purity of the extracted quartz, the OSL-IR-depletion ratio test (Duller, 2003) was performed. In practice, an irradiated aliquot (with regenerative β-dose close to the value of the expected D_e) was firstly illuminated with IR light at RT, recording the IRSL curve. A second OSL curve is subsequently recorded, but under blue stimulation (the so-called OSL-post-IRSL signal). Because in pure quartz no IRSL signal is observed at RT, the presence of a significant IR induced emission is an indication of a strong feldspar contamination. IRSL signals were observed in all samples, even from a purified extracted quartz. To reduce its presence another HF etching for 40 min was attempted and the test remade. Nevertheless, some samples showed again a significant contribution due to feldspars. This could be due to the presence in the same grain of both quartz and feldspar which could not be separated. An OSL-post-IRSL/OSL ratio higher than 0.90 is usually considered acceptable (Duller, 2003). In Figure 5, the

Table 3
Single aliquot regeneration sequence used for dating (Murray and Wintle, 2000).

Step	Treatment	Observed
1	Give dose, D_i[a]	–
2	Preheat[b] at 260°C for 10 s	–
3	Stimulate for 100 s at 125°C	L_i
4	Give test dose, D_t	–
5	Heat[b] to 160°C	–
6	Stimulate for 100 s at 125°C	T_i
7	Return to 1	–

[a] For the natural sample i = 0 and D_0 = 0 Gy.
[b] Aliquot cooled to <60°C after heating.

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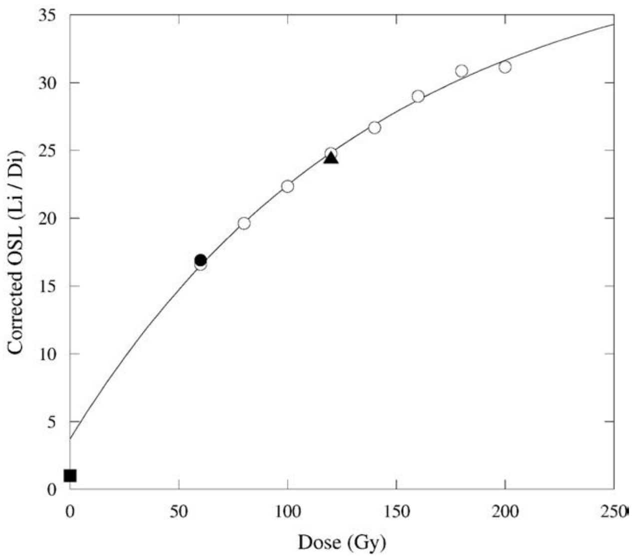

Figure 6. SAR dose response curve for quartz sample GeBa1. The regeneration doses (D_i, I = 1, 9) were 60, 80, 100, 120, 140, 160, 180, 200 (open circles), 0 (filled square) and 60 Gy (filled circle) and the test dose, D_t, was 1 Gy. The recycling ratio was 1.03 and recuperation was 3.4% of the natural signal (filled triangle).

shine-down curves obtained for a sample in which the contribution of feldspar was relevant (sample 3a, Fig. 5A) and one for which it was not (sample 2, Fig. 5B) are presented. The IRSL check was repeated on all the aliquots used for D_e determination and those showing feldspars contamination were rejected. The single-aliquot regenerative-dose (SAR) protocol was used to determine the radiation dose absorbed by sediment grains since deposition (Murray and Wintle, 2000).

The measurement sequence used is reported in Table 3. The preheating for the regenerative doses was 10 s at 260°C while in all the test doses the preheat was at 160°C. For all samples, the influence of the preheating temperature on the equivalent dose was investigated (*preheat plateau* test; Aitken, 1994) in the range 160–300°C in 20°C steps. This tests indicated no significant dependence of D_e on the preheat temperature up to 260–280°C. The first 3.6 s were used for D_e evaluation after background subtraction (mean of the signal in the last 20 s of the decay curve).

The growth curves were constructed using nine regenerative doses ranging from 0 to 200 Gy. The zero dose point and the recycling point (an additional measurement of the lowest regenerative dose) were measured at the end of the sequence. For all samples, the recuperation never exceeded 5% and the recycling ratio test always yielded a value near to unity (Wintle and Murray 2006). Figure 6 shows a typical SAR dose–response curve for sample 1 with the natural OSL signal interpolated in the sensitivity corrected growth curve.

In total, 30 aliquots for each sample were analyzed: 22 to determine D_e and 8 to select the suitable preheat temperature.

Results

The OSL chronology of sand samples taken in the Pertusillo depocenter provided an initial framework for understanding the timing of braid plain and alluvial fan processes associated with (paleo-) environmental conditions.

Of the 9 analyzed quartz samples, six (1, 2, 3b, 3c, 5 and 6a) could be dated and yielded optical ages ranging from 5.2 ± 0.5 ka (the uppermost sample 5) to 45.8 ± 2.3 ka (sample 3c) (Table 2 and Fig. 3). For these samples, the equivalent dose histogram showed a set of values symmetrically clustering around a mean value and the observed scatter should arise from counting statistics only (Fig. 7). This indicates that the grains were well-bleached and that effects of bioturbation can be excluded. Table 2 reports the number of aliquots passing all tests and the mean D_e calculated. The six samples provided an internally consistent series of dates and showed a roughly increasing age with depth. Only sample 3b shown a slightly younger age compared to samples above (Table 2). Although the sample fits within the sequence of dates, it seems to underestimate the geological age. The other three samples (3a, 6b and 6c; Figs. 3 and 4) were rejected because they did not pass one of the tests or because they gave extremely scattered D_e values, showing a non-Gaussian distribution, so they possibly did not undergo an efficient solar resetting.

The younger sheetflood deposits at the top of the northern alluvial fan of the Torrente Casale alloformation were dated at 5.3 ± 0.5 ka (sample 5); the sample was taken from just ~ 1.5 m below the present-day topographic surface (Figs. 3 and 4, Log T1D33). Samples 2, 3b and 3c from the fine-grained braid plain deposits of Vallone dell'Aspro alloformation (Figs. 3 and 4, Logs IZ85 and IZ87) gave an age ranging from 42.9 ± 4.3 ka (sample 2) to 45.8 ± 2.3 ka (sample 3c). For the northern distal alluvial fan deposits of the Vallone dell'Aspro alloformation, an age of 42.8 ± 4.3 ka (sample 6a) was obtained 1.5 m below the surface S5 at the top of the unit (Fosso Scazzera terrace; Figs. 2 and 4, Log T1D4). In contrast, the top of Vallone dell'Aspro alloformation along the southern Vella river terrace (Fig. 2) yielded a considerably younger age of 32.1 ± 4.4 ka (sample 1; Fig. 4, Log T3D2). No absolute age information was available for VNA (sample 3a; Fig. 4, Log IZ87).

Radiocarbon and tephrochronology age determinations were available for comparison with the OSL data. Among the three samples collected for AMS ^{14}C dating (LTL1150A, LTL1675A and T3A4L8T4; Fig. 4, Log T2A1 and Log T3D4), only one yielded a reliable result. It was taken from an organic-rich level at the top of the Torrente Casale alloformation, just below the topographic surface (LTL1150A). AMS ^{14}C dating was carried out by CEDAD (Center for Dating and Diagnostic, Department of Engineering and Innovation, University of Salento). The ^{14}C age obtained for sample LTL1150A (3.331 ± 0.45 ^{14}C ka BP) was calibrated using OxCal Ver 3.10 (1700–1500 BC; Reimer et al., 2004). The optical age of the sample 5 (5.2 ± 0.5 ka; Table 2) is *ca.* 1500–2000 yr older than the ^{14}C age obtained for sample LTL1150A in a similar stratigraphic position (Fig. 3). However, this result falls within a comparable age range. It must be considered that the organic-rich layer was about 4 km away from sample 5 and that the materials (mineral grains and organic material, respectively) and the events (concealment of grains from daylight and fixation of atmospheric carbon) do not necessarily correspond.

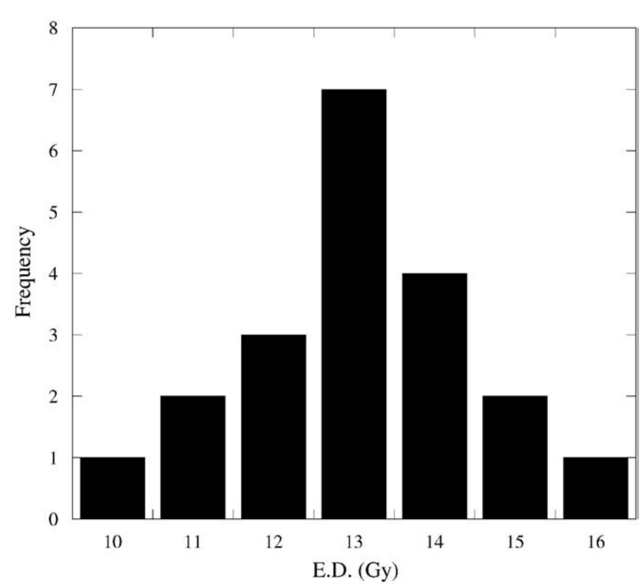

Figure 7. Histogram of the D_e distribution for the sample GeBa5. It was obtained on 18 aliquots.

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A cm-thick ash-fall deposit is locally preserved in the intermediate portion of the Vallone dell'Aspro alloformation (Figs. 3 and 4, Log T3D4). The tephra is composed of alkali trachytic and porous ash, partially weathered and could be correlated with the Ionian tephra Y-7 (Zembo, 2007) dated at 56 ± 4 ka (Allen et al., 1999). This fact is justified by the absence of amphibole and the presence of a conspicuous amount of aegirine–augite to aegirine clinopyroxenes with minor apatite, titanite, zircon (Zembo et al., 2008). Thus, we may exclude all the volcanic centers of the Campanian district except for the Ischia volcano, as it contains amphibole (Keller, 1978; Wulf et al., 2004). This mineralogical association allows us to consider the alkali trachitic tephra layer as a continental equivalent of the Tufo Verde Epomeo eruption deposits (Island of Ischia), that have their marine counterpart in the *ca.* 56 ka Y-7 ash layer found in deep-sea sediments of the Ionian Sea (Wulf et al., 2004).

The OSL ages of samples 1, 2, 3b, 3c and 6a (Figs. 3 and 4) are in good agreement with the possible age of the tephra layer, taking into account their relative stratigraphic position and the relative errors on the age determinations. Only sample 3b shows an OSL age inversion compared to the overlying sample 3c (Figs. 3 and 4, Log IZ87; Table 2). Nonetheless, these two samples yielded comparable ages that are compatible with the errors on the estimates.

Discussion

Integration of stratigraphic and geochronological data allows us to discuss the timing of the depositional events that mark the tectonic and climatic turning points in the framework of the Quaternary climate and geodynamic evolution of the Southern Apennines and Mediterranean areas. The available data permit us to constrain the evolution of the late Pleistocene to Holocene succession represented by the Vallone dell'Aspro and Torrente Casale alloformations to gain insight on age, the relative chronology (Table 1), time constraints and correlations with the regional evolution.

The luminescence age of the top of Torrente Casale alloformation is bracketed between ~5000 yr (sample 5; Fig. 3) and 1700–1500 BC (LTL1150A; Fig. 3) indicating a Holocene age for deposition at the top of this unit. The optical age at the top of Vallone dell'Aspro alloformation is ~32 ka (sample 1; Fig. 3) and provides a minimum age for onset of progradation of the Torrente Casale alloformation alluvial fans. As a consequence, the breakthrough of the basin threshold, the entrenchment of the drainage network and the development of the lowermost alluvial terraces must be assigned a latest Pleistocene to Holocene age.

Luminescence ages from Vallone dell'Aspro alloformation, which can be compared with tephrocronology (Zembo et al., 2008), indicate that the deposition of most of the unit is bracketed between ~56 and ~32 ka. This was the time of southwards tilting of the basin floor, development of an axial alluvial system and progradation of transverse alluvial fans. The southwestward shift of deposition is documented by younger alluvial deposits from the northern to southern basin margins. This is documented by the OSL data below surface S5 that change from ~43 (NNE, sample 6a; Fig. 3) to ~32 ka (SSW, sample 1; Fig. 3). The same surface S5 truncates a well-developed weathering profile at the top of Vallone dell'Aspro alloformation. It consists of a thick reddish-brown pedocomplex (North American Commission on Stratigraphic Nomenclature, 1983; International Commission on Stratigraphy, 1984) formed by two paleosols resulting from erosion and burial episodes (Fig. 4, Log T1D4; Zembo, 2008). Both of them can be tentatively classified as transitional brunified-fersiallitic paleosols (*sensu* Duchaufour, 1995) and indicate the establishment of short-living episodes of warm and humid climate. Based on OSL data and stratigraphic position, this pedocomplex developed between ~43 and ~32 ka.

The underlying Valle del Nasillo alloformation documents basin widening, filling of the pre-existing lacustrine area (Pietra del Pertusillo alloformation), rearrangement of the drainage network and progradation of alluvial fans from the southern basin margin. No OSL ages were obtained; nevertheless, timing can be inferred from stratigraphy. The highly mature fersiallitic paleosol at the top of Valle del Nasillo alloformation (Fig. 4, Logs IZ87, T3D4 and T3D2; Zembo et al., 2007) is correlated with a long “Mediterranean-like” climatic period (*sensu* Dudal et al., 1966; Suc, 1984; Duchaufour, 1995; Finke et al., 1998) older than ~56 ka. Comparable paleosols developed in the Apennine area during MIS 5 (Chiesa et al., 1990; Cremaschi, 1990; Scarciglia et al., 2003; Coltorti and Pieruccini, 2006) correspond to ages between 71 and 127 ka (Martinson et al., 1987; Shackleton et al., 2003). The most favorable conditions for development of this type of fersiallitic paleosols have been recognized in the Mediterranean region during MIS Substage 5e in southern Italy and Sardinia (Cremaschi, 1987; Blumetti et al., 1990; Trombino, 1998; Scarciglia et al., 2003; Carboni et al., 2006; Coltorti and Pieruccini, 2006). We conclude the soil-formation process at the top of Valle del Nasillo alloformation began during MIS Substage 5e and plausibly lasted until the end of MIS 5. For these reasons, the alluvial fan deposits forming Valle del Nasillo alloformation might be attributed to the late part of the middle Pleistocene, tentatively MIS 6 (also taking into account the significance of coarse clastic deposition typical of this unit).

Concerning the earliest stages of basin evolution, the chronostratigraphic constraints to opening, subsidence and lacustrine sedimentation (Pietra del Pertusillo alloformation) are still very poorly understood. On the basis of the previous considerations, the Pietra del Pertusillo alloformation should be middle Pleistocene or older in age.

The geochronological constraints permit us to compare the climatic signature of depositional and paleopedological events to the Mediterranean climate cycles calibrated with Marine Isotope Stages (Chappell and Shackleton, 1986; Martinson et al., 1987; Van Kolfschoten et al., 2003; Shackleton et al., 2003).

Three different evolutionary stages were recorded by the individual units forming the Agri Valley allogroup: 1) development of erosional surfaces (S2, S3, S4 and S5) during stages of tectonic activity and rhexistasy (Erhart, 1956), 2) progradation and aggradation of coarse clastic depositional systems (Valle del Nasillo, Vallone dell'Aspro and Torrente Casale alloformations) during stages of substantial erosion of devegetated slopes, 3) development of paleosols in areas subjected to morpho-tectonic stability during biostasy (*sensu* Erhart, 1956 and Tricart, 1978) and Mediterranean-like warm–humid climate conditions. The typical interglacial soil features recorded in the paleosols could be related to MIS 5 and MIS 3, respectively. As a consequence, the erosional surfaces and at least the lowermost parts of the coarse alluvial systems were developed during MIS 6 (lowermost Valle del Nasillo alloformation), MIS 4 (lowermost Vallone dell'Aspro alloformation) and MIS 2 (lowermost Torrente Casale alloformation).

Conclusions

This study provides an example of the usefulness of optical dating in intermontane continental settings where other geochronological constraints are limited. This technique provides chronological control when applied to a variety of depositional environments within the late Pleistocene to Holocene alluvial deposits of the VAB fill (“Agri Valley Allogroup”, Zembo, 2007, 2008), and allows us to develop a chronology of tectono-sedimentary and climatic evolution of the area.

OSL provides, for the first time, valuable information on the chronology of these sediments. The data obtained shows consistency between OSL ages and stratigraphy. In addition, optical ages broadly agree with the available radiocarbon, tephrochronology, and relative age assignments based on stratigraphy and geomorphic relationships. The multidisciplinary approach allowed us to unravel the sedimentary

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signature of tectonic and climatic controls in order to formulate an evolution scheme of the VAB (Fig. 3). This contributes to the verification of the reconstruction of the Quaternary climate and geodynamic evolution of the Mediterranean area, from a continental succession perspective. It can be summarized as follows:

1) Early–middle Pleistocene asymmetric tectonic subsidence related to fault activity of the northern Val d'Agri Fault System and basin filling by lacustrine and fan deltas deposits. Transition to a semi-arid climate period, eventually linked with the first evidence of icehouse conditions;
2) Middle Pleistocene fault activity along the southern Monti della Maddalena Fault System, basin widening and northwestwards progradation of the alluvial fan systems forced by erosion subsequent to rhexistasy (Valle del Nasillo alloformation);
3) Late Pleistocene pedogenesis in warm–humid "Mediterranean-like" climate conditions during MIS 5 in areas of morpho-tectonic stability;
4) The onset of cooling (MIS 4 ?) and erosion of fan surfaces, followed by progradation of coarse clastic alluvial fans (lower Vallone dell'Aspro alloformation) and by ash fall out comparable to Y-7 Ionian tephra;
5) Progressive re-establishment of interglacial conditions (MIS 3), pedogenesis of the ash layer, development of a wide axial alluvial plain and progradation of the transverse coarse-grained alluvial fans during tectonic activity (Vallone dell'Aspro alloformation);
6) Short-lasting Mediterranean-like pedogenesis between ~43 ka and ~32 ka (MIS 3) concurrent with progradation-aggradation of the southern alluvial fan deposits of the upper Vallone dell'Aspro alloformation and southwards tilting of the basin floor due to latest Pleistocene fault control by the Monti della Maddalena fault system;
7) Latest Pleistocene (possibly MIS 2) erosion and subsequent aggradation of the alluvial fans of Torrente Casale alloformation;
8) Regional uplift and substantial breakthrough of the basin threshold, entrenchment of the drainage network, and development of Holocene-historical terraces.

The results obtained by the OSL technique encourage a new attempt to date the oldest depositional systems of the VAB (lacustrine deposits of the opening stage, Pietra del Pertusillo alloformation, and the first alluvial fan deposits of the Valle del Nasillo alloformation). A complete record of Quaternary evolution of the VAB intermontane basin will allow for regional control of tectono-sedimentary and climatic events in the Southern Apennine area.

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