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INTEGRATED ANALYSIS FOR INTERMONTANE BASINS STUDIES: TECTONO-STRATIGRAPHIC AND PALEOCLIMATIC EVOLUTION OF THE L'AQUILA BASIN

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Integrated analysis for intermontane basins studies: tectono-stratigraphic and paleoclimatic evolution of the L'Aquila Basin

Abstract

Although the L'Aquila Basin is one of the central Apennines most seismically active intermontane basins, its long-term geological evolution has long been poorly understood even if, especially after the 6th April 2009 earthquake, several studies were carried out in this area. Particularly problematic in intermontane basins studies are the uncertainties associated with the onset of the extensional tectonic and the age of the older continental deposits, as well as the subsurface bedrock geometries and the stratigraphical relationships of the continental deposits within the basin.

A multidisciplinary approach that integrates stratigraphical, geomorphological and structural field surveys with paleontological analyses, geochronological (OSL; ^{14}C) dating, well log analyses and geophysical data interpretation (seismic reflection profile; HVSR), was used in order to reconstruct the L'Aquila Basin tectono-stratigraphic evolution, the regional tectonics and the climate forcing that controlled sedimentation processes within the basin. Our results allowed to review the L'Aquila Basin stratigraphy and to define seven synthems, partly matching stratigraphic units or synthems already described in previous works. In addition the comparison between the tectono-stratigraphic evolution of L'Aquila Basin and other intermontane basins (i.e., Tiberino, Rieti, Leonessa basins), together with the stratigraphy of the Plio-Quaternary succession of the Roman area, allowed to identify some similarities that help to constrain the major regional events that controlled the L'Aquila Basin geological history.

The occurrence of a *Caspiocypris* species flock at the base of the sedimentary fill of the eastern part of L'Aquila Basin (*San Demetrio-Colle Cantaro Synthem*), which possibly correlate the late Piacenzian-Gelasian ostracod fauna of the *Fosso Bianco Formation* of the Tiberino Basin, points to a late Piacenzian age for the onset of the extension in the L'Aquila Basin. Interpretation of a seismic reflection profile (Pettino1) shows the occurrence, above the Meso-Cenozoic bedrock, of a wedge shaped seismic unit corresponding to the basal deposits of the western L'Aquila Basin (*San Demetrio-Colle Cantaro Synthem*), pointing to a late Piacenzian-Gelasian syn-rift stage during the first phase of basin filling. As a result of the correlation among the stratigraphies of L'Aquila Basin and the stratigraphy of Plio-Quaternary successions of the central Italy, the main tectonic phase responsible for the increase of the accommodation space of the L'Aquila Basin ended close to the Gelasian/Calabrian transition with a regional uplift event. Indeed, the second phase of basin fill, which occurred mainly during the Calabrian (*Madonna della Strada Synthem*), happened in a post-rift stage and was mainly characterized by the development of a fluvial environment, with floodplains and extensive swamp areas close to meandering fluvial channels. After these two major phases of basin filling, the L'Aquila intermontane basin was affected by five shorter tectono-sedimentary events that gave rise to the formation of Middle and Upper Pleistocene unconformity-

bounded stratigraphic units, with the younger units carved into the previous ones or even into the pre- or syn-orogenic successions.
The Late Pleistocene evolution of the L'Aquila Basin was mainly characterized by the development of three order of fluvial terraces, two of which are strath terraces (T2 and T3). The second order fluvial terrace, belonging to the *Campo di Pile Synthem*, correlates MIS 3, since it shows a ^{14}C 2σ age of 41,854-40,464 yr cal BP. From this data, a late Quaternary river incision rate between 0.24 to 0.32 mm/yr can be estimated.
Our results showing an onset of the L'Aquila Basin that is synchronous with the onset of the Tiberino Basin call into question the notion that these extensional intermontane basins become younger from the Tyrrhenian towards the Adriatic side of the central Apennines.

1.0 INTRODUCTION: Framework of the central Apennines intermontane basins

Intermontane basins are key sites to understand the interaction between tectonic and climate after the central Apennines post-orogenic stages. Here landforms like fluvial terraces, fan geometry and low relief surface located on interfluves and valley flanks record the post-orogenic landscape evolution.

Several studies have been carried out to understand the onset and subsequent evolution of the Central Apennines intermontane basins, but it is worthy to note that, even if these extensional intermontane basins (Fig. 1.1) are among the most seismically active sectors of the central Mediterranean area (Amato et al., 1997; Bagh et al., 2007; Falcucci et al., 2011; Vannoli et al., 2012), their tectono-stratigraphic evolution is still poorly understood.

Although strike-slip tectonics was active during the post-orogenic stage of the central Apennines (Alfonsi et al., 1991; Salvini, 1991; Mattei et al., 1995; Faccenna et al., 1994; Cosentino et al., 2010), in this region intermontane basins are mainly related to: (1) a first stage of compressional tectonics linked to the building phases of the Apennines; and (2) a second stage of later extensional tectonics related to the opening of the Tyrrhenian back-arc basin and orogenic collapse of the Apennines. During the first stage, intermontane basins were characterized by compressional tectonics and developed on top of the Apennine tectonic units as thrust-top or piggy-back basins (Patacca and Scandone, 1989; Patacca et al., 1992; Cipollari and Cosentino, 1995; 1996; Cipollari et al., 1999a; 1999b; Cosentino et al., 2010), as a part of a foreland basin system. These intermontane basins have been developing since Late Miocene at the leading edge of the central Apennine chain during its migration towards the Adriatic foreland domain. The ages of the central Apennine thrust-top basins were useful to define the main steps of the Apennine orogeny and are consistent with late Tortonian (ca. 9 Ma) up to late Pliocene (ca. 3 Ma) migration of the Apennine chain from the Tyrrhenian side towards the Adriatic side of the Italian Peninsula (Patacca and Scandone, 1989; Patacca et al., 1992; Cipollari and Cosentino, 1995; 1996; Cipollari et al., 1999a; Cosentino et al., 2010).

The subsequent nucleation of the Tyrrhenian extensional province upon the Apennine orogen, as a lithospheric response of the upper plate to the rollback of the subducting Adria plate (Dewey, 1988; Faccenna et al., 1996), led to the continental rupture and oceanization of the Tyrrhenian area and enhanced the orogenic collapse of the Apennine tectonic wedge (Dewey, 1988), defining the onset of the second stage of intermontane basins in the Apennines. The extensional tectonics and significant uplift (by more than 1000 m) (D'Agostino et al., 2001) in the internal zones of the chain, occurs simultaneously with marginal thrusting in outer orogenic zones (Dewey, 1988; Cipollari et al., 1999b). The Tyrrhenian extensional tectonics propagated northeastward towards the Adriatic foreland (Cavinato and De Celles, 1999; Cipollari et al., 1999b; Cosentino et al., 2010) following both the migration of the Apennine thrust front and the slab retreat of the subducting Adria plate.

The arriving of the Tyrrhenian extensional front in different sectors of the Apennine chain gave rise to collapsing areas with the subsequent onset of extensional intermontane basins (Fig. 1.1).

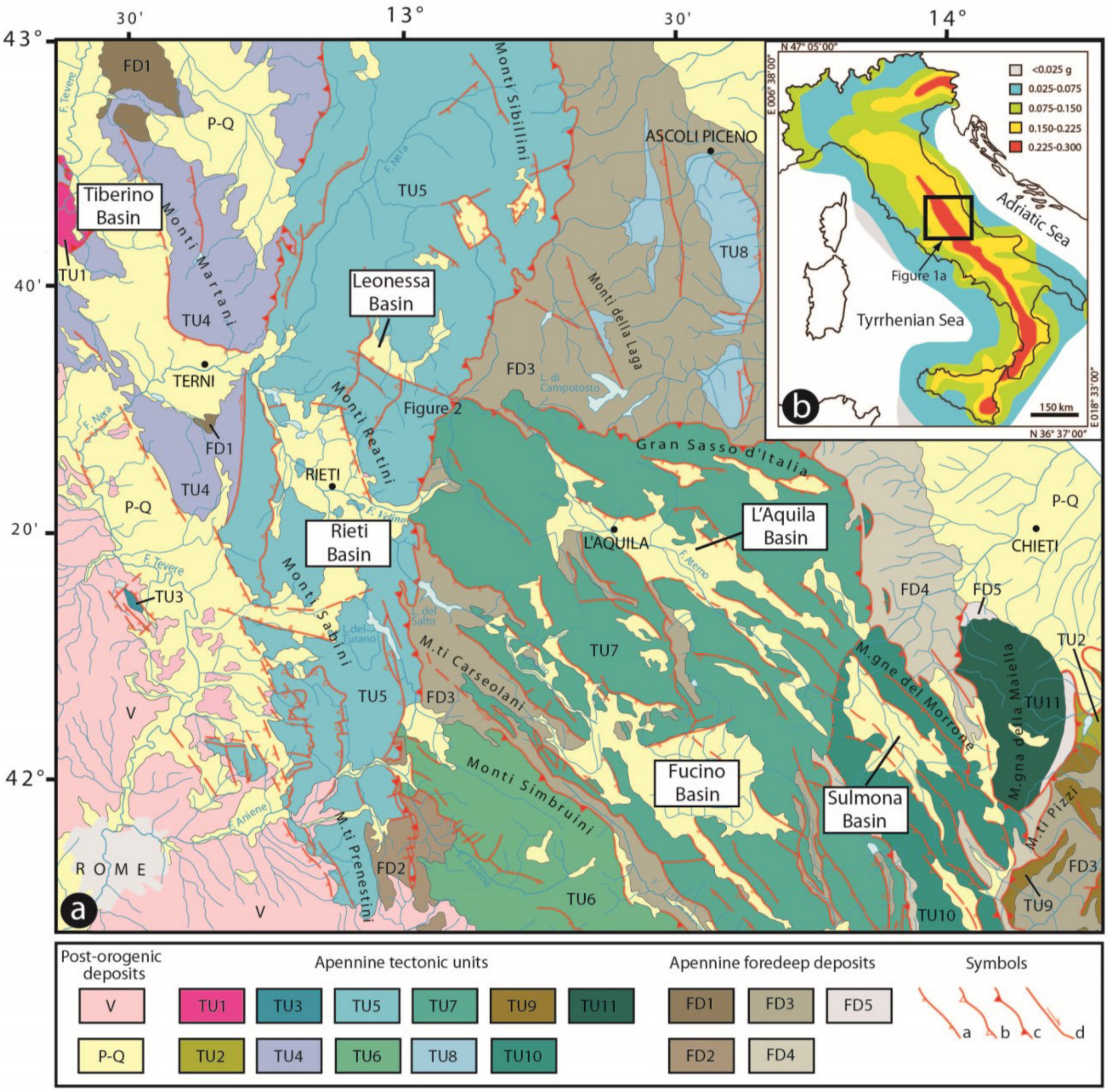


Fig. 1.1 – **a**) Structural sketch of the central Apennines. The main Plio-Quaternary intermontane basins of the central Apennines are shown. V: Quaternary volcanics; P-Q: Plio-Quaternary marine and continental deposits; TU1: External Ligurian Unit; TU2: Sannio Unit; TU3: Mt. Soratte Tectonic Unit; TU4: Inner Umbria Tectonic Unit; TU5: Umbria-Marchean-Sabine Tectonic Unit; TU6: Simbruini-Ernici-Matese Tectonic Unit; TU7: Gran Sasso-Western Marsica Tectonic Unit; TU8: Molise Tectonic Unit; TU9: Acquasanta-Montagnone Tectonic Unit; TU10: Morrone-Eastern Marsica Tectonic Unit; TU11: Maiella Tectonic Unit; FD1: Burdigalian foredeep deposits; FD2: Tortonian foredeep deposits; FD3: Messinian foredeep deposits; FD4: upper Messinian-early Lower Pliocene foredeep deposits; FD5: late Lower Pliocene foredeep deposits; a) normal fault; b) minor thrust; c) major thrust; d) strike-slip fault. **b**) Map of the seismic hazard in Italy, showing peak ground accelerations (g) that have a 10% chance of being exceeded in 50 years, data from Istituto Nazionale di Geofisica e Vulcanologia (INGV). It is worthy to note that in central and southern Apennines peak ground acceleration maxima correspond to intermontane basins.

The persistence of this extensional regime, characterized by a 3-5 mm/yr NE-oriented rate as testified by GPS and InSAR time-series (Devoti et al., 2011; D'Agostino et al., 2011), is confirmed by instrumental seismicity and earthquakes occurrence, like the 6^{th} April 2009 L'Aquila one (Mw = 6.1) (Bagh et al., 2007; Falcucci et al., 2015), along NW-SE trending normal faults; as well as by the numerous paleoseismological studies that evidenced the displacement of Holocene deposits within central Apennines intermontane basin (Galadini & Galli, 2000; Galli et al., 2010; Moro et al., 2013).

A high degree of doubtfulness mainly regards the age of the older continental deposits of these sedimentary basins. Attempts for correlating the older continental deposits of different extensional intermontane basins were mainly based on geomorphological observations (Bertini and Bosi, 1976; Bosi, 1989; Bosi and Messina, 1991; Bosi et al., 2003). Anyway, the age of the older continental deposits at the base of the central Apennine extensional intermontane basins are still unknown. The national geological mapping project (CARG project) ascribes to the Pliocene(?)-Middle Pleistocene the Aielli-Pescina Supersynthem, at the base of the continental successions of the intermontane basins mapped within L'Aquila, Torre dei Passeri, Avezzano, and Sulmona geological maps (ISPRA-Regione Abruzzo, 2006).

Generally, little is known about the subsurface geology of the intermontane basins of the central Apennines and their tectono-sedimentary evolution through time. Since the Early Pleistocene, the intermontane basins of Abruzzo have hosted isolated lakes that were fed by a centripetal drainage network (Galadini & Messina, 2004; Messina et al., 2007). Starting from the Middle Pleistocene, due to large-scale uplift, most of these were drained off through regressive erosion, with the exception of a few where normal fault activity (or exceptional travertine growth) preserved their damming.

Although all the extensional intermontane basins display generally similar tectono-stratigraphic characteristics, the evolutionary schemes suggested by different authors for those basins are quite different. For the L'Aquila (Giaccio et al., 2012; Mancini et al., 2012; Tallini et al., 2012), Sulmona (Miccadei et al., 1998, 2002; Gori et al., 2011; 2014), Fucino (Cavinato et al., 2002), and Rieti (Cavinato, 1993) basins, half-graben geometries controlled by normal faults with high seismic activity were suggested. Most of them (Tiberino, Rieti and Fucino basins) are characterized by a W – SW dipping master fault on the eastern margin and antithetical minor faults delimiting the western margin (Fig. 1.1).

According to the previously quoted authors, the stratigraphy of the infilling deposits of each basin are quite different. In the eastern part of the L'Aquila Basin, Giaccio et al. (2012) recognized three different synthems, whereas in the western part of the same basin only two main depositional phases were described by Mancini et al. (2012). On the contrary the Sulmona Basin, characterized by sedimentary infill with a total thickness of more than 400 m (Miccadei et al., 2002), shows a continuous deposition starting at least from the Early Pleistocene (Miccadei et al., 1998; Giaccio et al., 2009). The differences in their stratigraphy, including any potential tectonic or climatically induced forcing of sedimentation patterns, are still unexplained.

2.0 THE L'AQUILA BASIN

2.1 Geological and geomorphological setting

L'Aquila Basin (AB) is one of the wider and well developed central Apennines intermontane basin, characterized by high seismicity as evidenced by the 2009 Mw = 6.1 L'Aquila earthquake (Emergeo Working Group, 2010; Scognamiglio et al., 2010). It is located in the axial zone of the chain between the Gran Sasso Range to the N and the Ocre Mts. to the S., occupying the central part of the Aterno River Catchement between the Upper Aterno Valley (Arischia-Barete Basin) to the NW and the Middle Aterno Valley to the SE.

L'Aquila Basin is a semi-enclosed intermontane sedimentary basin created through the pervasive extensional deformation that affected the Apennines since Late Pliocene-Early Pleistocene (Messina et al., 2001; Centamore and Dramis, 2010; Mancini et al., 2012; Tallini et al., 2012).

The shape and extension of the AB are the expression of the activity of the southwestward dipping normal fault systems that bound the northeastern slopes of the basin. That systems are strongly segmented and, according to different authors, can be divided into major overlapping faults zone: the Pettino Fault (PTF), the Paganica-San Demetrio fault system (PSDFS), the Barisciano-San Pio Fault (BPF) and the Middle Aterno Valley fault system (MAVF) (Fig. 2.1) (Galli et al., 2010; 2011; Cinti et al., 2011; Falcucci et al., 2015). These faults are composed by several dextrally-stepping en-echelon segments, generally less than 5 km long and NW-SE to W-E oriented, cutting both the Meso-Cenozoic bedrock and the Quaternary deposits. They are responsible of the asymmetric half graben geometry of the AB and are associated to several antithetic northeastward dipping faults on the southern margin of the basin and to NNW-SSE transfer fault inside it (Galli et al., 2010; Falcucci et al., 2015).

L'Aquila Basin is a complex system formed by the coalescence of smaller morpho-tectonic depressions whose development and filling was driven by the interaction between extensional tectonic, presence of temporary hydrographic thresholds and climate changes during the Quaternary (Centamore et al., 2003; Giaccio et al., 2012; Blumetti et al., 2013). The basin is divided by the Bazzano-Monticchio ridge and the L'Aquila hill into two major sub-basin: the L'Aquila-Scoppito basin (ASB), to the west, and the Paganica-S. Demetrio-Castelnuovo basin (PSC), to the east, (Bosi et al., 2003; Mancini et al., 2012; Giaccio et al., 2012). Both of them are filled by a thick sequence of Plio-Quaternary continental deposits, which unconformably overlain the Meso-Cenozoic bedrock, composed by a succession of platform and slope limestones, stacked with Miocene turbidites in the Apennine orogeny during Mio-Pliocene (Fig. 1.1, 2.1) (Cipollari et al., 1999; Cosentino et al., 2010).

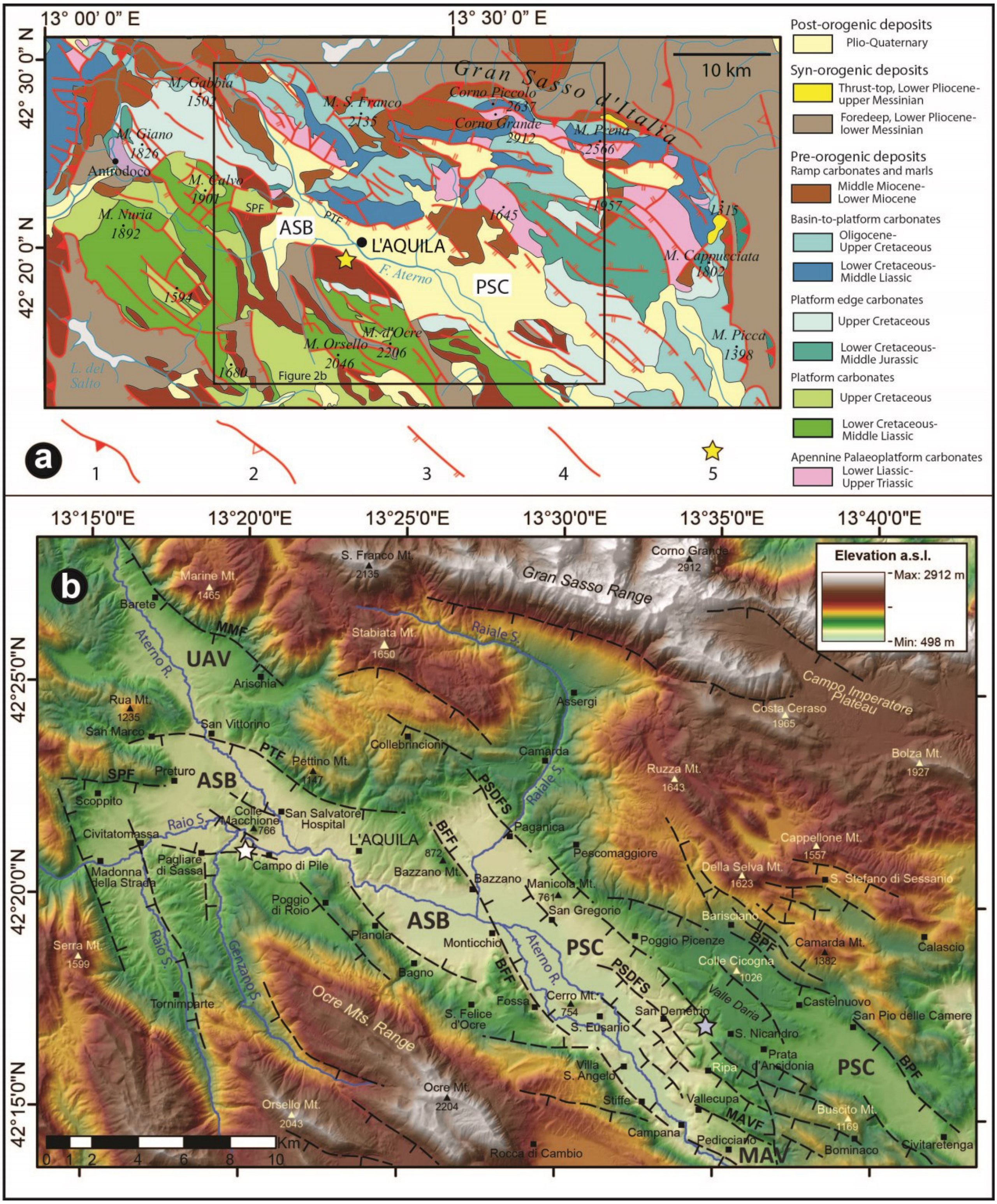


Fig. 2.1 – **a**) Geological sketch-map of L'Aquila intermontane basin and surrounding regions. 1) major thrust; 2) minor thrust; 3) normal fault; 4) undifferentiated fault; 5) epicenter of the April 6th 2009, Mw 6.1 earthquake **b**) Topography of L'Aquila intermontane basin and surrounding regions. **UAV**=Upper Aterno Valley: **ASB**=L'Aquila-Scoppito Basin; **PSC**=Paganica-San Demetrio-Castelnuovo Basin; **MAV**=Middle Aterno Valley; **MMF**=Mt. Marine fault; **SPF**=Scoppito-Preturo fault; **PTF**=Pettino fault; **BFF**=Bazzano-Fossa fault; **PSDFS**=Paganica-San Demetrio fault system; **BPF**=Barisciano-San Pio fault; **MAVF**=Middle Aterno Valley fault system. White star is the location of BAR 20 section (Fig. 4.16). Grey star is the location of Faccione section (Fig. 4.11).

The ASB extends, with a W-E and NW-SE trending for the northern and southern portion respectively, for more than 70 Km^2, from the San Vittorino threshold, to the N, up to the Bazzano-Monticchio ridge to the S (Fig. 2.1b).

The ASB is considered an half-graben, bordered to the north by both the south-dipping Scoppito-Preturo normal fault and the southwest dipping active Pettino Fault (Vezzani et al., 2009; Tallini et al., 2012). Although several others synthetic, antithetic and transverse elements are reported by some authors, especially as regard the southern border of the basin (Fig. 2.1b) (Bertini et al., 1992; Gruppo di Lavoro MS–AQ, 2010; Mancini et al., 2012; Storti et al., 2013).

The western, northern and southeastern basin's margin are defined by reliefs up to 1400-1500 m high, characterized mainly by Mesozoic and Tertiary carbonate rocks, while the southern border is formed by the northwestern termination of the Ocre Mts. and by the Tornimparte plateau, standing at 750-900 m a.s.l. and carved on Upper Miocene siliciclastic flysch deposits. The basin floor stands at elevation ranging between 580-700 and is crossed by the Aterno River, which flows the basin from northwest to southeast, and the Raio Stream, a right bank tributary of the Aterno River, which flows eastward.

Within the ASB several sub-horizontal surfaces are preserved at different elevations and were interpreted by different authors as remnants of paleo-landscapes or as tops of depositional terraces or treads. These surfaces are carved both on bedrock and Quaternary deposits, both at the basin margins (1500-1400m; 900-800m) and within the basin (800-780m; 750-730m; 670-650m; 640-620m) (Bosi et al., 2003; Messina et al., 2003; Mancini et al., 2012).

The ASB is characterized also by the presence of some small reliefs inside it, such as the Civitatomassa-Collettara ridge, up to 750 m high, and the Colle Macchione ridge, up to 760 m high, where Mesozoic and Tertiary carbonate and terrigenous rocks, capped with some Quaternary covers, crop out. According to Mancini et al. (2012) the presence of these reliefs is related to the existence of NNW-SSE trending structural elements. Another morphological high is represented by the L'Aquila hill, up to 730-750 m high, made of calcareous megabreccias, that separates the western portion of the ASB from the Pianola-Bagno area to the SE (Fig. 2.1b).

All these intra-basinal reliefs separate different sector of the ASB and are characterized by a strong fluvial incision, as evidenced by the presence of narrow valleys, gorges or knick-points through which the Aterno and Raio rivers flow. These morphological features suggest that these isolated reliefs played an important role during the Quaternary evolution of the ASB acting as thresholds, damming and connecting different parts of the basin through time.

The PSC Basin extends from the Paganica village to the north, to the Campana gorge to the south and the Castelnuovo-Civitaretenga plateau to the east, over more than 130 km^2. It is characterized by a rectangular NW-SE elongated shape with a rectilinear southwestern border and a more articulated northeastern one, expression of the main bounding normal fault systems: the Paganica-San Demetrio

Fault System and Barisciano-San Pio Fault in the northeastern side and the Bazzano-Fossa Fault in the southwestern (Fig. 2.1b) (Giaccio et al., 2012; Blumetti et al., 2013; Santo et al., 2014).

The basin is entrenched between NW-SE elongated ridges of carbonate rocks, whose elevations range from 1000 m to 2000 m, up to the 2912 m high Gran Sasso massif to NE, and to the 2204 m high Mts. Ocre to SW. The southwestern border is characterized by very steep slopes, mainly composed of Meso-Cenozoic platform and ramp carbonate rocks, abruptly passing to the present Aterno valley floor, in correspondence of the NE dipping Bazzano-Fossa Fault. The northeastern boundary, carved on basinal to platform limestones, presents a different morphology, with a rectilinear margin in the Paganica area and a stairway path in the southeastern sector with several slope breaks alternating to sub-horizontal surfaces towards the basin floor, related to the SW dipping Paganica-San Demetrio and Barisciano-San Pio fault systems, which have been active during Quaternary times and represent the most still active fault zones of the L'Aquila Basin (Bertini & Bosi, 1993; Giaccio et al., 2012; Santo et al., 2014). This boundary is deeply incised by a NE-SW oriented fluvial network, the main one represented by the Raiale River, that flows from the Gran Sasso footslope to the PSC basin, forming a wide active alluvial fan between the Paganica village and the confluence to the Aterno River near Bazzano.

Several narrow E-W to NW-SE oriented carbonate ridges, like Mt. Cerro, Colle Cicogna, Colle Separa, Mt. Manicola and Mt. Caticchio, crop out within the PSC basin, both in the uplifted Bazzano-Castelnuovo area and in the basin floor. Different authors related these reliefs either to the presence of synthetic and antithetic tectonic elements cutting through the basin or as remnants of the paleomorphology of the basin (Bertini & Bosi, 1993; Centamore et al., 2006; Gruppo di Lavoro MS–AQ, 2010; Giaccio et al., 2012).

Starting from Bosi & Bertini (1970) many authors highlighted the presence of numerous sub-horizontal surfaces in the PSC basin, carved on both the bedrock and Quaternary deposits at elevations ranging from more than 1200 m to the present day valley floor (550-650 m). These surfaces were alternatively interpreted by the authors as depositional or erosional, referred to tectonic or climatic origin and to different depositional environments (Bertini & Bosi, 1993; Giaccio et al., 2012; Santo et al., 2014). The most evident and well preserved of these surfaces is the Valle Daria one (sensu Bertini & Bosi, 1993) standing at ca. 850 m a.s.l., considered by almost all the authors as the depositional top of an ancient lacustrine system.

2.2 Maximum age for the onset of the L'Aquila Basin

A maximum age for the onset of this intermontane basin derives from the latest compressional event that affected the area. The orogenic tectonics was responsible for the deformation of the Mesozoic and Tertiary successsions as well as for the onset of intermontane compressional basins (thrust-top or piggy-back basins) developed on top of the highly deformed Gran Sasso tectonic wedge. A first compressional event in the area is constrained by the age of the *Conglomerati di*

Monte Coppe, which represents the deposition in a late Messinian-early Pliocene thrust-top basin (Fig. 2.1a) (Ghisetti et al., 1993; Cipollari et al., 1999a; Centamore et al., 2006; Cosentino et al., 2010) on the leading edge of the central Apennine chain. Since the *Conglomerati di Monte Coppe* contains marker species that point up to a basal Pliocene age (*Sphaeroidinellopsis* biozone; Ghisetti and Vezzani, 1986; Ghisetti et al., 1993; Centamore et al., 1992; 2006) the first event of compressional tectonics was active at least up to the early Zanclean. However, according to several authors (Ghisetti and Vezzani, 1986; 1990; 1991; Patacca et al., 1992; Ghisetti et al., 1993; Cipollari et al., 1997; Vezzani and Ghisetti, 1998), the last compressional event affected the Gran Sasso Chain late in the Early Pliocene (top Zanclean) with a north-verging out-of-sequence thrusting of the chain along E-W trending faults (northern Gran Sasso front). This compressional phase is constrained by the occurrence of a thrust-top basin (*Conglomerati di Rigopiano*) containing planktonic assemblages up to the *G. puncticulata* biozone (Ghisetti and Vezzani, 1986; Patacca et al., 1992; Ghisetti et al., 1993; Centamore et al., 2006). According to this data, the maximum age for the onset of the extensional tectonics in the Gran Sasso-L'Aquila area is the Zanclean/Piacenzian transition (ca. 3.59 Ma).

2.3 L'Aquila Basin stratigraphy: the state of the art

An overall stratigraphical setting for the whole L'Aquila Basin do not exist, because all the authors consider the ASB and PSC as two isolated and disconnected basin, at least until Upper Pleistocene, treating them separately and defining different units for each part of the AB (Fig. 2.2).

The national geological mapping project (CARG project) defines five synthems for the ASB, ranging from the Lower Villafranchian (Piacenzian) to the Upper Pleistocene, while in the PSC Basin the oldest three synthems were grouped together into the *Aielli-Pescina Supersynthem* and ascribed to a generic Pliocene(?)-Middle Pleistocene (Centamore et al., 2006; Centamore and Dramis, 2010). According to these mapping project (sheets 358 and 359) only the upper Middle Pleistocene (*Catignano Synthem*) and Upper Pleistocene (*Valle Majelama Synthem*) synthems are in common within the AB. Also the three synthems defined by Giaccio et al. (2012) for the PSC Basin *(Lower*, *Upper*, and *Late PSC)* roughly corresponds to the CARG ones, from which differs only for some age constrains (Fig. 2.2).

The ***Aielli-Pescina Supersynthem*** occupies a large portion of the AB and surrounding areas, extensively outcropping on the basin margins, particularly in the southeastern sector of the PSC Basin, between Poggio Picenze and the Castelnuovo-Civitaretenga plateau. It includes deposits with very different lithological, sedimentological, paleoenvironmental characteristics, referable to the *Lower fluvio-lacustrine Complex* (Bosi & Bertini, 1970), the *First Depositional Cycle* (Bagnaia et al., 1989) and the *Poggio Picenze*, *Vall'Orsa* and *Valle dell'Inferno* cycles described by Bertini & Bosi (1993).

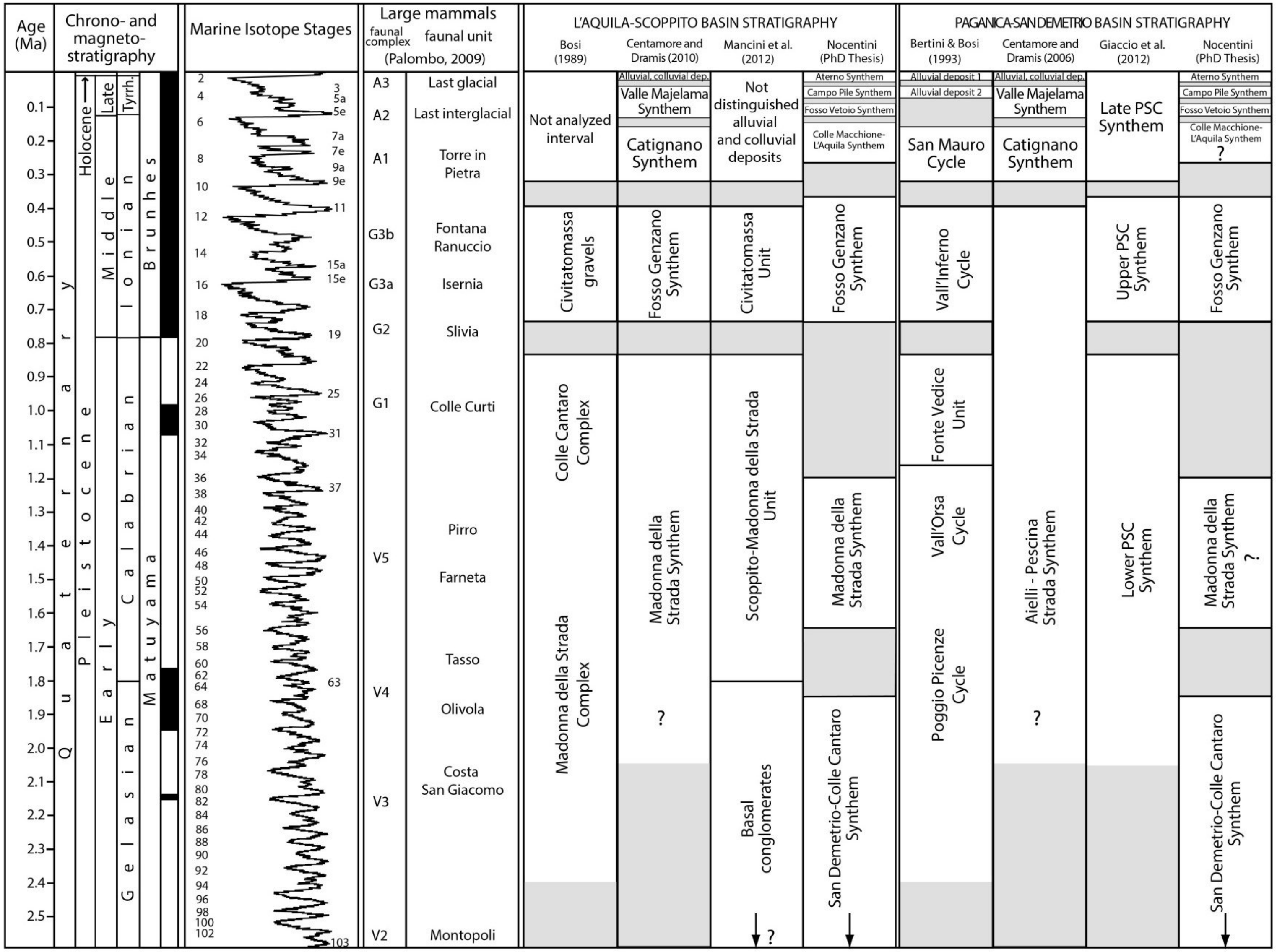


Fig. 2.2 – Quaternary stratigraphy of the ASB and PSC Basin according to different authors. Centamore and Dramis (2010) consider the *Colle Cantaro-Cave Synthem*, at the base of the ASB fill, as lower Villafranchian (Piacenzian), not represented in the figure. The arrow in Mancini et al. (2012) and in Nocentini (PhD thesis) indicate a possible (?) or a real extension to the Piacenzian of the AB basal deposits, respectively. In Nocentini (PhD thesis), *Campo di Pile Synthem* contain the *Ponte Peschio Sub-synthem*.

According to Centamore et al. (2006) the oldest deposit of that synthem is represented by heterometric calcareous breccias, up to 100 m thick and often tilted, related to gravitative transport. This kind of deposit forms the L'Aquila hill and outcrops at Colle Macchione, to the west, along the Raiale Valley, to the north, and is widespread at the eastern boundary of the PSC Basin, where it matches the *Valle Valiano Fm*. and the *Fonte Vedice Fm*. of Bertini & Bosi (1993).

The rest of the *Aielli-Pescina Supersynthem* includes several formations described by Bertini & Bosi (1993) and, as revised by Giaccio et al. (2012), is composed by various sediments related to different depositional environments belonging to a lacustrine system associated with a delta environment and laterally bordered by alluvial fan and slope deposits. According to different authors the wide flat Valle Daria surface, standing at about 850 m a.s.l., represent the depositional top of that synthem (Bosi & Bertini, 1970; Bertini & Bosi 1993; Bosi et al., 2003; Giaccio et al., 2012; Blumetti et al., 2013) . The lacustrine system is characterized by whitish calcareous silt sediments, matching the *Limi di S. Nicandro Fm*. of Bertini & Bosi 1993, whose thickness range from >100 m (Ludovico, 2005) up to 200 m according to electrical resistivity tomography (Piscitelli et al., 2010). Above or laterally to the lacustrine deposits, the delta sediments, up to 80 m thick, are composed by sandy bottomset beds (*Prata d'Ansidonia Fm*. Bertini & Bosi 1993), marked inclined gravelly foresets beds, up to 30° dipping (*Valle Orsa Fm*. Bertini & Bosi 1993), and coarse gravel topset beds with sub-parallel horizontal stratification (*Valle dell'Inferno Fm*. Bertini & Bosi 1993). All along the northeastern margin, the lacustrine deposits pass to alternations of silts and conglomerates (*Madonna della Neve Fm*. Bertini & Bosi, 1993), alluvial fan conglomerates (*Valle Valiano Fm*. Bertini & Bosi, 1993), matching the *PAG-7 Unit* of Galli et al. (2010), and slope breccias (*Fonte Vedice Fm*. Bertini & Bosi, 1993) (Bertini & Bosi, 1993).

The *Aielli-Pescina Supersynthem* is extensively dissected by the Paganica-San Demetrio and Barisciano-San Pio faults and often outcrops in the footwall of these faults. A syn-depositional activity of these faults is suggested by Giaccio et al. (2012) considering the tilting of the bedding planes and the deposits thickness variations within the PSC Basin. Paleomagnetic analyses have been carried out on samples belonging to both coarse and fine sediments of that synthem showing a reverse polarity (D'Agostino et al., 1997; Giaccio et al., 2012). Some tephra layers, founded within the fine sediments of the *Aielli-Pescina Supersynthem*, have been analysed revealing a calc-alkaline composition (Giaccio et al., 2012). The reverse polarity and the presence of calc-alkaline tephra layers allowed Giaccio et al. (2012) to constrain these synthem between 0.8 – 1.8 Ma, that is Calabrian (Lower Pleistocene).

In the western sector of AB, the oldest deposits pertain to the ***Colle Cantaro-Cave Synthem*** (Centamore and Dramis, 2010), which includes slope-derived breccias and debris flow deposits, as well as alluvial clayey-sandy conglomerates. The *Colle Cantaro Complex* (Bosi, 1989), as well as the clayey-sandy-gravelly and gravelly-sandy-clayey complexes drilled by GE.MI.NA. (1963), can be ascribed to this synthem. According to the stratigraphy of the boreholes drilled in the western part of the ASB, the thickness of the *Colle Cantaro-Cave Synthem* is around 70 m (GE.MI.NA., 1963). The transition from these basal deposits to the younger *Madonna della Strada Synthem* is marked by a 1-3 m thick paleosol (Centamore and Dramis, 2010), which would point to a large hiatus in the sedimentary record. Although Mancini et al. (2012) described an Early Pleistocene succession with no hiatus for the ASB, the *Basal Conglomerates* of those authors should be ascribed to the *Colle Cantaro-Cave Synthem* as well.

The *Colle Cantaro-Cave Synthem* was highly deformed during the Quaternary, as indicated by the tilting of the bedding planes (15-20°) and many outcrop-scale faults affecting the deposits. Sandy-silty deposits pertaining to this synthem, cropping out at the northernmost area of ASB (close to Barete village) have been analyzed for paleomagnetic purposes. The resulting normal polarity for the analyzed samples allowed Messina et al. (2001) to assign ages older than 1.77 Ma to the earliest infilling deposits of the ASB. For this reason, and considering that the overlying synthem is well constrained to the Upper Villafranchian (Calabrian) by large mammal remains, the *Colle Cantaro-Cave Synthem* was referred by Centamore and Dramis (2010) to the Lower Villafranchian (Piacenzian).

The ***Madonna della Strada Synthem*** (Centamore and Dramis, 2010), which unconformably overlies the *Colle Cantaro-Cave Synthem*, consists mainly of clayey silts, sandy silts, and sands, containing up to five intercalations of lignite beds. Sediments referable to this synthem outcrop only in the western sector of the L'Aquila Basin, between Scoppito to the W and the Bazzano-Monticchio ridge to the E, while in the PSC Basin no trace of that synthem is reported.

This synthem corresponds to the "sandy-clayey complex with lignite beds" (GE.MI.NA., 1963), the *Scoppito-Madonna della Strada Unit* (Mancini et al., 2012), and the *Madonna della Strada Complex Auct*. This synthem is interpreted as mainly due to swamp and fluvio-lacustrine environments developed in a temperate and wet climate (GE.MI.NA., 1963). According to the pollen record from the Santarelli quarry (Magri et al., 2010), the unit corresponds to a warm Early Pleistocene interglacial period. Following the stratigraphy of the GE.MI.NA. boreholes drilled through the lignite-rich deposits, they are at least 40 m thick (GE.MI.NA., 1963). Thicker deposits were suggested by Tallini et al. (2012) in a depocentral area based on interpretation of a seismic profile crossing the northern part of the ASB. There, they recognized a seismic facies, up to 200 m thick, which was drilled by some boreholes to reveal fine-grained lacustrine deposits referable to the *Madonna della Strada Synthem* (Amoroso et al., 2010).

The *Madonna della Strada Synthem* is rich in Early Pleistocene large mammal remains. They were found not only from the classical site of the Santarelli quarry (Maccagno, 1962; Magri et al., 2010; Mancini et al., 2012), but more recently also from the industrial area of Campo di Pile (Agostini et al., 2012). At both sites, large mammal remains were found in sandy-silty layers from the upper portion of the *Madonna della Strada Synthem*.

Summing up the chronostratigraphical indications from both large mammals and pollen record, *the Madonna della Strada Synthem* were referred by Centamore and Dramis (2010) to the Upper Villafranchian, (Calabrian, and possibly Gelasian).

A younger synthem, the ***Fosso di Genzano Synthem*** (Centamore and Dramis, 2010), unconformably overlies either the Mesozoic-Tertiary substratum or the older synthems of the ASB. It corresponds to the *Ghiaie di Civitatomassa* (Bosi and Messina, 1991), the *Civitatomassa Unit* (Mancini et al., 2012), and the *Fosso di Genzano Complex Auct*. Its basal portion is mainly characterized by clast-supported, structureless coarse gravels, mainly composed of limestone clasts. At Sella di Corno, the basal portion of the *Fosso di Genzano Synthem* contains a volcanic horizon, up to 7-10 m thick, consisting of several ash layers with large crystals of biotite (0.5 cm), clinopyroxene, and sanidine. $^{39}Ar/^{40}Ar$ dating yelded an age of 520 ±5 kyr (Gaeta et al., 2010). Going upwards, the synthem is represented by alternating silty and sandy deposits with rare, thinly laminated clayey silt. They display evident trough cross-bedding (sandy layers) or horizontal tabular-bedding (silts or clays). These deposits are mainly related to the distal portions of alluvial fans, laterally passing to floodplains. At Pagliare di Sassa, within the basal portion of this synthem, large and small mammal remains referable to the middle Galerian Mammal Age (0.7 Ma; early Middle Pleistocene) were found within a normal polarity chron (Palombo et al., 2010).

Considering both the chronological constraints from large and small mammals of the Pagliare di Sassa site, and the $^{39}Ar/^{40}Ar$ dating of the ash layers from Sella di Corno, the *Fosso di Genzano Synthem* can be referred to the lower Middle Pleistocene (early Ionian).

The ***Catignano Synthem*** (Centamore et al., 2006; Centamore and Dramis, 2010) was mapped both in the ASB and in the PSC Basin, even if its areal extension and lithological characteristics are quite different from one basin to the other.

In the ASB the *Catignano Synthem* unconformably overlies the older *Fosso di Genzano Synthem* and is characterized by small and isolated terraced alluvial deposits, consisting mainly of well rounded gravels in a sandy-silty matrix. These alluvial deposits are carved both into the bedrock and the previous synthems. According to Centamore et al. (2006) the alluvial terrace east of Coppito (i.e. San Salvatore Hospital alluvial terrace), fitting with the *E Sequence* of Blumetti et al. (1996) and the *Vetoio terraced alluvial deposit* of Tallini et al. (2002), pertains to the *Catignano Synthem*, that is referred to a late Middle Pleistocene.

In the PSC Basin the *Catignano Synthem* corresponds to the *San Giovanni* and *San Mauro* cycles described by Bertini & Bosi (1993), made of medium well-sorted gravels with planar and through cross stratification of fluvial and alluvial fan environments, passing vertically and laterally to silty sands with abundant volcaniclastic material and overbank deposits. The *Upper PSC Synthem* (Giaccio et al., 2012), as well as the *Paganica 5* and *Paganica 4* units of Galli et al. (2010), stratigraphically correspond to the CARG project *Catignano Synthem*, differentiating from it for the age attribution, because it is chronologically equivalent to the *Fosso di Genzano Synthem*. This synthem is about 30 m thick and is deeply carved into the *Aielli-Pescina Supersyntem*, unconformably overlaying it and occupying a smaller portion of the PSC Basin. In particular Giaccio et al. (2012) described the sporadic existence of a reddish palaeosol developed on the eroded silt and/or gravel deposits of the *Aielli-Pescina Supersyntem (Lower PSC Syntheme*), marking the stratigraphical unconformity between these two synthems. Several others pedogenic horizons have been reported in different portion of that synthem (Galli et al., 2010; Giaccio et al., 2012).

Many authors highlighted the presence of up to four K-alkaline tephra layers, PAG-t1 to PAG-t4 in Galli et al. (2010). These tephras have been correlated to well-known and well-dated eruptions of the Colli Albani and Mt. Sabatini volcanic complexes, ranging between 561 ±2 ka (PAG-t1) and 365 ± 4 ka (PAG-t4) (Galli et al., 2010). These dating allowed Giaccio et al. (2012) to redefine the age of the *Upper PSC Synthem* (*Catignano Synthem)*, referring that synthem to 0.78 – 0.35 Ma instead of the generic late Middle Pleistocene suggested by Centamore et al. (2006). So in the PSC Basin the *Catignano Synthem* has to be referred to the *Fosso di Genzano Synthem* of the ASB.

Finally, the ***Valle Majelama Synthem*** (Centamore et al., 2006; Centamore and Dramis, 2010) mainly consists of alluvial fan and terraced alluvial deposits characterized by well-rounded gravels in a sandy-silty matrix. Slope-derived deposits (*éboulis ordonnées*), made of angular to sub-angular fine gravels with poor clayey-silty matrix, are also present at the edge of the basin and in the hanginwall of the main active faults (i.e. Pettino, Bazzano-Fossa and Barisciano-San Pio faults).

The *Paganica 2b (110-60 ka)-2a (41-33 ka) Unit* (Galli et al., 2010), the upper part of the *Late PSC Synthem* (Giaccio et al., 2012), the *Ancient terraced and alluvial fan deposits* of Bosi & Bertini (1970) and the *Ancient alluvial and colluvial deposits* reported in Bertini & Bosi (1993) belong to the *Valle Majelama Synthem*.

These deposits are widespread all over the L'Aquila Basin, characterizing the uppermost Pleistocene covers of the basin, unconformably overlaying both the older synthems and the Meso-Cenozoic substratum. In the Paganica area deposits belonging to that synthem unconformably overlay a blackish paleosol, dated between 41 ka and 33 ka, developed on the older *Catignano Synthem* (Galli et al., 2010). Also the pedocomplex described by Coltorti & Pieruccini (2006) at the top of the Valle Orsa alluvial fan (near Barisciano) can be ascribed to the *Valle Majelama Synthem*.

A yellow volcanic material rich layer is reported in the upper part of that synthem in the Raiale Valley (Demangeot, 1965) and at the top of the Varranone alluvial fan, near Fossa. This layer was referred by Centamore et al., 2006 to the Tufo Giallo auctt, dated between 15.4 to 10.1 ka.

According to Centamore and Dramis (2010) this synthem can be related to the last interglacial phase (Eemian) and its age is Upper Pleistocene.

The youngest synthem is Holocene in age and corresponds to the alluvial and colluvial deposit that cover the present day valley floor.

3.0 METHODOLOGY

In order to reconstruct the Plio-Quaternary geological evolution of the L'Aquila Basin this study adopts a multidisciplinary approach that integrates stratigraphical, structural and geomorphological field surveys with subsurface data from borehole logs and geophysical investigations, alongside with geochronological and micropaleontological analyses, carried out on samples purposely collected during the field campaign.

A new geological map (1:25000) of the study area was produced combining newly collected data and previously published maps and data, which have been checked during the field survey.

3.1 Field methods

3.1.1 Geological-geomorphological survey and mapping

Field mapping has been done using the 1:5000 CTR topographic maps of Abruzzo Region; however the final map has been compiled at 1:25000 scale using both the IGM and CTR 1:25000 topographic maps.

In particular geological mapping focused on the spatial distribution, geometry and facies association of the continental deposits of the L'Aquila Basin.

The geological mapping of the Plio-Quaternary basin infill has been carried out using the UBSU method, integrating the newly collected data with literature and making, were possible, a review of the old continental units described by the Authors (Bosi & Bertini, 1970; Bertini & Bosi, 2003; CARG maps; Gruppo di Lavoro MS-AQ, 2010; Pucci et al., 2014).

As regards the Meso-Cenozoic bedrock we refer to the formal lithostratigraphic Units of the "L'Aquila" (sheet 359) and "Pescorocchiano" (sheet 358) CARG maps (1:50000). Those units were grouped and mapped according to their paleogeographical domain, using the facies associations defined by the CARG project.

Additionally, stratigraphic log were produced in order to define sedimentary facies and architectural elements (*sensu* Miall, 2006) of the studied synthems and to recognize suitable deposits to be sampled for micropaleontological analysis and geochronological dating.

3.1.2 Well logs

To define the lithology, the thickness and the geometry of the basin infill a comprehensive review of the available borehole log has been carried out.

The available dataset included: 1) more than 400 private boreholes drilled before and after the 6th April 2009 earthquake (Gruppo di Lavoro MS-AQ, 2010); 2) some boreholes drilled for mining exploration by Ge.Mi.Na. (1963); 3) the boreholes stratigraphies available from the ISPRA dataset [ISPRA: Archivio nazionale indagini del sottosuolo (Legge 464/1984)]; 4) the four deep boreholes drilled by the CERFIS after the 2009 earthquake (Amoroso et al., 2010); 5) three deep boreholes drilled for the restoration of the Basilica di Collemaggio (ENI, 2013); and 6) the Pizzoli1 (PB1) borehole drilled by the ISPRA for the Antrodoco CARG map (sheet 348).

In order to standardize the stratigraphy of the overall dataset, some of these deep boreholes were directly studied (Tab. 3.1) (Fig. 4.41), allowing the reconstruction of the stratigraphies of S1 (S45 in Fig. 4.44) and S4 (CERFIS), Collemaggio1, Collemaggio2 and Collemaggio3 (S80 in Fig. 4.45) (ENI), and Pizzoli1 PB1 (ISPRA) boreholes. In addition the preliminary stratigraphy of the LAquicore well log (S59 in Fig. 4.45), provided by the INGV, was reinterpreted (Fig. 4.42).

Borehole	Coordinate (WGS84)	Elevation (m asl)	Depth (m)
S1	42° 20' 59.493" N 13° 23' 24.1" E	630	140
S4	42° 20' 41.587" N 13° 23' 31.673" E	617	85
Collemaggio1	42° 20' 33.867" N 13° 24' 13.981" E	688	80
Collemaggio2	42° 20' 34.792" N 13° 24' 14.084" E	689	120
Collemaggio3	42° 20' 33.43" N 13° 24' 19.326" E	682	275
Pizzoli1 PB1	42° 26' 27.475" N 13° 17' 4.887" E	730	200
LAquicore	42° 19' 7.7" N 13° 26' 22.5" E	590	151

Tab 3.1 – Position, elevation and depth of the analyzed deep boreholes.

3.1.3 Structural survey

Structural data, including bedding attitude, fault orientations and kinematics, were systematically collected throughout the study area both on the Meso-Cenozoic bedrock and on the Plio-Quaternary sedimentary cover.

Documentation of cross-cutting relationships and sin-sedimentary faults allowed to define a relative chronology between tectonic and depositional events within the basin and, moreover, to reconstruct the relationships between the boundary faults and the minor structures located inside the L'Aquila Basin.

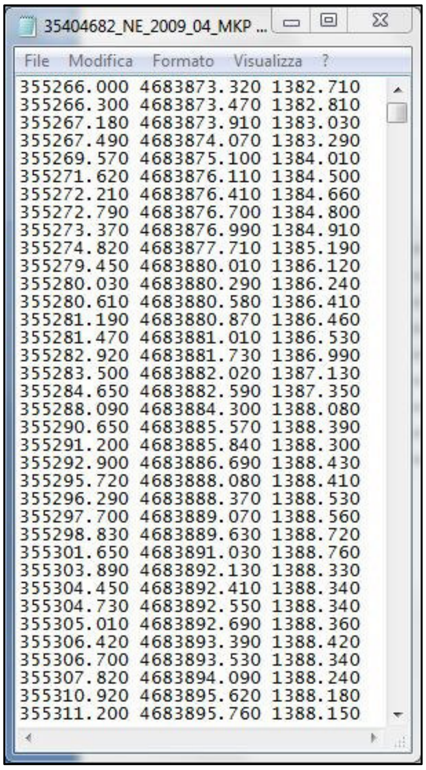
Particular attention has been placed on recognizing recently active faults by identifying geomorphological or stratigraphical markers, such as displaced surfaces, fault scarps or Upper Pleistocene (LGM) deposits cut by the faults.

Furthermore some paleosismological trenches, dug by the INGV, along some of the main lineaments, allowed to confirm the presence of these elements and to characterize the faulting style and timing.

3.1.4 LIDAR data processing

High resolution LIDAR data of the area affected by the 6th of April 2009 earthquake, provided by the Servizio Aereo di Telerilevamento e di Sorveglianza regionale della Protezione Civile della Regione Autonoma Friuli Venezia Giulia, were used to build an accurate Digital Terrain Model of the L'Aquila Basin.

The data provided by the DPC are in the ASCII format .xyz (longitude, latitude and elevation) (Fig. 3.1). Each file represents the Model Key Point (MKP) of the rectified points of the ground, namely they correspond to the coordinates and elevation of the point cloud of the ground surface filtered from vegetation and buildings.



35404682_NE_2009_04_MKP ...

File Modifica Formato Visualizza ?

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355266.000 4683873.320 1382.710
355266.300 4683873.470 1382.810
355267.180 4683873.910 1383.030
355267.490 4683874.070 1383.290
355269.570 4683875.100 1384.010
355271.620 4683876.110 1384.500
355272.210 4683876.410 1384.660
355272.790 4683876.700 1384.800
355273.370 4683876.990 1384.910
355274.820 4683877.710 1385.190
355279.450 4683880.010 1386.120
355280.030 4683880.290 1386.240
355280.610 4683880.580 1386.410
355281.190 4683880.870 1386.460
355281.470 4683881.010 1386.530
355282.920 4683881.730 1386.990
355283.500 4683882.020 1387.130
355284.650 4683882.590 1387.350
355288.090 4683884.300 1388.080
355290.650 4683885.570 1388.390
355291.200 4683885.840 1388.300
355292.900 4683886.690 1388.430
355295.720 4683888.080 1388.410
355296.290 4683888.370 1388.530
355297.700 4683889.070 1388.560
355298.830 4683889.630 1388.720
355301.650 4683891.030 1388.760
355303.890 4683892.130 1388.330
355304.450 4683892.410 1388.340
355304.730 4683892.550 1388.340
355305.010 4683892.690 1388.360
355306.420 4683893.390 1388.420
355306.700 4683893.530 1388.340
355307.820 4683894.090 1388.240
355310.920 4683895.620 1388.180
355311.200 4683895.760 1388.150
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Fig. 3.1 – Example of a .xyz (longitude, latitude, elevation) ASCII file of the LIDAR survey.

The LIDAR survey covers mainly the urbanized area; it extends approximately from Barete to Tione degli Abruzzi and from Assergi to Rocca di Mezzo which mark the northwestern, southeastern and northern and southern edge of the area, respectively. The reference coordinate system is WGS1984_UTM33N for latitude and longitude values, while elevation values are ellipsoidic and not referred to a specified geoid. The data consist of more than 133 million data points, with a mean points spacing of 2.4316 m; its accuracy ranges from 10 to 20 cm for elevation values, while the horizontal accuracy ranges between 1,5 and 63 cm.

That data were processed with ArcInfo 9.3 GIS software. Several available ArcInfo tools have been used to obtain the final DTM and some of that tools have been purposely combined, using the ArcInfo 9.3 Model Builder, into a routine to accelerate the processing. First of all the *Point File Information* tool has been linked with the *ASCII 3d to Features Class* tool, in order to assign the corresponding average point spacing to each file and to convert each .xyz text files into a 3d multipoint shapefile (Fig. 3.2, 3.3).

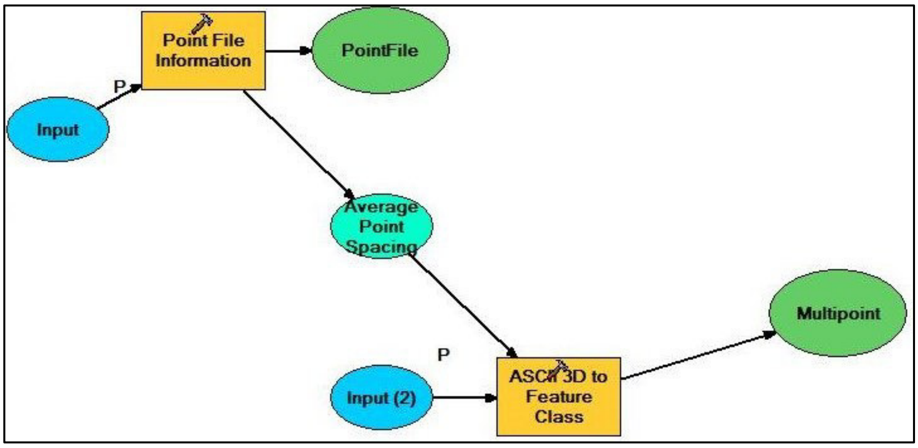


Fig. 3.2 – Screenshot of the tool created for LIDAR processing.

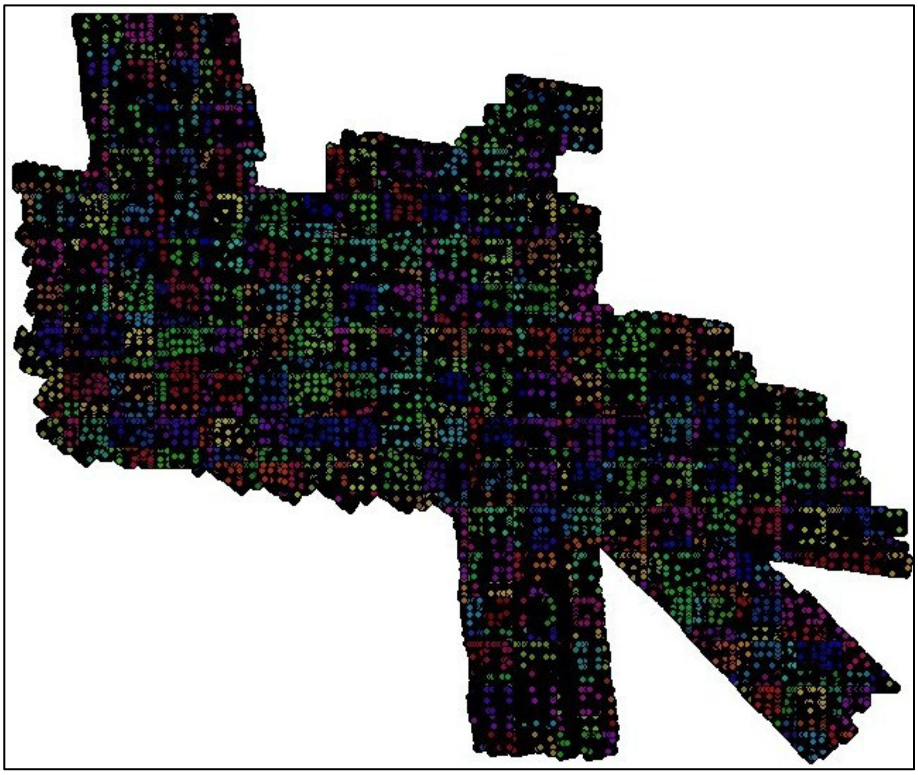


Fig. 3.3 – Multipoint shapefiles obtained using the tool in Fig. 3.2.

Successively the previously created shapefiles have been grouped into small chunks of the entire area and converted into a triangulated irregular network (TIN) using the tool *3Dmultipoints to TIN*. Each TIN has been converted into a raster GRID file using the *TIN to GRID* tool. Finally all the created GRID have been merged together with the *Mosaic GRID* tool to produce a final DTM with 1x1 m cell size (Fig. 3.4).

This DTM has been used to identify large and small scale features like fault scarps, ridges, talus cone, extension and shape of alluvial fan and fluvial deposits, landslides, fluvial terraces or flat surfaces. Additionally it has been used to verify and validate published geological maps and to support geomorphological, geological and structural investigations in the field.

The LIDAR DTM was also extremely useful to produce the geological map of the investigated area, allowing to draw with accuracy geological boundaries, fault trends and morphological features.

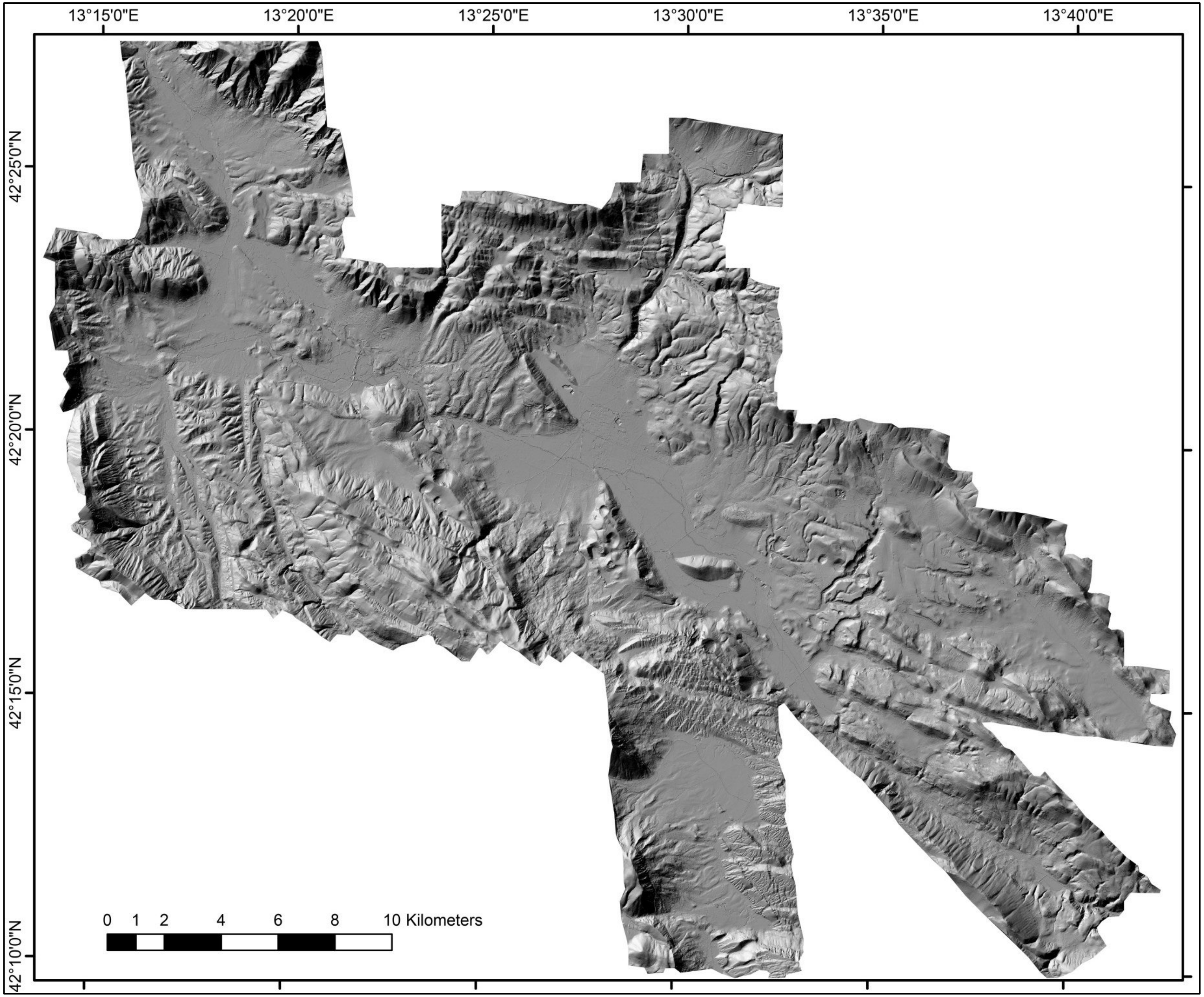


Fig. 3.4 – Hillshade of the L'Aquila Basin and surrounding regions derived from the 1 x 1 m DTM obtained from LIDAR data processing.

3.2 Laboratory methods

During field works several samples, belonging to different units and facies of the continental deposits, have been collected for micropaleontological and geochronological analysis to provide paleoenvironmental information and age constrains useful to understand the geological evolution of the L'Aquila Basin.

3.2.1 Micropaleontological analyses

Micropaleontological analyses of the ostracods and, in some cases, gastropods faunas have been carried out on samples belonging to both outcrops and boreholes, in order to provide information about depositional environment, possible age, past climatic conditions and, possibly, to help to correlate deposits through the basin.

During the field work more than 70 samples were collected from outcrops all over the L'Aquila Basin. They come from, more or less, all the identified synthems, where suitable continental deposits were present.

Other sediments for micropaleontological studies were sampled from some boreholes with the aim to characterize their deposits and to correlate boreholes stratigraphy with surface deposits. In this regards, 16 samples were taken from S4 (CERFIS) borehole drilled at Madonna del Ponte, south of L'Aquila city; 7 samples of cuttings were gathered from the Collemaggio3 (ENI) well-log drilled behind the Basilica di Collemaggio and 24 samples were collected from PB1 (ISPRA) borehole located near Pizzoli (Fig. 4.41).

For these analyses, samples were soaked in a 5% H_2O_2 solution for 24 hours to mechanically separate sediments, than they were sieved through a 125 μm and a 63 μm mesh sieves and dried in an electric oven at 40°C for at least 24 hours. Samples that were not completely dissolved after this procedure were treated with a REWOQUAT WE 15 solution (EVONIK Industry®) to separate grains, then they were sieved and dried again.

The obtained 125 μm residuals were observed under a stereomicroscope (7,5x – 150x) LEICA S6D at the micropaleontological lab of Roma TRE University. Ostracods and gastropods remains were hand-picked under the microscope and arranged in a small case with sample's name. Gastropods were manually isolated and, apart preliminary observations, they were sent to Prof. Daniela Esu at the Sapienza University of Rome for specific identification.

As regards ostracods, where possible, at least 300 valves were picked from each sample and subdivided into group having similar morphological characteristics (Patterson & Fishbein, 1989; Buzas, 1990; Fatela & Taborda, 2002). Samples were considered barren when no valves were found over 10 observations of the same sample.

Ostracods species identification was done under Prof. Elsa Gliozzi supervision, where number and quality of valves made it possible.

By using the Leica DM1000 microscope and the multi-focus LAS Leica Microsystems, microphotos of the identified ostracods were taken, in order to better define their morphological and morphometrical characteristics.

In addition, adult ostracod valves were observed by using the Scanning Electron Microscope (SEM) of the LIME lab of Roma TRE University. SEM photographs of the more interesting specimens were also taken. The use of the SEM allowed a more detailed morphological study of the external and internal surfaces of the valves and carapaces with respect to the observations performed using the optical microscope.

The occurrence of some particular ostracod species and assemblages, not yet advised in the L'Aquila Basin and very rarely in Italy, required a dedicated taxonomic and paleoecologic study carried out by Dr. Marco Spadi using a geometrical-morphometrical approach and a multivariate statistical analysis (Cluster Analysis, nMDS and ANOSIM) (Spadi et al., 2015). For this reason, other 55 samples belonging to the San Nicandro calcareous silts were collected from four sections outcropping between San Demetrio ne' Vestini and San Nicandro villages (Fig. 4.11).

During these analyses, in addition to ostracods valves other organic materials were founded, such as gastropods opercula and shells, lacustrine sponges spicules, diatoms, plants remains and fish bones fragments. No small mammals were recovered in the sieved samples.

3.2.2 Geochronological dating

3.2.2.1 OSL dating

The Optically Stimulated Luminescence (OSL) technique dates the last time sediments were exposed to sunlight, which zeros the luminescent signal.

It is based on the emission of light, luminescence, by commonly occurring minerals, principally quartz and feldspar, if properly stimulated. This is due to the accumulation of electronic charges in atomic lattice sites that are generally distributed throughout the crystal volume. The luminescence signal corresponds to the number of trapped electrons and it grows with time due to exposure to radioactive isotopes within the sediment and incoming cosmic rays (Duller, 2008).

For dating, the amount of absorbed energy per mass of mineral ($1\ J*kg^{-1} = 1\ Gy$ (Gray)) due to natural radiation exposure since zeroing, known as the Paleodose, is determined by comparing the natural luminescence signal from the grains in their natural state, with that induced in the grains by exposure to a laboratory source of radioactivity, usually beta emission from a $^{90}Sr/^{90}Y$ source (Wintle, 2008). When doses of different size are given to the same aliquot, a dose-response curve (growth curve) can be constructed, making possible to estimate the Paleodose of that aliquot. When the palaeodose is determined in the laboratory it is called Equivalent Dose (Ed or De).

The time elapsed since the last daylight exposure is calculated by dividing the Equivalent Dose by the Dose Rate, the latter representing the amount of energy deposited per mass of mineral due to radiation exposure acting on the sample over a certain time (Gy*a^{-1}) (Preusser et al., 2008). Thus the age equation for luminescence can be expressed by the following simple equation:

Luminescence age (a) = Equivalent Dose (Gy) / Dose Rate (Gy*a^{-1})

Several laboratory techniques have been developed to accomplish the necessary stimulation and recording of the luminescence emitted from minerals. Actually the Single Aliquot Regenerative dose protocol (SAR) has become the routine method of choice for measurement of De in quartz (Fig. 3.5). The underlying assumption of the single-aliquot regenerative-dose (SAR) protocol is that it is possible to measure a signal after each dose and stimulation cycle, which acts as a surrogate measurement of the sensitivity applicable to the prior measurement cycle. This allows the effects of sensitivity changes to be corrected for, in both natural and regenerated signals, so a sensitivity corrected De can be calculated. For an exhaustive methodology and SAR protocol description refer to Murray & Wintle 2000, Mauz et al. 2002, Murray & Wintle 2003, Duller 2008, Preusser et al. 2008, Wintle 2008.

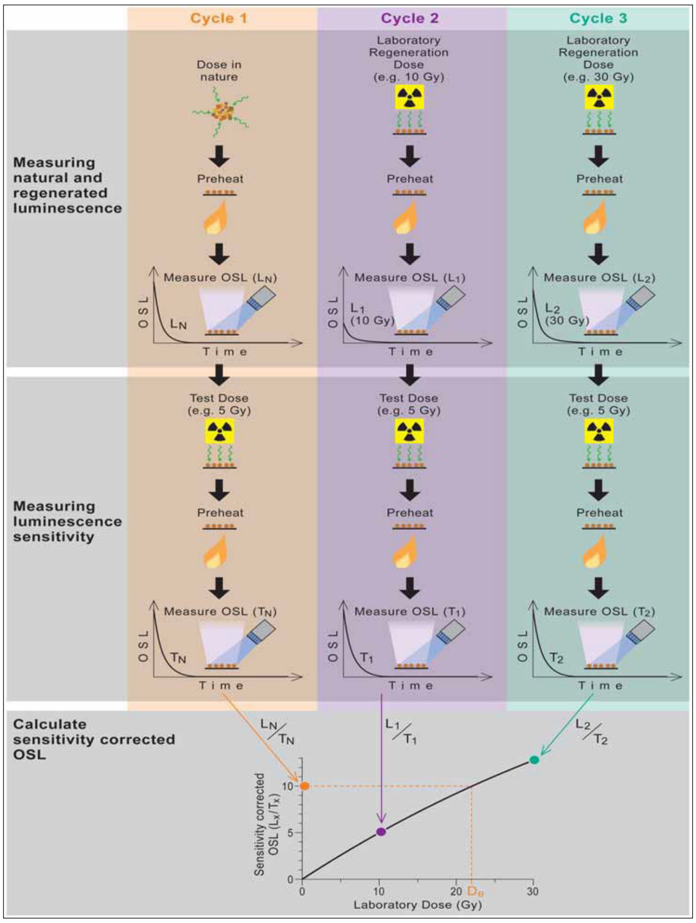


Fig. 3.5 – The single aliquot regenerative dose (SAR) procedure applied to quartz: the growth of the signal with dose is characterized by administering a number of laboratory doses (regeneration doses) of different sizes (10Gy, 30Gy, etc) and measuring the resulting OSL signals L1, L2, etc. After each measurement the luminescence sensitivity is measured by giving a fixed dose (here 5Gy) and measuring the resulting OSL signal (T1,T2, etc).The effect of changes in sensitivity can be corrected for by taking the ratio of the luminescence signal (Lx) to the response to the fixed dose (Tx).The plot of the sensitivity-corrected OSL (Lx/Tx) as a function of the laboratory dose (bottom) can be used to calculate De (here 22Gy) for that aliquot when the ratio of the initial measurements on the natural sample (LN/TN) is projected onto the dose response curve. (from Duller 2008)

During field work, twelve samples, coming from different localities and deposits of the ASB, were collected for optical dating. For each site we collected also samples for Dose Rate and moisture determination and we made stratigraphic logs in order to define depositional environments and facies of each sample.

OSL dating has been personally performed on seven of the collected samples, in collaboration and under the supervision of Dr Barbara Mauz, at the Luminescence Dating Laboratory in the Department of Geography of the University of Liverpool.

Besides conventional facilities for sample preparation (oven, sieving machine, flatbed shaker, etc.), the laboratory equipment comprises:

-1 Risø DA-15 automated TL/OSL reader equipped with a $^{90}Y/^{90}Sr$-source, delivering ~0.083 Gy/s, 41 blue LED's, providing ~30 mW cm^{-2} and a 1W IR laser diode delivering 160 mW cm^{-2} at 90% power;

-1 Risø DA 15B/C automated TL/OSL reader equipped with a $^{90}Y/^{90}Sr$-source, delivering ~0.108 Gy/s, 21 blue LED's, delivering ~30 mW cm^{-2}, 21 IR LED's providing ~110 mW cm^{-2} at 90% power;

-1 Littlemore β-irradiator delivering ~0.125 Gy/s;

-1 Littlemore α-irradiator equipped with 6 ^{241}Am sources delivering ~0.043 Gy/s;

-1 SOL II sunlight simulator;

-Coaxial n-type HPGe Gamma-Ray Detector with Nominal Relative Efficiency: 30-34%.

Samples were prepared using conventional techniques to extract quartz grains in the size of 90–300 µm from the sediment (Mauz et al., 2002). Where possible, different grain-size fractions (90–125, 125–200 and 200–300 µm) were prepared. For each sample the best grain-size fraction has been chosen for De measurement according to sedimentary facies and amount of material.

To extract pure quartz the samples were treated firstly with 10% and 33% HCl, successively with 10% and 33% H_2O_2, to remove carbonates and organic matter, respectively. Subsequently to gain quartz grains from the bulk samples, density separation of minerals using sodium heteropolytungstates (LST fastfloat, $Na_6H_2W_{12}O_{40}$) was performed. Firstly a LST density of 2.62 g*cm^{-3} was used to separate Quartz, Glauconite, Beryllium and some plagioclases from Kaolinite, K-rich feldspars and Na-and Ca-rich plagioclases. Than a LST density of 2.75 g*cm^{-3} was used to separate Quartz, K-rich feldspars, Kaolinite, Glauconite, Beryllium, Mg-Muscovite and most plagioclases from heavy minerals.

After density separation of minerals the grains were treated with 40% HF for about 35 min to remove impurity and to etch the grain; this step was followed by 10% HCl washing to remove fluoride precipitates. Successively residual fraction of the sample was sieved again to remove smaller detrital material caused from HF etching.

Small (3 mm ≈ 100 grains) and very small (1 mm ≈ 40 grains) aliquots were prepared for Equivalent Dose (De) determination.

All OSL measurements were carried out by a blue LED (λ=470±20 nm) stimulation at 125 °C readout temperature for 40 s, using the Risø DA-15 automated TL/OSL reader (Bøtter-Jensen et al., 2003) of the laboratory.

For De estimation a SAR-dose protocol (Murray & Wintle, 2000) was applied (Fig. 3.5, 3.6). Preheats of 240–260 °C for 10 s and Cut heats of 220 °C, were chosen on the basis of results from preheat test that included monitoring De, recycling ratio and thermal transfer (recuperation). Generally the sequence we used consist of: a measurement of natural OSL, five irradiation steps (200, 400, 800, 1600, 3200 s) and associated OSL measurements, a 0 dose OSL measurement, an IR-OSL measurement and two repeated irradiation steps, generally 200 and 1600 s, and relative OSL measurements. Each of these steps was followed by a constant Test Dose of 200 s, that made possible to calculate sensitivity corrected De values.

The purity of the quartz was checked using the IR/OSL depletion ratio. The amount of recuperation was assessed using the ratio $(L_0/T_0)/(L_N/T_N)$, where L_0/T_0 is the corrected OSL recorded after 0 Gy dose and L_N/T_N is the corrected OSL of the natural dose (Duller, 2003).

Due to high level of thermal transfer we modified the SAR protocol by the addition of a high temperature (280 °C) optical stimulation for 40 s [Fig. 3.6 (Set8)], called hot blue wash (HBW), following each measurement of the Test Dose signal, this additional step has the aim to minimize the recuperation as explained by Murray & Wintle 2003.

The OSL signal of the first 0.5 s of stimulation was used after subtracting the background obtained from the last 10 s of stimulation.

	Samples	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9
Set 1	1,3,5,7,11,13,15,		Beta 200s	Beta 400s	Beta 800s	Beta 1600s	Beta 3200s		Beta 200s	Beta 1600s
Set 2	1,3,5,7,11,13,15,	TL 241°C, 5.00°C/s, 250Pts., PH=240°C for 10s	TL 241°C, 5.00°	Pre Heat 240°C	Pre Heat 240°C	Pre Heat 240°C	Pre Heat 240°C	Pre Heat 240°(	Pre Heat 240°C	Pre Heat 240
Set 3	1,3,5,7,11,13,15,									
Set 4	1,3,5,7,11,13,15,	OSL 125°C Blue LEDs;40.00s;5°C/s;90.0%	OSL 125°C Blu	OSL 125°C Blu	OSL 125°C Blu	OSL 125°C Blu	OSL 125°C Blu	OSL 125°C Blu	OSL 125°C Blu	OSL 125°C Bl
Set 5	1,3,5,7,11,13,15,	Beta 200s	Beta 200s	Beta 200s	Beta 200s	Beta 200s	Beta 200s	Beta 200s	Beta 200s	Beta 200s
Set 6	1,3,5,7,11,13,15,	Pre Heat 220°C;5°C/s;0s	Pre Heat 220°C	Pre Heat 220°C	Pre Heat 220°C	Pre Heat 220°C	Pre Heat 220°C	Pre Heat 220°(	Pre Heat 220°C	Pre Heat 220
Set 7	1,3,5,7,11,13,15,	OSL 125°C Blue LEDs;40.00s;5°C/s;90.0%	OSL 125°C Blu	OSL 125°C Blu	OSL 125°C Blu	OSL 125°C Blu	OSL 125°C Blu	OSL 125°C Blu	OSL 125°C Blu	OSL 125°C Bl
Set 8	1,3,5,7,11,13,15,	OSL 280°C Blue LEDs;40.00s;5°C/s;90.0%	OSL 280°C Blu	OSL 280°C Blu	OSL 280°C Blu	OSL 280°C Blu	OSL 280°C Blu	OSL 280°C Blu	OSL 280°C Blu	OSL 280°C Bl
Set 9										

Fig. 3.6 – Modified SAR-dose protocol including HBW (e.g., Set 8) for De measurements.

For each sample we measured at least 24 aliquot. Only aliquots that had: 1) Recycling Ratios comprised between 1.0±0.1; 2) IR/OSL depletion ratios between 1.0±0.1; 3) insignificant thermal transfer (recuperation <5% of the natural signal); 4) natural dose bracketed by at least two regenerated dose points; 5) De values not in dose saturation (De<2b, where b is the slope of the dose-response curve).

The cosmic ray dose rate was estimated for each sample as a function of depth, altitude and geomagnetic latitude. Gamma ray spectroscopy was done by Dr Barbara Mauz using a Coaxial n-type HPGe Gamma-Ray Detector. The elemental concentrations were then converted into Dose Rate, taking into account also the water content effect, showing Dose Rate ranging between 2.10 and 2.51 Gy/Ka.

3.2.2.2 ^{14}C dating

Radiocarbon dating was one of the first radiometric techniques to be developed and, despite the fact that it is applicable to only a relatively short span of Quaternary time (≈ 50000 years), it is perhaps the most widely used of all the radiometric techniques, probably because it’s applicable to all organic materials including shell, charcoal, wood, peat, carbonates, etc.

^{14}C is the instable isotope of the three isotopes of carbon and like the others it's part of the global carbon cycle. This means that ^{14}C is assimilated by plants and animals during their life cycle. Once an organism dies, however, it becomes isolated from the ^{14}C source and the 'radiocarbon clock' runs down by radioactive decay. Hence, by measuring the amount of ^{14}C that remains in a sample of fossil material and comparing this to modern ^{14}C in standard material, an age can be inferred for the death of the organism. Further information and references about ^{14}C dating can be found in Walker 2005.

Considering the aim of this study and the inferred age of the analyzed deposits, ^{14}C dating method was not the best way to try to date these sediments due to his upper age limit.

However a preliminary OSL age estimation for sample LV550 between the ^{14}C age range, made us confident to try to date that deposits using ^{14}C method to have an independent age and a check on OSL ages. The presence of charcoaled plant remains founded within a sandy layer of the BAR20 Section (*Campo di Pile Synthem*), very close to LV550 sample site, made possible to try ^{14}C dating of this deposits.

Sample Pile4 (LTL13519A) was collected from that layer making attention to avoid contamination. At the RomaTRE rock laboratory that sample has been washed with distilled water to separate sand from organic material and, successively, charcoaled plant remains has been manually selected. The selected material has been sent to the CEDAD laboratory of the Salento University to be submitted to ^{14}C dating using high resolution mass spectrometry (AMS).

The CEDAD give us a conventional ^{14}C not calibrated age; so that age has been calibrated to refer to calendar years and not to radiocarbon years. The calibration was done with the free software OxCal 4.2, developed by the Oxford University, using the IntCal13 atmospheric calibration curve (Reimer et al., 2013).

The obtained age allow us to constrain the depositional age of the *Campo di Pile Synthem*, to check the reliability of OSL method and to calculate river incision rate for that synthem as explained in chapter 5.4.

3.2.3 SEM observations and analyses

As stated in chapter 3.2.1 the SEM of the LIME lab of Roma TRE University was basically used to better characterize and to take some pictures of the ostracod valves picked during the micropaleontological analyses.

Observations were carried out using a Philips XL30 LaB6 Analytical Scanning Electron Microscope equipped with an EDAX 134 eV microanalysis device. It is completely controlled via a PC and the dedicated software enables an easy access to all the main functions (beam alignment, specimen movements, adjustment of the electronic gun, etc.). The high tension output can be linearly regulated from 0,2 to 30 kV and the magnification from 10 to 400.000X. The LaB6 electron source enables a very high definition. The presence of the EDAX (Energy Dispersive X-ray Analysis) device allows to carry out the elemental analysis and chemical characterization of the sample.

In addition the SEM was used to have some other information about granulometry, mineralogy and chemical composition of some particular samples. In particular it allowed to better define the mineralogy of both the San Nicandro carbonate silts and the tephra layer within them, the granulometry, and the chemical composition. The SEM allowed also to better identify and characterize the sponges spicules found within the San Nicandro carbonate silts and to reveal the presence of freshwater diatoms inside them.

3.3 Geophysical methods

After 6th April 2009 several geophysical surveys were done by many authors belonging to different institutions (University, CNR, INGV, DPC). These studies comprises seismic refraction tomography; gravimetric surveys; seismic reflection profiles; Downhole and Crosshole surveys; seismic-noise analysis (HVSR); multichannel analysis of surface waves (MASW); geoelectric surveys; strong motion network analysis (Gruppo di Lavoro MS-AQ, 2010; Tallini et al., 2010, 2012; Lanzo et al., 2011; Improta et al., 2012; Del Monaco et al., 2013).

All these works were used to get useful information about subsurface stratigraphy and internal architecture, geophysical and geotechnical characteristics of sediments, bedrock geometry and depth.

In particular, some of the seismic reflection profiles (Pettino 1 and Pettino 2) carried out by the CERFIS after the 2009 earthquake (Tallini et al., 2010) were reinterpreted considering our stratigraphic model.

Moreover, a collaboration to perform seismic microzonation studies of the western portion of the L'Aquila Basin (Sassa-Preturo area) made possible to directly apply the HSVR method to reconstruct the subsurface geometry of the area, as explained in chapter 3.3.2.

3.3.1 Seismic reflection profiles analysis

As stated before, one of the seismic-reflection profiles (Pettino 1) gathered by the CERFIS (Tallini et al., 2010) and previously interpreted by Tallini et al. (2012), was re-analyzed. In addition a shorter seismic-reflection profile (Pettino 2), acquired transversally to Pettino 1, was interpreted to obtain a 3D image of the subsurface setting of the L'Aquila-Scoppito Basin (ASB) close to its northern margin, where some seismogenic faults affect the basin.

The Pettino 1 profile is a 1300 m long high resolution multi-fold wide-angle seismic profile, carried out across the Mt. Pettino fault zone (Fig. 4.38, 4.39). The acquisition layout consisted of an array of 164, 14 Hz, vertical geophones deployed with a 5 m interval. The receivers recorded shots fired with a spacing of 10 m by a Minipulse (2800 Joule) source with 1000 Hz sampling rate. Initial part of the profile (from 0 to 515 CDPx) being also interested in high-resolution seismic tomography to get information on the velocity distribution in depth. The Pettino 2 profile is a 360 m long profile, acquired transversally to Pettino 1 near the S. Salvatore hospital. The acquisition layout consisted of an array of 69 vertical geophones (10 Hz), deployed with a 5 m interval. The receivers recorded shots fired with a 10 m spacing by a Minivib source with a sweep-up of 10-150 Hz.

Other information about data acquisition and processing or P wave velocity field can be found in Tallini et al. (2010, 2012)

3.3.2 Seismic-noise analysis (HVSR or Nakamura method)

During the seismic microzonation of Preturo and Sassa areas we had the possibility to directly apply the HVSR, or Nakamura, method to gain information about seismic site effects, resonance frequencies, seismic amplification and to estimate the bedrock depth.

The HVSR technique assumes that microtremors are mainly composed of surface Rayleigh waves that propagate through a soft-hard stratified body and that this contrast is the cause of site amplification effects. (Nakamura, 1989)

The HVSR method consists of recording ambient vibrations from three directions (one vertical, and two horizontal). Signals are processed numerically to obtain the corresponding Fourier spectra and the horizontal to vertical spectral ratio is calculated (H/V). This ratio results in a curve that presents a peak corresponding to the site's fundamental resonance frequency. The presence of spikes on the H/V ratio curves is related to the site fundamental resonance frequency (f_o) and allow to assess the magnitude of the amplification and provide rough estimates of the impedance contrast depth that causes the seismic resonance.

This principle is expressed by this simple equation:

$$f_o = V_s/4Z$$

where f_o is the resonance frequency, V_s is the mean velocity of S waves and Z is the depth of the impedance contrast at the site. (Nakamura, 1989)

The study area is located in the L'Aquila-Scoppito sub-basin and it's comprised between Preturo, Sassa and Genzano di Sassa villages (Fig. 4.38). In this area 120 single station seismic noise measurements were collected using a three components velocimeters (0.1 - 20 Hz), with two differently spaced array, 255 m and 500 m, for the urbanized and suburban areas respectively. To have a good data quality a 20 minutes recording window was used for each measurement station. Measurements were acquired between December 2012 and April 2013. All data were processed using the Grilla® software; with a frequency interval between 0.1 – 20 Hz, splitting the signal into 30 seconds time window. A Konno & Ohmachi smoothing (b = 40) was applied and high energy transient windows were manually removed.

Apart from site effects characterization, these measurements made possible to reconstruct the isobaths and isopachs of the seismic bedrock of the central sector of the L'Aquila-Scoppito Sub-basin (Fig. 4.40). This was done using the relationship between f_o, V_s and depth (Z) illustrated before.

In fact, an empirical relationship was established by correlating the estimated depth of the seismic bedrock (h), calculated using the HVSR equation, with the bedrock depth derived from boreholes data. This relation can be expressed with the equation:

$$\mathbf{Z} = \boldsymbol{a} * \boldsymbol{f}_{\mathbf{o}}^{\boldsymbol{b}}$$

were a and b are parameters derived from the correlation curve between Z and f_o (Ibs-von Seht & Wohlenberg, 1999). In particular the calculated relation show an R^2 = 0.8827, while *a* value is 135.11 and *b* value is -1.276 (Fig. 3.7).

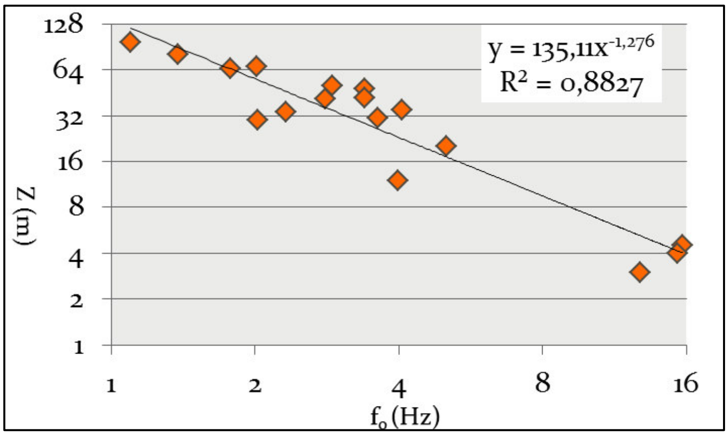


Fig. 3.7 – Correlation curve between measured frequency values (f_o) and corresponding boreholes bedrock depths (Z).

Using that empirical relation the bedrock depths was estimated for each measurements, even if V_s was unknown. Obtained depth values were digitalized using ArcInfo ESRI® and interpolated using the *Topo to Raster* tool to reconstruct a raster that represents the thicknesses of continental deposits. From that raster, isopachs were successively extracted using an existent tool of ArcInfo. Using the Raster Calculator these isopachs were then converted into isobaths of the bedrock, using the 20 x 20 m DEM released by the PCN (Portale Cartografico Nazionale-Ministero dell'Ambiente) as elevation reference system.

4.0 RESULTS

4.1 Pre-orogenic succession

As described in par. 3.1.1 the Meso-Cenozoic bedrock units were mapped according to their paleogeographical domain (Fig. 2.1), using the facies associations defined in the "L'Aquila" (sheet 359) and "Pescorocchiano" (sheet 358) CARG maps (Centamore et al., 2006; Centamore & Dramis, 2010). This resulted in six pre-orogenic paleogeographical successions, each of ones composed by several lithostratigraphical units characterized by lateral heteropy and complex stratigraphic and tectonic boundaries. A detailed descriptions of each unit can be found in Centamore et al. (2006) and Centamore & Dramis (2010).

The (1) **Mesozoic carbonate paleo-platform succession** ("Paleo-piattaforma appenninica" *Auct*.) comprises the *Dolomia Principale* (DPR) and the *Calcare Massiccio* (MAS) formations, made of shallow water Triassic to Lower Jurassic dolostones, dolomitic limestones, mudstones-wackestones, and grainstones.

The (2) **Mesozoic inner carbonate platform succession** includes Lower to Upper Cretaceous (Valanginian – Campanian) shallow-water carbonate deposits related to open shallow-water platform or restricted shallow-water platform environments, with occasional sub-aerial exposures. It is made of wackstones, grainstones, dolomitic limestones, dolostones, floatstones with benthic forams, gastropods and hippurites; alternating marly limestones and marls; mudstones and wackestones with intercalated bauxites. These deposits belong to the *Calcari Ciclotemici a Gasteropodi* (CCG), the *Calcari a Requienie, Caprotine e Ostreidi* (RCO); *Calcari e Marne a Salpingoporella dinarica e Charophyta* (CMS); the *Calcari Ciclotemici a Requienie* (CIR); the *Calcari Intrabauxitici* (IBX) and the *Calcari a Radioliti* (RDT).

The lithofacies belonging to the (3) **Mesozoic carbonate platform margin (edge) succession** are mainly made of organogenic grainstones and rudstones with echinoderms, algae, corals and mollusks related to patch-reef environment; subordinately micritic limestones, wackestones, and fossiliferous grainstones are present. These deposits are eteropic to the previous ones and they cover a time span from Lower Jurassic to Upper Cretaceous (Sinemurian – Campanian). This succession comprises the *Calcari Bioclastici* del Monte della Selva (MSE), the *Calcareniti ad Echinodermi e Coralli* (ECO); the *Calcari ad Ellypsactinie* (ELL); the *Calcari a Clasti Neri e Gasteropodi* (CNE); the *Calcari a Coralli e Diceratidi* (CCD); the *Calcari a Rudiste e Orbitoline* (RDO); the *Calcari Bioclastici ad Ippuriti e Coralli* (BIC) of the F.359-L'Aquila CARG map (Centamore et al., 2006).

Deposits referable to the (4) **Mesozoic carbonate ramp-upper slope succession** are very rare in the study area. This succession includes the *Calcari Bioclastici Inferiori* (BLI); the *Calcari Cristallini ad Echinodermi e Coralli* (ECC); the *Calcari Bioclastici Superiori* (BLS); *the Calcari Cristallini* (CTN) and the *Calcari a Calcispherulidi* (SPH). This Upper Jurassic to Upper Cretaceous (Aalenian? – Maastrichtian) succession is characterized by bioclastic grainstones and rudstones, often recrystallized, with rudists, gastropods, echinoderms and hydrozoan fragments. Subordinate wackestones containing planktonic forams are present.

A (5) **Meso-Cenozoic lower slope-basin succession** characterizes the northern and north-eastern sectors of the basin margins. Deposits belonging to this succession consist of pelagic mudstones, calcareous marls and marls with chert lists, radiolarians, tintinnids and planktonic forams; frequently grainstones and rudstones intercalations of reworked platform and shallow-water carbonates are present within pelagic deposits. Inside this Lower Jurassic to Upper Miocene (Sinemurian – Tortonian) succession the *Corniola* (COI), the *Verde Ammonitico-Calcari e Marne a Posidonia* (VAP), the *Calcari Diasprigni Detritici* (CDI), the *Maiolica Detritica* (MAD), the *Calcareniti e Calciruditi a Fucoidi* (CCF), the *Scaglia Detritica* (SCZ), the *Scaglia Cinerea Detritica* (SCC-CDZ), the *Bisciaro* (BIS), and the *Marne con Cerrogna* (CRR) units are grouped together.

The (6) **Cenozoic carbonate-ramp/open-platform succession** is composed of bioclastic grainstones and packstones with benthic macroforams; alternating calcarenites, calcareous marls and marls with sponges spicules; bioclastic grainstones and rudstones with bryozoan, algal fragments, echinoderms and bivalves; marls, calcareous and argillaceous marls with ichnofossils and planktonic forams. These deposits are Paleocene? to Upper Miocene and are refereable to the *Calcareniti a Macroforaminiferi* (CFR); the *Unità Spongolitica* (SPT); the *Calcari a Briozoi e Litotamni* (CBZ), and the *Unità Argilloso-Marnosa* (UAM) of the CARG maps (Centamore et al., 2006; Centamore & Dramis, 2010).

4.2 Syn-orogenic succession

In the western sector of the L'Aquila Basin (L'Aquila-Scoppito sub-basin) and around Bagno and Bazzano villages, a **Neogene (Upper Miocene) syn-orogenic succession** crops out. It's made of Lower Messinian siliciclastic flysch deposits, characterized by an overall fining-upward succession of well-bedded sandstones and pelites. This succession comprises some members of the *Complesso Torbiditico Alto-Miocenico Laziale-Abruzzese Auct*. and part of the *Formazione della Laga*, as represented in the 358-359 CARG maps (Centamore et al., 2006; Centamore & Dramis, 2010).

Great importance has the thin and limited well-rounded coarse-grained clastic deposit unconformably overlaying the Meso-Cenozoic platform edge succession north-eastward of S. Stefano di Sessanio. This **late-orogenic deposit** is referred to the *Conglomerati di Monte Coppe* and the *Conglomerati di Rigopiano* of the F. 359 – 360 CARG maps (Centamore et al., 2006; Centamore & Dramis, 2010), which represent deposition in Late Messinian-Early Pliocene thrust-top basins (Ghisetti et al., 1993; Cipollari et al., 1999a; Centamore et al., 2006; Cosentino et al., 2010) on the leading edge of the central Apennine chain.

4.3 Stratigraphy of the L'Aquila Basin continental deposits (Post-orogenic succession)

L'Aquila Basin hosts a thick continental succession unconformably deposited above the Meso-Cenozoic bedrock and internally distinguished by several unconformities. Somewhere the different stratigraphical units are juxtaposed by normal faults that controlled the AB onset and subsequent evolution.

Field surveys coupled with paleontological, geochronological analyses, well-log and geophysical data interpretation allowed us to review the AB stratigraphy and to define up to seven synthems (Fig. 4.1), partly matching stratigraphic units or synthems already described in previous works (Fig. 2.2) (GE.MI.NA., 1963; Bosi & Bertini, 1970; Bertini & Bosi, 1993; Centamore et al., 2006; Centamore & Dramis, 2010; Giaccio et al., 2012; Mancini et al., 2012). Some of these synthems are common to the whole AB and in some cases are composed by two Sub-synthems, while some others are peculiar of the ASB or PSC Basin. Almost all are composed of several lithological units related to different depositional environment.

In the following section, we provide a description of these synthems, focusing on their palaeo-environmental meaning, lateral heteropic relationships, and correlations between the different sectors of the basin.

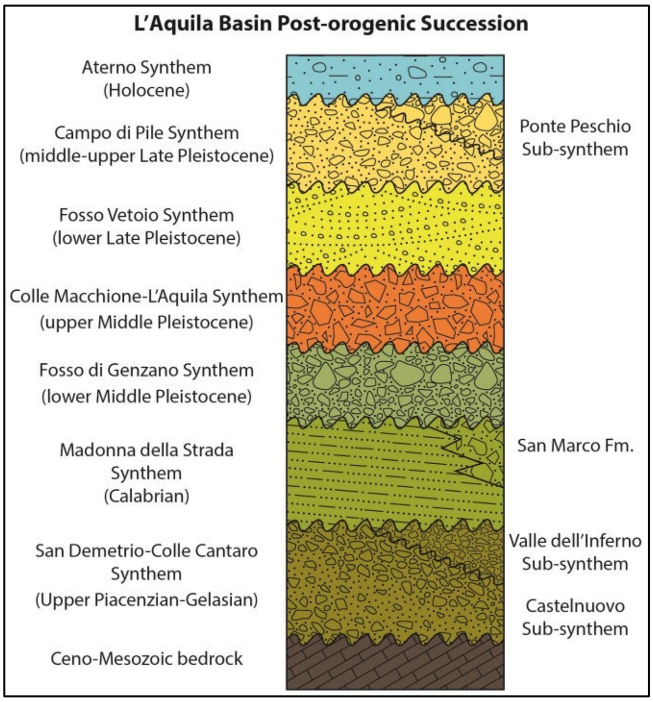


Fig. 4.1 – Unconformity-bounded stratigraphic unit (UBSU) of the L'Aquila Basin post-orogenic succession.

4.3.1 San Demetrio-Colle Cantaro Synthem

The ***San Demetrio-Colle Cantaro Synthem*** represents the first depositional phase within the L'Aquila Basin, principally fitting with the *Aielli-Pescina Supersynthem* (Centamore et al., 2010) and *Lower PSC Synthem* of Giaccio et al. (2012), from which it differs for the age attribution and for some stratigraphic interpretations. This synthem is well preserved in the SE sector of the PSC Basin, extensively outcropping in the San Demetrio-Castelnuovo area, while in the western sector of the basin it outcrops discontinuously in response to the Paganica-San Demetrio Fault System activity.

Due to the presence of a minor unconformity in the upper part of the synthem, it can be split into two Sub-synthems: the ***Castelnuovo Sub-synthem***, including several formations deposited in different environments of a lacustrine system (San Nicandro Paleolake), and the ***Valle dell'Inferno –Sub-synthem***, mainly related to a fluvial environment.

In the ASB the *San Demetrio-Colle Cantaro Synthem* is represented by the ***Colle Cantaro-Cave Fm.*** (*Colle Cantaro Cave Synthem* in Centamore & Dramis, 2010), cropping out in very few places at the base of the northwestern slopes of the basin, between Vallinsù, Scoppito, and Collettara.

4.3.1.1 Castelnuovo Sub-synthem

The ***Castelnuovo Sub-synthem*** basal unconformity is directly entrenched onto the Meso-Cenozoic substratum, while its upper boundary with the *Valle dell'Inferno Sub-synthem* is represented by a discontinuous erosional surface carved mainly into the topset and foreset of the *Valle Orsa Fm.* and, locally, into the *San Nicandro Fm.*. This erosional surface, sometimes marked by a 0.3-1 m thick dark reddish paleosol, is mainly developed in the San Demetrio-Castelnuovo area, up to Poggio Picenze, while in the western sectors it seems to be absent and a continuity of the *San Demetrio-Colle Cantaro Synthem* cannot be ruled out.

The first formation (*San Nicandro Fm*.) within the *Castelnuovo Sub-synthem* matches the *Limi di San Nicandro Fm.* of Bosi & Bertini (1970) and the *Low energy lacustrine deposits* in Giaccio et al. (2012). It is composed by laminated to massive whitish calcareous silts bearing freshwater ostracods, sponges spicules (*Spongilla lacustris*), mollusc fragments, diatoms and rarely leaves traces (Fig. 4.2, 4.3). When well preserved a rhythmic alternation of white calcareous silts and light grey clayey-silts couplets has been observed, often separated by a thin rusty (oxidized) silty-sands layer (Fig. 4.2). In some localities, close to the basin boundary (i.e., San Martino), in the upper portion of the *San Nicandro Fm*. small ripples and poorly preserved cross stratifications are present.

Fig. 4.2 – Rhythmic alternation of white calcareous silts and light grey clayey-silts of the San Nicandro Fm.

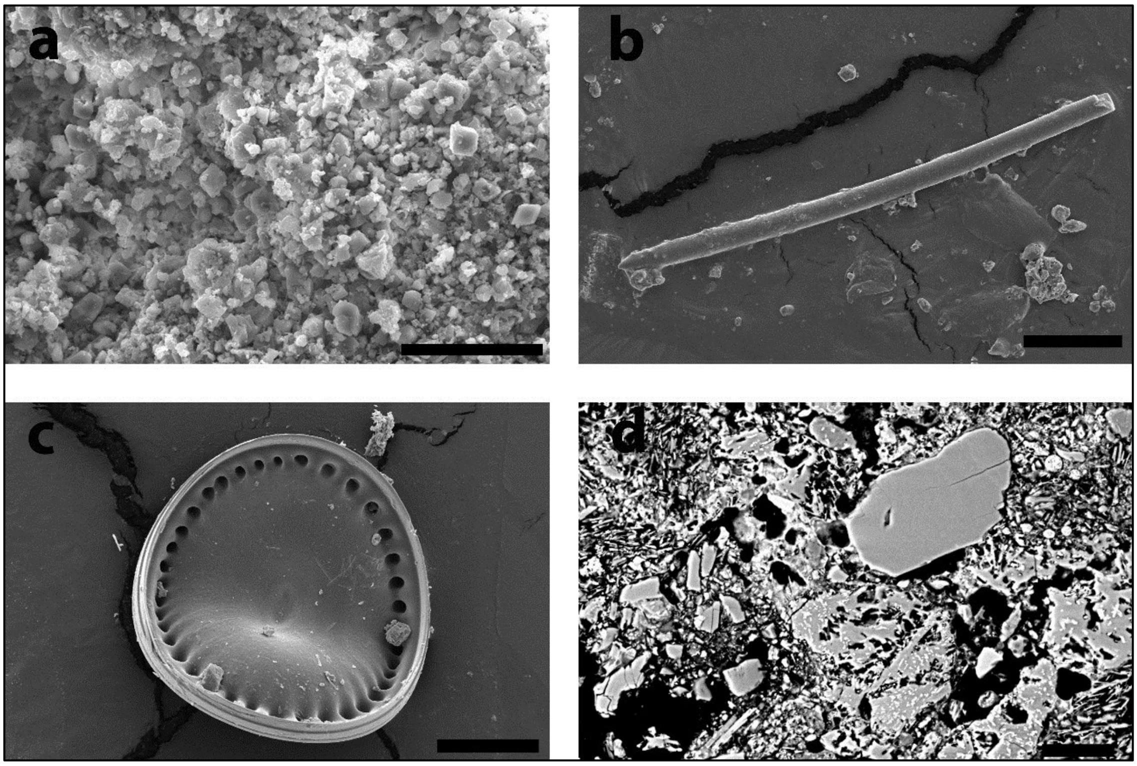


Fig. 4.3 – Details of the calcareous silt of San Nicandro Fm. **a:** Autigenic (biogenic-bioinduced) calcite; **b:** Spicula of *Spongilla lacustris*; **c:** Freshwater diatoms; **d:** Thin section of the calc-alkaline tephra layer, larger crystal is a Ca-Plagioclase. Black bar is 0.1 mm.

The lithological characteristics and sedimentary structures, together with the fossil assemblages that will be further illustrated, point to a relatively deep-water and low energy lacustrine environment for the *San Nicandro Fm*. (San Nicandro Paleolake). The maximum outcropping thickness of this formation is ca. 40 m, as measured in the Faccione section (Fig. 4.11), located between San Demetrio and San Nicandro villages, while in the northeastern sector, Paganica-San Gregorio area, only few meters outcrop. According to electrical resistivity tomography data (Piscitelli et al., 2010; Boncio et al., 2011) and boreholes (Ludovico, 2005) the total thickness of this formation is not much higher than 100 m (102 m in S97 Fig. 4.45).

In the middle part of the Faccione section a dark brown 4-5 cm thick tephra layer, with a fining upward grain-size, was founded (Fig. 4.4, 4.11). This level has a very fine grain-size and is characterized by a calc-alkaline mineralogy with abundant plagioclase and mica, rare pyroxene and absence of K-feldspars (Fig. 4.3c), as the tephras described by Giaccio et al. (2012). The absence in K-rich minerals and the fine grain-size do not permit to date this tephra, anyway, due to its composition, an origin from the Middle-Late Pleistocene Roman Comagmatic Province can be excluded.

Fig. 4.4 – Calc-alkaline tephra founded within the San Nicandro Fm. in the Faccione section (Fig. 4.11). Black arrow shows the polarity of the layer. Black bar is 1 cm.

The lacustrine deposits of the *San Nicandro Fm*. pass heteropically to coarse grain deposits of a Gilbert-type delta system, hereafter called *Valle Orsa Fm.* This formation fits with the *Vall'Orsa Fm.* in Bertini & Bosi (1993), the *Ghiaie d'Ansidonia Fm.* and, partly, the *Conglomerati del Fosso dell'Inferno Fm*. (Bosi & Bertini 1970) and, apart from the upper portion, the *Delta system* of the *Lower PSC Synthem* (Giaccio et al., 2012).

The *Valle Orsa Fm.* extensively crops out on the left side of the Aterno River, from Paganica to the north, to the San Nicandro-Castelnuovo alignment to the south, overlaying both the *San Nicandro Fm*. and the marine bedrock.

This formation is characterized by lithological and sedimentological lateral and vertical variations, reflecting different depositional environment within the delta system. This results, from bottom to top, in the deposition of bottomset, foreset and topset beds.

Bottomset beds are formed by meter-thick layers of yellowish fine-medium sands and silty sands, with horizontal lamination (Sh) and isolated pebbles, sometimes as stone-line, deposited by high energy bottom currents in the upper flow regime (Fig. 4.5).

Fig. 4.5 – Laminated sandy silty level with isolated pebbles of the Valle Orsa Fm. (bottomset).

The foreset beds, arranged to form the delta slope, are composed by 0.5-1m thick steeply dipping (20° – 30°) beds of well-sorted and well-rounded polygenic calcareous gravels and conglomerates, with massive and, rarely, through cross-bedding (Gm, Gt) (Fig. 4.6). Deposits are generally clast-supported, with either a coarse sandy matrix or openwork; rare thin whitish calcareous silt layers are also present between gravel beds.

The total thickness of bottomset and foreset usually ranges between 30-50m, as visible along the Inferno Valley, between San Demetrio and Barisciano.

Foreset beds generally dip toward S-SE downlapping on the bottomsets and lacustrine deposits, as testified by the progressive decreasing of dipping and increasing of the fine fraction from N-NW to S-SE (Fig. 4.7). These observations together with bedding and paleocurrent analyses reveal that the Gilbert-type delta (*Valle Orsa Fm*.) prograded into the lake (*San Nicandro Fm*.) from N or NW.

Fig. 4.6 – Clinostratified conglomerate beds of the Valle Orsa Fm. (foreset).

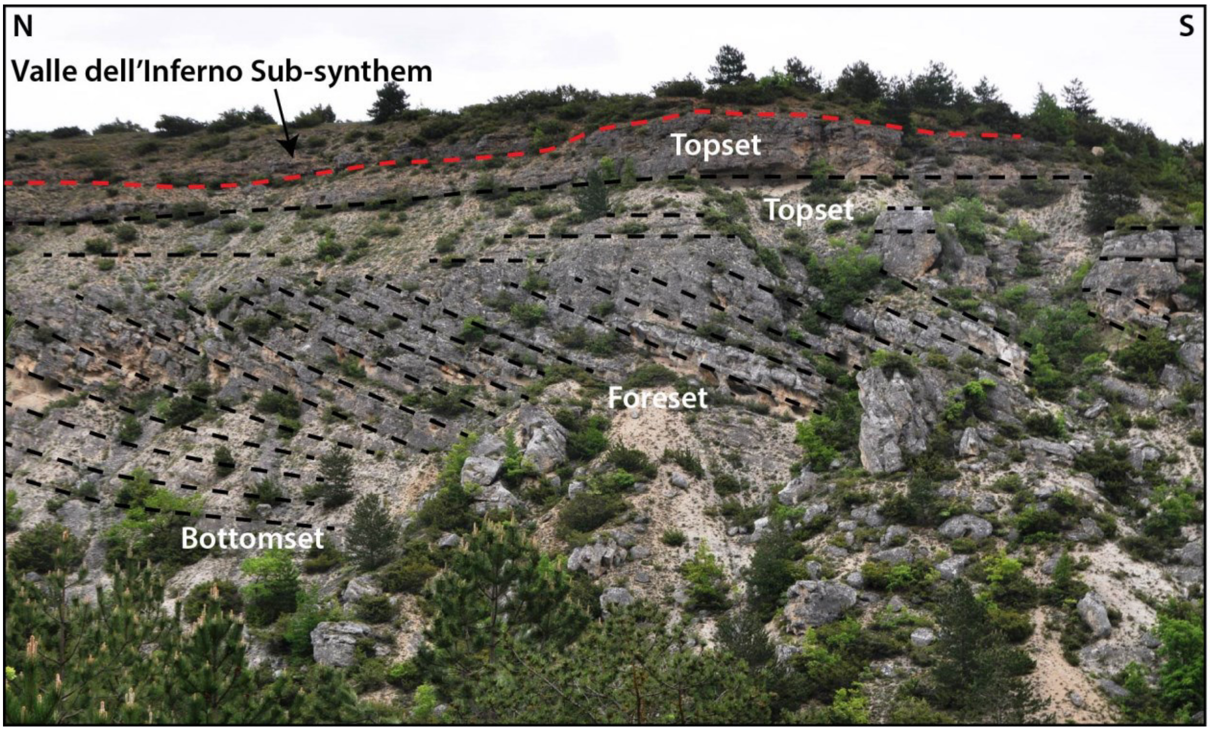


Fig. 4.7 – Panoramic view of the Gylbert-type delta system (Valle Orsa Fm.) of the San Nicandro Paleolake along the Inferno Valley.

Topset beds are made of well-rounded, poorly-sorted polygenic calcareous coarse gravels and conglomerates in a sandy silty matrix, characterized by sub-horizontal layers, from 0.5 m up to several meters thick, with massive or rarely planar cross-stratified bedding (Gm, Gp) (Fig. 4.8). Occasionally silty sand bedforms made of alternating sands and clayey silts are present, showing ripple and planar cross-stratification (Sr, Sp). As reported by different authors the topset thickness is highly variable, from a few meters up to 50 m, increasing from N to S, i.e. from the lake margin to the depocentral area (Bosi & Bertini, 1970; Bertini & Bosi, 1993; Giaccio et al., 2012).

Fig. 4.8 – Massive (Gm), poorly-sorted conglomerates of the Valle Orsa Fm. (topset).

Toward the northeastern slopes of the PSC Basin the *San Nicandro* and *Valle Orsa* formations are heteropically interfingered with coarser sediments, belonging to two different formations: *Madonna della Neve Fm*. and *Valle Valiano Fm*.

The *Madonna della Neve Fm*. extensively outcrops at the base of the slopes between Barisciano and San Pio delle Camere, with thickness up to 10 m, while only isolated and few meters thick deposits referable to that formation are exposed between San Gregorio, San Martino and Poggio Picenze. It consists of an alternation of whitish calcareous lacustrine silt layers and poorly-sorted, angular to sub-angular, matrix supported calcareous breccias both as stone-lines and as massive beds up to 1 m thick (Gm) (Fig. 4.9). This alternation represents the interaction between lacustrine sedimentation and slope-related sedimentary processes at the lake margin, with the occasional arrive of density current (debris-flow/hyperpycnal flow) into the lake. A thick succession referable to that formation, directly overlaying the bedrock, was also observed on the western slope of the Raiale Valley, along the road between Camarda and Cesarano plateau, suggesting a possible extension of the lake up to here.

Fig. 4.9 – Alternation of calcareous silt and poorly-sorted matrix-supported breccia layers (Madonna della Neve Fm.). Black bar is 10 cm.

The *Valle Valiano Fm*. can be recognised along the northeastern slope of the PSC basin, where it generally interposes between the Meso-Cenozoic bedrock, on which it lies, and the others formation of the ***Castelnuovo Sub-synthem*** *(San Demetrio-Colle Cantaro Synthem*), to which it heteropically passes. This formation is made by well stratified and well sorted, trough or planar cross-bedded (Gt, Gp), alluvial fan conglomerates, locally with carbonate sandy and silty layer or lenses, laterally passing to heterometric, angular to sub-angular, calcareous breccias both stratified and massive (disorganized-chaotic), clast-supported or with abundant whitish calcareous silty matrix, respectively (Fig. 4.10). The alluvial fan facies mainly characterize the outlet of the main valleys, like the Raiale or the Marra ones, between Paganica and San Gregorio; while the slope-related facies occupy the slopes between Poggio Picenze and San Pio delle Camere, extensively outcropping around Barisciano (i.e., Valiano Valley). Calcareous breccias referable to this formation outcrop also on the slopes of the relieves close to Campana and Ripa, in the southeastern PSC Basin, or at the top of the Monticchio-Fossa ridge (i.e., Sant'Angelo monastery). The thickness of the *Valle Valiano Fm*. is highly variable all over the PSC Basin and cannot be clearly constrained, anyway a succession more than 50 m thick was observed in the Valle Marra, beyond San Gregorio, and a maximum thickness of ca. 100 m, as suggested by different authors, seems reasonable (Bosi & Bertini, 1970; Centamore et al., 2006). The lithological and stratigraphical characters of the *Valle Valiano Fm*. suggest that it represents the lake paleo-margins, characterized by steep coastlines, as demonstrated by the breccia deposits, cross-cut by transverse river forming alluvial fan.

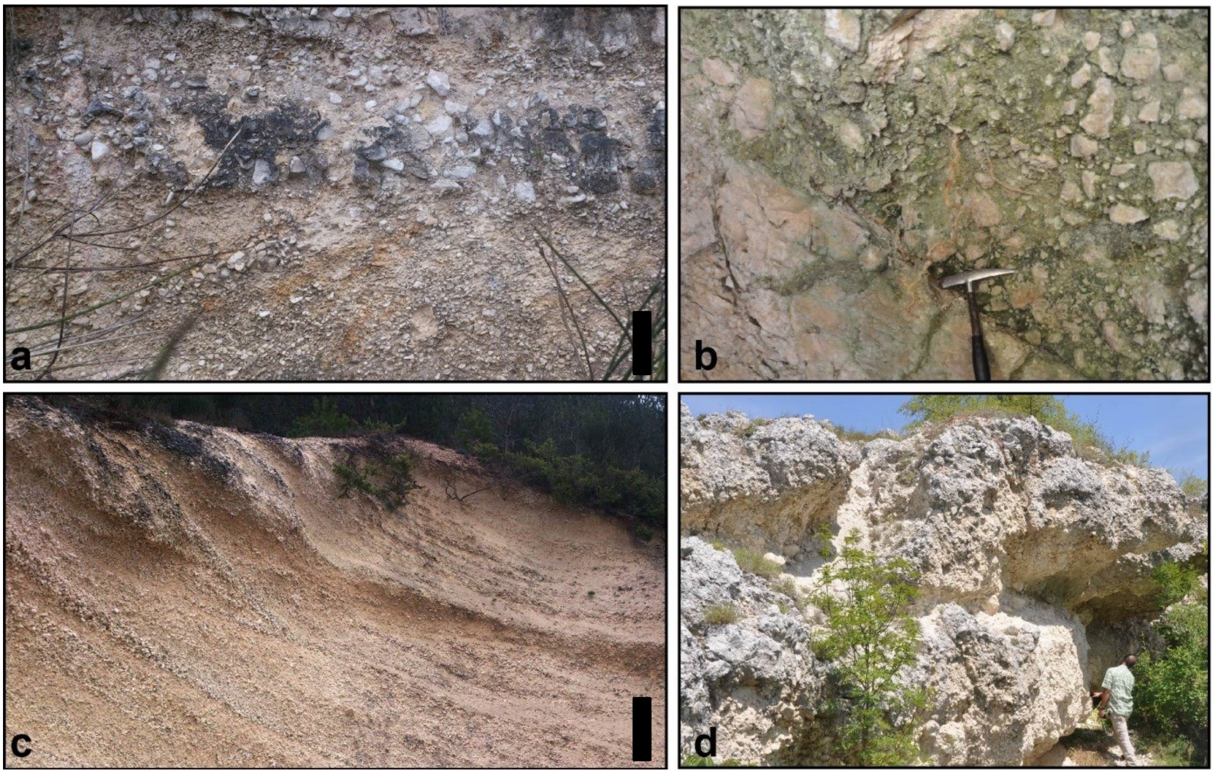


Fig. 4.10 – Lithofacies of the Valle Valiano Fm. **a**: Well-sorted matrix-supported breccias (i.e., San Martino). Black bar is 20 cm; **b**: Detail of the unconformity between bedrock limestones and breccias (i.e., Monticchio); **c**: Trough cross-bedded proximal alluvial fan conglomerates (i.e., Valle Marra). Black bar is ca. 1 m; **d**: Thick beds of poorly-sorted gravels and breccias (i.e., Sant'Angelo monastery).

Four sections of the *Castelnuovo Sub-synthem* [*Lago Sinizzo* (42°17’25’’N, 13°34’34’’E; h=2.50m); *Bordo Lago* (42°17’25’’N, 13°34’36’’E; h=1.50m); *San Nicandro* (42°17’06’’N, 13°35’14’’E; h=5m); and *Faccione* (42°17’13’’N, 13°34’52’’E; h≈50 m)], together with several other outcrops, where sampled for micropaleontological analyses. The samples belong to laminated to massive whitish calcareous silts of the *San Nicandro Fm*. and to the sandy-silty intercalations within the *Valle Orsa Fm*. (Fig. 4.11)

A rich freshwater faunal assemblage, consisting of ostracods, diatoms (Fig. 4.3c), *Characeae* gyrogonites (oospores), sponges spicules belonging to *Spongilla lacustris* (Linnaeus, 1759) (Fig. 4.3b) and mollusk fragments referable to genera *Succinea*, *Lymnaea* and *Bythinia* (Daniela Esu, pers. com.), was recovered both from *San Nicandro* and *Valle Orsa* formations.

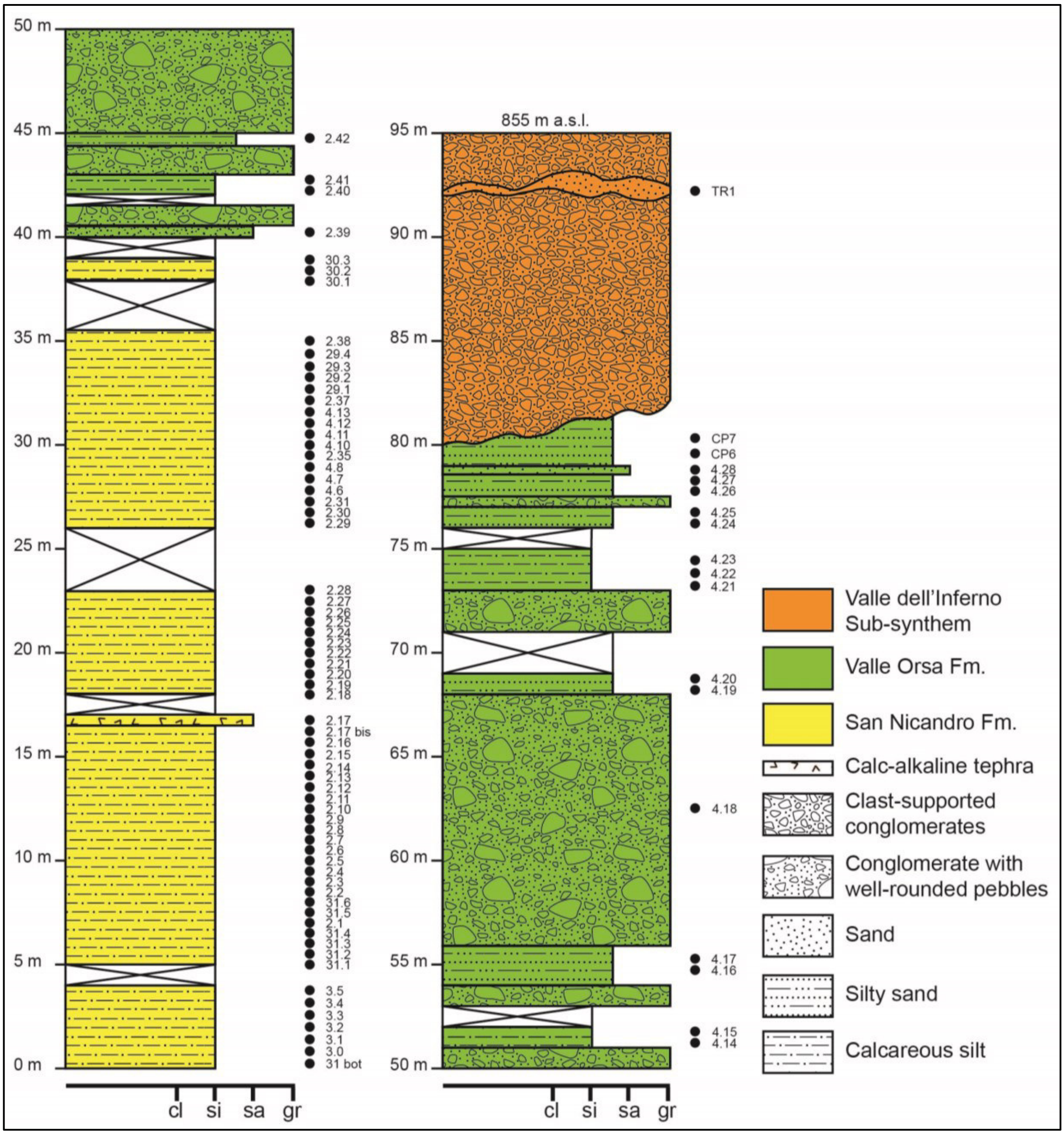


Fig. 4.11 – Stratigraphic composite section of the San Demetrio-Colle Cantaro Synthem. Samples for micropaleontological analyses are shown.

The peculiar ostracod associations recognized in the *Castelnuovo Sub-synthem* were the object of a dedicated taxonomical and paleoenvironmental study (Spadi et al., 2015) that revealed the presence of 13 ostracod species, referable to 8 genera. Among the identified species, only seven are already known, whereas the rest of them have been considered morphotypes pertaining to six different new species.

The two known peri-Mediterranean species found in the *Castelnuovo Sub-synthem* are represented by few valves of *Amnicythere* ex gr. *stanchevae* and by a fragmentary valve of *Paralimnocythere* cf. *P. dictyonalis* (Fig. 4.12), occurring in samples 2.37 (Fig. 4.11) and samples 4.13 (Fig. 4.11), respectively. These species have a Paratethyan origin (Krstić 1973, 1975b; Bassetti et al. 2003) and *Paralimnocythere* cf. *P. dictyonalis* is reported only in the lower Pliocene deposits of the Valdelsa Basin (Tuscany, central Italy), so this is the first discovery of that species outside that area (Medici et al. 2011).

Fig. 4.12 – SEM and transmitted light photos of the ostracod assemblage from the Castelnuovo Sub-synthem. White bar is 0.1 mm.

The most diversified genus is *Caspiocypris*, which is represented by four different new species (*Caspiocypris amiterni* sp. nov., *Caspiocypris bosii* sp. nov., *Caspiocypris nicandroi* sp. nov. and *Caspiocypris vestinae* sp. nov.), particularly abundant in the whitish calcareous silt of the *San Nicandro Fm*. (Fig. 4.12). It is followed by the genus *Ilyocypris* with one new species (*Ilyocypris ilae* sp. nov.) (Fig. 4.13), dominant in the *Valle Orsa Fm.* The last new species, which occurs in both formations, is represented by few specimens of the new species *Cypria bikeratia* sp. nov. (Fig. 4.12), belonging to the genus *Cypria*. More details about taxonomy of that species can be found in Spadi et al. (2015).

Ostracod assemblages recovered in the silty intercalations at the top of these formations show compositional changes, including assemblages in which the four Caspiocypris species are progressively replaced by assemblages made of *Candona (Neglecandona) neglecta* Sars, *Candona* cf. *C. permanenta* (Kristic 1993), *Potamocypris fallax* Fox, *Cypria ophtalmica* (Jurine) and *Cavernocypris* aff. *C. subterranea* (Wolf) (Fig. 4.13).

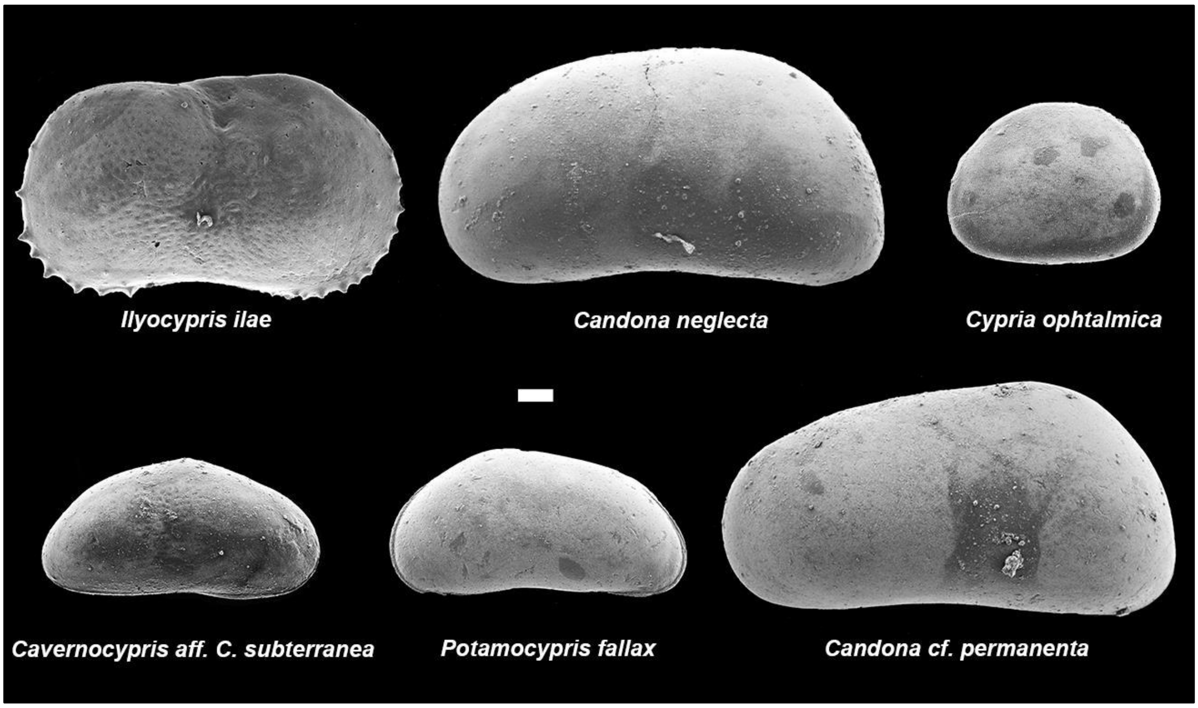


Fig. 4.13 – SEM photos of the ostracod assemblage from the Castelnuovo Sub-synthem. White bar is 0.1 mm.

Considering that *Caspiocypris* are euryhaline and euribate species (Gliozzi & Grossi, 2008), while *Ilyocypris* species live mainly in freshwater littoral environment, up to 30 m depth (Meisch, 2000; Fuhrmann, 2012), the variation in occurrences and relatively abundances of the *Caspiocypris* and *Ilyocypris* genus may be interpreted as an indicator of a significant change in depositional environment, passing from a relatively stable deep-water and low energy lacustrine environment to an higher energetic deltaic system (delta-slope), confirming what already highlighted by lithological and facies changes.

The lacustrine origin of the calcareous silts of the *San Nicandro Fm*. is also supported by the abundant presence of *Spongilla lacustris* spicules, freshwater diatoms and gyrogonites (oospores) of the Characee group, that are all proxy of a clear, not-flowing, carbonate rich permanent water body in a temperate climate (Fig. 4.3).

Concerning the age of the *Castelnuovo Sub-synthem* micropaleontological record, its ostracods assemblages, dominated by the Paratethyan genus *Caspiocypris*, have more affinity with the Paratethyan domain rather than with those of central and western Europe, as instead occurs in the others Italian Plio-Pleistocene assemblages (Barberi et al. 1995; Ambrosetti et al. 1995; Fubelli et al. 2008; Bellucci et al. 2012, 2013). Moreover, as far as we know, in all the Italian post-Messinian deposits, *Caspiocypris* spp. characterizes only the late Piacenzian-Gelasian ostracod fauna of the Fosso Bianco Formation of the Tiberino Basin (Medici & Gliozzi, 2008). So, following a possible correlation between the lake deposits of the Tiberino and L'Aquila basins, at least the lower portion of the *San Demetrio-Colle Cantaro Synthem* may be considered late Piacenzian-Gelasian in age.

4.3.1.2 Colle Cantaro-Cave Formation

As stated before, the ***Colle Cantaro-Cave Fm.*** represent the first depositional stage in the ASB, rarely outcropping but revealed by subsurface data. As showed by well-logs and geophysical data (Fig. 4.39, 4.44), it is present, up to L'Aquila Hill, at the base of the basin-filling succession with an unconformity surface directly carved into both the Meso-Cenozoic calcareous bedrock and the Miocene siliciclastic flysch deposits, characterized by an extremely articulated morphology, resulting in thickness variations and occurrence of subsurface ridges within the basin (Fig. 4.40, 4.44). The upper boundary of the *Colle Cantaro-Cave Fm.* is characterized by an angular unconformity with the younger synthem, and, according to Centamore & Dramis (2010), by the presence of a 1-3 m thick paleosol between them.

The small isolated remnants of the *Colle Cantaro-Cave Fm.* are mainly composed by highly heterometric, angular to sub-angular, slope-derived breccias and debris flow deposits, with limestone, marl and sandstone clasts, up to 50 cm in size, in an abundant clayey-silty matrix (Fig. 4.14). Also proximal alluvial fan deposits were preserved south of Scoppito (i.e. Colle Cantaro), consisting of clast-supported, sub-rounded, coarse to medium massive beds of calcareous gravels and conglomerates, alternating with sandy and silty layers or lenses, rarely showing lamination or planar cross-stratification (Sl and Sp). The alluvial fan deposits generally dip 15-20° toward E/SE, often back-tilted respect to the present morphology, testifying an old landscape no more preserved.

Fig. 4.14 – Colle Cantaro-Cave Fm. **a**: poorly-sorted sub-angular debris flow deposits, with limestone and sandstone clasts in an abundant clayey-silty matrix (i.e., Cave); **b**: back-tilted clast-supported cemented breccias (i.e., Scoppito); **c**: alternation of coarse to medium calcareous gravels with sandy and silty layers (i.e., Scoppito).

The alternating successions of gravels, sands and silts drilled in many boreholes (Fig. 4.44) and reported by several authors at the base of the ASB infilling deposits, can be referred to the distal facies of these alluvial fans and related floodplains. As stated before, the thickness of this formation changes quickly from few meters toward E/SE, to a maximum of 70-80 m in the westernmost part of the basin, as showed by wells S28 and S1 (Fig. 4.44).

The *Colle Cantaro-Cave Fm.* is highly deformed as indicated by the occurrence of many outcrop-scale faults (i.e. the Scoppito-Preturo Fault), the tilting of the bedding planes (>20°), the rapid changes of thickness and its complex geometries, both surficial and buried.

According to these evidence and to our interpretation of the Pettino1 seismic-reflection profile (see Section 4.4.1), this unit was deposited during a syn-rift stage, when the activity of normal faults at the basin margins controlled changes in the accommodation space.

Unfortunately, there are no direct data from the *Colle Cantaro-Cave Fm.* to constrain its age. However, its normal polarity (Messina et al., 2001), the similarities between the *Colle Cantaro-Cave Fm.* and the *San Demetrio-Colle Cantaro Synthem* (i.e., *Valle Valiano Fm.*), as the large amount of clastic materials or the presence of the paleosol in their upper portion, the stratigraphic position and the well constrained Calabrian age of the subsequent synthem, allowed to include the *Colle Cantaro-Cave Fm.* into the *San Demetrio-Colle Cantaro Synthem*, and to refer it to late Piacenzian-Gelasian.

4.3.1.3 Valle dell'Inferno Sub-synthem

As stated before, in the eastern sectors of the PSC Basin, the *Castelnuovo Sub-synthem*, in particular the topset and foreset of the *Valle Orsa Fm*., is eroded and unconformably overlaid by the ***Valle dell'Inferno Sub-synthem*** (Fig. 4.15). This latter is composed by sub-horizontal beds of well-sorted, well-rounded, clast-supported conglomerates, with coarse to medium calcareous pebbles in a sandy matrix. Beds are 0.5 m up to 5 m thick and are characterized by trough and planar cross-bedding (Gt, Gp) (Fig. 4.15a). Channel structures are often preserved and characterized by a pink massive calcareous silty level at the top of the channel (Fm). The typical pink color of the sandy silty fraction derived from the presence of sediments eroded from the reddish paleosol at the base of the *Valle dell'Inferno Sub-synthem* (Fig. 4.15b). Locally lenses or levels, up to 1 m thick, of pinkish calcareous sandy silt are interlayered to the gravels.

The outcropping thickness of the *Valle dell'Inferno Sub-synthem* changes drastically, from 2 m, close to Poggio Picenze, up to more than 20 m in the Inferno Valley (110-120 m according to ERT data (Bosi & Bertini, 1970), to ca. 5 m near Castelnuovo (i.e., Cava Prosciutto) (Fig. 4.15c).

The *Valle dell'Inferno Sub-synthem* belongs to a gravel-bed braided fluvial system developed, subsequently to a local erosional phase, above the *Castelnuovo Sub-synthem* deposits, as testified by the basal unconformity of the *Valle dell'Inferno Sub-synthem*, marked by the partial erosion of the topset and foreset and the occasional presence of a paleosol. The upper boundary of the *Valle dell'Inferno Sub-synthem* is represented by the flat Valle Daria surface, well-preserved between San Nicandro and Castelnuovo villages. This surface, partly representing the depositional top of the fluvial system, lies at ca. 850 m a.s.l. and locally can be correlated to some erosional surfaces carved into the marine bedrock. The higher remnants of that surface, which stand at 875-880 m a.s.l. in the *Peltuinum* and Castelnuovo areas, seem to be related to post-depositional tectonic activity, as testified by the numerous faults cutting the *San Demetrio-Colle Cantaro Synthem* in that area (i.e., Colle Cicogna Fault).

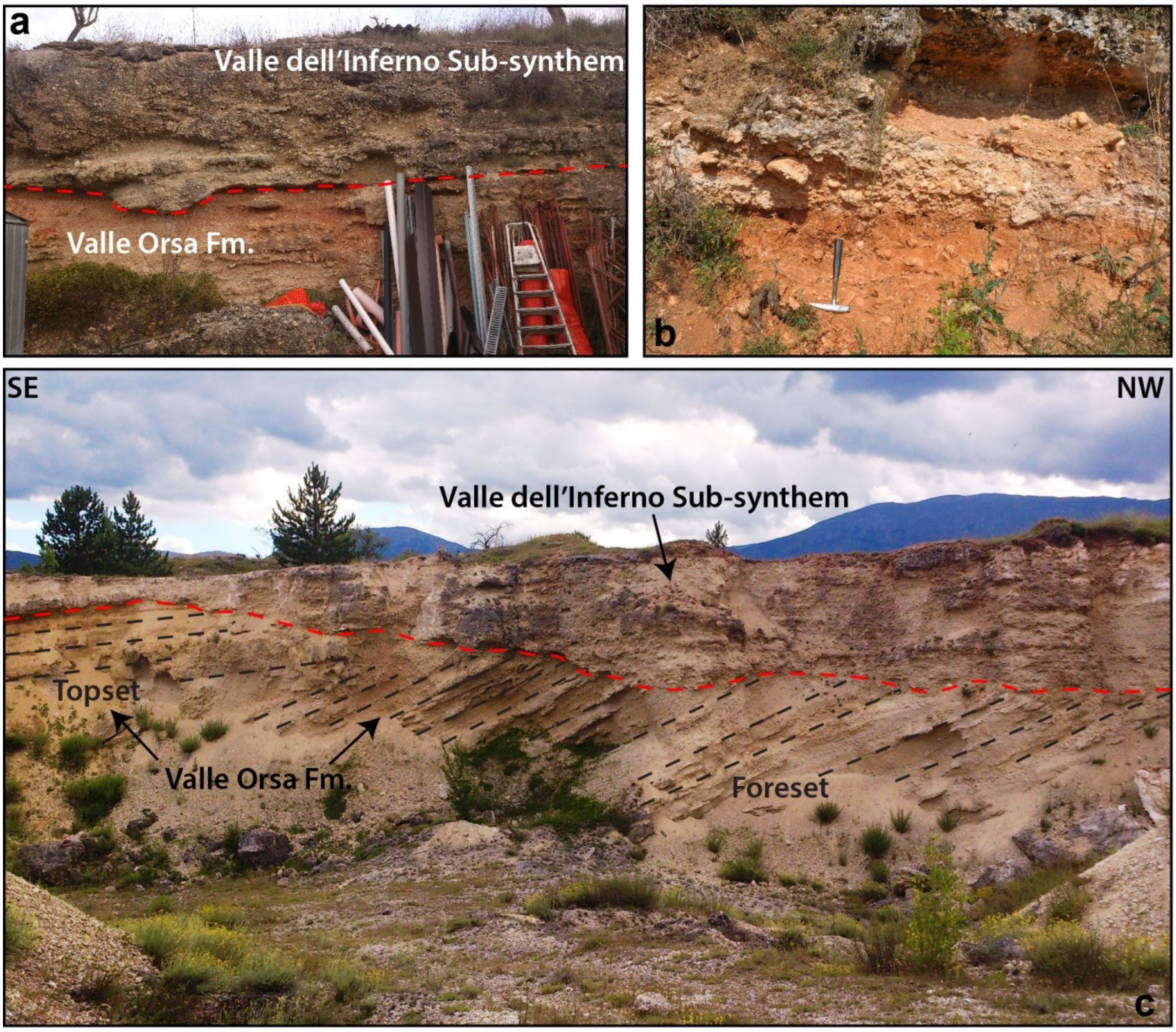


Fig. 4.15 – Valle dell'Inferno Sub-synthem. **a**: Unconformity between the topset of the Valle Orsa Fm., showing incipient pedogenesis, and the planar cross-bedded conglomerates of the Valle dell'Inferno Sub-synthem (i.e., Poggio Picenze); **b**: Detail of the paleosol at the base of the Valle dell'Inferno Sub-synthem (i.e., Inferno Valley); **c**: Angular unconformity of the Valle dell'Inferno Sub-synthem carved into both foreset and topset of the Valle Orsa Fm. The flat top surface is the Valle Daria surface (ca. 855 m asl) (i.e., Cava Prosciutto).

The *Valle dell'Inferno Sub-synthem* rarely contains fine deposits suitable for micropaleontological analyses, except for sample TR1 collected from some small lenses of pinkish silty sand in the hanging wall of the fault inside the paleosismological trench dug by the INGV (Lo Sardo et al., 2015) at the top of the Valle Daria surface. (42°17'49,1"N, 13°35'37,3"E). Within this sample no ostracods were found, but a rich gastropods fauna was recovered. This association is characterized by the presence of *Multidentula helenae* (Esu, 2000), *Truncatellina cylindrica* (Férussac, 1807), *Pupilla* sp. and *Hygromiidae* indet. All these species are terrestrial pulmonates; in particular *Truncatellina cylindrica* lives in sunny dry and moderately dry hills, up to 2800 m, on carbonate bedrock, grassland or sand, while *Hygromiidae* genus is typical of cool humid open habitats, such as grassy river valley or river bank (Welter-Schultes, 2012). These indications confirm the fluvial origin of that formation, as suggested by facies analyses.

Apart from *Multidentula helenae*, that is the westernmost known species of the genus *Multidentula*, nowadays widespread in eastern Mediterranean with many species, all the other specimens are living species. *Multidentula helenae* is considered extinct and, until now, it was recorded only in two localities of the Upper Tiber Valley (central Italy) where it was related to the Tasso F.U. (Early Pleistocene (Gelasian-Calabrian)) (Esu, 2000; Ciangherotti & Esu, 2000). This is the first discovery of that species outside the Upper Tiber Valley and it could constrain the upper age limit of the *Valle dell'Inferno Sub-synthem* to the Gelasian-Calabrian boundary (Tasso F.U.).

4.3.2 Madonna della Strada Synthem

The 2^{nd} stage of L'Aquila Basin infilling is marked by the presence in the ASB of the ***Madonna della Strada Synthem*** embedded into the previous synthem.

This synthem matches the *Madonna della Strada Synthem* mapped by Centamore & Dramis (2010) in the western AB, to which other deposits close to L'Aquila city or in the eastern AB, as the *Pianola Unit* (Bosi et al., 2003), previously referred to the *Aielli-Pescina Supersynthem* (Centamore et al., 2006), were grouped.

Sediments referable to this synthem occupies the whole ASB, widely outcropping between Scoppito to the W and the Bazzano-Monticchio ridge to the E, while in the PSC Basin no outcrops of this synthem are reported and only within some boreholes few meters thick sediments referable to the *Madonna della Strada Synthem* are present (e.g., S69, S72, S86, S100, S101 in Fig. 4.45). In the western part of the ASB, as far as the L'Aquila city to the E, the *Madonna della Strada Synthem* unconformably overlays the *San Demetrio-Colle CantaroSynthem*. According to Centamore & Dramis (2010) those synthems are separated by a 3 m thick paleosol. Instead, from L'Aquila Hill up to Monticchio to the E, the base of the *Madonna della Strada Synthem* lies on an deep erosive surface carved into the bedrock, as highlighted by field and subsurface data (see section 4.4).

Deposits belonging to the *Madonna della Strada Synthem* characterize both the basin floor, where they outcrops eroded and unconformably overlaid by the younger synthems, and the lower part of the basin margins, where the main faults often juxtaposed them to the bedrock. In both cases, the *Madonna della Strada Synthem* generally outcrops at lower elevations with respect to the well recognizable depositional top of the *San Demetrio-Colle Cantaro Synthem*, evidencing the existence of a strong uplift phase between these two synthems, that led to the entrenching of the *Madonna della Strada Synthem* into the previous one.

The *Madonna della Strada Synthem* shows different lithofacies within the ASB basin and is mainly composed by a thick alternating sequence of sandy silts, clayey silts and sands, with minor gravel beds and locally containing several lignite beds (GE.MI.NA., 1963).

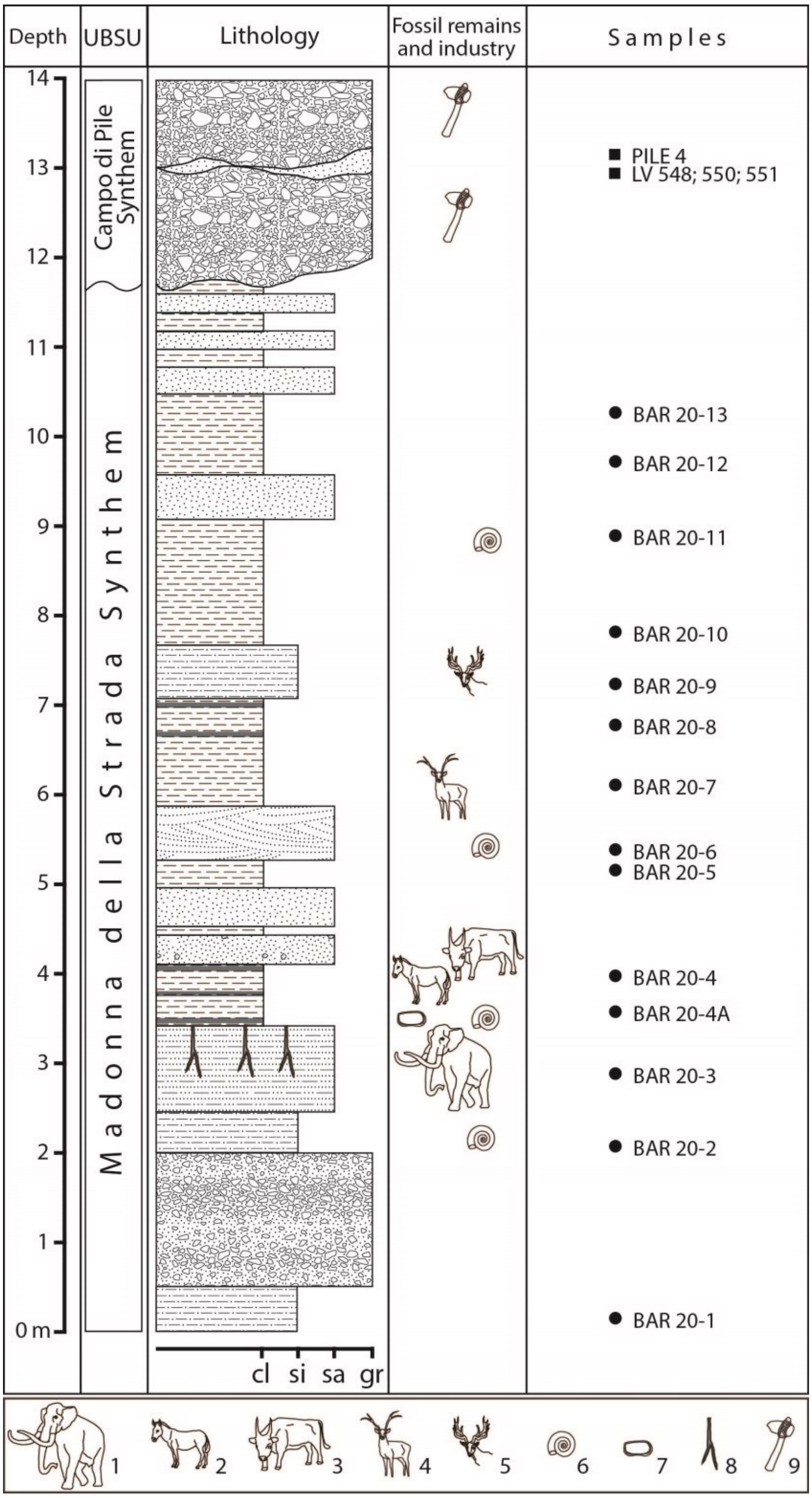


Fig. 4.16 – Stratigraphic log of the BAR20 section (42° 21' 09.3"N; 13° 20' 20.5"E), with location of samples for paleontological studies (dots).
LV are samples for OSL dating.
Pile 4 is the sample for 14C dating.
1 - *Mammuthus meridionalis*;
2 - *Equus* sp.;
3 - large bovid;
4 - *Axis eurygonos*;
5 - cfr. *Praemegaceros obscurus*;
6 - molluscs;
7 - ostracods;
8 - root trace;
9 - Mousterian industry.

In the western part of the ASB, the outcropping deposits are formed, from the bottom, by yellowish sandy silt and sand beds, rarely showing planar cross-stratification (Sp), densely interlayered with thin greyish clayey levels (i.e., Cava d'Argilla). These levels become more abundant and thick upward (i.e., Madonna della Strada, BAR20 section), passing to dark grey massive organic clays and clayey silts (Fm), containing several lignite seams intercalations, alternated with minor sandy silt and sand beds with planar cross-stratification and ripple marks (Sr, Sp) (Fig. 4.16, 4.17, 4.18). The *Mammuthus meridionalis* discovered in the Santarelli quarry

(Madonna della Strada) at the end of the '50s, as well as the mammal fossil remains collected at Campo di Pile (BAR20 section) (Fig. 4.16, 4.21), were founded in the sandy clayey beds of that portion of the *Madonna della Strada Synthem* (Maccagno, 1958, 1962, 1965; Ge.Mi.Na, 1963; Bosi & Bertini, 1970; Magri et al., 2010; Agostini et al., 2012; Mancini et al., 2012). In the upper portion of the *Madonna della Strada Synthem* (i.e., top of Colle Mancino) lignite seam and gravel bed intercalations disappear and the deposits are mainly composed by alternations of yellowish-reddish sand and silty sand beds, showing oxidized surfaces, planar cross-stratification and ripple marks (Sr, Sp), characterized by fining upward sequences ending with light grey clayey silt layers (Fig. 4.18).

In the middle and, more frequently, in the lower part of the synthem coarse to medium well-rounded sandy gravel beds, characterized by channelized geometries, variable thickness and planar or through cross-bedding (Gp, Gt), are also present. Lignite beds have a lenticular shape and shows highly variables thickness and frequency within the ASB. Several levels, up to meter thick, are present in the westernmost part of the ASB (i.e., Santarelli quarry, Madonna della Strada), while moving eastward lignite intercalations are less frequent (i.e., Pile) and usually centimeter thick, or completely absent (i.e., Pianola, Bagno).

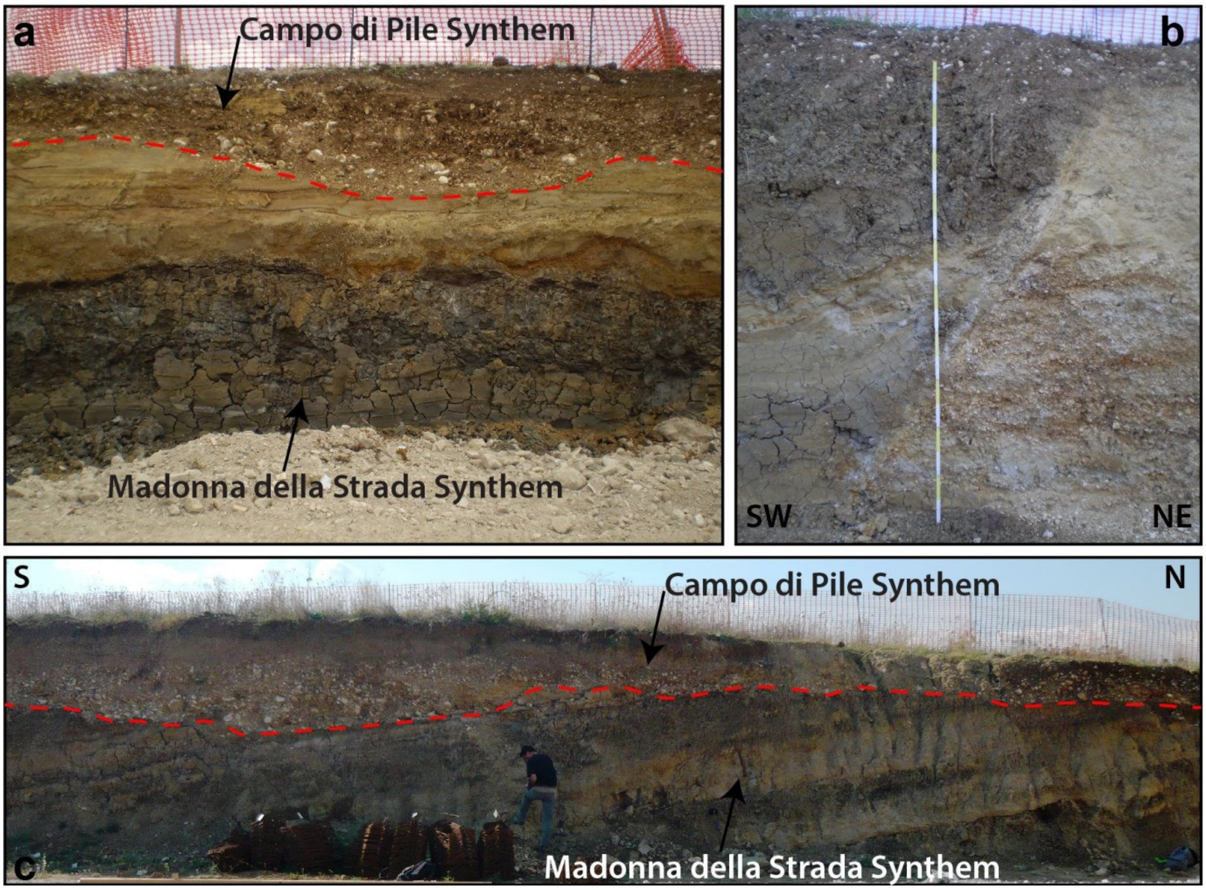


Fig. 4.17 – Characteristics of the Madonna della Strada Synthem at the BAR20 section. **a**: Dark grey massive organic clays and sandy bedform of the Madonna della Strada Synthem unconformably covered by the Campo di Pile Synthem; **b**: NNW-SSE trending normal fault, synthetic to the Palombaia Fault, that juxtaposed gravels (footwall) and clayey-silts (hangingwall) of the Madonna della Strada Synthem (i.e., Campo di Pile); **c**: Panoramic view of the BAR20 section showing the tilting of the Madonna della Strada Synthem toward the southern margin of the basin and the unconformity with the Campo di Pile Synthem.

Differently to the western ASB, the deposits referable to the *Madonna della Strada Synthem* outcropping at the base of the L'Aquila Hill and on the slopes between Pianola and Bagno are more homogeneous. They are almost entirely made of yellowish medium sand bedforms up to meter thick, showing fining upward sequences, planar cross-stratifications and rare ripples (Sp, Sr), capped by centimeter thick layers of laminated to massive greyish silts and clayey silts (Fig. 4.18). No lignite beds were observed in these deposits and only near Bagno (i.e., Civita lake) some thin, poorly-rounded, fine gravel beds, with both calcareous and arenaceous clasts, are interlayered to the sands, sometimes as stone-lines. In both successions, several pedogenized horizons, calcrete, mottles and root traces are present in different portion of the *Madonna della Strada Synthem*, testifying the existence of temporary emerged areas within this continental depositional system (Fig. 4.18c, d).

Fig. 4.18 – Sedimentary structures within the Madonna della Strada Synthem. **a**: Alternation of coarse sands and silty-clayey layers cut by cm-scale syn-sedimentary fault planes (i.e., south L'Aquila hill); **b**: Gray clays overlaid by laminated coarse sands, with angular clasts, grading into planar cross-stratified sand (i.e., BAR20 section); **c**: Root casts (rizholiths) with oxidized organic matter fill; **d**: Irregular shaped calcareous glaeboules (calcrete) and mottles in a silty sand layer of the Madonna della Strada Synthem; **e**: Sandy bedform showing irregular base and planar cross-stratification (lateral accretion bar) (i.e., Sassa scalo).

The described lithofacies, characterized by lithological and sedimentological variations, coupled with the paleoenvironmental data derived from paleontological analyses, allowed to refer the *Madonna della Strada Synthem* to a meandering fluvial system with wide floodplain and swampy areas. This led to the deposition of the lateral and vertical alternations of gravelly channelized deposits, sandy silty alluvial plain bedforms and clayey silty marshy deposits containing lignite beds. The differences between the sequences described for the western and eastern ASB, can be related to different setting of the same fluvial system, close to the fluvial channel, the first, and referable to distal wide floodplain, the second.

Moving toward the northern slopes of the western ASB, this succession heteropically pass into well-cemented, massive to well-stratified, clast-supported, angular, heterometric calcareous breccias with an abundant pinkish calcareous matrix (Fig. 4.19). These deposits, here renamed *San Marco Formation*, correspond to the *San Marco Breccias* in Messina et al. (2003), characterized by reverse magnetic polarity and referred to the Lower Pleistocene (0,78-1,77 Ma) (Messina et al., 2001). The *San Marco Formation* has thickness generally less than 25 m (50 m in Messina et al., 2001) and was always found in correspondence with the main northern boundary faults, as the Pettino Fault or the Scoppito-Preturo Fault (Fig. 4.19d). These fault systems displace the breccias of the *San Marco Fm.* putting them in contact with the cataclastic bedrock of the footwall. The formation of these deposits can be related to the abundance of clastic material and the high morphological gradient of the basin margins as a consequence of the activity of the fault system. Considering similarities on the lithology, morphology, thickness and stratigraphic relationships with other synthems, also the *Brecce Bisegna* (Bosi & Messina, 1990), the *Brecce di Fonte Vedice* (Bertini & Bosi, 1993) and the *Brecce Mortadella* (Demangeot, 1965; D'Agostino et al., 1997) outcropping in other parts of the L'Aquila Basin, can be related to the *San Marco Fm*.

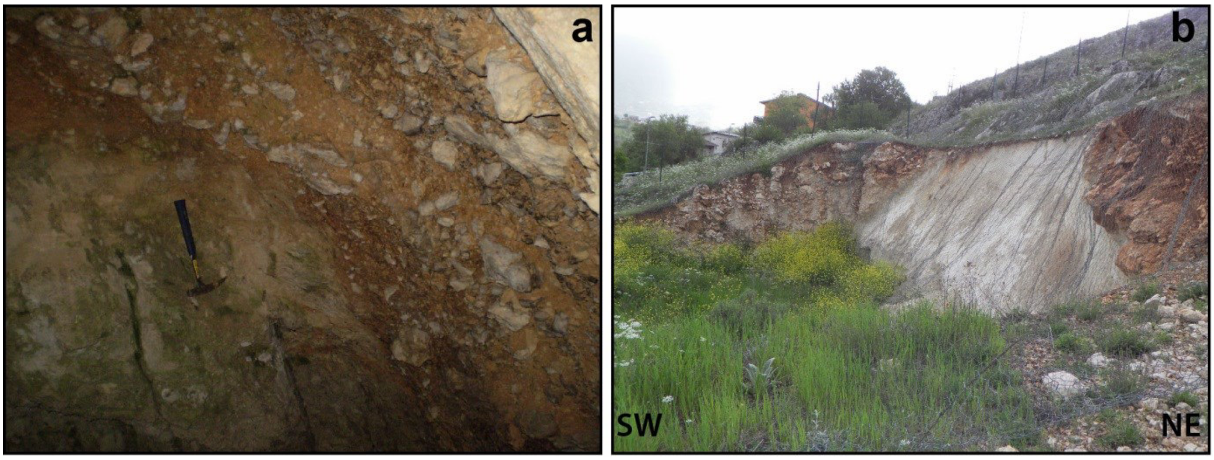


Fig. 4.19 – San Marco Fm. **a**: Angular unconformity between bedrock limestones and calcareous breccias with abundant pinkish matrix (i.e., Cese); **b**: Coarse-grain clast-supported breccias in the hangingwall of the Scoppito-Preturo normal Fault (cataclastic bedrock) (i.e., Cese).

The *Madonna della Strada Synthem* is extensively dissected by several normal fault systems, mainly NW-SE trending, both NE and SW dipping, with offset usually less than 1 m. These faults are generally parallel to the master faults of the ASB, which are the SW/S dipping Pettino and

Scoppito-Preturo faults, to the north, and the NNE dipping Pagliare Fault, to the south. These faults are responsible of the tilting of the deposits, generally about 15°, toward the basin margins. In the southern sectors, the Pagliare Fault is sealed by younger deposits, while the active Pettino Fault cut through the whole basin infilling succession, including the present colluvial deposits of the Pettino Mt. pediment, as also highlighted by seismic profiles interpretation (Fig. 4.17, 4.39). The activity of these faults before and after the deposition of the *Madonna della Strada Synthem* is testified also by the different outcrops elevations and its highly variable thickness, that increase toward the basin margin. Some deep boreholes showed that one of the depocenters of the *Madonna della Strada Synthem* was located close to the southern L'Aquila Hill, where deposits referable to this synthem are generally more than 100 m thick, with a maximum in the Collemaggio3 well, which drilled 215 m of fine-grained deposits referable to alluvial plain environments (*Madonna della Strada Synthem*), without reaching the Meso-Cenozoic bedrock. (Fig. 4.41)

The fine-grained deposits of the *Madonna della Strada Synthem* shows a different freshwater thanatocoenosis respect to the *San Demetrio-Colle Cantaro Synthem* (*Castelnuovo Sub-Synthem*), in particular as regards the ostracod fauna. This was pointed out by the study of the BAR20 section (14 samples) (Fig. 4.16) and other spot localities of the L'Aquila-Scoppito Basin. Apart from sample BAR 20-4A, which yielded a rich and well preserved ostracod assemblage, most of the samples were barren or contained very few valves, often broken, however in some cases attributable to someone of the identified species.

The ostracod assemblage is made of 7 species belonging to 6 genera, and is more diversified than the *San Demetrio-Colle Cantaro Synthem* one. In addition, *Candoninae* forms are not predominant as in the San Nicandro Paleolake. The ostracod assemblages of the *Madonna della Strada Synthem* consist of: *Candona (Neglecandona) neglecta* Sars, 1887, *Pseudocandona marchica* (Hartwig, 1899), *Ilyocypris bradyi* Sars, 1890, *Eucypris dulcifrons* Diebel & Pietrzeniuk, 1969, *Eucypris pigra* (Fischer, 1851), *Potamocypris zschokkei* (Kaufmann, 1900), and *Paralimnocythere messanai* Martens, 1992 (Fig. 4.20). All taxa are represented by both adult and juvenile valves, but the analysis of the population structures carried out on each species showed a prevalence of small larval stages (A-4 and A-5) and very few adult broken valves for *C. (N.) neglecta* and *P. marchica*. According to Whatley (1988) and Boomer et al. (2003), this population structure is typical of fossil allochthonous components of the thanatocoenosis, transported from a nearby high energy environment and deposited in a low energy one. Thus, *C. (N.) neglecta* and *P. marchica* must be considered displaced species transported from nearby, coeval waterbodies.

The remaining species are part of an autochthonous thanatocoenosis in which *Ilyocypris bradyi* dominates (65.9%), followed by *Potamocypris zschokkei* (14.1%), *Eucypris pigra* (8.2%), *Eucypris dulcifrons* and *Paralimnocythere messanai* (5.9% each) (Fig. 4.20) (Cosentino et al., submitted).

C. (*N.*) *neglecta*, *P. marchica*, *I. bradyi*, and *P. zschokkei* are living in the Italian inland waters and in central Europe (Meisch, 2000). *E. pigra* is a typical central European species that occurs only in northern parts of Italy, mainly in Alpine localities (Ghetti and McKenzie, 1981; Rossetti et al., 2006; Pieri et al., 2009, 2015; Stoch et al., 2011). *P. messanai* at present has been recovered with certainty only in Italy and Spain (Martens, 1992; Mezquita et al., 1999), although Martens (1992) supposes that some specimens from Germany identified by Petkovski (1969) as *Paralimnocythere relicta* (Lilljeborg, 1863) could likely belong to *P. messanai*. *E. dulcifrons* is a fossil species recovered up to present only in the Pleistocene cold intervals of Germany, Slovak Republic and United Kingdom (Griffiths, 1995). Its presence in the L'Aquila Basin represents the first recorded occurrence in Italy.

The autoecological characteristics of each species given by Meisch (2000) indicate that the fossil ostracod assemblage recovered in sample BAR 20-4A represents a true autochthonous thanatocoenosis made of oligothermophilic (at least cold stenothermal in the case of *P. zschokkei*), rheophilic and sometimes crenophile species, that inhabit mainly small and shallow permanent or temporary waterbodies. According to Fuhrmann et al. (1997) and Fuhrmann (2012), the fossil *E. dulcifrons* is typical of the cold climate assemblages of the Pleistocene glacial intervals, pointing to the occurrence of cold climate phases during the deposition of the *Madonna della Strada Synthem*.

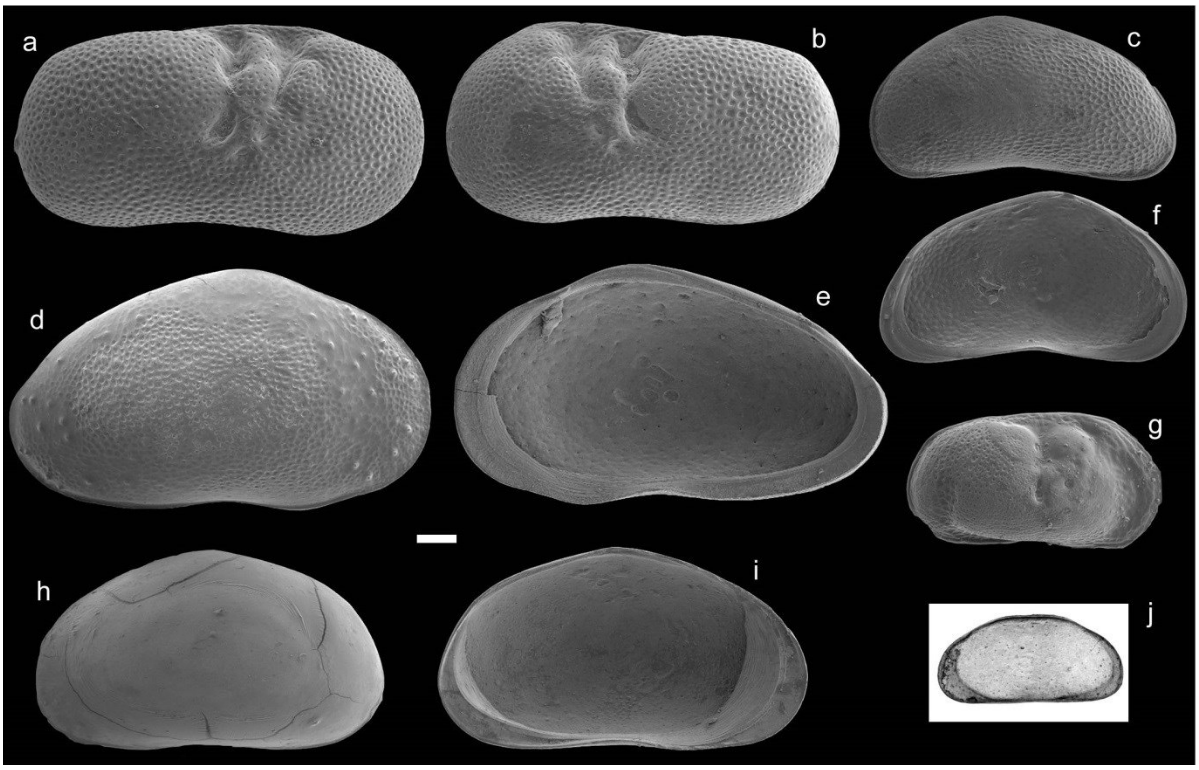


Fig. 4.20 – SEM and transmitted light photos of the ostracod assemblage from sample BAR 20-4A (**a**-**i**) (Madonna della Strada Synthem) and from sample AQ3 (**j**) (Colle Macchione-L'Aquila Synthem). **a**-**b**: *Ilyocypris bradyi* Sars, 1890; **a** right and **b** left valves in lateral outer view; **c**, **f**: *Potamocypris zschokkei* (Kaufmann, 1900); left valve in **c** lateral outer and **f** inner view; **d**, **e**: *Eucypris dulcifrons* Diebel & Pietrzeniuk, 1969; right valve in **d** lateral outer and **e** inner view; **g**: *Paralimnocythere messanai* Martens, 1992; right valve in lateral outer view; **h**, **i**: *Eucypris pigra* (Fischer, 1851); left valve in **h** lateral outer and **i** inner view; **j**: *Mixtacandona stammeri* (Klie, 1938); left valve in lateral outer view (transmitted light). White bar corresponds to 0.1 mm.

Silty and sandy-silty samples (BAR 20-2, 20-4, 20-6, 20-11 and ST41) barren of ostracods, have yielded several very fragmentary specimens of gastropods referable to Family Planorbidae, Lymnaeidae, Bithyniidae, Clausiliidae and Helicidae.

In particular, sample BAR 20-4 is rich in *Planorbis planorbis* (Linnaeus, 1758) and contains also few fragmentary specimens of *Stagnicola* sp. In samples BAR20-6 some fragmentary specimens of terrestrial gastropods, referable to Clausiliidae and Helicidae Family, were recovered. The abundance of *P. planorbis*, characteristic of shallow waterbodies liable to dry up, is indicative of shallow, up to 1 m depth, standing or slowly running well-vegetated freshwaters, with a temperature optimum of 19°C. *Stagnicola* species are also typical of permanent and silent shallow standing waters with rich vegetation (Girod et al., 1980; Welter-Schultes, 2012).

Sample ST41 (42°18'21,832"N, 13°26'33,356"E), collected from a laminated silty sand near Bagno village (i.e., Civita lake), contains an abundant gastropods fauna, characterized by the contemporary presence of the pulmonate *Gyraulus albus* (Müller, 1774) and the prosobranch *Bithynia leachii* (Sheppard, 1823). Both species indicates standing or slow moving waters with depth up to 3 m and dense vegetation (Welter-Schultes, 2012), suggesting the existence, in this portion of the L'Aquila Basin, of a less energetic environment respect to the Scoppito area.

Basing on paleoecological data on ostracods and molluscs, it is possible to infer that, at least, the middle-upper portion of the *Madonna della Strada Synthem* (BAR20 section) was deposited during a cool or cold climate interval in wetland with temporary swamps characterized by slow-moving waters, possibly associated with the seasonal overflow of adjacent streams.

A particular case is represented by the sample ST21 (42°22'12.7"N, 13°16'22.5"E), collected from a whitish calcareous laminated silt, lithologically quite similar to that of the *San Nicandro Fm.*, found in a small outcrop within Collettara village. The recovered ostracod assemblage is composed of a particular thanatocoenosis made of *Candona* sp. and *Ilyocypris* sp. specimens completely different from those collected in all others samples. Even if this faunal association would require a dedicated taxonomic study, currently not yet carried out, the absence of *Caspiocypris* sp., typical of the *San Nicandro Fm.*, together with the presence of two common genera of the *Madonna della Strada Synthem* and other stratigraphical considerations, made possible to refer this deposit to that synthem.

Also boreholes samples belonging to the *Madonna della Strada Synthem* were gathered for micropaleontological studies (Fig. 4.41). Within the 16 samples collected from S4 CERFIS borehole and the 7 samples of cuttings gathered from the Collemaggio3 well-log, between -60 m and -105 m, the larger part were barren and the other contain lots ostracods and gastropods remains partially or totally wrecked, anyway referable to the previous identified thanatocoenosis. As regards the 24 samples from the lower part of PB1 borehole, between -140 m and -179 m, only 4 samples (PB1_8bis; PB1_14bis; PB1_15A; PB1_17bis) contain rare and fragmentary ostracods remains. Apart from PB1_17bis, that contains only young valves of the genus *Candona*, all the other samples contain relatively abundant, but often shattered, adult specimens of *Ilyocypris bradyi* Sars, 1890, together with young valves of Candona sp. and, as in PB1_15A, very few valves referable to genus *Pseudocandona* and *Eucypris* (cf. Fig. 4.20). Even if scanty and bad preserved, these ostracod assemblages present, more or less, the same faunal association of the *Madonna della Strada Synthem*. Thus, considering also the complete absence of the typical *San Demetrio-Colle Cantaro Synthem Caspiocypris* species, coupled with their lithological characteristics, the analyzed well-log stratigraphies were referred to the *Madonna della Strada Synthem*.

As stated before, the BAR20 section contains also some large mammal remains, essential to constrain the age of the *Madonna della Strada Synthem* (Fig. 4.16). Those remains were studied by Prof. Kotsakis at Roma Tre University. These remains of fossil vertebrates consist of a horse molar, a fragment of a maxillary bone bearing two molars of a small deer, the proximal part of the radius of a large deer and part of the diaphysis of a long bone of a medium/small-sized mammal (Fig. 4.21). All the material will be stored at the *Soprintendenza per i Beni Archeologici dell'Abruzzo*, Chieti.

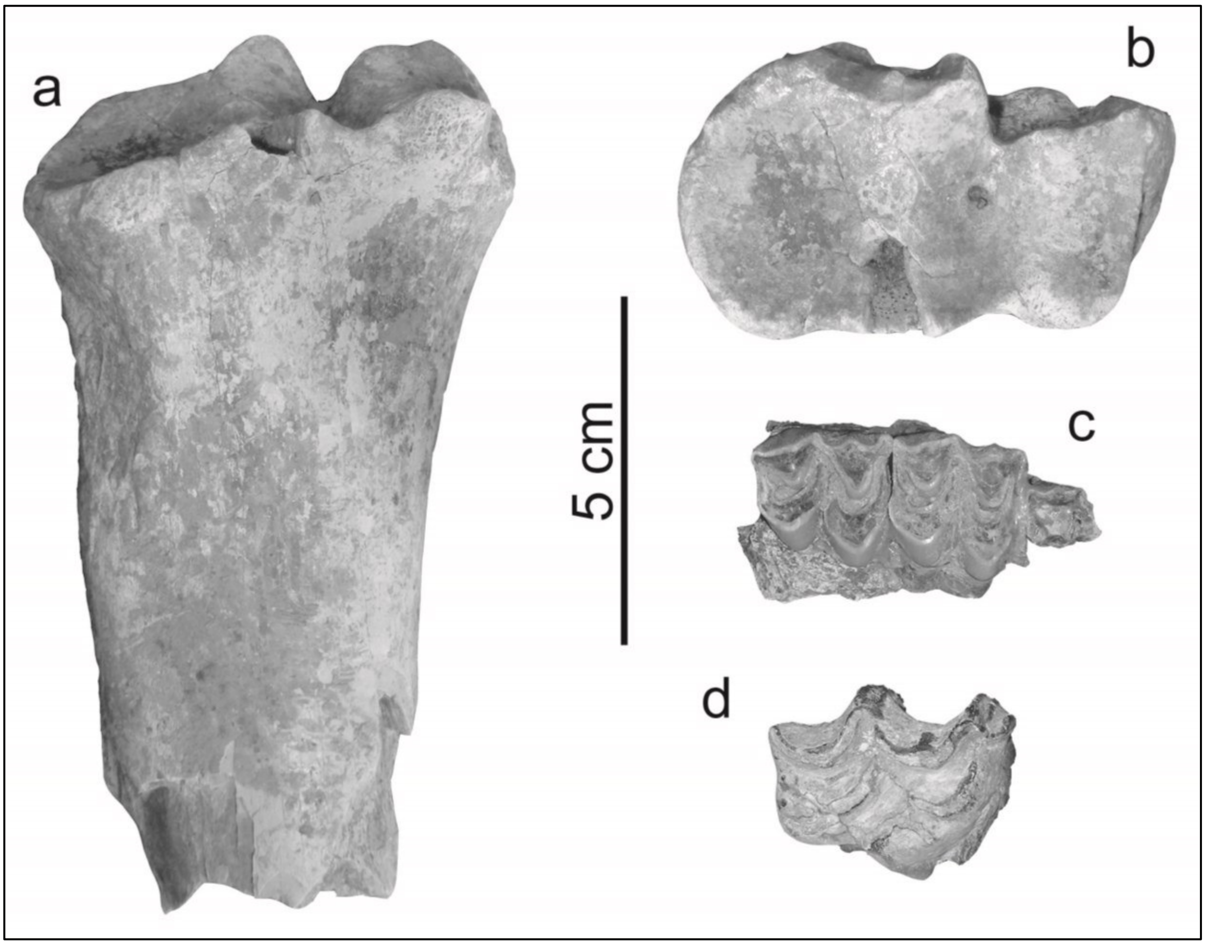


Fig. 4.21 – Large mammal remains recovered within the Madonna della Strada Synthem at BAR20 section. **a**: cfr. *Praemegaceros obscurus* vel *Arvernoceros giulii*, radius sin., proximal fragment, anterior view; **b**: the same, proximal articular face view; **c**: *"Axis" eurygonos*, M1, M2 and a small fragment of M3, fragment of maxillary sin. (the teeth are slightly displaced); **d**: *Equus* sp., M3 sin.

The small-sized cervid classified as *"Axis" eurygonos* covers a long time span from the Farneta Faunal Unit (FU) to the end of the Galerian Mammal Age (Mancini et al., 2012). If we accept the affinity of our equid remains with *E. suessenbornensis*, we can indicate for this species a time span starting from the Pirro Nord FU (and possibly from the Farneta FU) to the Isernia FU (Alberdi & Palombo, 2013). For the large-sized cervid, two very similar chronological distributions are possible: if we accept the attribution to *Arvernoceros giulii*, we observe that the species (and the genus) is reported only from two Italian localities (Selvella and Santarelli quarry) assigned to Farneta FU and Pirro Nord FU respectively (Petronio & Pandolfi, 2011), while it is also present in sites of more recent age in Germany and France(?) (Kahlke, 1997; Croitor, 2006a, 2009). If, on the contrary, we accept an attribution to *Praemegaceros obscurus,* in the Italian peninsula the species spans from Farneta FU to Pirro Nord FU (Abbazzi, 2004; Croitor 2012), while Croitor (2006b) reports a time span from 1.4 Ma to 1.2/1.0 Ma for the total chronological distribution of the species in Europe and the Near East.

From a palaeontological point of view, the small assemblage from the BAR20 section (with the addition of *M. meridionalis*, Agostini et al., 2012) corresponds to the Pirro Nord FU, although a slightly younger age (still older than Colle Curti FU) cannot be ruled out.

Concerning the age of the *Madonna della Strada Synthem,* according to Magri et al. (2010), although the mammalian fauna from the Santarelli quarry points to the latest Villafranchian Farneta or Pirro faunal units () (ca. 1.5-1.3 Ma, Gliozzi et al., 1997), the abundance of *Tsuga*, the high percentages of *Carya*, and the absence of *Liquidambar* from the pollen diagram of the Santarelli quarry point to a younger Early Pleistocene age, which could be ca. 1.3 Ma [disappearance of *Liquidambar* (Magri et al., 2010)] or even younger than the Jaramillo subchron (1.07 Ma) (*Tsuga* and *Carya* abundance). However, some uncertainties for the age of the Santarelli quarry site arise from: (1) uncertainties for the exact age of extinction of *Liquidambar* in Italy (Magri et al., 2010); (2) the possibility that *Liquidambar* might not be well represented in pollen diagrams because it is a low pollen producer (Magri et al., 2010); and (3) the ill defined chronostratigraphy of the Early Pleistocene pollen diagram of the Leonessa Basin (Ricciardi, 1965), which records the disappearance of *Liquidambar* from central Italy.

More recently, based mainly on unreliable stratigraphic correlations with the Santarelli quarry, the mammalian fauna from the industrial area of Campo di Pile was dubiously referred to the late Early Pleistocene Colle Curti Faunal Unit (Agostini et al., 2012), extending the age of the *Madonna della Strada Synthem* up to the uppermost part of the Lower Pleistocene (1.1-0.9 Ma). In contrast, the analysis by Prof. Kotsakis on our new mammalian remains collected from the industrial area of Campo di Pile (BAR20 section, the same fossil site of Agostini et al., 2012) suggest an age referable to the Pirro FU, or slightly younger, but definitely older than the Colle Curti FU.

Summing up, the complete absence in the *Madonna della Strada Synthem* ostracod assemblages of the *Caspiocypris* species typical of the previous late Piacentian-Gelasian synthem (*San Demetrio-Colle Cantaro Synthem*), the reverse magnetic polarity of its deposits, as reported in Messina et al. (2001) and in the preliminary analyses carried out by the IGAG-CNR (Dr. Scardia) on samples belonging to the lower part of the S1 and S4 boreholes, the mammal assemblages from the middle-upper part of the *Madonna della Strada Synthem*, which belong to the Pirro FU, constrain this synthem to the lower and middle part of the Calabrian, or in any case to an Early Pleistocene age older than 1.0-1.2 Ma.

4.3.3 Fosso di Genzano Synthem

Due to their lithological, sedimentological, paleontological, geomorphological and geochronological affinities, deposits previously referred in the PSC Basin to the *Catignano Synthem* (Centamore et al., 2006), corresponding to the *San Mauro* and *San Giovanni* cycle in Bertini & Bosi (1993) and to the *Upper PSC Synthem* by Giaccio et al. (2012), were grouped together into the *Fosso di Genzano Synthem* (Centamore & Dramis, 2010) (see section 2.3). Thus, in his new acceptation, the ***Fosso di Genzano Synthem*** is the first synthem outcropping both in the ASB and PSC Basin.

In the ASB, it lies above a flat erosional surface carved into both the *Madonna della Strada Synthem* and the Meso-Cenozoic substratum; on the contrary, in the PSC Basin it is deeply embedded into the *San Demetrio-Colle Cantaro Synthem*. According to Galli et al. (2010) and Giaccio et al. (2012), in the PSC Basin a reddish paleosol marks the unconformity between the two synthems.

Its upper boundary, when preserved, is represented by quite well developed sub-horizontal, or gently dipping toward the basin floor, surfaces, usually lying at about 40 m above the present day base level, at elevations ranging between 580 m and 770 m a.s.l. Remnants of its top surface standing at higher or lower elevations are related to post-depositional fault activity.

The *Fosso di Genzano Synthem* is characterized by sub-horizontal bedding, showing tilted deposits, usually less than 10°, only if deformed by faults activity, like in the Paganica or Civitatomassa areas (Fig. 4.22e), where they are cut by NW-SE and N-S trending normal and transtensive faults, respectively (e.g., Paganica Fault, Raio Fault).

Well exposed successions belonging to the *Fosso di Genzano Synthem* outcrop in the southern sectors of the ASB, i.e. at Civitatomassa, Pagliare di Sassa and on the western slope of the Genzano Creek; while in the PSC Basin the best outcrops are located south of San Demetrio ne' Vestini (i.e., San Mauro cemetery, Il Crocifisso quarry) (Fig. 4.22). Stratigraphic log analysis shows that all the mentioned outcropping successions are characterized, from the bottom, by coarse to medium, well-sorted, sub-rounded, clast-supported, sheet-type gravel beds, with massive or horizontal bedding (Gm, Gh), capped by thin layers and lenses of laminated to massive sandy silts (Fl, Fm) (Fig. 4.22c). These deposits grade upward into medium to fine, well-sorted, well-rounded calcareous gravel beds with a coarse sandy matrix, showing cut and fill structures with planar and through cross-bedding (Gp, Gt) (Fig. 4.22a, e), interlayered with coarse to fine, planar and through cross-stratified, fining upward yellowish sandy bedform (Sp, St) (Fig. 4.22b). Clasts are mainly limestones, both from platform and basinal successions, with rare sandstones in the lower part of the northern successions (i.e., ASB). These lithofacies belong to gravel-bed braided, sometimes wandering, fluvial systems associated with lateral alluvial fan systems, as testified by paleocurrents analyses showing eastward and northward trending respectively.

Laterally and vertically, the coarse deposits heteropically pass into well-stratified, fining upward overbank sediments, formed by yellowish-greyish coarse to fine sand beds, up to 2 m thick, with planar and, subordinately, ripples or through cross-stratifications (Sp, Sr, St), alternating with laminated grey silt and clayey silt beds (Fl), usually 0.2-0.4 m thick, rarely containing very small-scale ripples or undulating bedding.

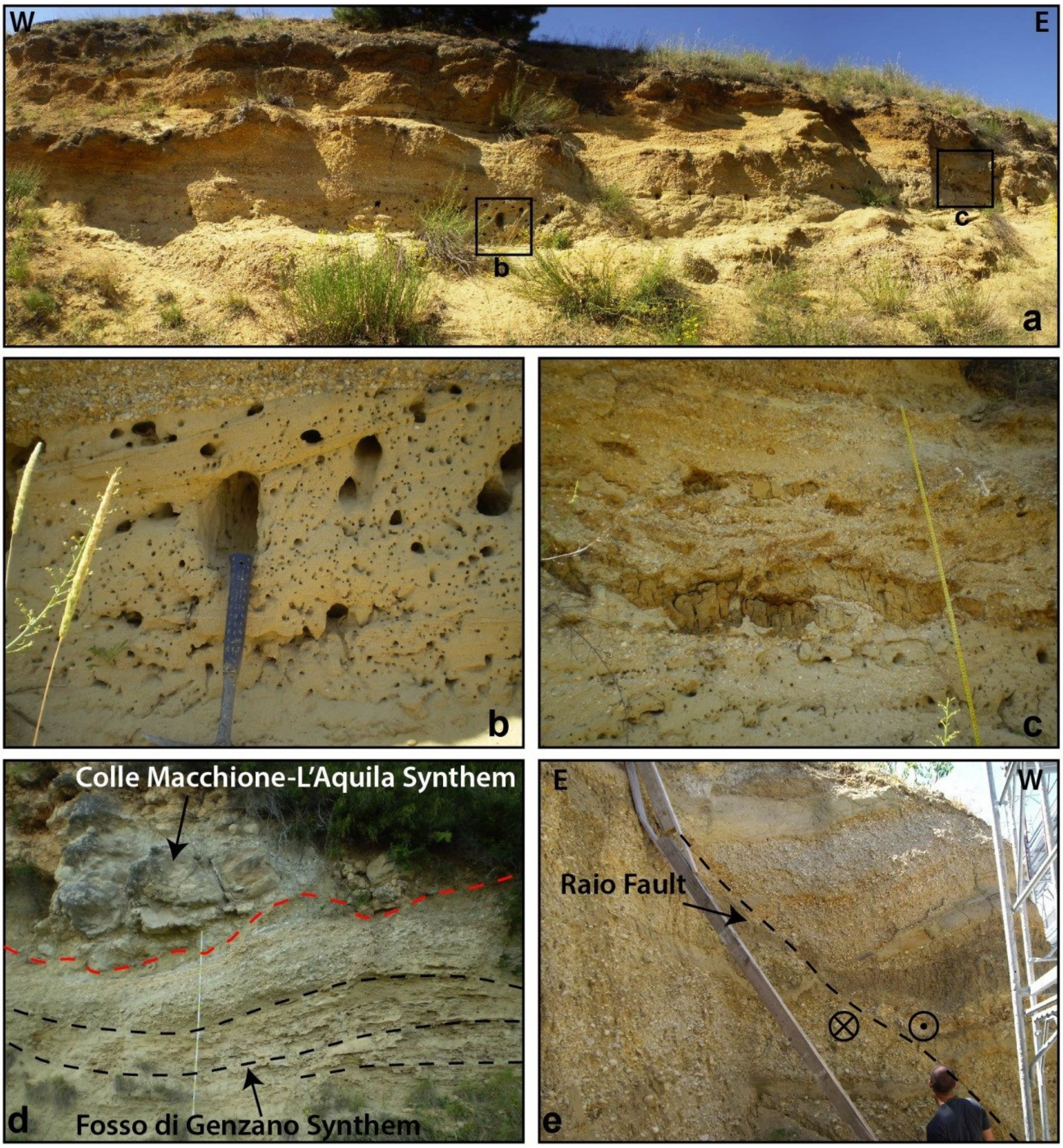


Fig. 4.22 – Fosso di Genzano Synthem. **a**: Panoramic view of the alternating gravel and sand beds of the Fosso di Genzano Synthem (i.e., Il Crocifisso quarry); **b**: particular of a trough-cross stratified coarse sand layer; **c**: massive sandy silt of an abandonment channel fill; **d**: deformed sandy and gravelly layers of the Fosso di Genzano Synthem below the unconformity with the Colle Macchione L'Aquila Synthem (i.e., Colle Macchione); **e**: alternation of gravel beds with silty and sandy level, displaced by the N-S trending transtensive Raio Fault. OSL sample LV555 comes from the sand layer at the top of the outcrop (i.e., Civitatomassa).

The fine fraction of the *Fosso di Genzano Synthem* is mainly composed by quartz and muscovite, belonging to the Miocene flysch deposits, but it contains also large amount of biotite, pyroxene, feldspar, and very small pumices, of volcanic origin. Indeed, as reported in section 2.3, several K-alkaline tephra layers are present within this synthem, both in ASB and PSC Basin, helping to constrain its age and to correlate its deposits across the basin.

Plant roots, oxidized surfaces, pedogenic horizons, as well as pedogenic nodules, mainly calcareous, are present in the whole synthem, more abundantly in its upper portion, testifying local pedogenic processes during the *Fosso di Genzano Synthem* deposition.

Particularly important for the stratigraphic reconstruction of the AB are the sediments outcropping close to the top of the Colle Macchione ridge, at about 720 m a.s.l., approximately the same elevation of the Pagliare di Sassa and Civitatomassa successions. In this location a succession, less than 10 m thick, made of laminated sandy silts and clayey silts (Fl) grading upward into fine to coarse-grained cross-stratified sands (Sp), with intercalated thin beds of well-rounded fine gravels, was observed (Fig. 4.22d, 4.23, 4.25a). It unconformably overlies the Miocene flysch deposits and its upper portion is strongly eroded and deformed by the succeeding synthem (*Colle Macchione-L'Aquila Synthem*) (Fig. 4.22d).

According to stratigraphical, paleontological, and geomorphological considerations, this succession pertains to distal alluvial fan or floodplain deposits referable to the *Fosso di Genzano Synthem*. Similar conditions were also observed at the base of the L'Aquila Hill southern slope, were small and thin lenses of sediments related to the *Fosso di Genzano Synthem* have been found between the older *Madonna della Strada Synthem* and the younger *Colle Macchione-L'Aquila Synthem*.

Due to tectonic activity and to the presence of erosive surfaces bounding this synthem, its thickness greatly changes within the AB, showing a medium thickness of ca. 30 m (i.e., Pagliare di Sassa) and a maximum thickness between 50 m and 60 m at Civitatomassa and Villa S. Angelo.

Several samples collected for micropaleontological analyses from silty-sandy deposits of the *Fosso di Genzano Synhem* were barren and only few yielded poor or wrecked ostracod and gastropod remains. The only recovered ostracod specimens come from sample ST88.2 (42°20'27.625"N, 13°18'59.015"E) and, to a lesser extent, from sample ST19.3 (42°16'3.791"N, 13°33'19.121"E). The ostracod assemblage is made almost entirely by adult specimens of *Ilyocypris bradyi* Sars, 1890, with a rare occurrence of young and fragmentary specimens attributable to the genus *Candona*.

Very fragmentary gastropods remains, identifiable only to the genus order, where recovered from some silty-clayey and sandy-silty samples [ST16.1, ST16.3 (Fig. 4.23); ST20.4 (42°21'23.708"N, 13°16'34.305"E); ST88.1, ST88.2 and ST88.4 (42°20'27.625"N, 13°18'59.015"E)] collected in different localities of the basin. Remnants of *Planorbis* and *Bythinia*, testifying the existence of standing waters in overbank areas, are present in all the ST88 and ST16 samples. Instead, sample

ST20.4 shows the occurrence of the genus *Carychium* and *Pupilla*, characteristics of riverside and sand dune deposits in a wet and warm habitat, confirming the presence of a fluvial channel close to Civitatomassa village, as suggested by facies analysis.

The presence of *Ilyocypris bradyi*, typical of slow flowing water (>1cm/s), together with the information provided by gastropods, confirm the existence of floodplain areas related to fluvial and alluvial fan systems overflows.

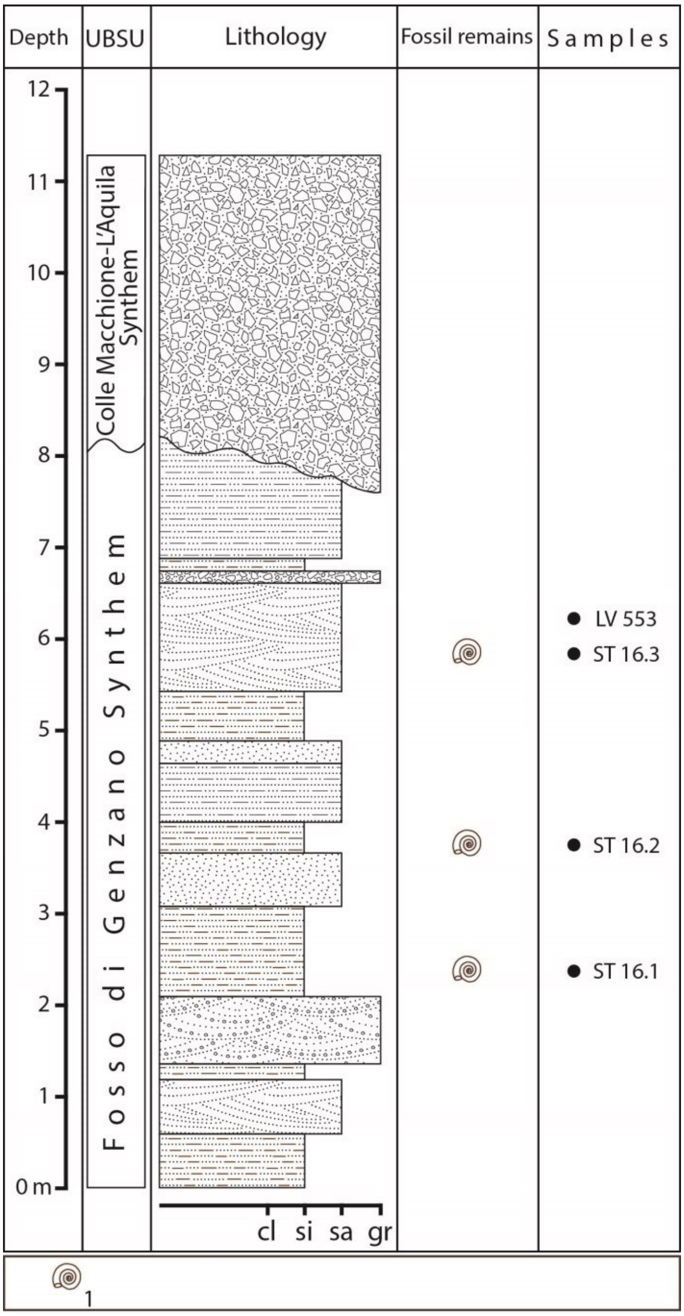


Fig. 4.23 – Stratigraphic log of the Colle Macchione section (42° 21' 44.1" N, 13° 20' 1.7" E), with location of samples for paleontological studies.
LV 553 is a sample for OSL dating.

Within the sandy and silty deposits of the *Fosso di Genzano Synthem* large and small mammal remains were reported, both in the ASB and PSC Basin, such as the *Elephas (Palaeoloxodon) antiquus* founded by Maini (1956) at S. Eusanio Forconese or the mammal assemblage recovered within the basal portion of this synthem at Pagliare di Sassa. The second one is referred by Palombo et al. (2010) to early-middle Galerian faunas, earlier than the *Isernia La Pineta FU* (0.7 Ma; early Middle Pleistocene).

According to Palombo et al. (2010), paleomagnetic data from the Pagliare di Sassa succession support continuous deposition from the late Early to the early Middle Pleistocene. Taking into account the succession drilled at Pagliare di Sassa (Palombo et al., 2010), together with the sequence of unconformity-bounded stratigraphic units recognized within the ASB filling (Centamore & Dramis, 2010; Mancini et al., 2012; Cosentino et al., submitted), this conclusion is open to challenge. Possibly, the marshy sediments of the Pagliare di Sassa core (Palombo et al., 2010), drilled between -30 to -24.5 m, could be referred to the *Madonna della Strada Synthem*, and the oxidized surface at -24.5 (i.e., the exposure surface in Palombo et al., 2010) could correspond to the erosional surface of the unconformable boundary between the *Madonna della Strada Synthem* and the *Fosso di Genzano Synthem* in the ASB and to the PAG-ES/PAG6-Pedomarker described by Galli et al. (2010) between the *Fosso di Genzano Synthem* and the *San Demetrio-Colle Cantaro Synthem* in the PSC Basin.

Sediments belonging to the *Fosso di Genzano Synthem* were sampled for OSL dating, even if its inferred age was close or above the method limit.

LV553 was collected from a planar cross-stratified coarse to medium sand (Sp) ripple cross-laminated sand (Sr) of a sandy bedform outcropping close to the Colle Macchione ridge top (Fig. 4.23, 4.25a). Coarse grain size, abundant micas and feldspars characterize this sample. A few quantity of 200-300 μm quartz grains was extracted, but after HF attack most of them were destroyed, probably due to the presence of fractures inside quartz grains. Initial test on 1mm aliquots revealed also poor OSL properties and the presence of feldspar contamination, so that sample was discarded.

Sample **LV555** came from a planar cross-bedded sand (Sp) of a transverse bar at the top of the alluvial fan/fluvial sequence exposed around Civitatomassa village (42°21'23.704"N, 13°16'34.377"E) (Fig. 4.22e). The sample presents an homogeneous grain size, 80% between 200-300 μm, and contains high percentage of quartz grains, but also feldspar, heavy minerals and micas are present. Saturated signals, feldspars contamination or OSL-insensitive quartz grains were observed during initial test on 8 aliquots of 3mm size and no aliquot was accepted (Fig. 4.24).

Considering both the chronological constraints from mammals remains and the normal polarity of the Pagliare di Sassa succession (Palombo et al., 2010), the $^{39}Ar/^{40}Ar$ dating of the ash layers from Sella di Corno (520 ± 5 ka) (Gaeta et al., 2010) and the ages suggested by Galli et al. (2010) for PAG-t1 (561 ±2 ka) and PAG-t4 (365 ± 4 ka) tephra layers, the *Fosso di Genzano Synthem* can be referred to the lower Middle Pleistocene (early Ionian).

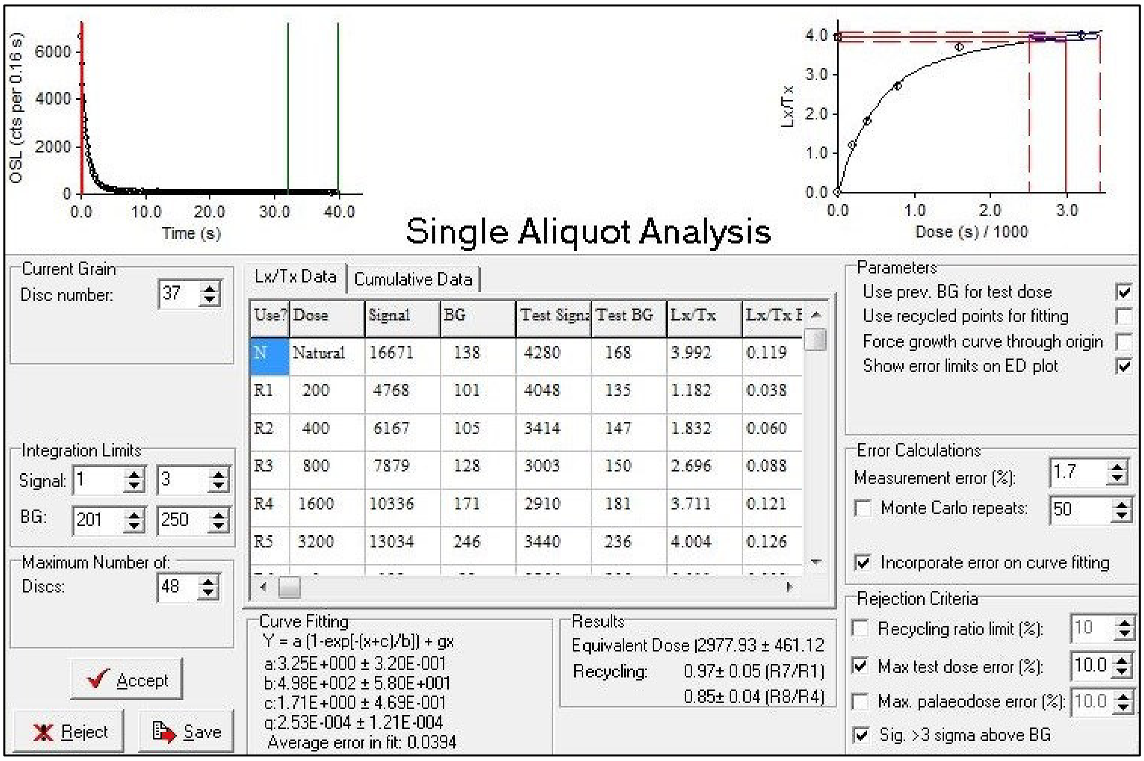


Fig. 4.24 – Single analysis of aliquot 37 of sample LV555 showing bright signal (left plot), poor IR/OSL depletion ratios (R8/R4 value below 1.0±0.1) and dose in saturation (right plot) evidencing feldspars contamination.

4.3.4 Colle Macchione-L'Aquila Synthem

In the central part of the L'Aquila Basin, the ***Colle Macchione-L'Aquila Synthem*** unconformably overlies either the older Quaternary synthems or the Mesozoic and Tertiary substratum. The deposits of this synthem outcrop at the top of the Colle Macchione ridge, to the north; form the L'Aquila hill elongating for 13 km to the NE, from L'Aquila city to the Assergi Plain; finally, to the southern margin of the AB, they are present as small isolated remnants at the foothills of the Ocre Mts. around Pianola.

It comprises deposits previously referred to the *Brecce dell'Aquila Auct.*, the *Mégabrèches (conglomérats "cataclastiques")* (Demangeot, 1965), the *Colle Cantaro-Cave Synthem* (Centamore & Dramis, 2010) and to the upper part of the *Aielli-Pescina Synthem* (Centamore et al., 2006).

The *Colle Macchione-L'Aquila Synthem* consists of breccias and megabreccias, with highly heterometric (from cm to m), poorly sorted carbonate blocks that are mostly angular to sub-angular in shape, in a whitish-yellowish calcareous sandy silty matrix (Fig. 4.25). These carbonate breccias show different textures and sedimentological characteristics. They can be characterized as clast-supported to matrix-supported breccias, usually massive but sometimes also stratified, both well cemented and incoherent (Fig. 4.25). Cementation is related to secondary processes (i.e. weathering), leading to the formation of a well cemented crust on the exposed surfaces of that synthem, while in fresh outcrops it is often incoherent. The clasts lithology changes through the basin, testifying different source areas. The breccias outcropping at the top of the Colle Macchione ridge are formed exclusively by Mesozoic carbonate cataclastic rocks, derived from the active extensional fault zone at the base of the southern slope of Pettino Mt., while around Pianola clasts are made of grainstones and calcarenites belonging to the Cenozoic carbonate-ramp/open-platform succession of the Ocre Mts. The breccia deposits from L'Aquila city hill are mainly composed by limestones, with rare cherts, belonging to Mesozoic-Tertiary slope-to-basin transitional facies, suggesting, coupled with the presence of similar deposits all along the northwestern slope of the Raiale Valley up to the Assergi Plain, the southern slope of the Gran Sasso Chain as possible source area.

At the eastern and southern margin of L'Aquila city, whitish to greyish calcareous clayey silts levels and lenses are interlayered, at different elevations, with the carbonate breccias of this synthem, testifying the presence of standing water within the basin (Fig. 4.25c). Carbonate silt deposits contain a monospecific ostracod fauna consisting of *Mixtacandona stammeri* (Klie, 1938) [sample AQ3 (42°20'40,607"N, 13°25'6,753"E); Fig. 4.20j], which is an hyporeic species and it is typical of interstitial waters living at depth, far from the influence of surface waters and sources of organic matter (Rogulj et al., 1994). Also some gastropods remains were collected from a clayey lens within the breccias. Their bad conservation status, probably due to the stress induced by load and depositional mechanism, allowed only to refer them to terrestrial pulmonate gastropods, belonging to the Helicidae family typical of open woodlands habitats.

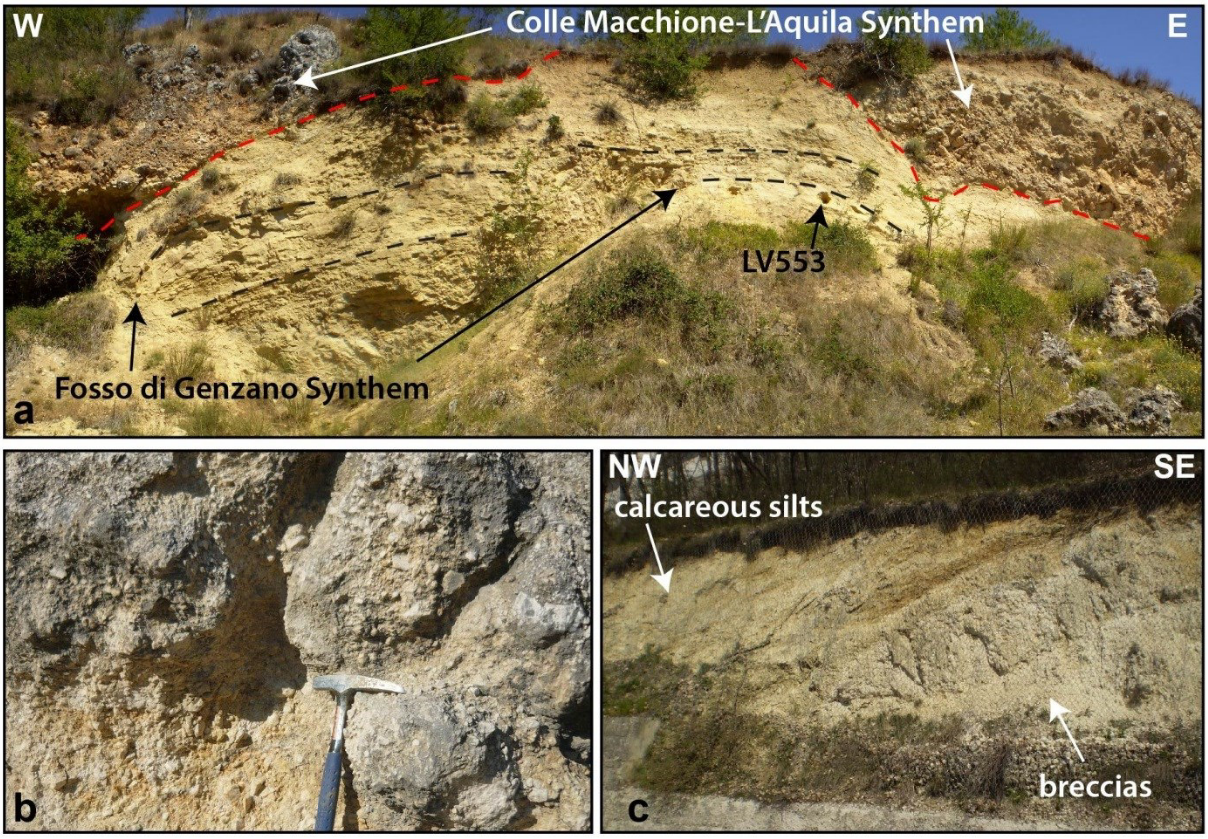


Fig. 4.25 – **a**: Scoop-shaped basal unconformity of the Colle Macchione-L'Aquila Synthem above the deformed deposits of the Fosso di Genzano Synthem (i.e., Colle Macchione, Fig. 4.23); **b**: Poorly-sorted, clast-supported massive breccia; **c**: Calcareous clayey silt level interlayered within stratified carbonate breccias (i.e. L'Aquila city).

In the L'Aquila hill area reddish to dark brown clayey silts deposits with sparse sub-angular small clasts, mainly limestones and cherts (*Terre rosse Auct.*), are present at different levels in the upper part of the *Colle Macchione-L'Aquila Synthem*, as karst conduit (pipe) filling deposits or as colluvium on the top surface of this synthem. These sediments show thickness up to 20 m and are generally interpreted as paleosol (Alfisol) formed onto the breccias in a wet and warm interglacial stage (Last Interglacial, Eemian, MIS 5e).

The base of that synthem is highly irregular and erosive, characterized by scooped or channelized surfaces deeply embedded into the older sediments (Fig. 4.25a). These sediments are eroded and deformed by the arrival of the breccias, as testified by the folding of the bedding following the shape of the channels and by the presence, in the first meters of the synthem, of sandy clasts ripped up by the underlying deposits. These conditions are clearly visible at the top of Colle Macchione ridge, where the *Colle Macchione-L'Aquila Synthem* unconformably overlies deformed fine- to coarse-grained cross-stratified sands and laminated sandy silts, with intercalated thin layers of well rounded, fine gravels pertaining to the *Fosso di Genzano Synthem* (Fig. 4.23, 4.24, 4.25a). The same characteristics are visible also at the base of the southern slope of the L'Aquila hill and on the opposite slope close to Malepasso locality, where the breccias unconformably overlies both the *Madonna della Strada Synthem* and thin remnants of the *Fosso di Genzano Synthem*.

The irregularity of its base, the depositional mechanism and the presence of younger erosive surfaces, directly reflects into thickness changes, from few meters in the Colle Macchione ridge and Pianola areas, to a medium thickness of ca. 40-50 m in the L'Aquila hill area, and a maximum thickness up to 72 m (S2_CERFIS borehole by Amoroso et al., 2010) in the city center.

The age of the *Colle Macchione-L'Aquila Synthem* is not well constrained, although the breccias are generally referred to a Middle Pleistocene age (Demangeot, 1965; Bosi et al., 2003). A possible late Middle Pleistocene age is supported by the stratigraphy of the Colle Macchione ridge, where it overlies the *Fosso di Genzano Synthem*, and the age of the overlying alluvial deposits of the *Fosso Vetoio Synthem*, as visible in the area of San Salvatore Hospital and in the S17 borehole stratigraphy (Fig. 4.44). For these reasons the *Colle Macchione-L'Aquila Synthem* should be younger than the early Middle Pleistocene (*Fosso di Genzano Synthem*) and older than the early Late Pleistocene (*Fosso Vetoio Synthem*), that is late Middle Pleistocene. As reported before, the paleosol and karst deposits in the upper part of the *Colle Macchione-L'Aquila Synthem* could be related to the Eemian interglacial stage (MIS 5e), thus the glacial event responsible for the formation of the huge amount of heterometric clastic deposits of this synthem could possibly correspond to MIS 6 or MIS 8.

The exposed sedimentological and lithological characteristics of the breccias of the *Colle Macchione-L'Aquila Synthem* point to debris-flow and rock avalanche processes, maybe triggered by seismic events (Demangeot, 1965), derived from the slopes of the mountain chains surrounding the L'Aquila Basin and deposited in a fluvio-lacustrine environment.

4.3.5 Fosso Vetoio Synthem

As testified by the presence of the ***Fosso Vetoio Synthem*****,** after the deposition of the huge clastic deposits of the *Colle Macchione-L'Aquila Synthem*, a fluvial environment established in the AB. It partly corresponds to the *Catignano Synthem* (Centamore et al., 2010) and to the *Fosso Vetoio alluvial terraced deposits* (Gruppo di Lavoro MS–AQ 2010), comprising also sediments previously referred to the upper part of the *Aielli-Pescina Synthem* (Centamore et al., 2006), the *Valle Majelama Synthem* (Centamore et al., 2006; Centamore et al., 2010), the *E sequence* in Blumetti et al. (1996) and the *UA 12* of Messina et al. (2003).

This synthem forms the first order of Late Pleistocene fluvial terrace (T1) very well preserved in the ASB, while in the PSC Basin it is represented by small isolated remnants, with few or absent deposits, that were related to this synthem only by geomorphological constrains.

In the ASB, its base is carved into both the *Colle Macchione-L'Aquila Synthem* and the *Madonna della Strada Synthem* and, locally, continues laterally on the bedrock. In this sector, well preserved alluvial terraces are present in the area of the L'Aquila hospital and of the airport, lying at an elevation between 685-645 m a.s.l., and showing an abandonment surface approximately 20-25 m above the present Aterno thalweg (Fig. 4.26c).

In the PSC Basin, the *Fosso Vetoio Synthem* is restricted in between the villages of S. Eusanio Forconese, to the N, and Villa S. Angelo, to the S. At S. Eusanio Forconese it is embedded into both the carbonate bedrock and the *Fosso di Genzano Synthem* and it is formed by coarse deposits less than 9 m thick (S87 in Fig. 4.45), while around Villa S. Angelo the *Fosso Vetoio Synthem* seems to be represented, due also to the difficulties in distinguishing its deposits from the older or younger ones, only by an erosive surface, carved exclusively onto the *Fosso di Genzano Synthem*. In both localities flat sub-horizontal surfaces, interpreted as depositional or erosive fluvial terraces, are preserved at elevations between 600-590 m a.s.l., ca. 30-40 m above the Aterno thalweg. The higher elevation of the T1 terrace in this part of the AB could be referred to tectonic activity and/or to a local deepening of the present base level.

The *Fosso Vetoio Synthem* is made, from the bottom, by fine to medium, well-sorted, well-rounded, sub-flattened, clast-supported cemented gravel beds, with well-preserved sheet-type channels characterized by trough cross-bedding and, rarely, horizontal bedding (Gt, Gh) (Fig. 4.26b, 4.27). Gravel beds contain an abundant coarse sandy matrix and locally, at the top of gravel beds, yellowish massive silty sandy lenses are present (Fm), representing abandoned channel filling deposits (Fig. 4.26a, 4.27). Pebbles are mainly carbonates, both from basinal or platform successions, sometimes assuming a blackish color due to the presence of Mn oxides. Clasts are usually imbricated, showing a fluvial transport generally toward E/SE, comparable to the present day flow direction. The gravel deposits grade upward into an alternating sequence of rust planar cross-stratified sands and yellow laminated silts (Sp, Fl) (Fig. 4.27), covered by grayish massive coarse sands and silts (Fm), both referable to overbank deposits. These fine sediments are rich in volcanic minerals, especially K-feldspars and pyroxenes, probably related to the Roman Comagmatic Province volcanism, as well as the tephra layer reported by Gruppo di Lavoro MS–AQ (2010) close to the top of that synthem.

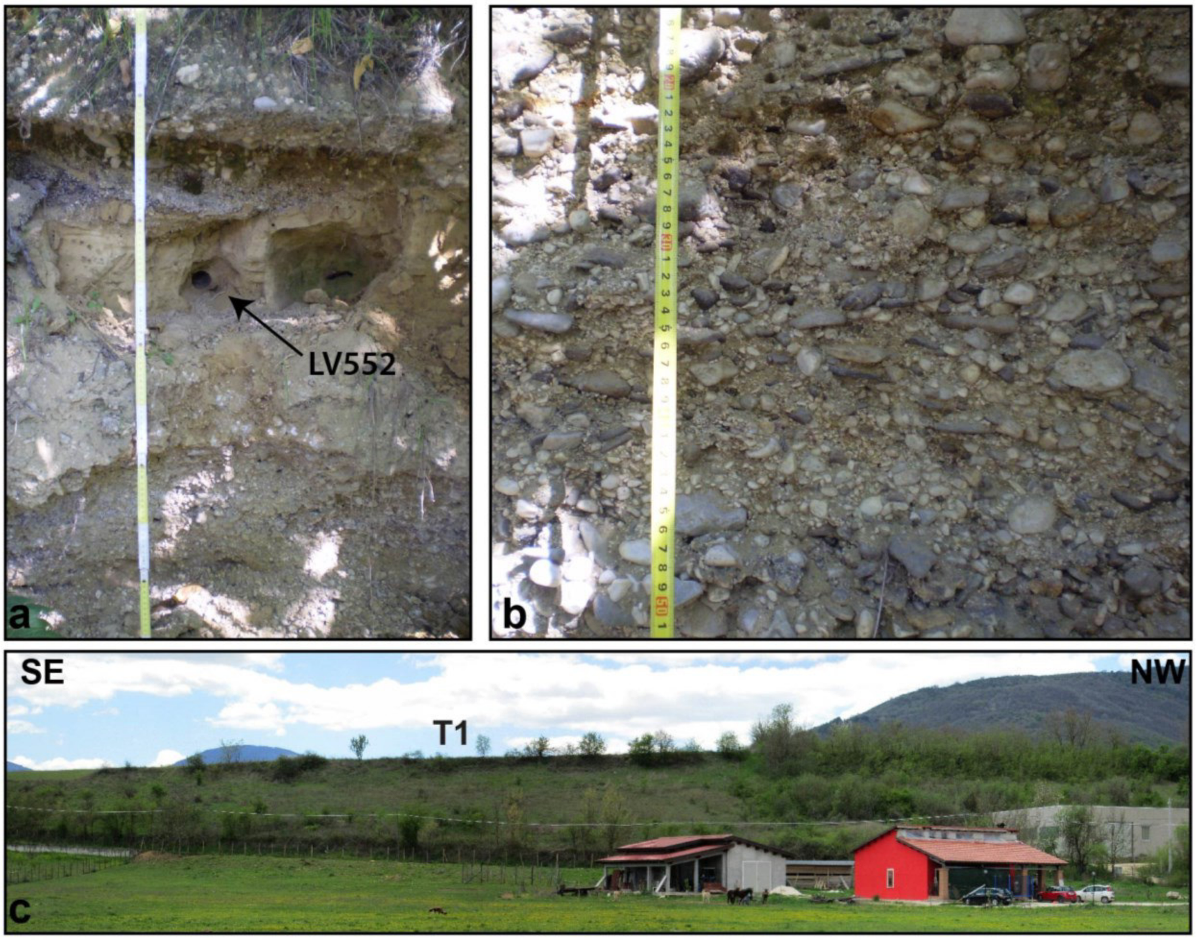


Fig. 4.26 – **a**: Massive silty lens of an abandoned channel fill within the gravels of the Fosso Vetoio Synthem. LV552 is the sample for OSL dating (location of Fig. 4.27); **b**: Detail of the well-sorted, clast-supported, trough-cross bedded gravels (location of Fig. 4.27); **c**: Panoramic view of the top surface of the Fosso Vetoio Synthem defining the first order fluvial terrace (i.e. L'Aquila airport).

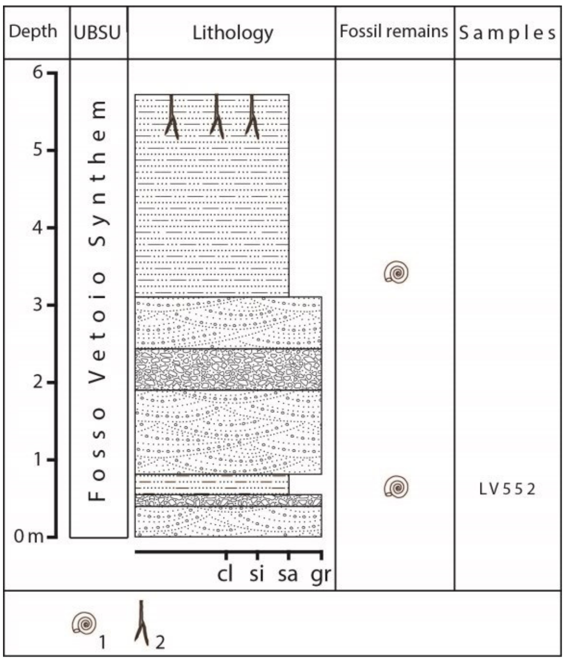


Fig. 4.27 – Stratigraphic log of the Fosso Vetoio Synthem (42°21'36.7"N, 13°21'58.9"E), with location of sample LV 552 for OSL dating.
1 – molluscs;
2 – root trace.

Samples collected from sandy silty lenses and layers were barren of ostracods and rarely contained few gastropod remains, referable to *Planorbis planorbis* (Linnaeus, 1758) and to Helicidae family (Fig. 4.27).

According to the described lithofacies, the *Fosso Vetoio Synthem* belongs to a braided fluvial system and relative floodplain flowing through the whole AB (PaleoAterno?).

The outcropping thickness of this synthem is generally lesser than 10 m, a maximum thickness of about 20 m can be estimated from S3 borehole (Fig. 4.44), drilled close to the L'Aquila airport.

To establish the age of the *Fosso Vetoio Synthem* sample **LV552** was collected for OSL dating. The sample was gathered from a small massive silty lens (Fm) of an abandoned channel fill, close to the Vetoio Lake (Fig. 4.27). It had a very fine grain size and was characterized by the prevalence of feldspars and heavy minerals relative to quartz, so just a small amount of 100-250 µm quartz grains were extracted. Preliminary tests and 10 De measurements were done on 1mm aliquots. They showed a very bright signal, good recycling ratios and low recuperation percentage, but unfortunately they had an high feldspars contamination and signals were often close to dose-saturation (Fig. 4.28). These problems, coupled with the poor quantity of quartz grains, made useless to continue measurements and led to the impossibility to define any age.

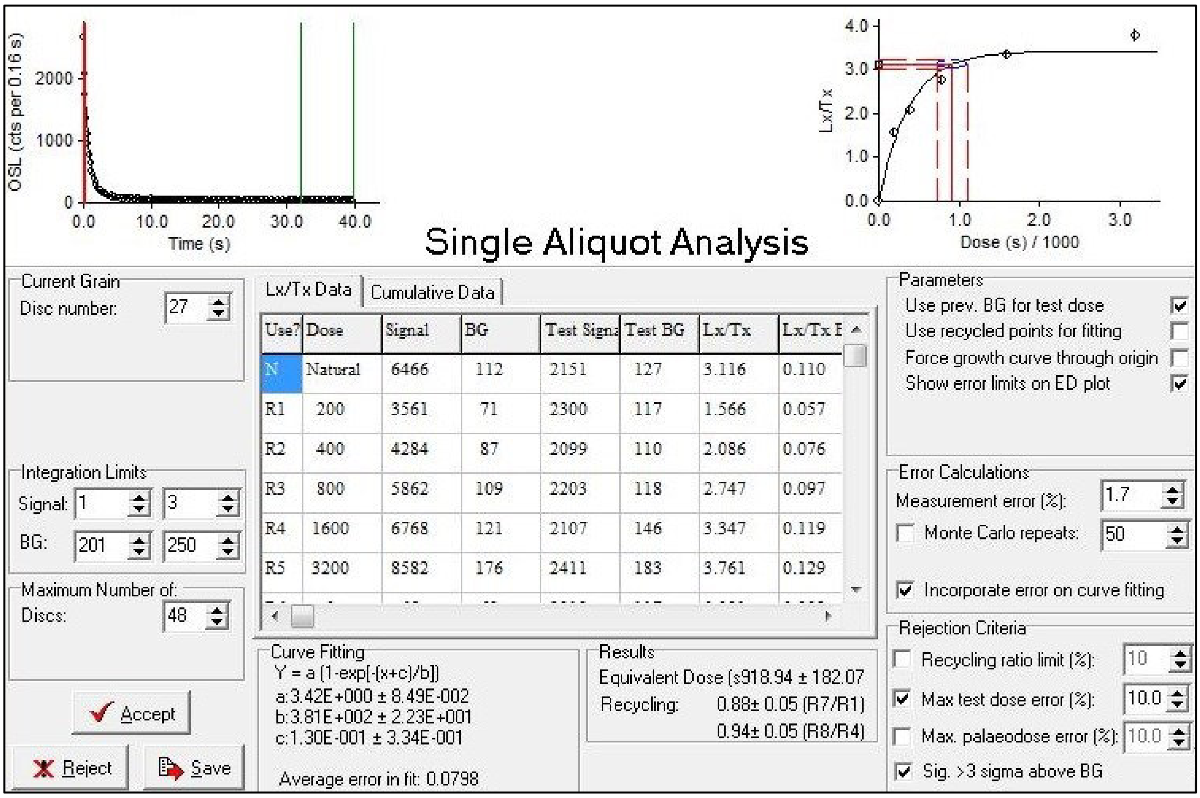


Fig. 4.28 – Single analysis of aliquot 27 of sample LV552 showing bright signal (left plot), poor Recycling Ratio (R7/R1 value below 1.0±0.1) and dose close to saturation (right plot).

In literature the *Fosso Vetoio Synthem* is generally referred to Middle – Late Pleistocene, due to the presence of abundant volcanic minerals and tephra layers (Bosi et al., 2003; Gruppo di Lavoro MS-AQ, 2010). Anyway, considering the late Middle Pleistocene age of the underlying *Colle Macchione-L'Aquila Synthem* and the morpho-stratigraphical relationships with the younger *Campo* *di Pile Synthem*, which is well constrained by ^{14}C dating, an early Late Pleistocene age for the *Fosso Vetoio Synthem* is suggested.

4.3.6 Campo di Pile Synthem

The ***Campo di Pile Synthem*** is the last infilling stage of the L'Aquila Basin referable to geological processes previous to the present day ones. This synthem essentially matches the *Valle Majelama Synthem* (Centamore et al., 2006; Centamore & Dramis, 2010), also comprising deposits previously referred to older CARG synthems as well as the *Paganica 2a Unit* (Galli et al., 2010), the upper part of the *Late PSC Synthem* (Giaccio et al., 2012), the *UA 8* in Messina et al. (2003), the *Barisciano Pedocomplex* and relative deposits (Coltorti & Pieruccini, 2006), the *Pettino Mt. Pediment deposits* (Gruppo di Lavoro MS–AQ 2010), the *Ancient terraced and alluvial fan deposits* of Bosi & Bertini (1970) and the *Ancient alluvial and colluvial deposits* reported in Bertini & Bosi (1993).

It is widespread both in the ASB and PSC Basin, mainly represented by fluvial, alluvial fan and slope-derived (pediment/talus) deposits. This synthem is embedded in the *Fosso Vetoio Synthem* and carved into both the older continental deposits and the pre-Pliocene bedrock.

Slope-derived deposits (*éboulis ordonnées*), belonging to the *Campo di Pile Synthem*, outcrops on the margins of the AB, both at the foot of the slopes and suspended at higher elevations. These sediments form the Pettino Mt. pediment, where they are interlayered with small and proximal alluvial fan facies, as well as they characterize the northern slopes of the Ocre Mts. and the base of the reliefs between Barisciano, San Pio delle Camere, and Santo Stefano di Sessanio. These deposits consist of stratified heterometric carbonate gravel beds, both matrix and clast-supported, occasionally open-work, usually poorly cemented, showing slope-parallel bedding with dipping decreasing from proximal to distal areas (Fig. 4.29). Clasts are angular to sub-angular in shape with a fine to medium grain-size (MPS = 10 cm), often moderately sorted. The matrix, mainly silty sandy in grain-size, has a pale brownish to pinkish color and contain both clayey and volcanic minerals. Sometimes gravel beds are interlayered with dark brown-reddish pedogenic horizons, marking the presence of minor internal erosive surfaces (Fig. 4.29a).

The slope-derived deposits of the *Campo di Pile Synthem* usually accumulate on the hangingwall of the main active faults (i.e., Scoppito-Preturo, Pettino, Bazzano-Fossa, Paganica-San Demetrio and Barisciano-San Pio faults) (Fig. 4.29b) as a result, during Late Pleistocene, of the continuous interaction between faults activity (uplift) and erosion processes, likely climate driven. This also results in thickness changes within the AB, from few meters, in the upper part of the slopes, up to more than 10 m, on the hangingwall of the faults at the base of the reliefs.

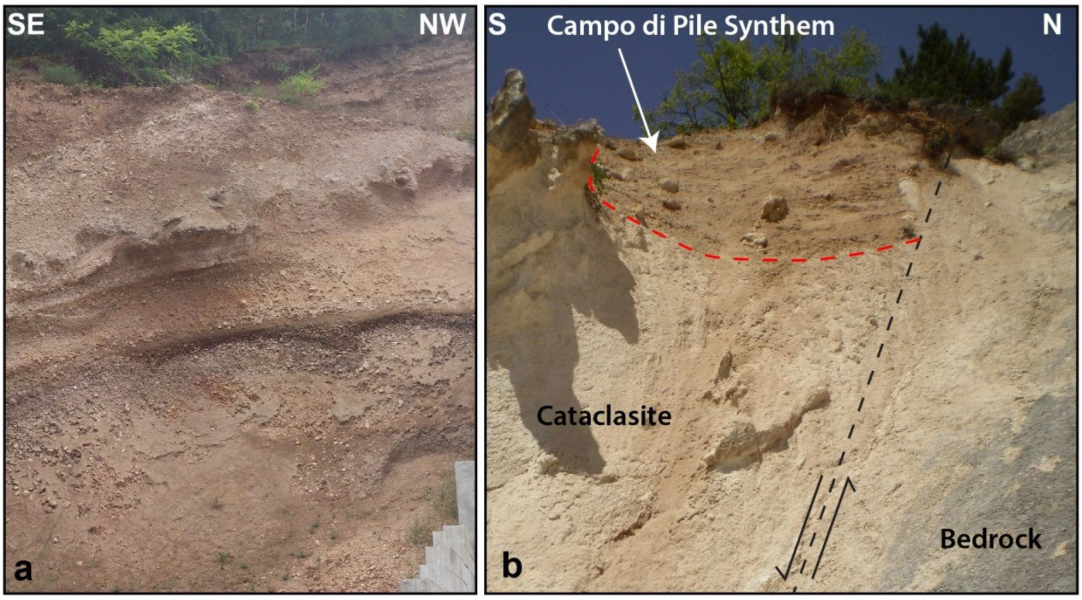


Fig. 4.29 – Slope-derived facies of the Campo di Pile Synthem. **a**: Well-stratified, clast-supported carbonate gravels interlayered with a dark brown-reddish pedogenic horizon (i.e., Fossa); **b**: Heterometric, matrix-supported deposits in the hangingwall of the Scoppito-Preturo Fault (i.e., Cese).

Several alluvial fan systems, referable to the *Campo di Pile Synthem*, are preserved at different elevations along the AB margins and at the outlet of the main valleys into the Aterno floodplain. These deposits mantle the slopes between Pianola and Bagno, form the lowermost terraced surface at the outlet of the Raiale Creek (Paganica area), and compose the gently sloping landforms *(bajada)* between San Gregorio, to the N, and San Demetrio ne' Vestini, to the S. Other remnants of alluvial fans belonging to this synthem are also present at higher elevation, close to the northwestern boundary of the basin, such as the Orsa Valley fan or those located at the base of the reliefs beyond Barisciano and San Pio delle Camere (i.e., Vedice Valley, Pilongo di Sopra, Pilongo di Sotto). The *Campo di Pile Synthem* alluvial fans are often incised and some of them are characterized by the absence of an active drainage system. Their top surface is suspended at different elevations above the present-day base level, with a minimum elevation of 5 m at the hangingwall of the Paganica Fault. Some of the mapped alluvial fans are still active, at least in their proximal portion, and covered by thin younger deposits, but were grouped into the *Campo di Pile Synthem* due to the reduced thickness of Holocene deposits and because the extension and morphology of fans are mainly related to climate conditions and drainage systems prior to the present-day ones.

They are mainly composed by fine to coarse, sub-angular to sub-rounded, well-sorted, clinostratified calcareous gravel beds, characterized by horizontal and, rarely, trough or planar cross-bedding (Gh, Gt, Gp), interlayered with thin lenses of pale brown-yellowish sandy silts (Fm) (Fig. 4.30). The thickness of that deposits usually ranges between 10 m and 25 m. Locally dark brown to blackish paleosols and pedogenic horizons, characterized by high organic matter content and calcic horizons (Bk), are present at the base and within these deposits (Fig. 4.30b). These paleosols can be classified as Chernozem (mainly formed in Continental climate with cold dry winter and hot wet summer) and they match with those reported above the *PAG-3 Unit* by Galli et al. (2010) and with the *Barisciano Pedocomplex* (Coltorti & Pieruccini, 2006), the lowermost respectively dated between 33 – 41 ka and 33 – 35 ka, while the uppermost was dated by both authors at about 23 ka.

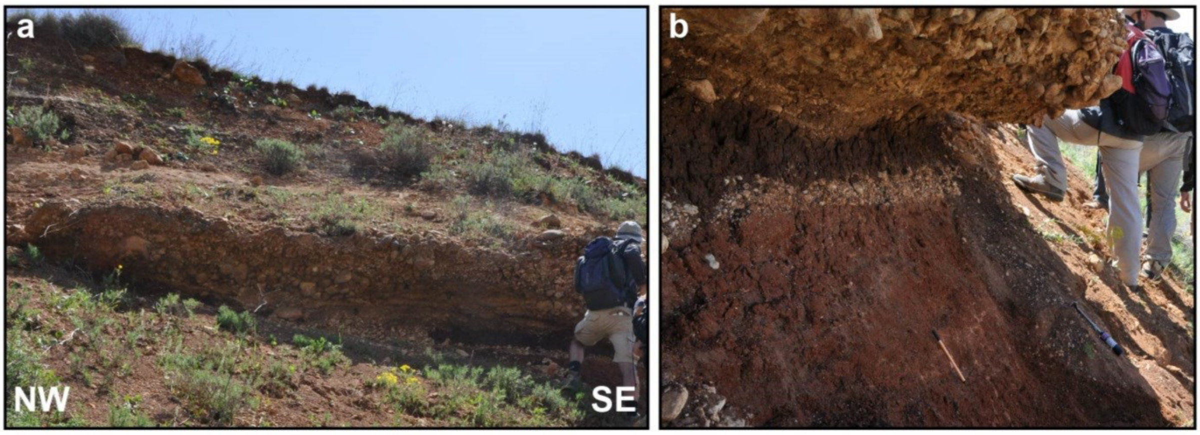
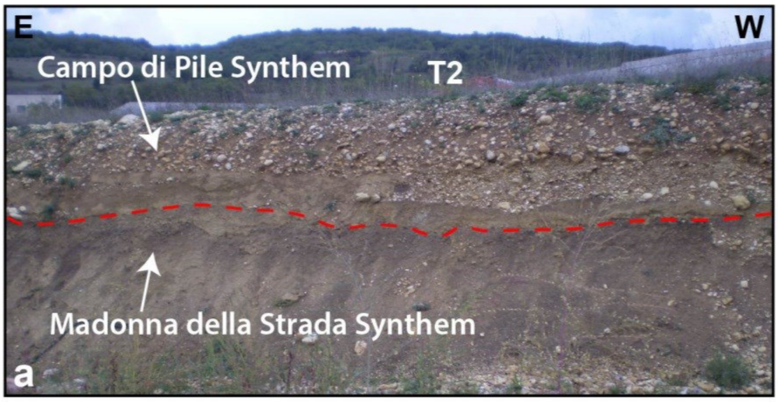


Fig. 4.30 – Alluvial fan facies of the Campo di Pile Synthem. **a**: Clast-supported gravel bed of the Orsa Valley fan interlayered with sandy level and pedogenic horizons (i.e. Orsa Valle quarry) **b**: Detail of the pedogenic horizons at the base of the gravel bed in Fig. a, corresponding to the Barisciano Pedocomplex (Coltorti & Pieruccini, 2006).

Fluvial deposits, characterized by sheet-type geometry with a flat basal unconformity(Fig. 4.17, 4.31), are mainly preserved in the southern and western sectors of the ASB, between L'Aquila Hospital, Campo di Pile (BAR20 section) and Madonna della Strada. They are made of medium to coarse, poorly sorted, sub to well-rounded, clast-supported gravel beds containing an abundant silty sandy matrix. Gravels, showing horizontal and, subordinately, trough cross-bedding (Gh, Gt), are interlayered and laterally pass to coarse to medium sands and gravelly sands bedform, with well-preserved planar and trough cross-stratifications (Sp, St), interpreted as levee and/or bar deposits (Fig. 4.16, 4.31). Thin lenses and levels of massive and laminated silts and clayey silts (Fm, Fl), occasionally showing plant roots and oxidized surfaces, are locally preserved above gravel beds, representing abandoned channel deposits. The clasts are usually imbricated toward E and they are predominantly composed by carbonates and more rarely bauxites (Fig. 4.31b), suggesting source areas from the reliefs at the southern and western margins of the ASB. The described deposits are usually less than 5 m thick and belongs to an eastward draining wandering-braided river system, that defines the second order fluvial terrace (T2) of the AB (Fig. 4.17, 4.31a). In the ASB, this terrace, interpreted as a strath, has its depositional top at 10-13 m above the present thalweg, at elevations ranging between 700 m at Madonna della Strada-Sturabotte, 680 m close to L'Aquila jail and 645 m a.s.l. in the Campo di Pile area.

As stated before, this terrace is quite well represented in the ASB, while in the PSC Basin only a flat horizontal surface referable to the T2 is preserved at Villa S. Angelo. Here, as well as the T1 (*Fosso Vetoio Synthem*), the T2 seems to be represented only by an erosive surface carved into the *Fosso di Genzano Synthem* and lying at higher elevation respect to the ASB T2 ones, ca. 15-20 m above the Aterno thalweg.

Samples collected for micropaleontological analyses from the rare fine sediments of the *Campo di Pile Synthem*, were barren of ostracods and only few gastropods remains, referable to Helicidae family, were recovered from a sandy layer within the ST25 sample, located few meters to the west of the BAR20 section.



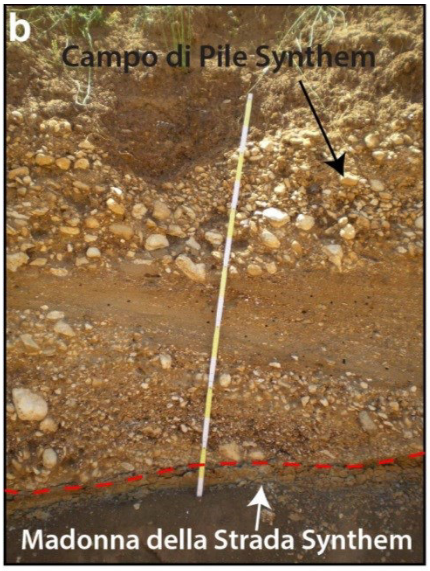


Fig. 4.31 – Fluvial facies of the Campo di Pile Synthem. **a**:Sub-horizontal basal unconformity of the Campo di Pile Synthem T2 strath terrace (i.e. BAR20 section); **b**: Trough-cross stratified coarse sands and gravels within the T2 fluvial deposits in Fig. 4.31a.

From the upper portion of the BAR20 section, and from other localities close to Ponte Peschio, some lithics and bone artifacts were found within the gravels of the *Campo di Pile Synthem*. The principal characteristic of the flake shown in Fig. 4.32 is the presence of a number of intersecting flake scars on the upper surface that represent the visible remains of the earlier trimming of the core (Levalloisian core). The margins of the flake have fractures due to transport in a rocky environment. The abundant lithic material collected is very slick and can be referred to Mousterian industry (late Middle Paleolithic), as other lithic industry findings reported by Tozzi (2003) in the Ponte Peschio area.

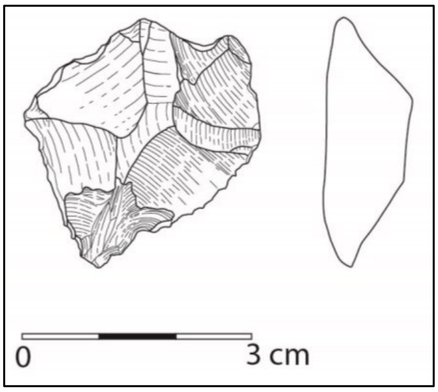


Fig. 4.32 –Drawing of one of the flakes discovered within the Campo di Pile Synthem (BAR 20 section), in dorsal (left) and lateral (right) view.

To constrain the age of the *Campo di Pile Synthem*, four samples (LV548 to LV551) were collected for OSL dating. **LV548**, **LV550** and **LV551** come from the well exposed BAR20 section (Fig. 4.16), while **LV549** comes from a gravel bar of the third order fluvial terrace (T3) outcropping along the SS 17 at the base of Colle Macchione ridge (42°21'25.761"N, 13°20'55.486"E).

Sample **LV548** comes from a trough cross-bedded fine sand (St) of a point bar of the T3 deposit within the BAR20 section. After sample preparation a good quantity of quartz (180-300 µm) was extracted even if a large part of the sample had a grain size smaller than 63 µm and feldspars, heavy minerals and charcoal remains were present. A Dose Rate of 2.21±0.08 Gy/ka was estimated for this sample. The first dose recovery/preheat test indicated that a standard SAR protocol was not suitable due to recuperation. It was possible to recover a given dose after incorporating high-temperature stimulation (HBW) within the SAR procedure, however some aliquots exhibited slow OSL decay curves and for these reasons the dose was underestimated. De measurements were performed on 1mm aliquots. Only 4 out of 72 aliquots have been accepted, showing wide De range (88-160 Gy). Some aliquots presented slow OSL decay curves and this may therefore indicate a feldspar contribution to the signal. For this reason these have been rejected from the analyses. The other aliquots were rejected from the analyses due to poor recycling or IR/OSL depletion ratios, signal in saturation, dim or no natural OSL signal.

LV549 was collected from an abandoned channel fill massive silt (Fm). That sample had a very fine grain size and it contained too much K feldspar and a very few quantity of quartz. A Dose Rate of 2.42±0.09 was measured and, due to facies and grain size, the 100-200 µm fraction was chosen for the analysis. Initial tests revealed that inherent luminescence sensitivity was poor and recuperation was present. A dose recovery test was conducted on 10 aliquots of 3 mm size employing an high test dose (21 Gy) and two out of the ten aliquots had poor sensitivity. Other measurements showed that all aliquots, except one, had slow OSL decay signals and many produced recuperated signals despite the incorporation of high-temperature stimulation (HBW). There was poor recycling ratios and three aliquots were rejected on the basis on their IR:OSL depletion ratios, revealing feldspar contamination (Fig. 4.33). For all that reasons this sample was considered unsuitable for dating.

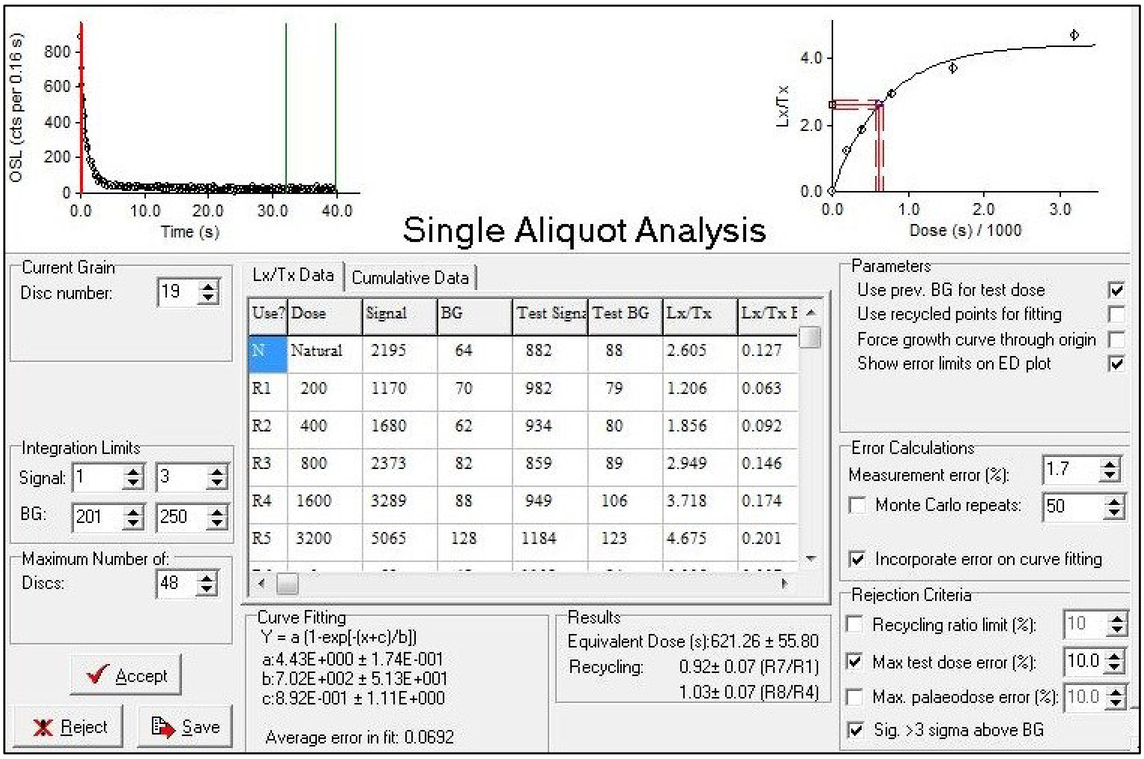


Fig. 4.33 – Single analysis of aliquot 19 of sample LV549 showing dim signal (left plot), low Recycling Ratio (R7/R1 value ca 1.0±0.1) and dose close to saturation (right plot).

LV550 was sampled from a planar cross-bedded sand (Sp) of a bar top within the BAR20 section. After sample preparation a good amount of quartz in the 180-300 µm fraction was extracted even if it had a small grain size and feldspar were present. The measured Dose Rate for LV550 was 2.51±0.11 Gy/ka. During initial tests recuperation, feldspar contamination and slow OSL decay curves were observed. The first 24 aliquots for De analysis revealed slow OSL decay and there was no screening for feldspar contamination, so these results were not incorporated with later measurements. High temperature stimulation (HBW) was employed to reduce recuperation, but this was not always brought below 5% of the normalized natural signal.

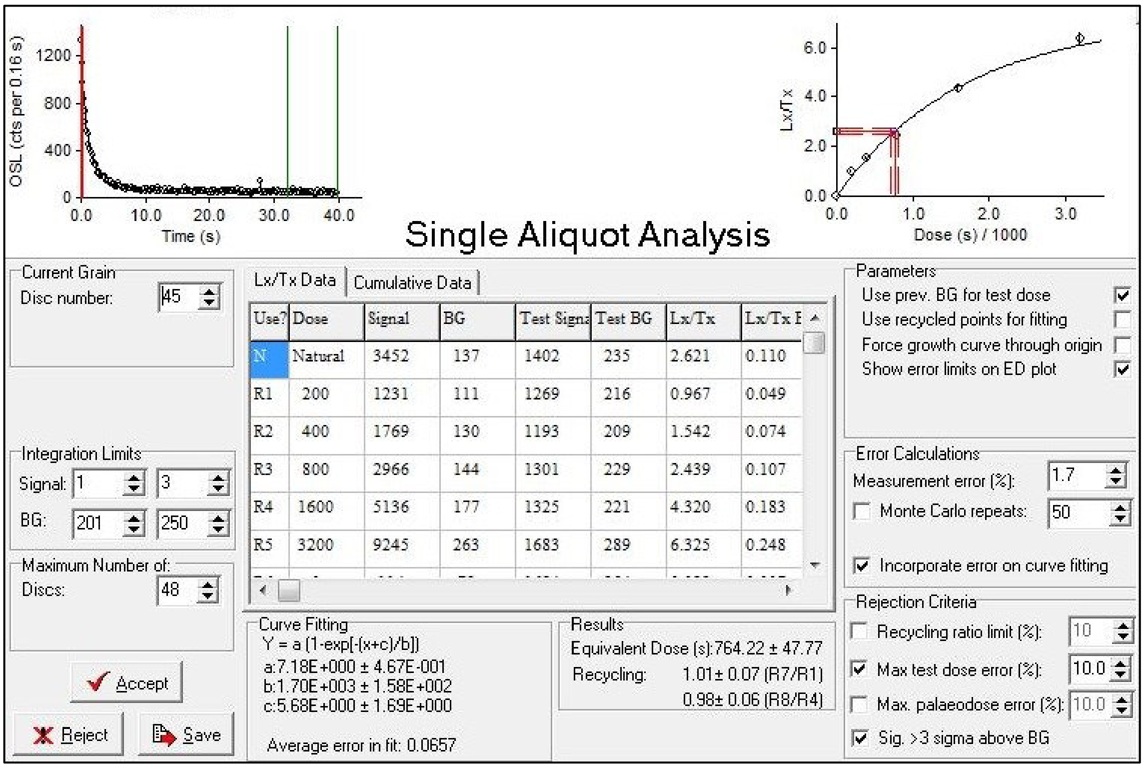


Fig. 4.34 – Single analysis of aliquot 45 of sample LV550 showing good Recycling Ratio (R7/R1 value between 1.0±0.1) and good IR/OSL depletion ratios (R8/R4 value between 1.0±0.1) allowing to accept Equivalent Dose estimation.

The first De measurement with HBW on 24 aliquots of 1 mm size (Fig. 4.34), gave promising results, allowing to make an indicative age estimation at about 34 ka (Tab. 4.1, 4.2).

In further measurements acceptance rate was poor and one anomalously low value (5 Gy) was observed within a wide range of De (5-213 Gy), indicating poor bleaching and suggesting that ages would be inaccurate. Also a set of 2mm aliquots were measured but poor sensitivity to dose continued, a greater number of aliquots were in dose saturation and acceptance rate was poor.

The last sample (**LV551**) comes from a bar-edge sand wedge planar cross-bedded sand (Sp) of the BAR20 section. LV551 had a coarse grain size and was very rich in quartz (180-300 µm) although heavy minerals and charcoaled plants remains were present. A Dose Rate of 2.10±0.05 Gy/ka was determined. Poor sensitivity was observed in initial tests, so a further dose recovery test was performed on 3mm aliquots employing high-temperature stimulation (HBW) to reduce recuperation although this was not always successful. The given dose was recovered only for two aliquots, but two others yielded overestimated doses. De measurements were undertaken on 24 aliquots of 1 mm size, but OSL signals were too dim to allow reliable analyses and, as LV550 indicated, larger aliquots were unlikely to be appropriate for these samples.

Tab. 4.1 – Equivalent Dose values and rejection criteria from first De measurements of sample LV550. 7 of the 24 measured aliquots gave no OSL signal (not reported in table).

Disc	Size (mm)	ED (sec)	ED_Err	N.Signal	BG.signal	RR	IR/OSL	rec%	2b	reject
3	1	1036,63	104,69	18277	119	0,95	0,96	0,12492	1068	
5	1	1038,81	101,35	2344	200	0,92	1	1,95667	2740	
13	1	1137,74	140,34	5035	224	0,95	0,94	0,78715	1264	
19	1	621,26	55,8	2195	64	0,92	1,03	0,19194	1404	
21	1	1724,07	149,94	4968	86	0,97	1,03	0,20022	2760	
23	1	2321,05	285,9	7282	82	0,95	0,97	0,28132	2300	2b
25	1	826,59	78,85	1742	86	0,98	1,11	0,88326	2300	IR/OSL
27	1	918,94	182,07	6466	112	0,88	0,94	0,03209	762	RR+2b
29	1	1539,88	195,13	6421	117	0,91	1,01	0,27732	1740	
33	1	1236,11	83,41	3741	209	1	1,06	1,61955	4720	
35	1	831,07	78,67	6520	262	0,91	0,98	0,47831	1346	
39	1	849,53	83,19	2147	142	0,94	0,98	1,02691	1712	
41	1	1102,08	84,3	3075	134	1,07	1	0,17953	2700	
43	1	554,03	55,82	1727	115	1	1,06	0,04782	1352	
45	1	764,22	47,77	3452	137	1,01	0,98	0,83937	3400	

Tab. 4.2 – Preliminary age estimation of sample LV550. De value (sec) is the mean of the 15 accepted De in Tab. 4.1; β is the dose rate of the $^{90}Y/^{90}Sr$-source of the Risø DA-15 automated TL/OSL reader, used to convert De (sec) in Gy.

Lab code	Equivalent Dose (sec)	β (Gy/s)	Equivalent Dose (Gy)	Dose rate (Gy/ka)	Age (ka)
LV 550	1036,28	0,083185	86,20	2,5	34,48

Summing up, the combination of poor bleaching with very poor OSL properties provided by the quartz of all samples suggested that ages would be inaccurate. We therefore decided to refrain from continuing the very time consuming measurements and data analysis.

However, even if raw and inaccurate, the preliminary age estimation for LV550 (≈ 34 ka) (Tab. 4.2) made us confident to try to date that deposit with ^{14}C.

The sample for ^{14}C dating, called **Pile 4**, consists of charcoaled plant remains collected from the same brownish coarse planar cross-bedded sand (Sp) layer from which OSL sample LV551 was taken (Fig. 4.16, 4.35b). **Pile 4** sample was sent to the CEDAD laboratory of the Salento University for AMS radiocarbon dating. We obtained a conventional not calibrated radiocarbon age (Stuiver & Polach, 1977) of 36,504±346 years BP and a $\delta^{13}C$ (‰) = 17.9±0.5 isotopic signature. IntCal13 atmospheric calibration curve (Reimer et al., 2013) and OxCal 4.2 online software, were used for calibration, giving back a 2σ (95.4%) age of 40,464–41,845 yr cal BP (Fig. 4.35a).

The age of **Pile 4** sample confirms the preliminary indications given by sample **LV550** and is comparable to the ages reported in literature for deposits referable to the *Campo di Pile Synthem*, as previously reported. This age is also in agreement with the founding of lithic industry of Mousterian age (late Middle Paleolithic) inside the gravels, allowing for a correlation with MIS 3. Thus the *Campo di Pile Synthem* has to be referred to the upper part of the Upper Pleistocene.

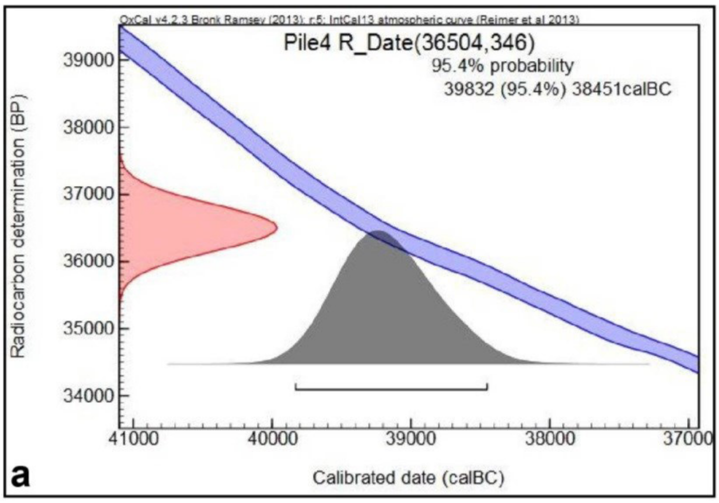


Fig. 4.35 – **a**: Calibration curve of Pile4 sample; **b**: Charcoaled plant remains within the sands of the Campo di Pile Synthem (Pile4 in Fig. 4.16).

Between the T2 top surface of the *Campo di Pile Synthem* and the active floodplain, small and isolated remnants of an intermediate fluvial terrace are interposed (Fig. 4.36). This terrace (T3) is well preserved only in the central part of the ASB, where it defines the ***Ponte Peschio Sub-synthem***, that has been identified by field observations and through the analysis of the high resolution DTM (1mx1m) derived from LIDAR survey. The T3 is represented by an erosive flat surface, with absent or very thin alluvial cover, lying at 5 – 7 m above both the Raio and the Aterno thalwegs. Near the S. Salvatore Hospital, it is embedded in the *Fosso Vetoio Synthem* (T2) and carved into the *Colle Macchione-L'Aquila Synthem*, while at Ponte Peschio, it is embedded into the *Campo di Pile Synthem* (T3) and carved directly into the pre-Pliocene bedrock (Fig. 4.36). There, the *Ponte Peschio Sub-synthem* may be interpreted as a strath terrace.

Fig. 4.36 – Panoramic view of the T3 strath terrace (Ponte Peschio Sub-Synthem) entrenched into the T2 terrace (Campo di Pile Synthem) and carved directly into the bedrock (i.e., Ponte Peschio).

The *Ponte Peschio Sub-synthem* represents a minor erosional phase occurred after the formation of the upper Late Pleistocene *Campo di Pile Synthem* fluvial terrace (T2) and probably referable to tectonic uplift in the ASB coupled with the cold LGM climate, as also results by age estimation provided in section 5.5. Thus the *Ponte Peschio Sub-synthem* can be related to MIS 2, so to the final part of the Late Pleistocene (< 29 ka). Due to the small extent related to the map scale (1:25000), the absence of deposits and the difficulties in identifying this synthem all over the ASB, it was mapped together with the *Campo di Pile Synthem*. This also because in several localities deposits dated to the LGM are present in the upper part of the *Campo di Pile Synthem*, so its continuity through MIS 3 and MIS 2 can not be definitively ruled out.

4.3.7 Aterno Synthem

The ***Aterno Synthem*** is the youngest synthem and is extensively diffused in the AB, comprising Holocene deposits related to the erosional and depositional processes still active in the intermontane basin, that formed the present basin floor and the pediment belt at the base of the slopes at the basin margins.

Alluvial, colluvial, and talus deposits, belonging to this synthem, are embedded and/or unconformably overlain both the older synthems and the Meso-Cenozoic bedrock.

Fluvial deposit are the most represented within the *Aterno Synthem* occupying both the actual floodplain of the Aterno River, from San Vittorino to Campana, and the valley floor of its main tributary (i.e., Raio, Genzano, Raiale creeks). Deposits are made of medium to fine, well-sorted, sub- to well-rounded loose sandy gravel beds, with horizontal, planar and trough cross-bedding (Gh, Gp, Gt), alternating with levee/overbank medium sand and silty sands layers (bedforms), horizontal or planar cross-stratified (Sh, Sp), locally passing to overbank laminated clayey silt thin layers and lenses (Fl) (Fig. 4.37). Pebbles are often imbricated and composed by limestones, cherts, bauxites and rare pottery fragments. These deposits buried some Bronze Age or Roman settlements (Fossa necropolis, Amiternum) and their thickness is usually less than 5 m, but locally could reach also 10 m, as indicated by borehole data.

Fig. 4.37 – Gravels and sands of the Aterno Synthem fluvial deposit.

Toward the basin boundaries fluvial deposits are interfingered with alluvial fan sediments consisting of well-sorted, well-rounded and well-stratified coarse gravel beds with minor sand layers. Alluvial fans referable to the *Aterno Synthem* are present at the outlet of the main valleys, like those at the mouth of the Forcella, Rio, Genzano, Roio, and Raiale creeks, or with more proximal facies along the slopes at the basin margins, as the alluvial fans close to Fossa and Casentino, and those between Barisciano and San Pio delle Camere. Sometimes they are entrenched into older alluvial fans, like the Raiale one or those between Bagno and Valle-Cavalleto.

Talus cone and scree deposits mantle the lower part of steep slopes and accumulate at the base of sub-vertical escarpments, composed by both bedrock carbonates and coarse granular deposit, locally covering, with a minor extent, the older wider and thicker slope-derived deposits, mainly formed during the LGM and belonging to the *Campo di Pile Synthem*. They are made of loose heterometric (up to several cubic meters), mostly angular calcareous pebbles and boulders with a greyish sandy silty matrix, both clast- and matrix-supported (dominated), generally less than 10 m thick. These deposits also occupy the bottom of the huge, sometimes collapsed, dolines and sinkholes widespread along the southern margin of AB (i.e. Ocre Mts.).

Colluvial deposits are present at the bottom of the flat (dry) valley, as those cutting the L'Aquila Hill or those draining the reliefs between Poggio Picenze and Campana (i.e., Inferno and Pantano valleys). They also widely outcrop at the base of the reliefs made of highly erodible siliciclastic bedrock or fine grain continental deposits, forming the gently dipping landforms connecting them to the basin floor. These deposits derived from the erosion of older soil and soft sediments, downslope transported by solifluction and gravity flow processes. Colluvium consists of massive to poorly stratified browinish-reddish sandy silts and silty clay, with abundant angular to sub-angular, poorly sorted medium to fine clasts, mainly limestones and cherts with sparse pottery remains. They contain abundant organic matter, plant remains, pedogenic horizons and volcanic material. The thickness is generally less than 15 m.

All over the AB, colluvial deposits are often displaced by the main active faults (i.e. Pettino Fault, Paganica-San Demetrio Fault System), forming colluvial wedge on the hangingwall of the fault and mantling the fault escarpments. Most of these deposits were extensively studied and dated for paleoseismological researches, prior and after the 2009 L'Aquila earthquake, showing ages spanning through the whole Holocene and allowing to better define the tectonic history of the AB.

The *Aterno Synthem* comprises also heterometric and heterogeneous anthropic deposits (not distinguished), as well as the landslides reported in the geological map.

4.4 Subsurface data

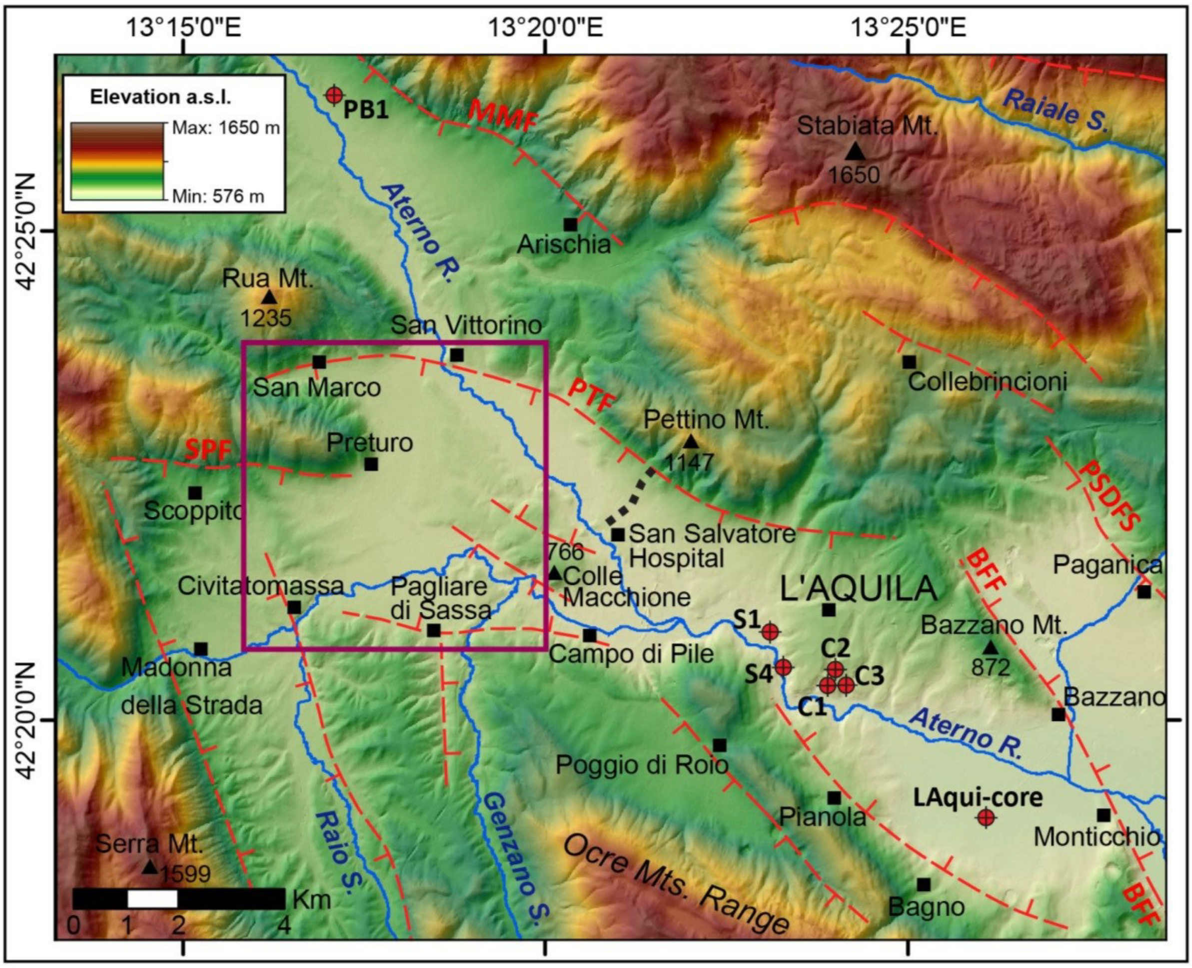


Fig. 4.38 – Shaded relief map showing location of subsurface data. Deep borehole: S1-S4 (CERFIS); C1-C2-C3 (Collemaggio boreholes, ENI), PB1 (Pizzoli1, ISPRA), LAqui-core (INGV). Pettino 1 seismic-reflection profile (black dashed line). Bedrock isobath map (purple square). MMF=Mt.Marine fault; SPF=Scoppito-Preturo fault; PTF=Pettino fault; BFF=Bazzano-Fossa fault; PSDFS=Paganica-San Demetrio fault system.

4.4.1 Seismic-reflection profile

From the seismic-reflection profile analyzed (Pettino 1, Fig. 4.38, 4.39), we distinguished five different seismic facies. One of them is correlated with the pre-Pliocene substratum, which corresponds to the tectonic units of the Apennine chain, whereas the other four seismic facies represent different deposits of the ASB sedimentary infill.

Seismic facies S is represented by a chaotic seismic facies with low-amplitude, apparently parallel, discontinuous reflectors. This seismic facies characterizes the lower portion of the Pettino 1 seismic reflection profile, as well as its margins. It is defined by a low-resolution signal, due to scarce penetration of the seismic pulse likely results from low transmission coefficients of the younger strata, the high tectonization of the rocks travelled by the acoustic waves, or both. This seismic facies is interpreted as the acoustic substratum of the ASB filling.

Seismic facies R is generally characterized by high amplitude, discontinuous or semi-continuous reflectors. It is recognizable almost throughout the whole seismic-reflection profile between ~100 and ~1200 m CDP (Common Deep Point), and shows a maximum thickness of ~200 ms. It is characterized by a highly disturbed signal, but its resolution is sufficient to recognize fairly continuous reflectors. They usually show a divergent internal configuration, pointing to wedge geometries. Locally, this seismic facies is highly disturbed, in which cases it is difficult to distinguish from seismic facies S. However, its lower boundary is extremely irregular, pointing to an erosional contact with the S seismic facies. The high amplitude and discontinuous character of this seismic facies is consistent with clastic deposits deposited through gravitational or debris flow processes, like the slope-derived breccias, debris flow deposits, and alluvial clayey-sandy conglomerates of the *Colle Cantaro-Cave Fm* (*San Demetrio-Colle Cantaro Synthem*). The wedge geometries that characterize this seismic facies, together with the structural setting of the ASB, point to syn-rift clastic deposition into a tectonically controlled sedimentary basin.

Seismic facies L is characterized by continuous and parallel reflectors, with medium to high amplitude. This facies, as well as the seismic facies R, is present along the whole seismic-reflection profile. Seismic facies L shows highly variable thicknesses across the Pettino 1 seismic-reflection profile, with ~300 ms in the southwestern area, ~200 ms in the northeastern area, and ~100 ms in the central area. Usually the continuous and parallel reflectors of this seismic facies are horizontal, except for the southwestern margin of the Pettino 1 profile, where they appear to be dragged down along an extensional fault plane. The lower boundary between L facies and the seismic facies R is highly irregular and unconformable. Following the stratigraphy of some boreholes drilled in the northern part of ASB (GE.MI.NA., 1963; Amoroso et al., 2010), it is possible to correlate seismic facies L with the *Madonna della Strada Synthem*. According to the internal configuration of this seismic facies, its deposition might have occurred during a post-rift stage.

Seismic facies BC is defined by fairly continuous, low-amplitude reflectors, with parallel to irregular and chaotic geometries. Both the basal and upper boundaries of this seismic facies are highly irregular. It was recognized in the Pettino 1 seismic-reflection profile between ~200 and ~350 m CDP, at ~100 and ~200 ms. Both the stratigraphic position and the internal geometries of this seismic facies allow us to refer it to the chaotic breccias and megabreccias of the *Colle Macchione-L'Aquila Synthem*, that crop out southwest of the Pettino 1 seismic-reflection profile (Colle Macchione ridge) and near Coppito.

Seismic facies AD is generally characterized by a chaotic facies, with seismic reflectors of medium-low amplitude. This facies is distributed throughout the seismic-reflection profile. Its lower boundary, which is extremely irregular, is located at a depth between ~100 and ~200 ms. In the southwestern portion (starting from ~700 m CDP) of Pettino 1 seismic-reflection profile, it is possible to distinguish some continuous reflectors within the prevailingly chaotic facies, whereas in the northeastern zone, the AD facies is characterized by more chaotic geometries. It is possible to refer this seismic facies to the youngest deposits of the ASB filling, including Mt. Pettino's pediment and the Late Pleistocene alluvial deposits of the Aterno River (*Fosso Vetoio, Campo di Pile, Aterno* synthems).

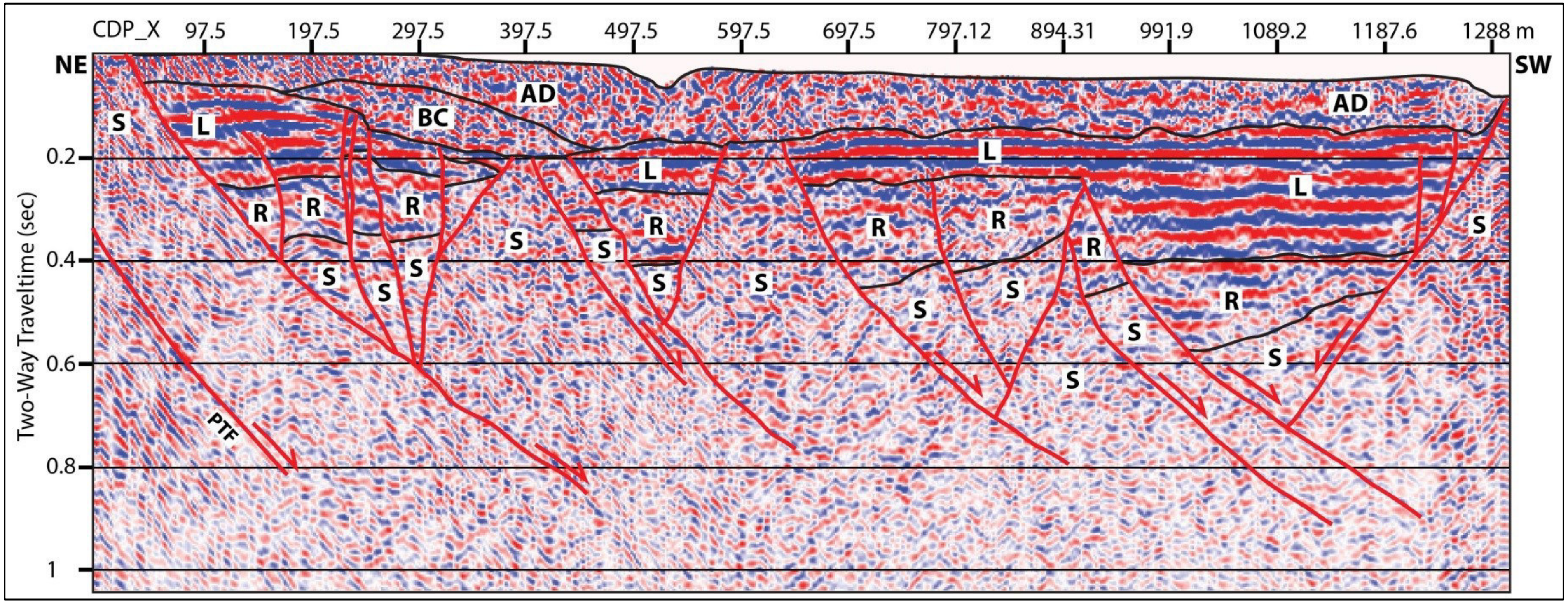


Fig. 4.39 – Interpretation of the Pettino 1 reflection seismic line (see location in Fig. 4.38). The recognized seismo-stratigraphic units are: S - acoustic substratum of the ASB filling; R - deposits sedimented during the syn-rift stage (San Demetrio-Colle Cantaro Synthem); L - deposits sedimented during the post-rift stage (Madonna della Strada Synthem); BC - chaotic breccias and megabreccias (Colle Macchione-L'Aquila Synthem); AD - Mt. Pettino's pediment and Upper Pleistocene-Holocene alluvial deposits of the Aterno River; PTF - Pettino's normal fault. CDP=Common Deep Point.

4.4.2 Bedrock Isobath Map derived from HVSR seismic-noise analyses

During the seismic microzoning studies of the Sassa-Preturo area, HVSR seismic-noise measurements, coupled with borehole data, were used to reconstruct the subsurface geometry of the central part of the ASB (Fig. 4.38). The isopachs of the continental infilling were extracted using the relationship $f_o = V_s/4h$, then converted into a Bedrock Isobath Map, as explained in section 3.3.2.

Isopachs were useful to draw the base of the ASB in the geological profiles (Fig. 4.40a) and to define the Plio-Quaternary deposits thickness in this sector of the AB.

The Bedrock Isobaths Map highlighted an irregular geometry of the substratum, showing the existence of a very sharp paleomorphology with morpho-structural highs (susbsurface ridges), bordered by steep buried escarpments, alternated to deep incised valley (Fig. 4.40b). The isobaths show a basin depth generally deeper than 60 m, with a N-S elongated depocenter (wide paleovalley), lying at 560-580 m a.s.l. between Preturo and Sassa, where the continental deposits reach a thickness of about 100 m with a maximum of 120 m close to L'Aquila airport. Toward the southern margin of the basin the depocenter is connected to a narrow paleovalley, W-E trending, about 80 m deep. This paleovalley, which is parallel to the Pagliare Fault, is entrenched in between the carbonate reliefs close to Genzano and Palombaia, southward with respect to the present-day Raio Stream thalweg. The latter is incised directly into the bedrock, as evidenced by the reduced thickness of continental deposits in the isopachs map (Fig. 4.40a) and by the outcropping of the Cenozoic substratum close to Ponte Peschio. The presence of this paleovalleys, filled up mainly by deposits from the *Madonna della Strada Synthem*, testifies the existence of a completely different drainage system during the Calabrian. The shifting toward north of the present-day drainage pattern (present day Raio Stream thalweg) is consistent with a northward migration of the active faults after the Middle Plesitocene (activation of the Colle Macchione- Palombaia faults?).

Between Sassa and Sassa Scalo, the mentioned depocenters are separated from the western sector of the ASB by a structural high above the valley floor (Collettara ridge), where the bedrock lie at a depth of ca. 20-40 m, while westward it deepen again up to 80 m depth (620-640 m a.s.l.).

The Bedrock Isobaths Map usually shows a progressive deepening from the slopes toward the base of the basin, with slope dipping with 30°, although sharp bedrock-infilling contacts and buried scarps are also present. These can be related to inherited morphologies, as the escarpments at the boundary of the Pagliare paleovalley, or to the presence of faults, like the steep buried slopes along the Scoppito-Preturo Fault and the buried scarp at the western boundary of the Colle Macchione ridge (Palombaia Fault?).

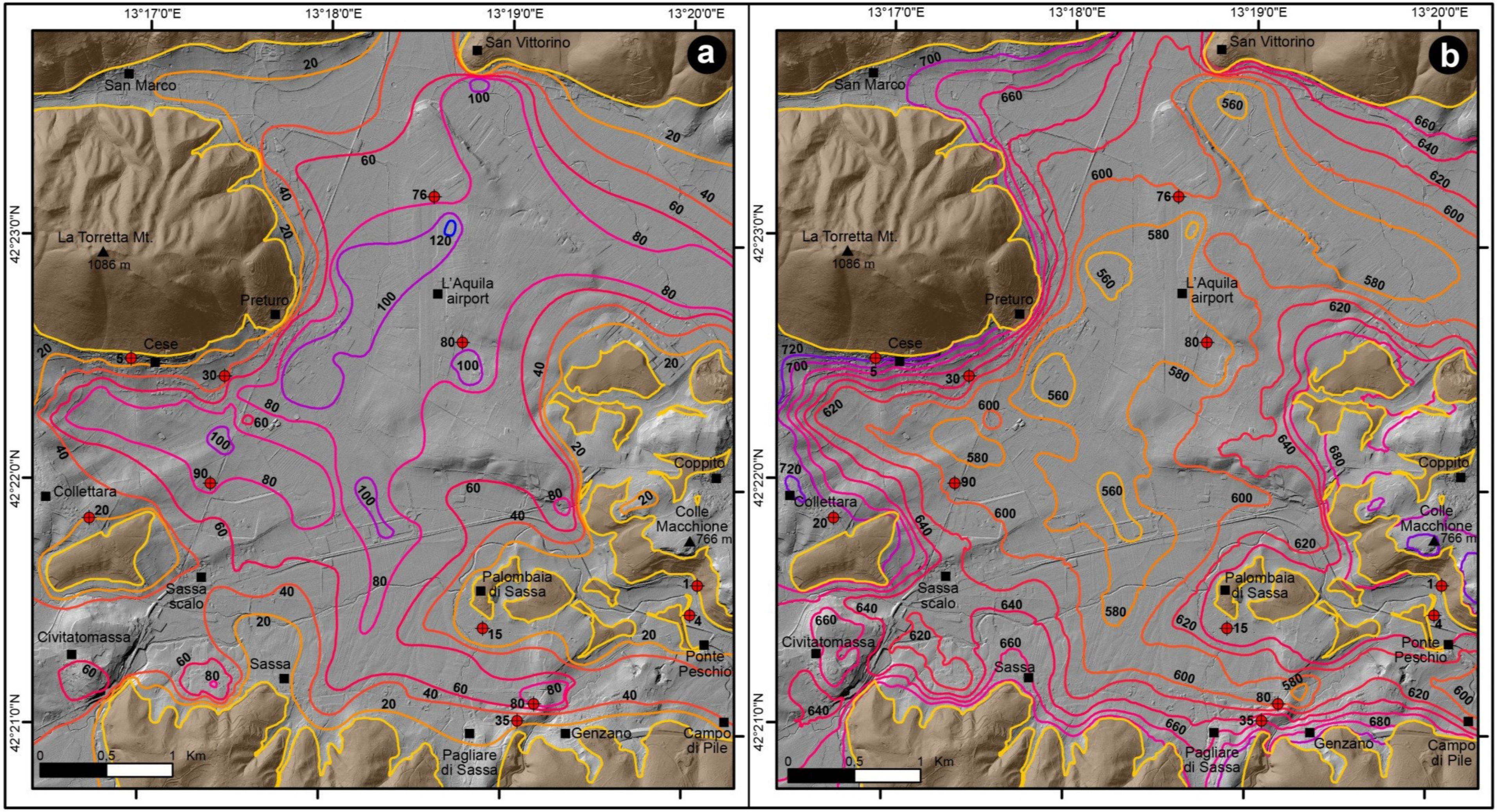


Fig. 4.40 – a: Isopachs map of the Plio-Quaternary continental infilling of the western ASB derived from boreholes and HVSR measurements. Location of boreholes, with relative bedrock depth (Z), used to correlate f_0 and Z are shown. The yellow line correspond to the boundary of outcropping Meso-Cenozoic bedrock; **b**: Bedrock Isobaths map, expressed in m asl, of the western ASB. Location of boreholes, with relative bedrock depth (Z), used to correlate f_0 and Z are shown. The yellow line correspond to the boundary of outcropping Meso-Cenozoic bedrock.

4.4.3 Deep Boreholes stratigraphy

The stratigraphy of 6 deep boreholes were reconstructed by analyzing their sedimentary cores (Fig. 4.41). This reconstruction made it possible to correlate the stratigraphy of those boreholes with the different synthems recognized at the surface of ASB.

Five of those boreholes (S1 and S4 CERFIS (Amoroso et al., 2010); Collemaggio1-2-3) were drilled in the southern part of the L'Aquila Hill, while PB1 was drilled close to Pizzoli, in the northern Arischia-Barete Basin (Tab. 3.1; Fig. 4.38). In addition, the preliminary stratigraphy of the LAqui-core well (Porreca et al., 2013), provided by the INGV and located in the Aterno floodplain between L'Aquila Hill and the Bazzano-Monticchio ridge, was reinterpreted (Fig. 4.42).

All these deep boreholes drilled continental deposit successions, up to 275 m thick in the Collemaggio3 well, without reaching the Meso-Cenozoic bedrock.

Micropaleontological analyses were carried out on 47 samples collected from the fine sediments of the lower part of the S4, Collemaggio3 and PB1 boreholes. Most of them were barren, and only few samples contained ostracods and gastropods remains, often partially or totally wrecked. Nevertheless all the recovered faunal assemblages are similar to those of the *Madonna della Strada Synthem*, helping to refer the analyzed intervals to this synthem (see section 4.3.2).

The 140 m deep CERFIS S1 (S45 in Fig. 4.44) and the 85 m deep CERFIS S4 boreholes (Fig. 4.41) (Amoroso et al., 2010) were drilled at the base of the southern slope of the L'Aquila Hill, close to the "99 Cannelle" fountain and the "Madonna del Ponte", respectively. Apart from their upper part, composed by less than 15 m of breccias pertaining to the *Colle Macchione-L'Aquila Synthem* in the S1, or by few meters of fluvial deposits belonging to the *Campo di Pile Synthem* in the S4, their stratigraphies can be correlated by using well recognizable stratigraphic markers, such as sedimentary structures like highly deformed laminations, oxidized surfaces, and pedogenic horizons.

In both boreholes, below the breccias or the fluvial deposits, yellowish sub-horizontal laminated fine-grain sands and silty sands, containing Fe or Mn oxidized levels, are present. The presence of abundant volcanic minerals within the sands, allowed to refer these deposits to the *Fosso di Genzano Synthem.* In both boreholes at about 600 m a.s.l., -30 m and -16.7 m for S1 and S4 respectively, a more or less defined pedogenic horizon (oxidized surface) marks the boundary between the *Fosso di Genzano Synthem*, above, and finer deposits referable to the *Madonna della Strada Synthem*, below (Fig. 4.43b). The latter deposits consist of massive to laminated sandy silts and sands, with oxidized surface and rare pedogenic horizons, passing toward the bottom to alternations of silts, clayey silts, clays, and fine sands, containing ostracods, mollusks and plant remains. Starting from ca. 560 m a.s.l., these deposits contain dm-thick lignite levels, whose frequency increases downward. In both S1 and S4, the deposits of the *Madonna della Strada Synthem* generally show a gentle tilting (< 10°) with respect to the the deposits of the *Fosso di Genzano Synthem*, indicating the existence of an angular unconformity between them (Fig. 4.43b). Within the silty sandy layers of the upper portion of the *Madonna della Strada Synthem*, particular sedimentary structures, likely related to fluid expulsion, such as highly deformed lamination (convolute-like or deformed/broken laminae), are present (Fig. 4.43c). These structures, recognizable at different depths and in both the analyzed boreholes, could represent soft-sediment deformations in response of palaeoearthquakes (paleo-seismites), indicating strong seismic activity in the L'Aquila Basin during the Calabrian, as already reported by Storti et al. (2013) from the *Madonna della Strada Synthem* of the ASB.

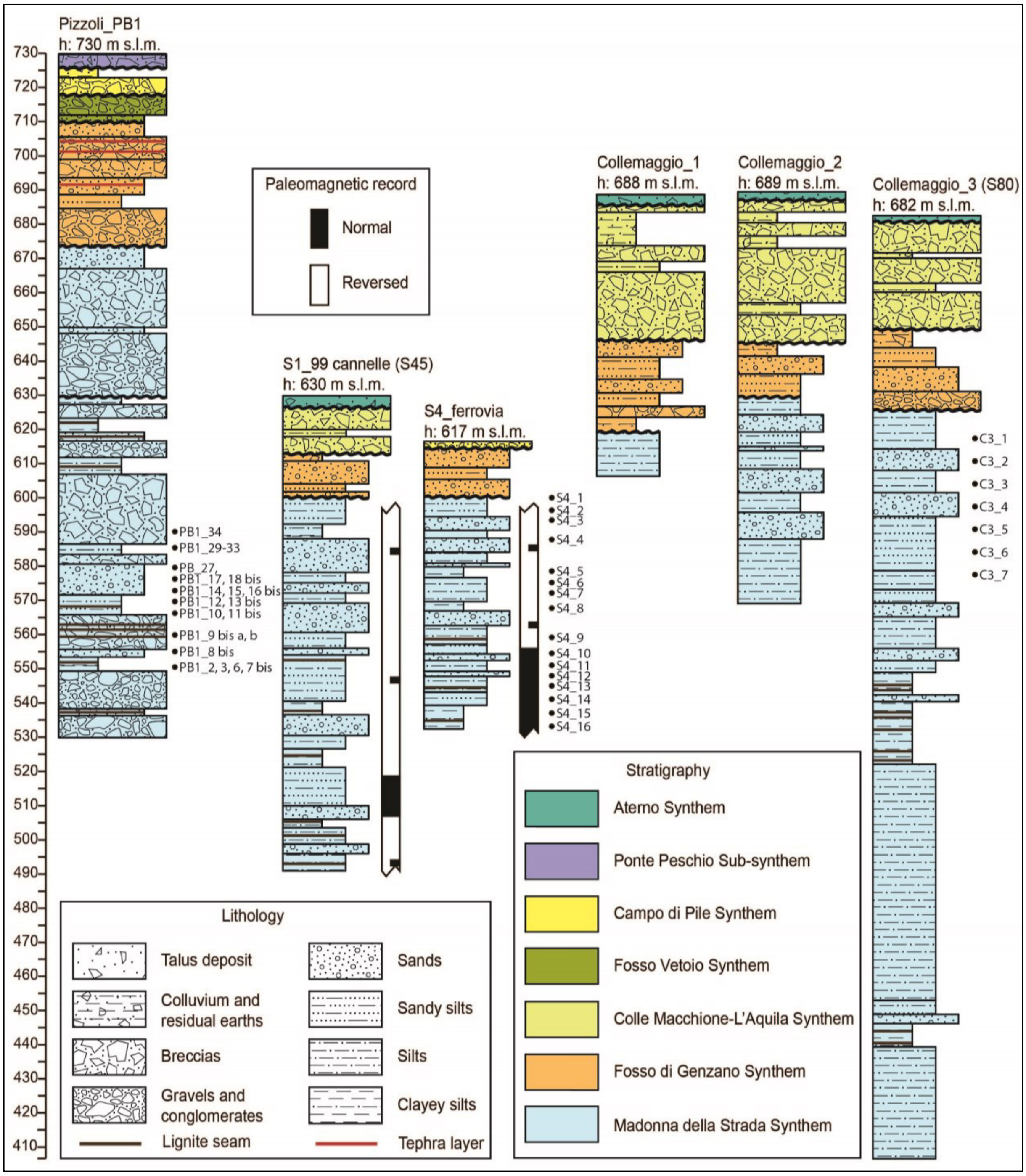


Fig. 4.41 – Stratigraphies of the analyzed deep boreholes. Samples for micropaleontological analyses (black dots) and preliminary paleomagnetic results for S1 and S4 are shown.

As reported in the description of the *Madonna della Strada Synthem* (par. 4.3.2), samples for paleomagnetic analyses, which were carried out by the IGAG-CNR (Dr. Scardia), were collected from the lower part of S1 and S4 boreholes. Preliminary results show a general reverse magnetic polarity with small inversions in the upper part and a relatively long normal polarity in the lower portion of both boreholes (Fig. 4.41). The reverse polarity (Matuyama chron), together with the fossil content, helped to refer these deposits to the *Madonna della Strada Synthem*, which, according to large-mammal paleontological constraints, is older than the Colle Curti F.U. Given that in the L'Aquila Basin samples from the *Madonna della Strada Synthem* (BAR20 section), containing large-mammals of the Pirro Nord F.U. (1.4-1.3 Ma), show remagnetization processes in magnetite-bearing samples (Cosentino et al., submitted), thus caution should be taken in considering the normal polarity samples from the lower part of both boreholes in a magnetostratigraphy perspective (Lucifora et al., 2012).

The Collemaggio1, 2 and 3 were drilled few meters apart from each other around the Basilica di Collemaggio, respectively reaching depth of 80 m, 120 m, and 275 m (Fig. 4.41).

Their upper part consists of coarse calcareous breccias, up to 42 m-thick, belonging to the *Colle Macchione-L'Aquila Synthem*. This deposit contains peculiar thin levels of whitish carbonate silt at the bottom and lies below an up to 10 m-thick reddish clayey silt colluvium. The breccias have an erosive base, which approximately lies at the same elevation in all these boreholes (645-650 m a.s.l.). Beneath the calcareous breccias, the stratigraphies of these boreholes show alternations of sandy silts, sands, and rare gravels referring to the *Fosso di Genzano Synthem*, with thickness variations between 15 m to 25 m. The lower portion of the Collemaggio boreholes consists in alternating silts and fine-grained sands passing, at -135 m depth, into a very homogeneous succession of grayish laminated silt and silty clay layers (Fig. 4.43a). These layers contain cm-thick lignite levels and sparse organic material and plant remains, which are referable to swamp or floodplain environments. Due to lithological affinities, in particular for the presence of lignite levels, these deposits are referable to the *Madonna della Strada Synthem,* which in the Collemaggio area is thicker than 215 m (Collemaggio3 in Fig. 4.41) (S80 in Fig. 4.45).

LAqui-core (Fig. 4.42, S59 in Fig. 4.45), a 151 m deep borehole, drilled by the INGV close to the epicentral area of the 2009 Mw=6.1 L'Aquila earthquake, presents at the top 41.40 m of fluvial and alluvial deposits. Through a clear unconformity, those fluvial deposits pass to fluvio-palustrine grey clays with sandy intervals and lignite levels, which contain a 32.40 m-thick coarse gravel bed referring to an alluvial fan. According to our defined stratigraphy from surface data and to the stratigraphy of other boreholes, the unconformity at -41.40 m could match with that marking the boundary between the *Madonna della Strada Synthem* and the *Fosso di Genzano Synthem*. Thus, the grey clays in the lower part of LAqui-core could correspond to the *Madonna della Strada Synthem*, while the upper fluvial deposits could be likely ascribed to the *Fosso di Genzano Synthem* (brown silty sands with clay levels between -23.30 m to -41.40 m), the *Fosso Vetoio* or *Campo di Pile* synthems (alternations of gravels and silty layers between -10.70 m to -23.30 m), and to the *Aterno Synthem* (brown silty clays and rounded gravels from the top down to -10.70 m) (Fig. 4.42).

The 30 m thick gravels interval, not recorded in the previous boreholes within the clays of the *Madonna della Strada Synthem*, testifies that a more energetic environment, referable to fluvial channel, was present during the Calabrian in this part of the AB respect to the L'Aquila Hill area, almost entirely characterized by fine-grained deposits related to a distal floodplain environment.

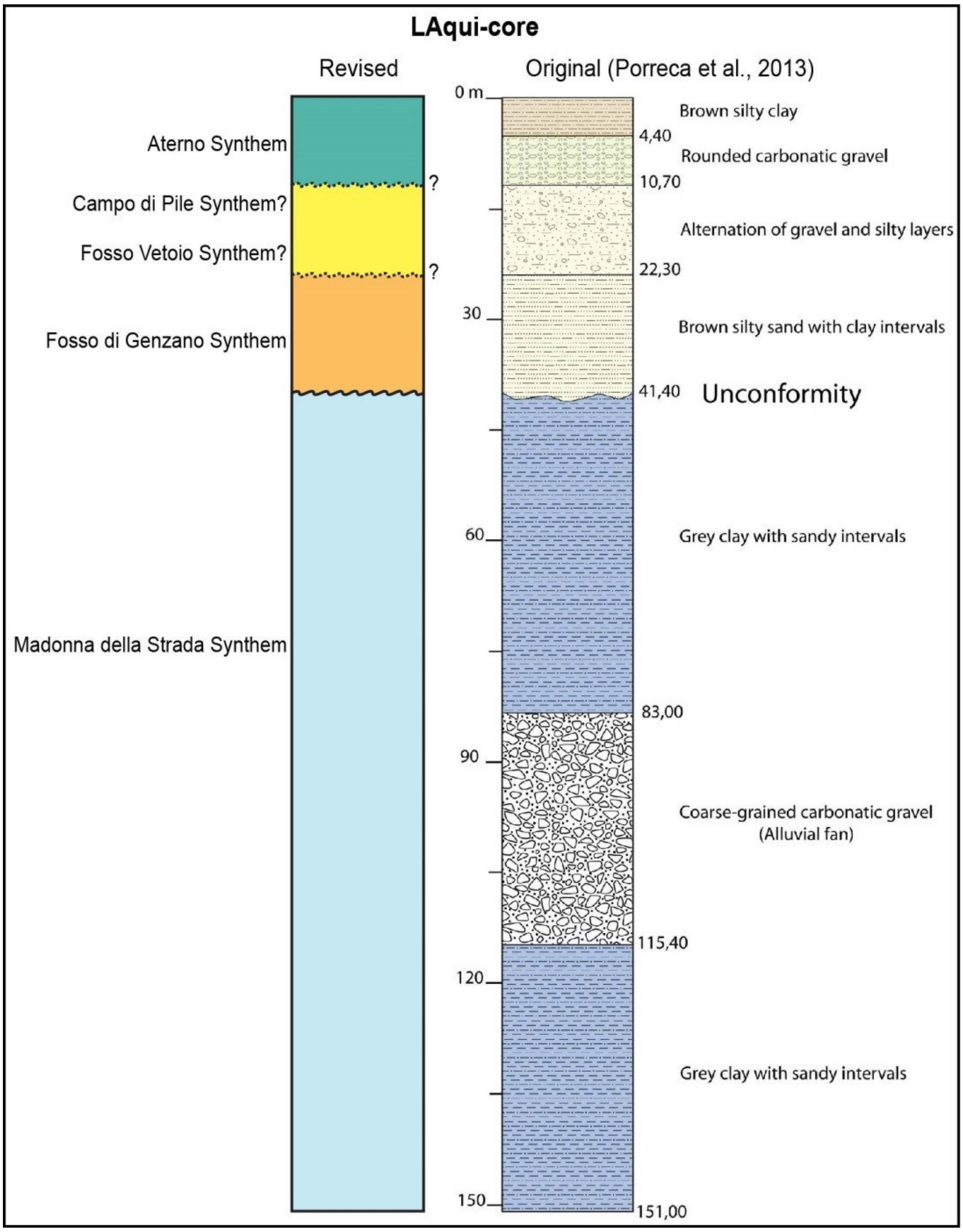


Fig. 4.42 – Reinterpreted stratigraphy of the LAqui-core borehole (modified from Porreca et al., 2013).

With respect to the previous described stratigraphies, the Pizzoli PB1 borehole shows completely different lithofacies, almost entirely composed by coarse-grained deposits (Fig. 4.41). The first 4.30 m are made of loose carbonatic breccias of the *Ponte Peschio Sib-synthem*, followed by 7.40 m of fluvial rounded gravels with sandy layers referable to the *Campo di Pile Synthem* and by ca. 7 m of analogous deposits belonging to the *Fosso Vetoio Synthem*. This distinction into three synthems is based on the presence of colluvial sediments or poorly developed paleosols, at depths of -4.30 m - 12.40 m and -20.30 m. The last one is a 1.30 m-thick dark brown paleosol developed on coarse sands rich in volcanic minerals. These sands pass toward the bottom into rounded medium gravels and angular coarse breccias, both with abundant volcaniclastic matrix, alternating with dm-thick sand and silty sand levels. A 0.30 m thick tephra layer is very well preserved at a depth of -36.60 m, allowing to refer this sediments to the *Fosso di Genzano Synthem* (Fig. 4.43d). The base of this synthem is located at about -56 m (674 m a.s.l.), in correspondence with the lowermost gravel bed containing volcanic material. In addition, below this level, down to -200 m (530 m a.s.l.), the PB1 shows inclined layer, usually dipping between 10° to 15°, with higher values for the conglomerates in relation to depositional mechanism (clinostratification). This portion of the PB1, which is 144 m-thick, consists of thick beds of very well-cemented, mainly clast-supported, conglomerates and breccias, often with imbricated clasts, referable to fluvial, proximal alluvial fan, and talus environments. These sediments are interlayered with thinly laminated whitish to pinkish silt and silty sand layers, showing oxidized surfaces. These fine-grained deposits contain ostracods and mollusks. Starting from -107 m (623 m a.s.l.), massive to laminated grey clays and silts, containing thin lignite levels and/or abundant organic matter deposits, are locally present below the silty-sandy layers and rarely between the coarse deposits.

Considering the absence of volcanic materials, the tilting of the deposits, the presence of lignite levels and the paleontological indications (see section 4.3.2), the deposits below -56 m depth can be referred to the *Madonna della Strada Synthem*, here formed mainly by coarse-grain proximal alluvial fan and fluvial facies.

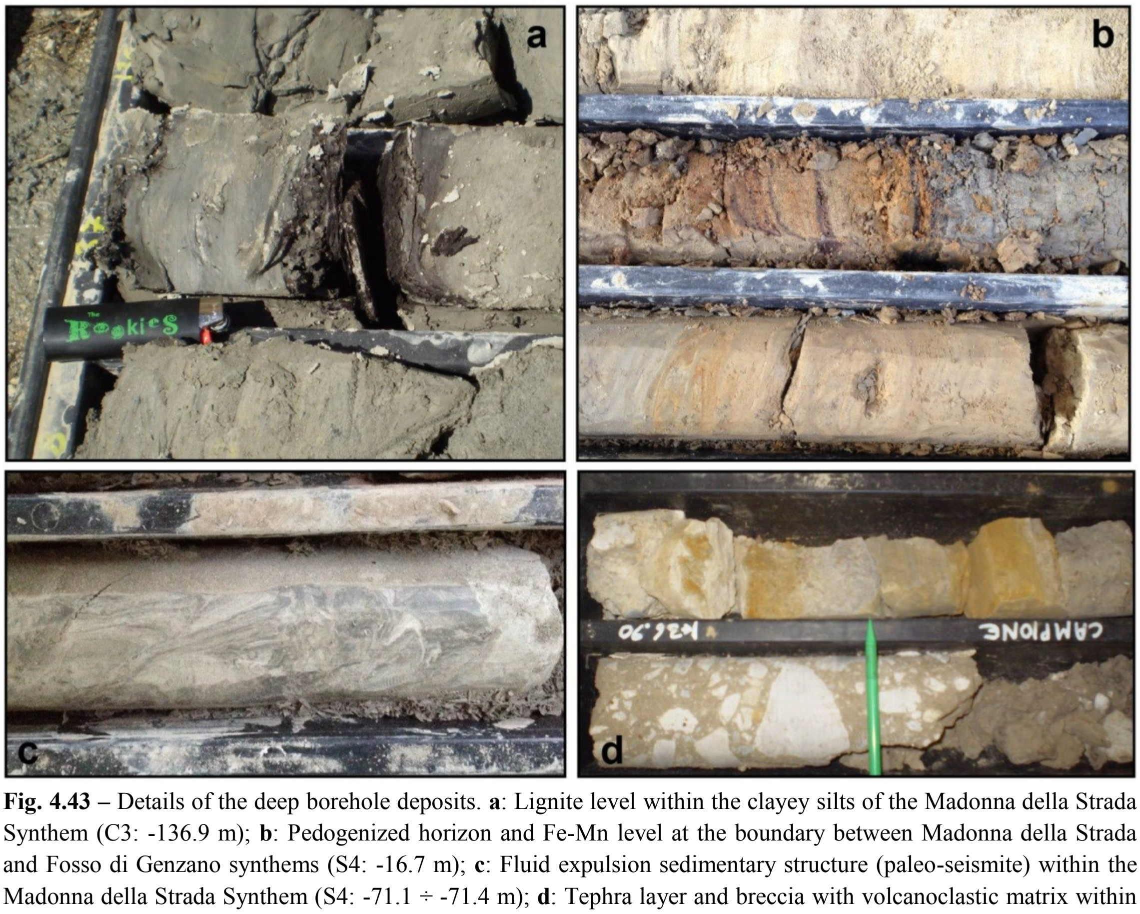


Fig. 4.43 – Details of the deep borehole deposits. **a**: Lignite level within the clayey silts of the Madonna della Strada Synthem (C3: -136.9 m); **b**: Pedogenized horizon and Fe-Mn level at the boundary between Madonna della Strada and Fosso di Genzano synthems (S4: -16.7 m); **c**: Fluid expulsion sedimentary structure (paleo-seismite) within the Madonna della Strada Synthem (S4: -71.1 ÷ -71.4 m); **d**: Tephra layer and breccia with volcanoclastic matrix within the Fosso di Genzano Synthem (PB1: -36 ÷ -37 m).

4.4.4 Well logs analysis

Taking into account the stratigraphy of the described deep boreholes, a comprehensive review of the available well logs (> 400 wells) has been carried out to define the lithology and the geometry of the basin fill, as well as to reconstruct the depth variation of the bedrock through the basin and the thickness changes of the AB synthems.

This was done separately for the ASB and PSC Basin because in the western part of the L'Aquila Basin boreholes are well distributed and a sufficient number of them reach the bedrock, while eastward of L'Aquila Hill boreholes are concentrated in the urbanized areas, often close to the basin boundary, and hardly ever they drilled the bedrock.

Well logs analysis shows rapid changes of the bedrock depth, resulting in the occurrence of subsurface ridges within the basin (see profiles C-C', D-D' in Fig. 4.44, 4.45), as well as rapid changes of thickness and facies of the AB Plio-Quaternary deposits, which reflect the intense deformation that occurred in the area during and after the onset of the L'Aquila intermontane basin.

The *San Demetrio-Colle Cantaro Synthem* was drilled in almost all of the wells except for the boreholes between the L'Aquila Hill and the Bazzano-Monticchio ridge (e.g., S46 in Fig. 4.44; S80, S57, S59 in Fig. 4.45), as well as the borehole drilled near the Collettara ridge (e.g., S31 in Fig. 4.44) or those located close to San Gregorio and Fossa Stazione (e.g., S70, S82 in Fig. 4.45). This synthem shows its maximum thickness close to the basin margins, ranging from ca. 70 m (e.g., S28, S1 in Fig. 4.44) in the western part of the ASB, to more than 100 m in the eastern sector of the PSC Basin (e.g., S97 in Fig. 4.45), whereas in the central part of the AB it seem to be absent (e.g., S28, S1 in Fig. 4.44). The *San Demetrio-Colle Cantaro Synthem* is extensively cut by faults (Paganica-San Demetrio Faults System), as testified by the tectonic displacement, more than 200 m, between the deposits entrenched beneath the present valley floor and those uplifted in the Castelnuovo-Civitaretenga plateau (see profile D-D' in Fig. 4.45).

Well logs highlight the presence of the *Madonna della Strada Synthem* in all the boreholes drilled in the ASB, lying above an irregular surfaces carved both in the Meso-Cenozoic bedrock and the *San Demetrio-Colle Cantaro Synthem*. This surface is related to the erosive phase and to the regional tectonics (mainly uplift event) that affected the AB close to the Gelasian/Calabrian transition, resulting in an highly variable thickness of the *Madonna della Strada Synthem* all over the basin. This synthem shows thickness about 70 m (S28 in Fig. 4.44), in the western ASB, that reduces to 10-20 m toward the central part of the basin to increase again between the L'Aquila Hill and the Bazzano-Monticchio ridge (see profile C-C' in Fig. 4.44). In this area boreholes mark the existence of a deep depocenter, with a maximum thickness of the *Madonna della Strada Synthem* from well S80 (Collemaggio3 in Fig. 4.41), which drilled 215 m (see profile B-B', D-D' in Fig. 4.44, 4.45) of fine-grained deposits referable to alluvial plain environments.

On the contrary, in the PSC Basin only the boreholes drilled within the Aterno floodplain, contain sediments, few meters thick, that could be related to the *Madonna della Strada Synthem*, such as grey clayey silts, lignite levels or organic rich clays (e.g., S69, S72, S86, S100, S101, 103 in Fig. 4.45). The impossibility for a direct checking of the sediment cores of those boreholes makes impossible to confirm the existence of the *Madonna della Strada Synthem* in the PSC Basin.

The presence of this synthem mainly in the ASB could be related to the existence, during the Calabrian, of the Bazzano-Monticchio threshold, controlled by the NE dipping Bazzano-Fossa Fault, that dammed this part of the AB, trapping huge amount of sediments within this portion of the basin.

As already pointed out by deep boreholes analyses, the *Madonna della Strada Synthem* shows different lithofacies within the basin. The boreholes drilled in the northern and western part of the ASB (e.g., S28, S1, S23 in Fig. 4.44), as well as those drilled in the Campo di Pile area (e.g., S8, S43 in Fig. 4.44), mostly show fine-grained deposits mainly referable to marshy and swamp environments, whereas those drilled close to the L'Aquila Hill (e.g., S45, S46, S80 in Fig. 4.44, 4.45) are mainly from alluvial plain, and close to fluvial channel environment those located in the eastern part of the ASB (e.g., S59 in Fig. 4.44; L'Aqui-core in Fig. 4.41).

Deposits belonging to the *Fosso di Genzano Synthem* are present in all the wells of the PSC Basin, except for those located in the footwall of the Paganica-San Demetrio Fault System (e.g., S91, S96, S97 in Fig. 4.45), entrenched beneath the present-day valley floor and often covered by younger synthems. It shows a quite regular, scoop-shaped, base and an homogeneous thickness of about 20-30 m with the maximum values (ca. 40 m) in correspondence with the Raiale alluvial fan (see profiles D-D', E-E' in Fig. 4.45). In the ASB the *Fosso di Genzano Synthem* is not present in the boreholes drilled in the western sector (e.g., S28, S1, S23 in Fig. 4.44), while in the rest of the basin it was found discontinuously and with reduced thicknesses (see profile A-A', B-B' in Fig. 4.44).

Close to L'Aquila Hill and surrounding areas, this synthem is overlaid by the coarse-grained deposits of the *Colle Macchione-L'Aquila Synthem*, as evidenced by wells S17, S18, S45, S66, S80 (Fig. 4.44, 4.45). The presence of such deposits above the *Fosso di Genzano Synthem* confirms the field observations, and help to constrain the stratigraphic position of the *Colle Macchione-L'Aquila Synthem*.

The stratigraphic relationships among the Middle-Late Pleistocene synthems of the AB fill are illustrated by well S17 (Fig. 4.44), drilled close to the San Salvatore Hospital.

Apart from the *Aterno Synthem* alluvial and colluvial sediments that characterize the first meters of almost all boreholes, the Late Pleistocene synthems were only sporadically drilled in the whole AB. Due both to their reduced thickness and the similarities between their deposits, the *Fosso Vetoio* and *Campo di Pile* synthems were mainly distinguished taking into account geomorphological considerations, such as fluvial terrace order (e.g., S8, S17, S20, S87, S100 in Fig. 4.44, 4.45) or alluvial fan order (e.g., S66, S68, S76, S104 in Fig. 4.45).

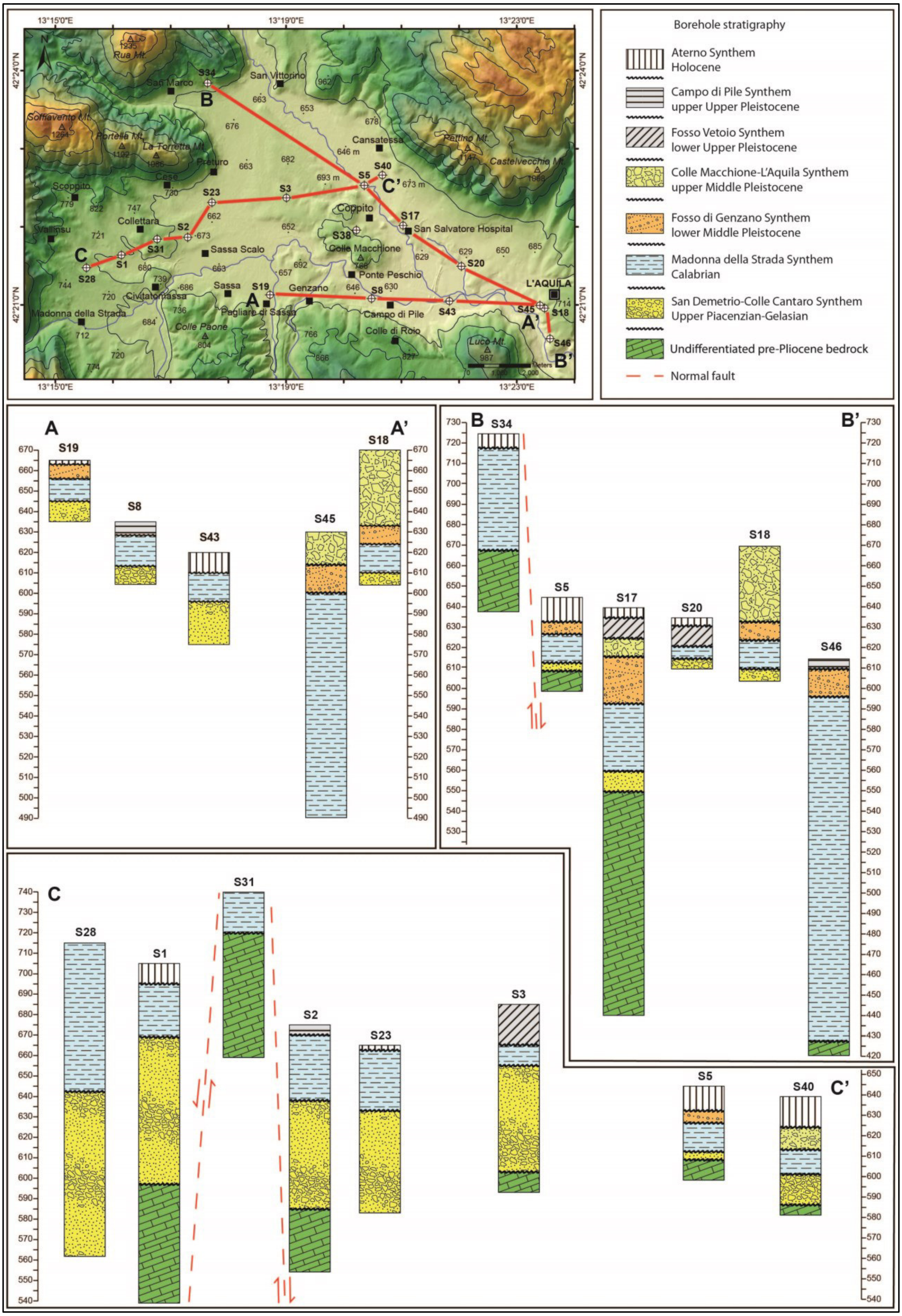


Fig. 4.44 – Selected well logs from the western L'Aquila-Scoppito Basin. The selected stratigraphies show both the depth variation of the bedrock throughout the basin and the thickness changes of the ASB synthems.

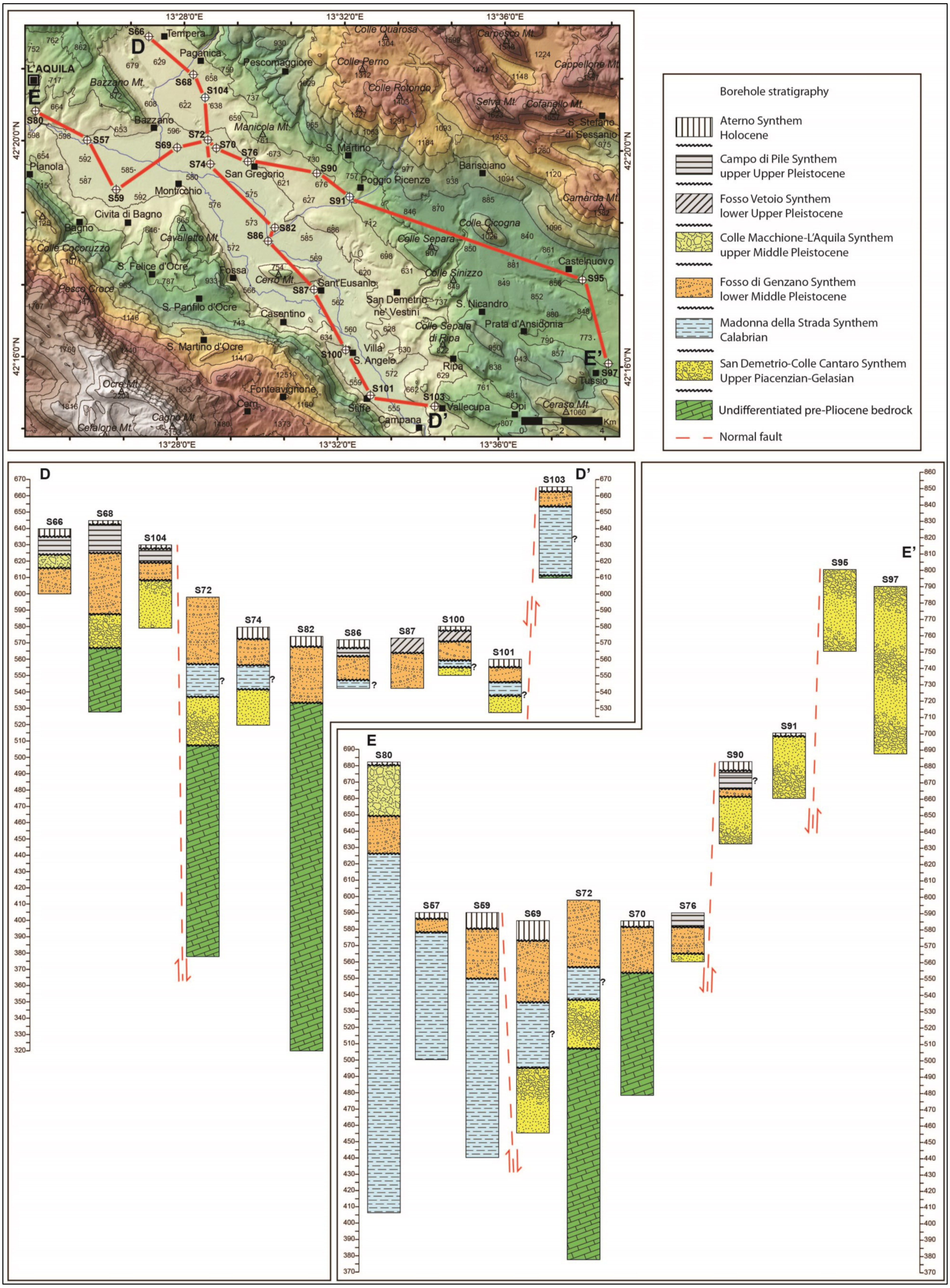


Fig. 4.45 – Selected well logs from the eastern L'Aquila-Scoppito Basin and the Paganica-San Demetrio-Caselnuovo Basin. The selected stratigraphies show both the depth variation of the bedrock throughout the basin and the thickness changes of the AB synthems.

5.0 DISCUSSION

5.1 Remarks on the San Demetrio-Colle Cantaro Synthem

Important results for reviewing both the creation of the L'Aquila Basin and the correlation among the basin filling deposits, come from the ostracod assemblages of the lacustrine facies of the *San Demetrio-Colle Cantaro Synthem (Castelnuovo Sub-synthem,)*, which show the occurrence of twelve ostracod species ascribed to nine genera, six of which are new species (see section 4.3.1.1) (Spadi et al., 2015).

Among the new species the most diverse genus is *Caspiocypris*, which is represented by four new species (*C. amiterni* sp. nov., *C. bosii* sp. nov., *C. nicandroi* sp. nov. and *C. vestinae* sp. nov.), particularly abundant in the *San Nicandro Formation*. It is followed by *Ilyocypris*, with one new species (*I. ilae* sp. nov.), dominant in the *Valle Orsa Formation*, and *Cypria*, represented by a few specimens of *C. bikeratia* sp. nov. which occur in both formations (Fig. 4.12, 4.13).

The peculiar composition of this ostracod association, characterized mainly by new species, indicates that the San Nicandro Palaeolake was an isolated environment in which endemic speciation was enhanced.

One more peculiarity of the PSC ostracod association is that it shows greater affinity with genera and/or species of the Paratethyan realm (*Caspiocypris*, *Cypria* and *Amnicythere*) than with the non-marine ostracod faunas of central and western Europe. This contrasts with the pattern seen in other Italian Pliocene and early Pleistocene assemblages (Ambrosetti et al. 1995; Barberi et al. 1995; Fubelli et al. 2008; Bellucci et al. 2012, 2013). In particular, the ostracods of the San Nicandro Palaeolake are very different from the ostracod assemblage recovered in the L'Aquila-Scoppito Basin (ASB) within the younger deposits of the *Madonna della Strada Synthem* (early Pleistocene, Calabrian), cropping out at the BAR 20 section. This latter assemblage contains very few candonids (*Candona neglecta* Sars and *Pseudocandona marchica* (Hartwig)) and is dominated by *Ilyocypris bradyi* Sars, followed by some *Cyprididae* (*Eucypris dulcifrons* Diebel & Pietrzeniuk, *Eucypris pigra* (Fischer) and *Potamocypris zschokkei* (Kaufmann)) and *Paralimnocythere messanai* Martens (Fig. 4.20). All of the listed species show a clear Palearctic or Holarctic distribution and were widely distributed in central and western Europe since the early Pleistocene (Meisch 2000).

Differently, *Caspiocypris*, the dominant genus of the San Nicandro Palaeolake, is well represented mainly in the eastern European Paratethyan domain, with few Paratethyan *Caspiocypris* species occurring in the Mediterranean area since Upper Miocene (Gliozzi & Grossi, 2008; Cosentino et al., 2012).

In Italy, *Caspiocypris* was also recorded with Pliocene-Pleistocene endemic species: *Caspiocypris sambucensis* (Medici, Ceci & Gliozzi) from the Early Pliocene of the Valdelsa Basin (Medici et al. 2011) and five as-yet-undescribed new species from the late Piacenzian-Gelasian *Fosso Bianco Formation* in the Tiberino Basin (Medici & Gliozzi 2008). Like the San Nicandro Palaeolake, the Tiberino Palaeolake was considered to be an isolated environment that gave rise to a "*Caspiocypris*" species flock (Medici & Gliozzi 2008) and, because of its long duration as a stable lacustrine environment, was interpreted as a fossil 'ancient' lake (*sensu* Gorthner 1994).

For this reason, we suggest a correspondence between the lake deposits of the *Castelnuovo Sub-Synthem (San Demetrio-Colle Cantaro Synthem)* (PSC Basin) with the lacustrine succession of the *Fosso Bianco Formation* (Tiberino Basin), constraining the *Castelnuovo Sub-Synthem (San Demetrio-Colle Cantaro Synthem)* to the late Piacenzian-Gelasian (Fig. 5.1). In contrast, previous authors pointed to Calabrian or late Gelasian times for the oldest deposits of the L'Aquila Basin (Fig. 2.2) (Bertini & Bosi, 1993; Centamore & Dramis, 2006, 2010; Giaccio et al., 2012).

According to the paleoenvironmental reconstruction based on the location of the deep lacustrine sediments (*San Nicandro Fm.*) (Fig. 4.2), the San Nicandro Paleolake had an elongated shape NW-SE oriented, with a length of at least 20 km and a maximum width of 7-8 km. The lake extended from Paganica-San Gregorio villages, to the north, to Civitaretenga, to the south (Fig. 2.1b), on a surface of about 100 km^2. It is possible to state that during the late Piacenzian-Gelasian the PSC Basin was largely occupied by the San Nicandro Paleolake. The Gilbert-type delta (*Valle Orsa Fm.*) (Fig. 4.7) with 30-50 m thick foresets, prograding from N-NW into the San Nicandro Paleolake, developed on equally high-submerged escarpments (Basilici, 1997). This indicates that nearby the margins the lake was at least 50 m deep. However, it is possible to suppose that distally the lake was deeper, as suggested by the dominance of *Caspiocypris*. The lake margins were characterized by steep coastlines, as demonstrated by the coarse and disorganized slope-related sediments at the basin boundaries (*Valle Valiano Fm*) (Fig. 4.10).

The paleomorphological characteristics inferred for the San Nicandro Paleolake suggest that its origin and evolutive history was strongly controlled by tectonics in a rapid subsiding basin. The extensional tectonics responsible for the earliest evolution of the sedimentary basin acted along NW-SE trending normal faults (i.e. the SW dipping Barisciano-San Pio Fault) at the northeastern boundary of the PSC Basin (Fig. 2.1). In fact, the lacustrine marginal deposits (*Valle Valiano Fm., Madonna della Neve Fm.*) of the *San Demetrio-Colle Cantaro Synthem* are generally arranged along these tectonic features.

The San Nicandro Paleolake was progressively filled by both the (biogenic-bioinduced) calcareous silt of the *San Nicandro Fm.* and the southeastward prograding delta deposits of the *Valle Orsa Fm.*

Before the Gelasian-Calabrian boundary the lacustrine system disappeared, or was strongly reduced only to the western part of the PSC Basin, as testified by the unconformity, mainly recorded in the eastern sector of the PSC Basin, between the *Castelnuovo Sub-Synthem* and the fluvial deposits of the *Valle dell'Inferno Sub-synthem* (Fig. 4.7, 4.12).

According to Giaccio et al. (2012), this process was driven by the progressive migration of the faults activity from the eastern (Barisciano-San Pio Fault) to the westernmost structures (Colle Cicogna, San Demetrio faults) and/or by the breach of the basin threshold, probably located in correspondence of the N-S Prata-Fontecchio Fault, related to the activity of the Middle Aterno faults (Galadini & Galli, 2000; Falcucci et al., 2011).

Close to the Gelasian-Calabrian transition the PSC Basin underwent a strong erosional phase (tectonic uplift), probably linked to the 260 m relative sea-level drop which occurred at the Tyrrhenian margin of the central-northern Apennines (Fig. 5.1) (Cosentino et al. 2009), that led to the abandonment of the Valla Daria surface, the complete emptying of the San Nicandro Paleolake and the entrenching of the drainage network within it.

As stated before, the San Nicandro Paleolake occupied the entire PSC Basin, while in the ASB no lacustrine environment developed during late Piacenzian-Gelasian and this part of the AB was filled by the clastic deposits of the *Colle Cantaro-Cave Fm* (Fig. 4.14). They were grouped into the *San Demetrio-Colle Cantaro Synthem* and considered coeval because, according to seismic-reflection profiles and well-log analyses (Fig. 4.39, 4.44, 4.45), the *Colle Cantaro-Cave Fm.* was deposited in a syn-rift stage, like the late Piacenzian-Gelasian deposits of the PSC Basin. Moreover, the angular unconformity developed, in the ASB, between the *Colle Cantaro-Cave Fm.* and the Calabrian *Madonna della Strada Synthem*, could be correlated to the abandonment surface of the *Valle dell'Inferno Sub-synthem* [Valle Daria (ca. 850 m a.s.l.)] (Fig. 4.12, 5.1), that close the *San Demetrio-Colle Cantaro Synthem* in the PSC Basin.

In conclusion, during the formation of the *San Demetrio-Colle Cantaro Synthem*, the ASB and PSC were two separated basins, divided by a basement threshold, possibly located in correspondence with the Bazzano-Monticchio Ridge and controlled by the Bazzano-Fossa NE dipping normal fault, as also evidenced by seismic-tomography profiles (Improta et al., 2012).

5.2 Development of the extensional intermontane basins in Central Italy

The absence of outcrops of the oldest sedimentary filling of extensional intermontane basins in Central Italy, together with the scarcity of biochronologically and/or geochronologically well-constrained stratigraphic successions, make the attempt to define the timing of their initial development challenging, if not impossible. However, using the age of the youngest thrust-top basin of the study area (*Conglomerati di Rigopiano Auct.*), we can establish that the maximum age for the onset of the extensional deformation is the Zanclean/Piacenzian transition (ca. 3.59 Ma).

According to Giaccio et al. (2012) the early stage of basin development for the eastern part of the L'Aquila Basin (PSC Basin) is as old as 2 Ma (Gelasian, lowermost Early Pleistocene), whereas Cavinato & De Celles (1999) suggested a Selinuntian age (lower Early Pleistocene, <1.8 Ma) for the onset of extension. In the western part of L'Aquila Basin (ASB), the *Basal Conglomerates* (Mancini et al., 2012), corresponding to the basal infilling of ASB (*Colle Cantaro-Cave Synthem*, Centamore and Dramis, 2010), are attributed by Mancini et al. (2012) to the lowermost Early Pleistocene (Gelasian), and dubitatively to the Upper Pliocene (Piacenzian) (Fig. 2.2). Centamore & Dramis (2010) tentatively correlated the *Colle Cantaro-Cave Synthem* with the Lower Villafranchian

Mammal Age, that is Upper Pliocene (Piacenzian) (Fig. 2.2). These contrasting ages demonstrate that the timing of the L'Aquila basal basin-filling is still a matter of debate.

To try to reduce these uncertainties, we have attempted to regionally correlate the stratigraphy and tectonic setting of the L'Aquila Basin with those of other intermontane basins of the central Apennines [Tiberino Basin (Basilici 1995; 1997), Rieti Basin (Cosentino et al., in press)] and their possible relation with the Plio-Quaternary relative sea-level changes of the Tyrrhenian Sea [Plio-Quaternary succession of Rome and neighbouring areas (Cosentino and Fubelli, 2008; Cosentino et al., 2009)] (Fig. 5.1).

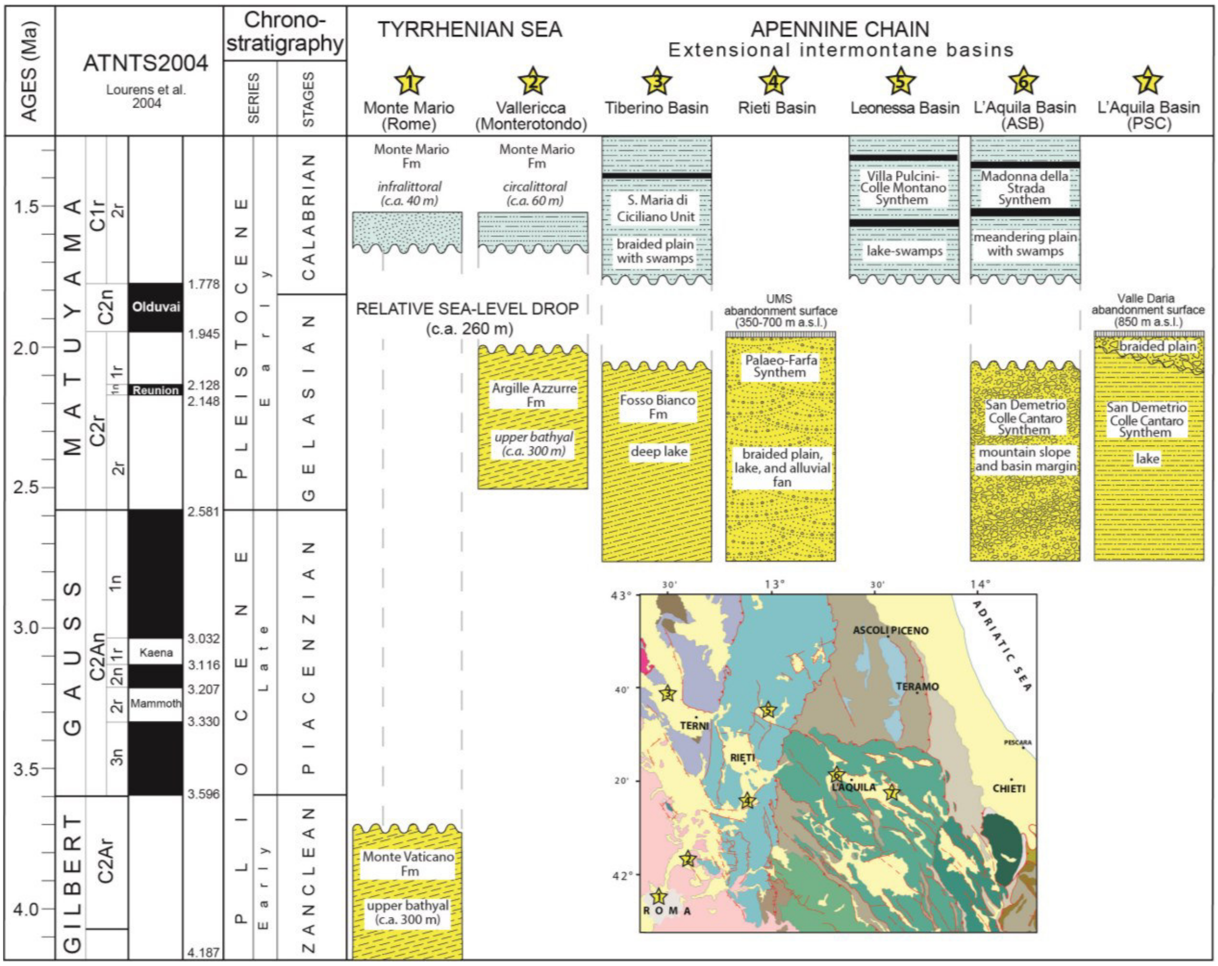


Fig. 5.1 – Correlation panel among different Pliocene-Early Pleistocene stratigraphic sections from the Roman area and the main intermontane basins discussed in the text. The relative sea-level drop of ca. 260 m at the Gelasian/Calabrian transition correlates the major stratigraphic discontinuities detected both in the Roman area and in the intermontane basins of the central Apennines. UMS=Monteleone Sabino Unit.

As stated before, in the L'Aquila Basin, the oldest deposits pertain to the *San Demetrio-Colle Cantaro Synthem*. Due to the presence, in the PSC Basin (*Castelnuovo Sub-synthem*), of a "*Caspiocypris*" species flock similar to those recognized in the *Fosso Bianco Formation* (Medici and Gliozzi, 2008) of the Tiberino Basin (Basilici 1995; 1997; Napoleone et al., 2003), the *San Demetrio-Colle Cantaro Synthem* has been related to the late Piacenzian-Gelasian (Fig. 5.1). Thus, a late Piacenzian age for the onset of deposition in both the L'Aquila and Tiberino basins is suggested.

A late Piacenzian age for the onset of the extension in the L'Aquila Basin contrast with the geodynamic model proposed by Cavinato & De Celles (1999), according to which a 2-4 Ma lag time interposed between the last thrusting events and the onset of the extension in Central Apennines. In fact, in the study area the last compressive events occurred at 3.59 Ma, less than 1 Ma (ca. 600 ka) before the formation of the *San Demetrio-Colle Cantaro Synthem*.

In the Tiberino Basin, above the lake sediments a strong angular unconformity separates the *Fosso Bianco Formation* from the Lower Pleistocene deposits related to braided and marshy alluvial plains (*S. Maria di Ciciliano Unit*) (Basilici, 1995; 1997). This younger unit bears large mammal faunas referable to the *Olivola*, *Tasso*, and *Farneta Faunal Units* (uppermost Gelasian-Calabrian p.p.) (Sardella et al., 2003). The *S. Maria di Ciciliano* deposits (Tiberino Basin) are correlatable with the Calabrian deposits of the *Madonna della Strada Synthem* (L'Aquila Basin) (Fig. 5.1).

Similarly, in the L'Aquila Basin, the *Madonna della Strada Synthem* is carved into the abandonment surface of the *San Demetrio-Colle Cantaro Synthem* (i.e. Valle Daria at 850 m a.s.l.), which regionally corresponds to the abandonment surface of the Gelasian *Monteleone Sabino Unit* (*Paleo-Farfa Synthem*) in the Rieti Basin (Fig. 5.1) (Cosentino et al., 2009; Fubelli et al., 2014; Cosentino et al., in press). The Gelasian abandonment surface of both the L'Aquila and Rieti intermontane basins, as well as the angular unconformity between the *Fosso Bianco* and the *S. Maria di Ciciliano* units (Fig. 5.1), were triggered by the 260 m relative sea-level drop (tectonic uplift + glacio-eustatism) that occurred close to the Gelasian/Calabrian transition at the Tyrrhenian margin of the central Apennines, as evidenced by the Plio-Quaternary succession in the Rome area (Fig. 5.1) (Cosentino and Fubelli, 2008; Cosentino et al., 2009).

Summing up, the *San Demetrio-Colle Cantaro Synthem* constrains the onset of the extension in the L'Aquila Basin, to the late Piacenzian time interval, whereas the strong tectonic uplift occurred in central Italy close to the Gelasian/Calabrian transition (Cosentino et al., 2009) is responsible for both the angular unconformity at the base of the *Madonna della Strada Synthem* in the ASB and the abandonment of the Valle Daria surface in the PSC Basin (Fig. 5.1).

5.3 Paleoenvironmental reconstructions and Large Mammal age constraints for the Madonna della Strada Synthem

According to previous authors (Magri et al., 2010; Agostini et al., 2012; Mancini et al., 2012), during the Pleistocene, the L'Aquila Basin was a large lake. Nonetheless, except for the Upper Piacenzian-Gelasian *San Demetrio-Colle Cantaro Synthem* (Spadi et al., 2015), no lacustrine environments were recognized within the Pleistocene deposits of L'Aquila Basin.

According to the ostracod and mollusc assemblages from the *Madonna della Strada Synthem* (BAR20 section) (Fig. 4.16, 4.20), coupled with both the outcrops and boreholes (S1, S4 CERFIS; Collemaggio1, 2, 3) (Fig. 4.17, 4.18, 4.41) lithostratigraphy of the Early Pleistocene deposits of ASB (*Madonna della Strada Synthem*), which shows at least 5 horizons of lignite, the fine-grained deposits of the *Madonna della Strada Synthem* can be referred to floodplains with extended swamp areas close to meandering fluvial channels. This interpretation is also supported by the presence, in the western ASB, of buried paleovalleys, mainly filled by the *Madonna della Strada Synthem*, as revealed by the Bedrock Isobath Map (Fig. 4.40). The showed subsurface morphology is definitely more referable to a fluvial environment than to a lacustrine one.

Thus, during the Early Pleistocene (Calabrian), the ASB environment was quite similar to that developed in the Tiberino and Leonessa basins during the deposition of the Early Pleistocene *S. Maria di Ciciliano Unit* and *Villa Pulcini-Colle Montano Synthem* (Fig. 5.1) (Basilici, 1995; 1997; Fubelli et al., 2008). In fact all these units are characterized by sandy clayey deposits, containing lignite seams and very similar ostracod assemblages.

The analysis of pollen grains from the fine-grained deposits of the Santarelli quarry (*Madonna della Strada Synthem*) suggests the occurrence of a forest phase corresponding to a warm interglacial period (MIS 37 or 35; Magri et al., 2010). However, the occurrence of *Eucypris dulcifrons* in the ostracod assemblage from the BAR 20 section, which is typical of the cold climate assemblages of the Pleistocene glacial intervals (Fuhrmann et al., 1997; Fuhrmann, 2012), points to the occurrence of a cold climate phase. These observations are therefore consistent with Early Pleistocene glacial/interglacial climate changes in the intermontane L'Aquila Basin, likely forced by the cyclical variation of the Earth's orbital obliquity (e.g., 41 kyr cycle).

According to Magri et al. (2010), the rich fauna of large mammals (including a complete skeleton of *Mammuthus meridionalis*) (Maccagno, 1958, 1962, 1965; Magri et al., 2010; Mancini et al., 2012) and small vertebrates (Kotsakis, 1988; Esu et al., 1992) discovered at the Santarelli quarry point to the latest Villafranchian *Farneta* or *Pirro FU*, whereas Mancini et al. (2012) referred those faunas both to the *Pirro* and *Colle Curti FU* (latest Villafranchian to earliest Galerian Mammal Ages). In addition, recent findings of a non-advanced form of *Mammuthus meridionalis* and of scanty material referable to *Equus* sp. and to a large-sized cervid from the upper part of the *Madonna della Strada Synthem* at BAR 20 section (Campo di Pile) were considered by Agostini et al. (2012) to possibly pertain to the *Colle Curti FU* (earliest Galerial Mammal Age). In contrast, our large mammal findings within the BAR 20 section (Fig. 4.21), together with those reported in Agostini et al. (2012) for the same locality, suggest an age referable to the *Pirro FU*, or slightly younger, but definitely older than the *Colle Curti FU* (Fig. 2.2).

Both Early Pleistocene large mammal sites from the ASB (Santarelli quarry and BAR 20 section) are from the uppermost part of the *Madonna della Strada Synthem*, very close to the boundary with the Middle Pleistocene *Fosso di Genzano Synthem*. Thus, the age constraints from the large mammals should be referred to the uppermost part of the *Madonna della Strada Synthem*.

Paleomagnetic results from the S1 and S4 CERFIS boreholes (Fig. 4.41)reveal a general reverse polarity for the *Madonna della Strada Synthem,* constraining its age to the Early Pleistocene. The normal polarity samples from the lower part of both boreholes had to be considered with caution, due to the presence of remagnetization processes in magnetite-bearing samples from the *Madonna della Strada Synthem* (Cosentino et al., submitted), analogously to other Tertiary sections in the Mediterranean area (Lucifora et al., 2012).

5.4 Late Pleistocene river incision rates from the ASB

During the Late Pleistocene a series of erosional, depositional and tectonic events, coupled with the persistence of a fluvial system within the L'Aquila Basin, generated three order of fluvial terraces, generally better preserved in the ASB (Fig. 5.2).

These terraces belong to the *Fosso Vetoio* (T1) and *Campo di Pile* (T2) synthems, with the youngest one corresponding to the *Ponte Peschio Sub-synthem* (T3).

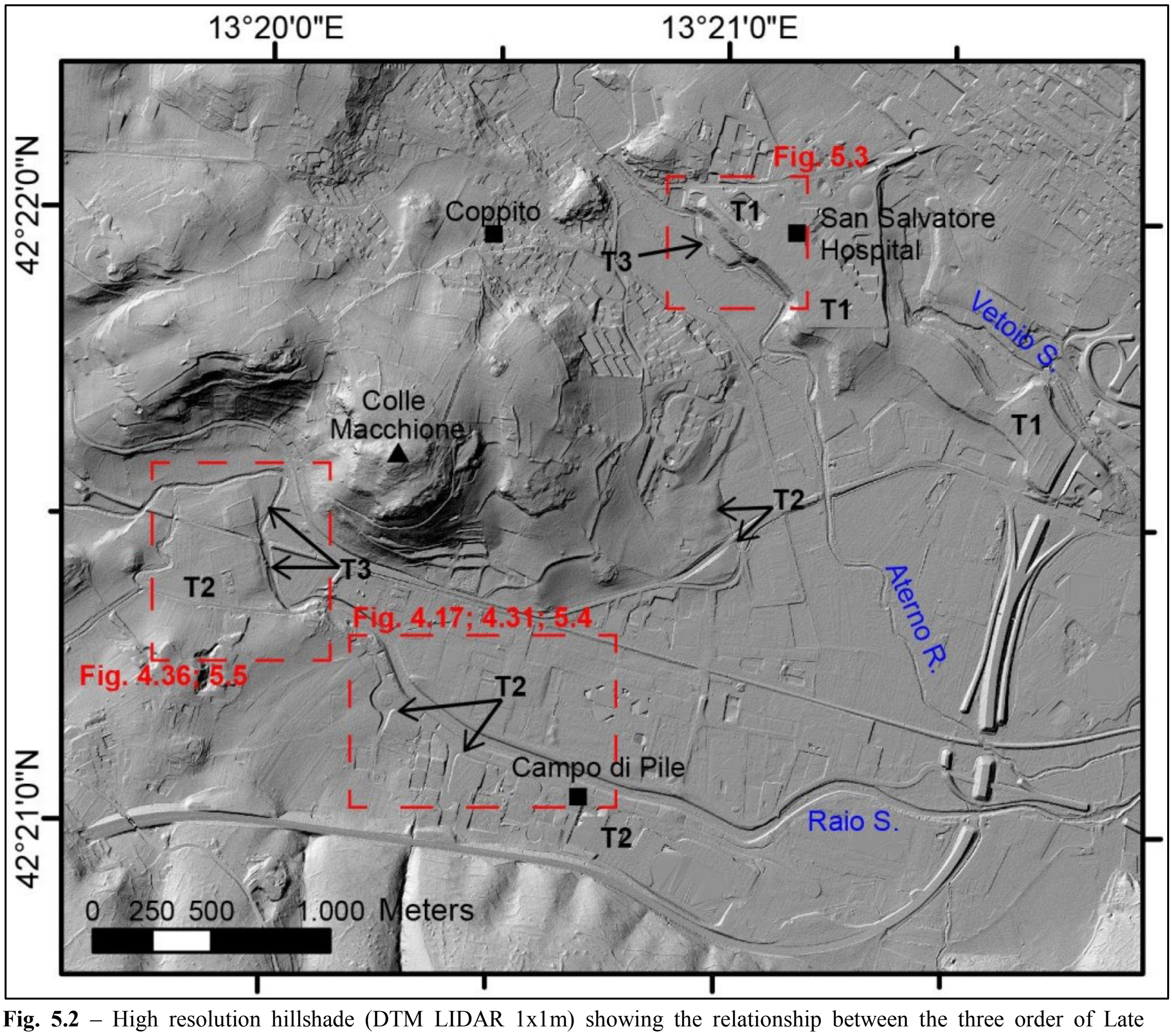


Fig. 5.2 – High resolution hillshade (DTM LIDAR 1x1m) showing the relationship between the three order of Late Pleistocene fluvial terraces in the ASB.

Using the ^{14}C age obtained for the *Campo di Pile Synthem*, a river incision rate was determined for the second order terrace of the ASB. We considered the elevation difference between the treads to be the reliable expression of the elevation change for the entire set of terraces instead of the difference between the straths, as properly used for base level computations, because two of them are strath terraces and for the other one (T1) is hard to define the base elevation, because it is rarely exposed.

In addition, assuming a constant river incision rate for the L'Aquila-Scoppito Basin, during late Quaternary, the obtained incision rate was used to evaluate a possible age for the *Fosso Vetoio Synthem* and *Ponte Peschio Sub-synthem*.

The first order of fluvial terrace (T1) (Fig. 5.3, 4.26c), belonging to the *Fosso Vetoio Synthem*, is a fill terrace carved into both the *Colle Macchione-L'Aquila Synthem* (upper Middle Pleistocene) and the *Madonna della Strada Synthem* (Calabrian). Its top surface is preserved near both the L'Aquila airport and the S. Salvatore hospital (Fig. 5.2), approximately at 20-25 m above the present thalweg of the Aterno River. As reported in section 4.3.5, remnants of the T1 terrace are preserved also in the PSC Basin, where they lie at higher elevations, probably due to tectonic uplift. For this reason the T1 terraces of the PSC Basin were not considered to estimate the age of the *Fosso Vetoio Synthem*.

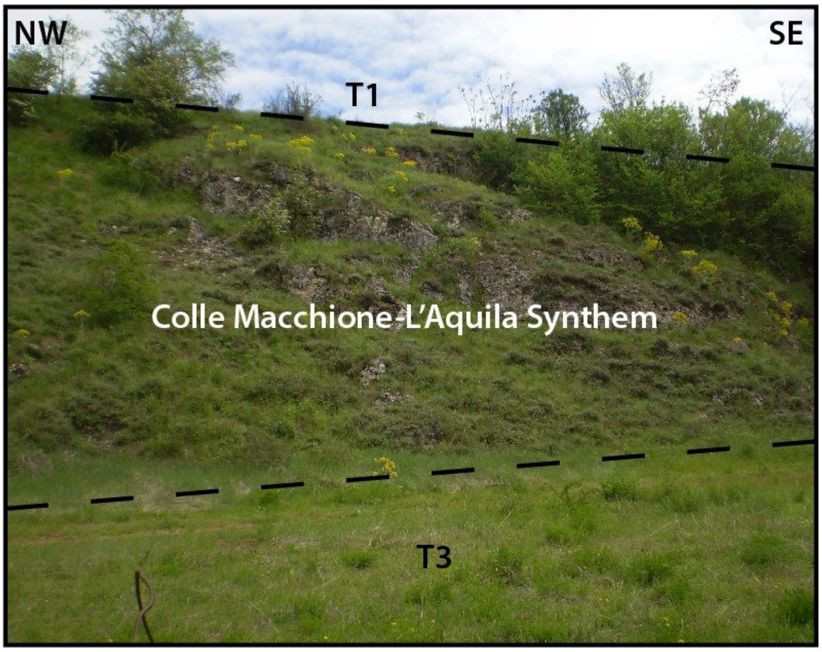


Fig. 5.3 – T1 (Fosso Vetoio Synthem) top surface carved into the Colle Macchione-L'Aquila Synthem and T3 fluvial terrace (Ponte Peschio Sub-synthem) entrenched into previous synthems (i.e., San Salvatore hospital).

The abandonment surface of the wandering (braided) fluvial deposits of the *Campo di Pile Synthem* forms the second order of terrace (T2) of the ASB (Fig. 4.17, 4.31a, 5.4). This is interpreted as a strath terrace, embedded into the T1 terrace and carved into both the previous synthems and the pre-Quaternary bedrock. In the ASB the abandonment surface of the T2 fluvial terrace, well-preserved in the Campo di Pile area (Fig. 5.2, 5.4, 5.5) and close to L'Aquila jail, lies at elevations ranging between 10-13 m above the thalweg of the Raio Stream.

Charcoaled plant remains (Pile4 sample) (Fig. 4.35) found within a sandy layer of the *Campo di Pile Synthem*, 1 m below the T2 top surface, gave a ^{14}C 2σ age of 41854-40464 yr cal BP (MIS 3).

Basing on this age and considering the T2 terrace maximum and minimum elevations, we calculated a river incision rate for the second order fluvial terrace ranging between 0.24 and 0.32 mm/yr. These rates are similar to the incision rate (0.3–0.35 mm/yr) established by Pucci et al.

(2014b) for the Upper Tiber Valley and to estimates of sediment yield (0.12–0.44 mm/yr), river incision (0.35 mm/yr), and uplift (0.01−1.0 mm/yr) rates inferred from other methods, for the northern and central Apennines since the Early Pleistocene (Cyr and Granger, 2008).

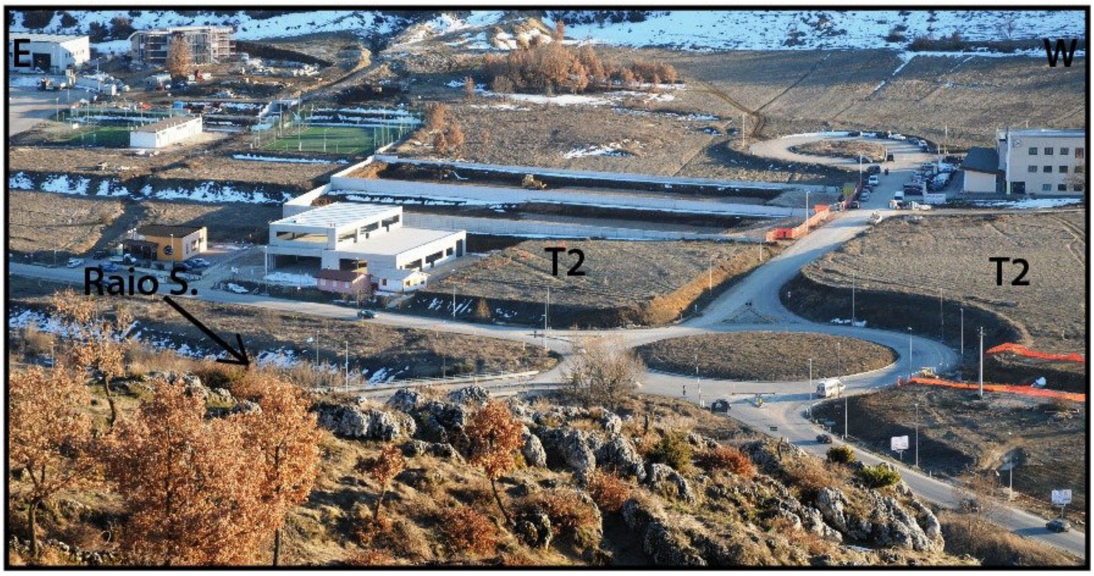


Fig. 5.4 – Panoramic view of the T2 fluvial terrace (Campo di Pile Synthem) at Campo di Pile (i.e., BAR20 section).

The youngest order of fluvial terrace (T3) is formed by small remnants of a flat surface belonging to the *Ponte Peschio Sub-synthem*. This terrace, mainly erosive and preserved only in the ASB, lies 5-7 m above both the Raio and Aterno thalwegs (Fig. 4.36, 5.5). The T3 terrace is embedded into the *Fosso Vetoio Synthem* (T1) and carved into the *Colle Macchione-L'Aquila Synthem*, near the S. Salvatore hospital (Fig. 5.2), while at Ponte Peschio it is embedded into the *Campo di Pile Synthem* (T2) and is carved directly into the pre-Pliocene bedrock (Fig. 5.5). Thus, due to the erosive character of this surface, also the T3 may be interpreted as a strath terrace.

Fig. 5.5 – Panoramic view of the T2 (Campo di Pile Synthem) and T3 (Ponte Peschio Sub-synthem) fluvial terraces at Ponte Peschio.

To try to estimate the age of the T1 and T3 fluvial terraces we assume a steady incision rate from Late Pleistocene to Present. We calculated an age of 71–89 ka for T1 and of 18–25 ka for T3, allowing to correlate the *Fosso Vetoio Synthem* and *Ponte Peschio Sub-synthem* to MIS5a and MIS2.

5.5 Tectonostratigraphic evolution of L'Aquila Basin and surrounding regions

The first phase of basin filling in the L'Aquila Basin occurred during the late Piacenzian-Gelasian interval (*San Demetrio-Colle Cantaro Synthem*). In the eastern part of the basin (PSC Basin) lacustrine and delta deposits gave way to transitional deposits and carbonate slope breccias towards the lake margins (*Castelnuovo Sub-Synthem*); finally the establishment of a braided fluvial environment close the initial phase of deposition (*Valle dell'Inferno Sub-synthem*). In the western part of the basin (ASB), slope-derived breccias, debris flow deposits, and alluvial clayey-sandy conglomerates characterized the first phase of basin filling (*Colle Cantaro-Cave Fm.*) (Fig. 5.1). We interpret the Pettino 1 seismic reflection profile (Fig. 4.39) to show a wedge-shaped seismic unit (seismic facies R, syn-rift stage) in the basal portion of the ASB filling, just below the reflectors referable to the *Madonna della Strada Synthem* (seismic facies L). This basal seismic unit correlates with the *Colle Cantaro-Cave Fm.* (Upper Piacenzian-Gelasian p.p.), belonging to the *San Demetrio-Colle Cantaro Synthem*, which was deposited during the syn-rift stage of the ASB, defining the onset of the extension responsible for the development of the L'Aquila intermontane basin.

The Pettino 1 seismic reflection profile (Fig. 4.39) shows an asymmetric intermontane basin with thicknesses of the basin fill increasing towards the Pettino Mt. fault zone, responsible for the development of the basin. The angular unconformity separating the *San Demetrio-Colle Cantaro* and the *Madonna della Strada* synthems defines the boundary between the syn-rift and post-rift stages of the basin (first phase and second phase of basin fill). We suggest that the abandonment of the Valle Daria surface, the complete emptying of the San Nicandro Paleolake, the entrenching of the *Madonna della Stada Synthem* within the *San Demetrio-Colle Cantaro Synthem*, and the formation of the relative angular unconformity are related to the regional tectonics (mainly uplift event) that, close to the Gelasian/Calabrian transition, was responsible for a ca. 260 m relative sea-level drop at the Tyrrhenian margin of the Central Apennines (Fig. 5.1) (Cosentino et al., 2009).

The second phase of L'Aquila Basin filling, which occurred during the Calabrian, was mainly characterized by the development of a fluvial environment, with floodplains and extensive swamp areas close to meandering fluvial channels (*Madonna della Stada Synthem*) (Fig. 5.1).

A Calabrian depocenter, more than 215 m deep (Collemaggio3 in Fig. 4.41, S80 in Fig. 4.45), was located in the western L'Aquila Basin, in between the L'Aquila Hill, Colle Macchione, and the Pettino active Fault. The Pettino 1 seismic profile, as well as the Bedrock Isobaths Map and the well-logs analyses (Fig. 4.39÷4.45), show variable thicknesses of the deposits that can be referred to the *Madonna della Strada Synthem*, pointing to a highly irregular top of the substratum during the post-rift stage of the AB. The huge thickness of this synthem in the ASB is probably also related to the existence, during the Calabrian, of the Bazzano-Monticchio threshold, controlled by the NE dipping Bazzano-Fossa Fault, that dammed this part of the AB, trapping huge amount of sediments within this portion of the basin. Inversely the absence or reduced thickness of the *Madonna della Stada*

Synthem in the PSC Basin, could reveal that during the Calabrian the Campana threshold was open, justifying the strong erosion underwent by this part of the AB during this stage.

The geometric relationships between the basin fill and the fault planes also show, in the ASB, a northeastward migration of the fault deformation toward the present-day Pettino active Fault at the northern margin of the basin. In fact, whereas in the southern part of the Pettino 1 seismic profile some faults are sealed by the seismic facies L (*Madonna della Strada Synthem,* Calabrian), moving towards the Pettino Mt. slope, they become sealed by the seismic facies BC (*Colle Macchione-L'Aquila Synthem,* upper Middle Pleistocene) and AD (youngest deposits of the ASB filling, Upper Pleistocene), while, finally, the Pettino active Fault cuts through the AD seismic facies (Fig. 4.39).

After the two major phases of basin filling, the L'Aquila intermontane basin was affected by five shorter tectono-sedimentary events. Those events gave rise to the deposition of Middle and Upper Pleistocene unconformity-bounded stratigraphic units (Fig. 2.2, 5.6), with the younger unit carved into the previous ones or even into the pre- or syn-orogenic successions. Tectonically driven variations of the local base level and/or climate changes were responsible for the Middle to Upper Pleistocene stratigraphic evolution of the L'Aquila Basin. The derived synthems are progressively entrenched each other and, in the PSC Basin, they lie in the hangingwall of the youngest faults (PSDFS), testifying a progressive migration of faulting toward the inner part of the PSC Basin (Giaccio et al., 2012; Blumetti et al., 2013).

The *Fosso di Genzano Synthem*, carved into the previous synthem or the pre- and syn-orogenic successions, is mainly related to the distal portions of alluvial fans, laterally passing to braided alluvial plains (Fig. 4.22). This synthem is well constrained to lower Middle Pleistocene by the appearance of mammalian taxa typical of the Italian early to middle Galerian faunas, earlier than the *Isernia La Pineta Faunal Unit* (Fig. 2.2) (Palombo et al., 2010), as well as by the occurrence of volcanic rocks with a $^{39}Ar/^{40}Ar$ age of 520 ± 5 ka, in the ASB (Gaeta et al., 2010), and ranging from 561 ± 2 ka (PAG-t1) to 365 ± 4 ka (PAG-t4) in the PSC Basin (Galli et al., 2010). Due to geochronological, geomorphological, paleontological and paleoenvironmental similarities it can be related to the *Casale Giannantoni* and the *Leonessa* synthems, outcropping in the Rieti and Leonessa basins, respectively (Fubelli et al., 2008; Cosentino et al., in press). The *Fosso di Genzano Synthem* widely outcrops and is well correlated in the whole AB, testifying that, since at least the lower Middle Pleistocene, the ASB and PSC Basin were definitively connected and no threshold interrupted the fluvial system forming the *Fosso di Genzano Synthem*. According to different authors, the regressive erosion that led to the connection of the different sectors of the Aterno Valley is related to the fast uplift phase occurred at the end of the Early Pleistocene (Demangeot, 1965; Dramis, 1992; Bosi et al., 2003; Centamore et al., 2003; Galadini et al., 2003).

The occurrence of an arid climate phase, possibly linked to a late Middle Pleistocene glacial event, was responsible for the partial erosion of the *Fosso di Genzano Synthem* and the formation of the *Colle Macchione-L'Aquila Synthem* (Fig. 4.22d, 4.23, 4.25). The latter is mainly characterized by carbonate breccia and megabreccia deposits supplied by lithofacies outcropping to the north of the L'Aquila Basin and related to debris flow and rock avalanche originated from the Gran Sasso Range. For the relative stratigraphic position of this synthem with respect to the Upper Pleistocene deposits of the AB, this glacial event could correlate with MIS 6 or MIS 8 (Fig. 2.2, 5.6).

This cold and arid phase, responsible for the formation of the huge amount of heterometric clastic deposits of the *Colle Macchione-L'Aquila Synthem*, was followed by a wet and warm early Late Pleistocene interglacial stage (MIS 5e, Eemian), that formed the paleosol and karst deposits at the upper boundary of this synthem.

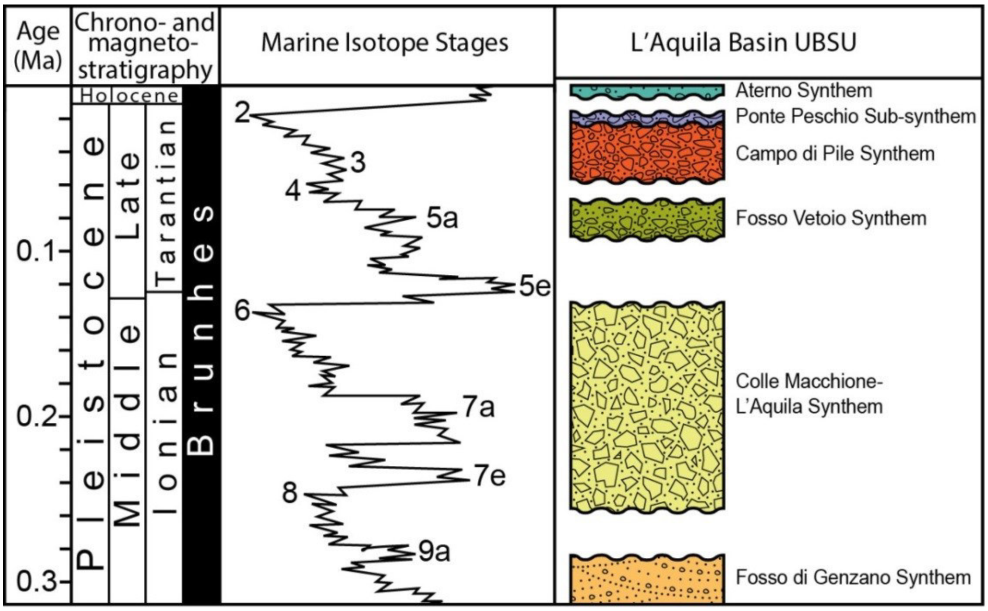


Fig. 5.6 – Middle-Late Pleistocene UBSU of the L'Aquila Basin.

The Upper Pleistocene *Fosso Vetoio* and *Campo di Pile* synthems, the latter comprising the *Ponte Peschio Sub-synthem*, represent the late Quaternary evolution of the L'Aquila Basin (Fig. 2.2, 5.6). At that time the AB was mainly characterized by confined fluvial systems, in narrow alluvial braided plains, and alluvial fan systems, at the basin margins, both formed by channelized gravel deposits related to the Aterno River and to its main tributary (i.e., Raio and Raiale streams).

The *Fosso Vetoio Synthem* is carved into the *Colle Macchione-L'Aquila Synthem* and forms the first order of Late Pleistocene fluvial terrace (T1) (Fig. 5.2, 5.3), interpreted as a fill terrace, very well preserved upstream of the L'Aquila Hill, while downstream it is represented by small isolated remnants, with few or absent deposits. This difference could be, tentatively, related to the presence, in correspondence of the L'Aquila Hill, of the *Colle Macchione-L'Aquila Synthem*, acting as a temporary threshold between the western and eastern L'Aquila Basin. As reported in section 5.4, a possible age of 71-89 ka (MIS 5a) was estimated for the *Fosso Vetoio Synthem*.

An erosional phase followed the formation of the *Fosso Vetoio Synthem* cutting the older deposits and forming a strath terrace (T2), belonging to the *Campo di Pile Synthem* (Fig. 5.2, 5.4). Charcoaled plant remains recovered from the *Campo di Pile Synthem* gave a ^{14}C 2σ age of 41854-40464 yr cal BP (Fig. 4.35), in agreement with findings of Mousterian lithic industry (Middle Paleolithic) inside the gravels of this synthem and with OSL dating indications (Fig. 4.32, 4.34). This age allows to constrain the T2 strath terrace to MIS 3 (Fig. 5.6) and to calculate a river incision rate between 0.24 and 0.32 mm/yr, which is consistent with the Quaternary incision rate estimated for the central-northern Apennines (Cyr & Granger, 2008; Pucci et al., 2014).

After the formation of the *Campo di Pile Synthem*, another erosional phase occurred in the L'Aquila Basin, leading to the formation of the *Ponte Peschio Sub-synthem*, represented by a strath terrace (T3), mainly erosive and entrenched into the previous terraces or the Meso-Cenozoic bedrock (Fig. 5.5). This is the youngest order of fluvial terrace in the AB and is likely referable to tectonic uplift coupled with the cold LGM climate (MIS 2). In fact, assuming a steady incision rate from Late Pleistocene to Present, the *Ponte Peschio Sub-synthem* corresponds to MIS 2 (18-25 ka) (Fig. 5.6).

The last infilling stage, bringing to the *Aterno Synthem*, comprise Holocene deposits and is related to the erosional and depositional processes still active in the L'Aquila Basin, which have been forming the present basin floor and the pediment belt at the base of the slopes at the basin margins.

5.6 New insights into the evolution of the Apennine post-orogenic extensional domain

Our results showing the same age (late Piacenzian, ca. 3 Ma) for the onset of the Tiberino and L'Aquila basins (Fig. 5.1) call into question previous suggestions that the onset of these extensional intermontane basins becomes younger from the Tyrrhenian towards the Adriatic side of the central Apennines (Cavinato and De Celles, 1999; Galadini and Messina, 2004). Indeed, according to the syn-rift ages of the intermontane basins across the northern and central Apennines, only two major extensional domains can be recognized: 1) the late Miocene Syn-Rift (LMSR), which includes all the late Miocene extensional basins in Tuscany (Liotta, 1996; Pascucci et al., 1999; Brogi, 2006); and 2) the late Pliocene to the lowermost Pleistocene Syn-Rift (LPSR), which in the central Apennines possibly includes all the intermontane basins from Tiberino to the Sulmona Basin (Fig. 5.7).

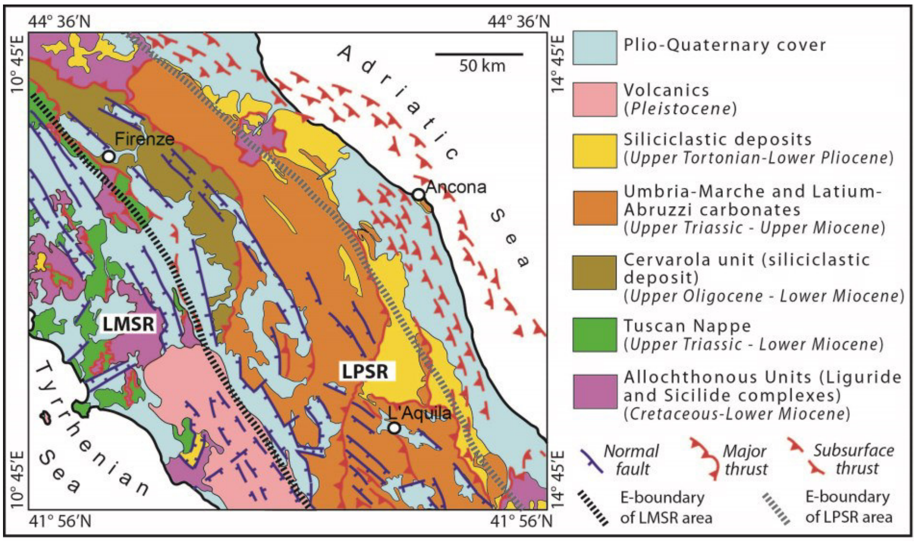


Fig. 5.7 – Geological map of central-northern Italy with extension of the post-orogenic syn-rift domains. LMSR – Late Miocene Syn-Rift area (data from: Liotta, 1996; Pascucci et al., 1999; Brogi, 2006) ; LPSR – Late Pliocene to the lowermost Pleistocene Syn-Rift area (data from: Collettini and Barchi, 2002; Pucci et al., 2014; this thesis).

Our results also challenge the time gap between compression and extension that has been used to reconstruct a seismotectonic model for central Italy; this model assumes that extensional deformation migrated eastward ca. 2 Ma after the Apennine compressional front (Lavecchia et al., 1994). Although this temporal evolution of deformation could be true for L'Aquila Basin, for the Tiberino Basin, which records late Serravallian (ca. 12 Ma) compressional deformation (Belvedere-Vallocchia thrust-top basin, Cipollari & Cosentino, 1997) and a late Pliocene-early Pleistocene syn-rift stage (Collettini & Barchi, 2002; Pucci et al., 2014b), the time gap between compression and extension is much longer (ca. 9 Ma) (Fig. 5.8b).

The different time gaps between compressional and extensional deformation could indicate a decoupling of processes responsible for (1) the migration of the compressional front toward the foreland (i.e, convergence and roll-back of the subducting plate; e.g., Doglioni et al., 1997; Funiciello et al., 1999; Faccenna et al., 2001), (2) the development of the hinterland extensional domain and back-arc basin formation, as well as (3) the uplift of the compressional tectonic wedge and intermontane extensional basin formation (i.e, mantle upwelling; Dewey, 1988; Doglioni, 1995; Cavinato and De Celles, 1999; D'Agostino et al., 2001) (Fig. 5.8).

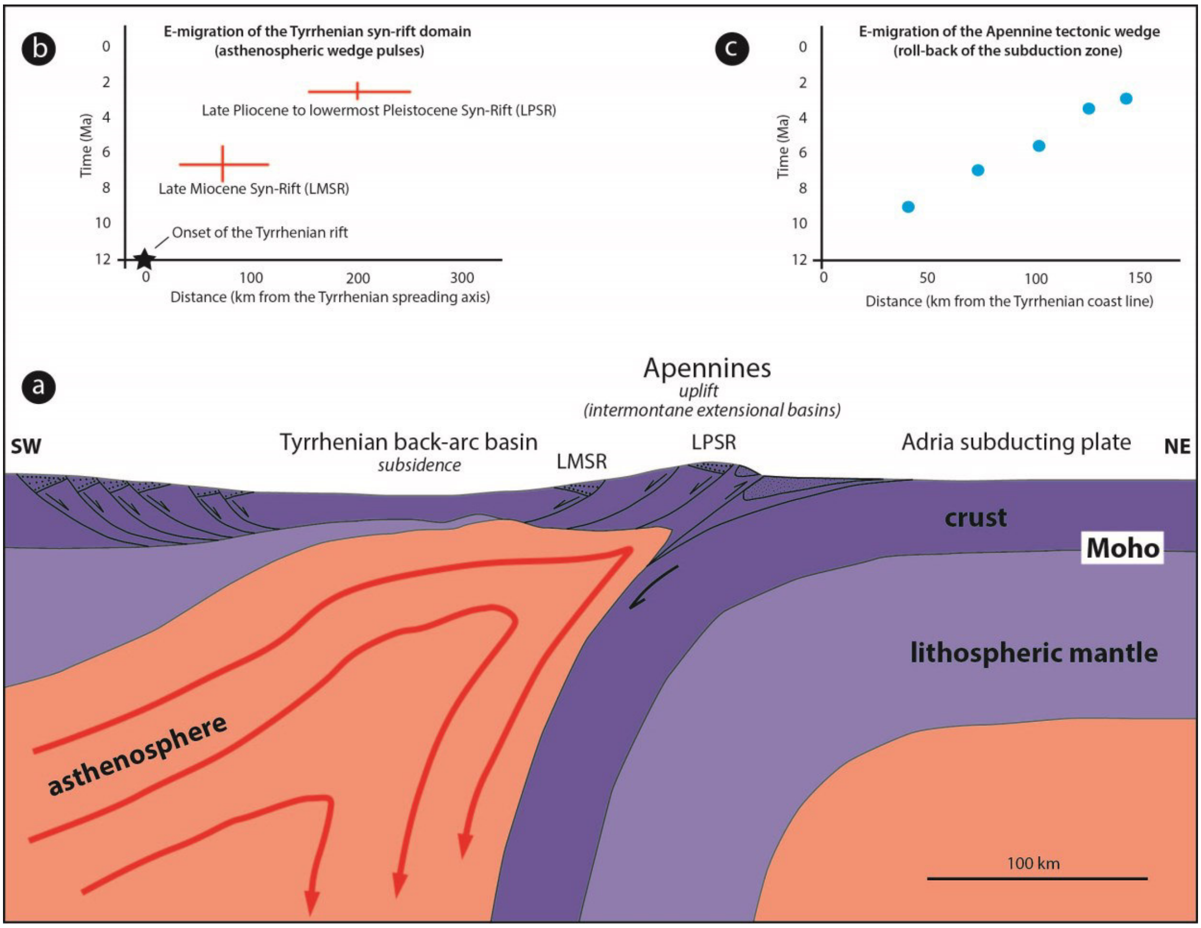


Fig. 5.8 – In an eastward migrating subducting system, such as the Apennine orogenic system (a), although both the Tyrrhenian syn-rift domain (b) and the Apennine tectonic wedge (c) migrate toward the foreland, their migration is not in phase. During the Tortonian-Pliocene migration of the Apennine orogenic system, four episodes of Apennine tectonic wedge formation (c, data from: Patacca et al., 1992; Cosentino et al., 2010) correspond only to two Tyrrhenian syn-rift stages (b, data from: Liotta, 1996; Pascucci et al., 1999; Collettini and Barchi, 2002; Brogi, 2006; Pucci et al., 2014; this thesis), possibly evidencing a decoupling between the roll-back of the subduction zone and the episodes of mantle upwelling in the Tyrrhenian area.

6.0 CONCLUSIONS

The comparison between the tectono-stratigraphic evolution of L'Aquila Basin and other intermontane basins (i.e., Tiberino, Rieti, Leonessa basins) (Fig. 5.1), allows us to identify some similarities that help to constrain the major regional events of the AB geological history.

Ostracod assemblages from the *San Demetrio-Colle Cantaro Synthem* (Fig. 4.12, 4.13) allow us to suggest that the lacustrine deposits of the *Castelnuovo Sub-synthem* (*San Nicandro Fm.*; *Limi di S. Nicandro Auct.;* PSC Basin) correlate with the late Piacenzian-Gelasian *Fosso Bianco Formation* of the Tiberino Basin.

In the western part of the L'Aquila Basin (ASB), deposits correlating with this first phase of basin filling pertain to the *Colle Cantaro-Cave Fm.* [*San Demetrio-Colle Cantaro Synthem* (Upper Piacenzian-Gelasian)]. The Pettino 1 seismic reflection profile (Fig. 4.39), which is close to the northern margin of the ASB (southern Pettino Mt. slope), shows wedge-shaped seismic facies and progressive angular unconformities characterizing the older basin fill of the western L'Aquila Basin (i.e., the *Colle Cantaro-Cave Fm.*). These observations are consistent with a late Piacenzian-Gelasian syn-rift stage, which was responsible for the development of the L'Aquila extensional intermontane basin.

The occurrence of the *San Demetrio-Colle Cantaro*/*Madonna della Stada* angular unconformity (western L'Aquila Basin) and the abandonment surface of Valle Daria at the top of the *San Demetrio-Colle Cantaro Synthem* (eastern L'Aquila Basin) can be related, respectively, to the *Fosso Bianco*/*S. Maria di Ciciliano* angular unconformity (Tiberino Basin) and the abandonment surface at the top of the Gelasian *Monteleone Sabino Unit* (Rieti Basin). All these features are possibly related to the 260 m relative sea-level drop, mainly due to tectonic uplift, which occurred at the Tyrrhenian margin of the central-northern Apennines close to the Gelasian/Calabrian transition (Cosentino et al., 2009).

No lake environments developed in the L'Aquila Basin after the Gelasian/Calabrian unconformity (*Madonna della Strada Synthem*). During the Calabrian stage, floodplains with extended swamp areas close to meandering fluvial channels developed in the L'Aquila Basin. Our new large mammal findings from the BAR20 section (Fig. 4.16), coupled with previously reported mammalian fauna from the Santarelli quarry (Magri et al., 2010) and the BAR20 section (Campo di Pile, Agostini et al., 2012), point to an age referable to the *Pirro FU*, or slightly younger, but definitely older than the *Colle Curti FU* (Fig. 2.2).

The main active fault of the extensional fault system responsible for the onset of the L'Aquila intermontane basin migrated from southwest to northeast, in the ASB, and from (north)east to (south)west, in the PSC Basin, reaching the present position of the active Pettino Fault and the Paganica-San Demetrio Fault System (Giaccio et al., 2012), respectively.

Since the early Middle Pleistocene the ASB and PSC Basin were definitively connected and no threshold interrupted the "paleoAterno" fluvial system flowing through the L'Aquila Basin, as testified by the presence of the *Fosso di Genzano Synthem* all over the basin.

This synthem is well constrained to lower Middle Pleistocene by the appearance of mammalian taxa typical of the Italian early to middle Galerian faunas, earlier than the *Isernia La Pineta Faunal Unit* (Palombo et al., 2010) (Fig. 2.2), as well as by the occurrence of volcanic rocks (Gaeta et al., 2010; Galli et al., 2010). Outside the L'Aquila Basin, it can correlate the *Casale Giannantoni* and the *Leonessa* synthems, outcropping in the Rieti and Leonessa basins, respectively (Fubelli et al., 2008; Cosentino et al., in press).

The breccia and megabreccia deposits of the *Colle Macchione-L'Aquila Synthem* (*Brecce dell'Aquila Auct.*) overlie the *Fosso di Genzano Synthem* (Fig. 4.23, 4.25). The coarse-grained deposits of the *Colle Macchione-L'Aquila Synthem* are related to debris flows and rock avalanches originated from the northern margin of the L'Aquila Basin, likely during a late Middle Pleistocene glacial event that could correlate with MIS 6 or MIS 8 (Fig. 5.6).

The Late Pleistocene evolution of the L'Aquila Basin was characterized by the development of three order of fluvial terraces (T1, T2, and T3) (Fig. 5.2), two of which are strath terraces (T2 and T3). The second order terrace belongs to the *Campo di Pile Synthem* and correlates MIS 3, since it shows a ^{14}C 2σ age of 41,854-40,464 yr cal BP. From this age, a late Quaternary river incision rate between 0.24 to 0.32 mm/yr was calculated. In addition, assuming these incision rates to be constant for the L'Aquila Basin from late Pleistocene to Present, we estimate ages of 71-89 ka (MIS 5a) and 18-25 ka (MIS 2) for the *Fosso Vetoio Synthem* (T1) and the *Ponte Peschio Sub-synthem* (T3), respectively (Fig. 5.6).

Our results showing the same age for the onset and subsequent evolution of L'Aquila, Tiberino and Rieti basins call into question previous suggestions that the onset of these extensional intermontane basins becomes younger moving from the Tyrrhenian towards the Adriatic side of the central Apennines (Cavinato & De Celles, 1999), suggesting the existence of two major extensional domains in the northern-central Apennines: a western Late Miocene syn-rift area and an eastern Late Pliocene-Early Pleistocene (Gelasian) syn-rift area (Fig. 5.7, 5.8).

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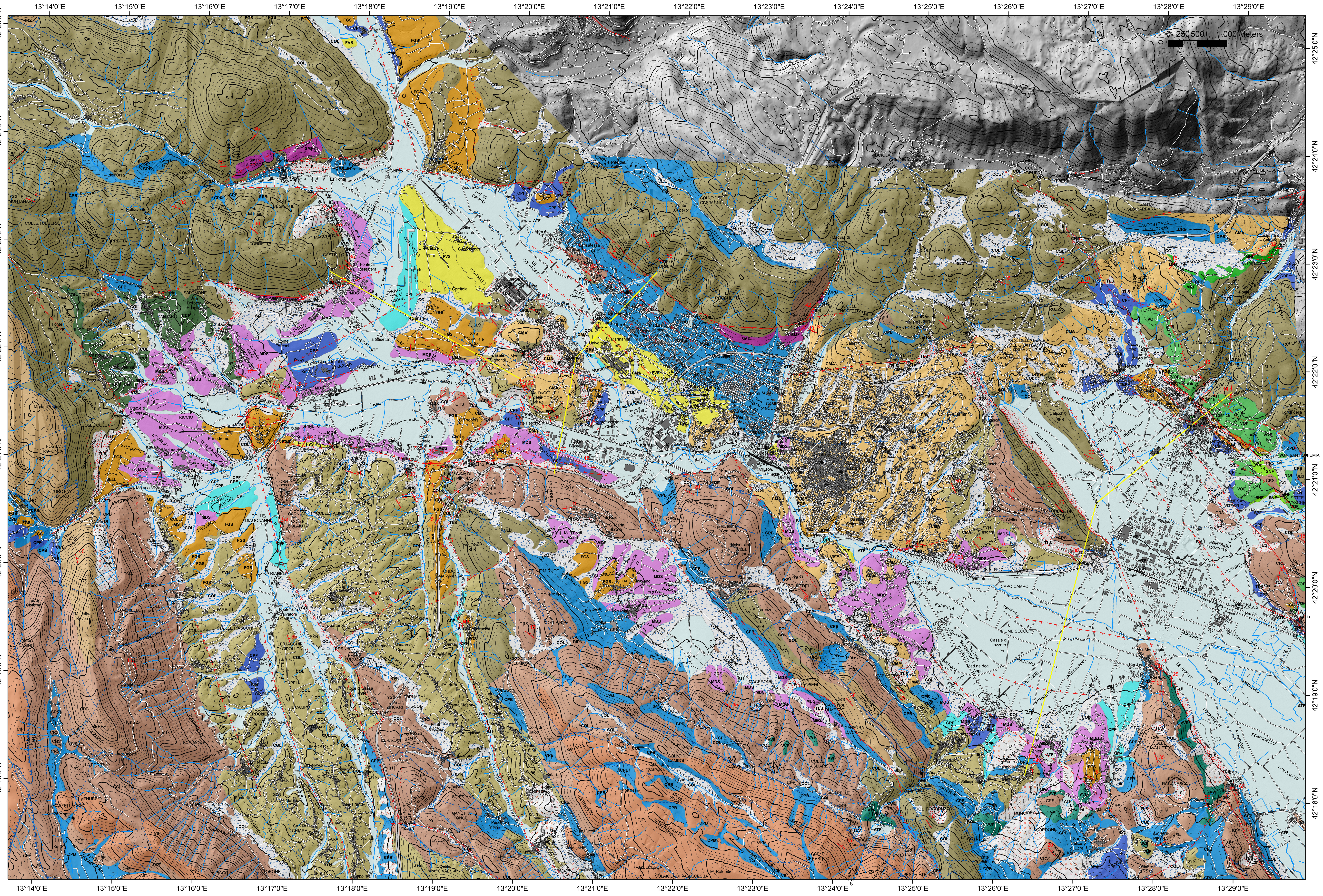
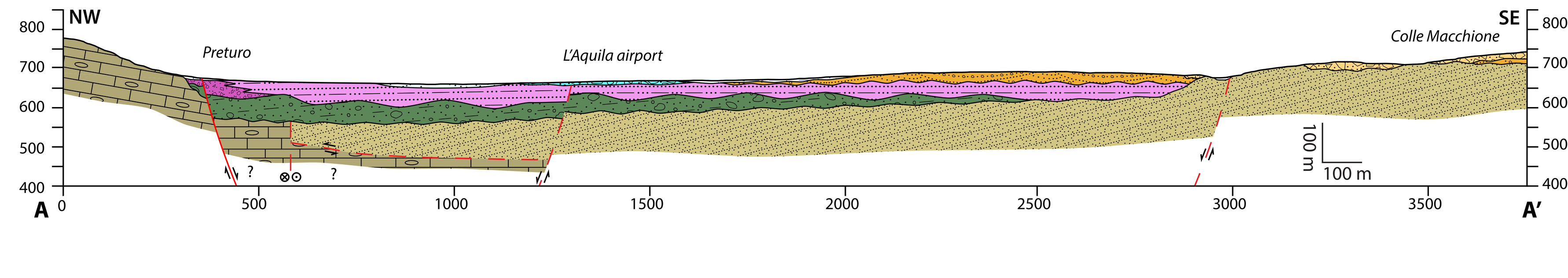
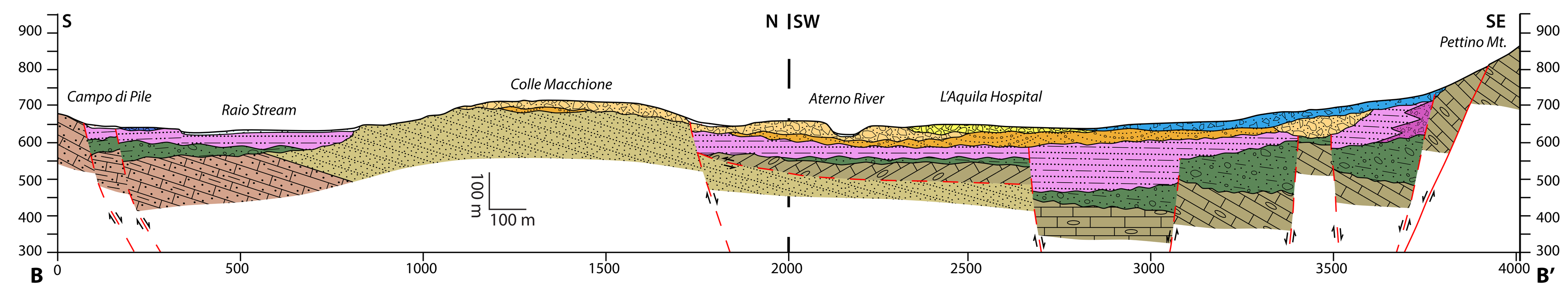
Quaternary Geological Map of the L'Aquila-Scoppito Basin (western L'Aquila Basin) (Italy) (1:25.000)







Author: Dr. Marco Nocentini

Legend

Post-orogenic Succession

ATERNO SYNTHEM (Holocene)

ATF Medium to fine, well-sorted, sub- to well-rounded loose sandy gravel beds, with horizontal, planar and trough cross-bedding, alternating with levee/overbank medium sand and silty sands bedforms, horizontal or planar cross-stratified, locally passing to overbank laminated clayey silt thin layers and lenses. Pebbles are imbricated and composed by limestones, cherts, bauxites and rare pottery fragments.
Fluvial and alluvial fan deposits of the Aterno River and its main tributary.

COL Massive to poorly stratified browinish-reddish sandy silts and silty clay, with abundant angular to sub-angular, poorly sorted medium to fine clasts, mainly limestones and cherts with sparse pottery. They contain abundant organic matter, plant remains, pedogenic horizons and volcanic material.
Colluvium deposits derived from the erosion of older soil and soft sediments, downslope transported by solifluction and gravity flow processes.

TLS Loose heterometric, mostly angular calcareous pebbles and boulders with a greyish sandy silty matrix, both clast- and matrix-supported, both chaotic and stratified.
Talus cone and scree deposits mantling the lower part of steep slopes and accumulate at the base of sub-vertical escarpments.

LDS Landslide deposits with variable grain size, both matrix- and clast-supported.

CAMPO DI PILE SYNTHEM (Late Pleistocene, MIS 3)

CPF a b Poorly sorted, sub to well-rounded, clast-supported medium to coarse gravel beds containing an abundant silty sandy matrix and showing both horizontal and trough cross-bedding. Clasts are carbonates, cherts, rarely bauxites and contain lithics and bone artifact of Mousterian industry. Gravels are interlayered and laterally pass to coarse to medium sands and gravelly sand bedforms, with well-preserved planar and trough cross-stratifications, and thin lenses and levels of both massive and laminated silts and clayey silts, occasionally showing plant roots and oxidized surfaces. Charcoaled plant remains within the sands are dated to 40,464–41,845 yr BP.
Gravelly wandering-braided fluvial system defining the second order of Late Pleistocene fluvial terrace (T2) (**a**).
Small and isolated remnants of an erosive flat surface (T3), with absent or very thin alluvial cover, are entrenched into the T2 surface at 5 – 7 m above both the present thalwegs (**Ponte Peschio Sub-synthem, MIS 2**) (**b**).

CPB Well-stratified, moderately sorted, angular to sub-angular, fine to medium carbonate gravel beds, both matrix and clast-supported, occasionally open-work, usually poorly cemented, showing slope-parallel bedding with dipping decreasing from proximal to distal areas. The pale brownish to pinkish silty sandy matrix contain both clayey and volcanic minerals. Sometimes dark brown-reddish pedogenic horizons are interlayered with gravel beds.
Slope-derived, talus and scree deposits.

FOSSO VETOIO SYNTHEM (Late Pleistocene, MIS 5a)

FVS Well-sorted, well-rounded, sub-flattened, clast-supported cemented, fine to medium gravel beds, showing trough cross-bedding and, rarely, horizontal bedding. Gravel beds contain an abundant coarse sandy matrix and grade upward into an alternating sequence of rust planar cross-stratified sands and yellow laminated silts covered by grayish massive coarse sands and silts.
Gravelly-sandy braided fluvial system and relative floodplain forming the first order of Late Pleistocene fluvial terrace (T1).

COLLE MACCHIONE-L'AQUILA SYNTHEM (upper Middle Pleistocene, MIS 6-8)

CMA a Clast- to matrix-supported, massive or stratified, both well cemented and incoherent debris flow and rock avalanche breccias and megabreccias, with highly heterometric (up to m^3), poorly sorted, angular to sub-angular carbonate blocks in a whitish-yellowish calcareous sandy silty matrix. Whitish to greyish calcareous clayey silts levels and lenses are interlayered at different elevations (**a**).
In the upper part colluvium and karst deposits made of reddish to dark brown clayey silts with sparse sub-angular clasts.

FOSSO DI GENZANO SYNTHEM (Middle Pleistocene)

FGS Coarse to medium, well-sorted, sub-rounded, clast-supported gravel beds, with massive or horizontal bedding, capped by thin layers and lenses of laminated to massive sandy silts, grading upward into medium to fine, well-sorted, well-rounded calcareous sandy-gravel beds showing planar and through cross-bedding, interlayered with coarse to fine, planar and through cross-stratified, yellowish sandy bedforms with abundant volcanoclastic material and tephra layer. Lateral and vertical heteropy with yellowish-greyish coarse to fine sand beds, with planar and, subordinately, ripples or trough cross-stratifications, alternating with laminated grey silt and clayey silt layers.
Gravel-bed braided fluvial and alluvial fan environments.

MADONNA DELLA STRADA SYNTHEM (Calabrian)

MDS ***Madonna della Strada Fm.:*** Yellowish sandy silt and sand beds, rarely showing planar cross-stratification, densely interlayered with thin greyish clayey levels, passing to dark grey massive organic clays and clayey silts, containing several lignite seams intercalations. In the middle and lower part, intercalations of coarse to medium well-rounded sandy gravel beds, characterized by planar or trough cross-bedding. Meandering fluvial environment with wide floodplain and swampy areas.

SMF ***San Marco Fm.:*** Well-cemented, massive to well-stratified, clast-supported, angular, heterometric calcareous breccias with an abundant pinkish calcareous matrix.

SAN DEMETRIO-COLLE CANTARO SYNTHEM (late Piacenzian-Gelasian)

CCF ***Colle Cantaro-Cave Fm.:*** Highly heterometric, angular to sub-angular, slope-derived breccias and debris flow deposits, with limestone, marl and sandstone clasts in an abundant clayey-silty matrix. Rarely proximal alluvial fan deposits made of clast-supported, sub-rounded, massive beds of calcareous gravels, alternating with sandy and silty layers or lenses, rarely showing lamination or planar cross-stratification.

Valle dell'Inferno Sub-synthem

VIF ***Valle dell'Inferno Fm.:*** Well-sorted, well-rounded, clast-supported, planar and trough-cross bedded conglomerates of braided plain environment, with coarse to medium calcareous pebbles in a pinkish sandy-silty matrix.

Castelnuovo Sub-synthem

VOF ***Valle Orsa Fm.:*** Gylbert-type delta deposits composed by yellowish fine-medium sands and silty sands, with horizontal lamination and isolated pebbles (bottomset); clino-stratified, well-sorted, well-rounded, clast-supported, massive or trough-cross bedded conglomerates with thin calcareous silt layers (foreset); sub-horizontal, poorly-sorted, massive or planar cross-bedded conglomerates in a sandy silty matrix (topset).

SNF ***San Nicandro Fm.:*** Laminated to massive whitish calcareous silts of deep-water lacustrine environment, bearing freshwater ostracods, sponges spicules (*Spongilla lacustris*), mollusc fragments, diatoms and rarely leaves traces.

MNF ***Madonna della Neve Fm.:*** Alternating whitish calcareous lacustrine silt layers and poorly-sorted, angular to sub-angular, matrix-supported , slope-derived calcareous breccias both as stone-lines and as massive beds up to 1 m thick.

VVF ***Valle Valiano Fm.:*** Well-sorted, sub-angular to sub-rounded, trough or planar cross-bedded alluvial fan conglomerates, locally with carbonate sandy and silty layers or lenses. Heterometric, angular to sub-angular, calcareous breccias both stratified and massive, clast-supported or with abundant whitish calcareous silty matrix, respectively.

Syn-orogenic Succession

SYN **Neogene syn-orogenic succession**

Pre-orogenic Succession

CRP **Cenozoic carbonate-ramp/open-platform succession**

SLB **Meso-Cenozoic lower slope-basin succession**

CIP **Mesozoic inner carbonate platform succession**

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Symbols

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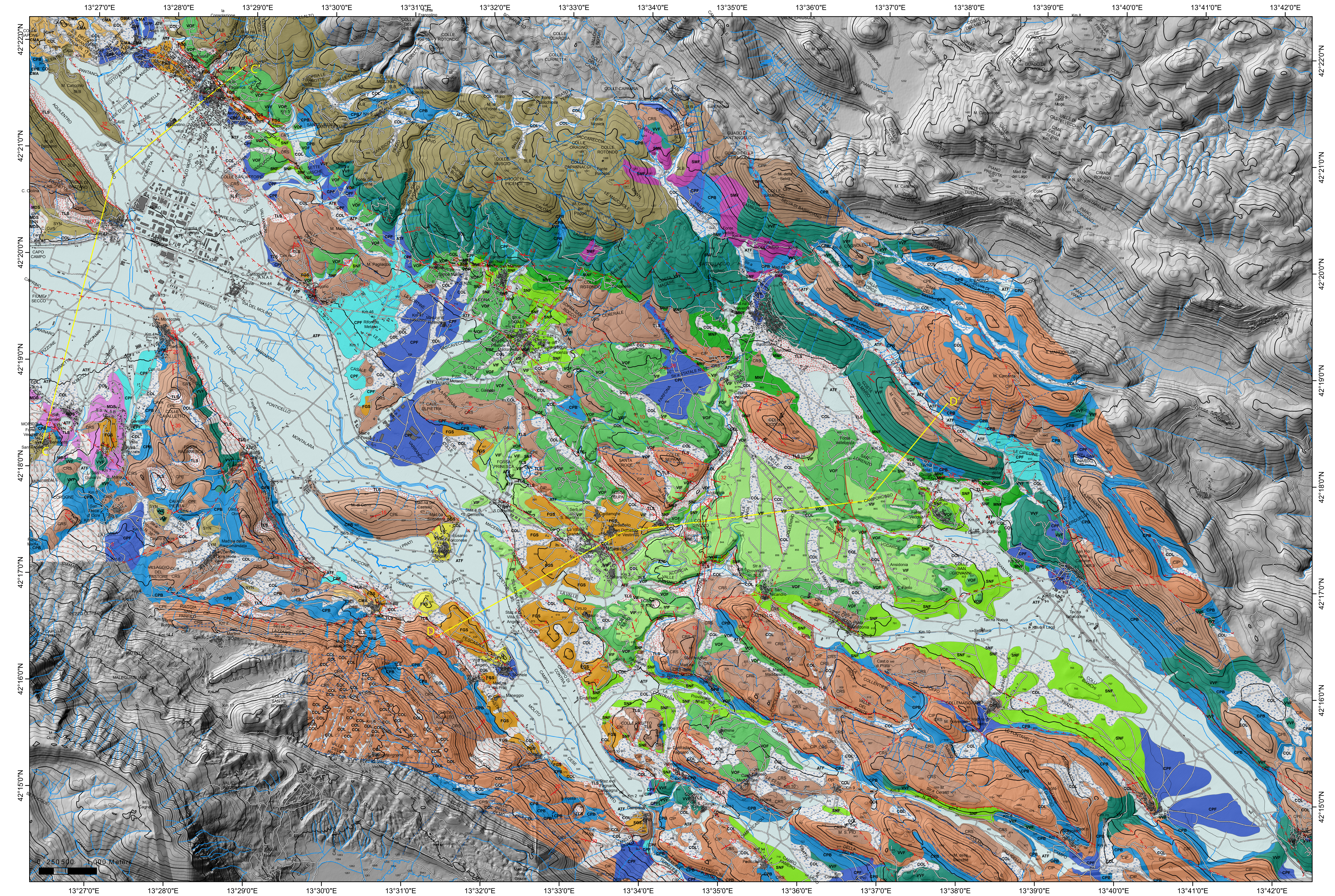
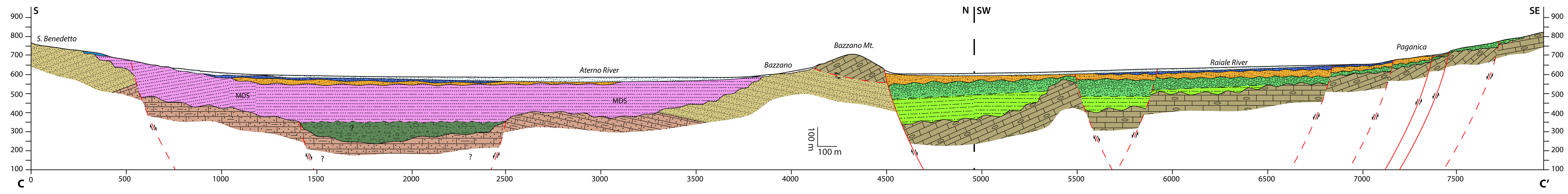
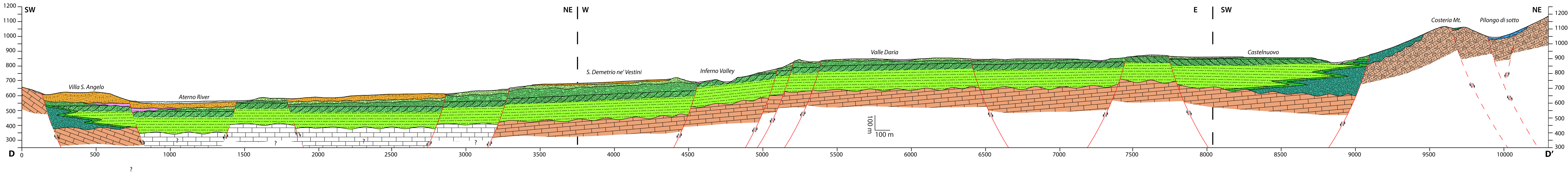
- Normal or transtensive fault with pre-Quaternary activity (inferred)
- Major thrust (certain)
- Major thrust (inferred)
- Strike-slip fault (certain)
- Strike-slip fault (inferred)
- Undifferentiated fault

Quaternary Geological Map of the Paganica - San Demetrio - Castelnuovo Basin (eastern L'Aquila Basin) (Italy) (1:25.000)

Author: Dr. Marco Nocentini







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