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Pliocene to Quaternary evolution of the Ofanto Basin in southern Italy: an approach based on the unconformity-bounded stratigraphic units

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ABSTRACT

The Ofanto Basin is an actively evolving intra-chain basin of the Southern Apennines, Italy. It has an elongated shape, about 7 km large and 45 km long, and is E-W striking, representing a marked bend in the NW-SE regular orientation of the south-Apennines morphostructures. The basin is filled up by Pliocene to Quaternary clay, sandstone, and conglomerate, deposited in both marine and continental environments. The main sedimentary deposits are grouped into six units bounded by stratigraphic discontinuities marked by unconformities and abrupt lithological variations. Three of those discontinuities are recognisable on a regional scale and represent the physical boundaries of three supersynthems, in turn subdivided into synthems and subsynthems by basin-scale unconformities. The sedimentary evolution of the basin is herewith reported. Facies analyses and architecture of the sedimentary bodies revealed that each unit formed different alluvial and deltaic depositional systems located on the southern and northern margins of the basin. The morphology of the northern slope was probably steeper than the southern one. The oldest units were deposited in the Western sector of the Ofanto basin. Starting from the late Zanclean to the early Gelasian, the sedimentary bodies underwent an Eastward shift in their deposition, suggesting a basinward relocation of the depositional systems. Such variations in time and space seem to reflect relevant changes in accommodation space and sedimentary supply during the tectonic evolution of the basin. Eventually, correlations among adjacent basins and the meaning of the discontinuities as former erosional surfaces have been pointed out.

KEY WORDS: *Ofanto Basin, Pliocene-Quaternary sedimentary sequences, Southern Apennines, Southern Italy.*

INTRODUCTION

A twenty-year period of application of the criteria of the Unconformity Bounded Stratigraphic Units in geological mapping led to a significant increase in knowledge of stratigraphic setting of many regions and methodological advancements in stratigraphy. Application examples in this direction for the Italian territory concern volcanic areas, Quaternary continental deposits and Tertiary marine basins. However, the effort of the operators has been often focused on formal issues and little has been done to understand the side effects of such an application, such as interbasinal correlations on a regional scale, the morpho-evolutionary meaning of the erosional surfaces separating different units, or the role of some palaeosols and other indicators marking the discontinuities as environmental and palaeoclimate proxies. The goals of this paper involve both a better definition of the Pliocene to Quaternary evolutionary history of an Italian intra-chain basin and an original methodological contribution in the directions mentioned above. To this scope, a detailed geological survey and sedimentological, geomorphological, and biostratigraphical analyses have been performed in the Ofanto basin, located in the Southern Apennines. In particular, this paper is based on the new geological map of the eastern sector of the basin: the fieldwork started with the CARG Project for the realization of the Sheet 451-Melfi at the scale 1:50,000, promoted by the National Geological Service of Italy for the realization of the new geological cartography of Italy (SERVIZIO GEOLOGICO D'ITALIA, FOGLIO 451 "MELFI", 2010); the survey was ultimately refined with the attached map (scale 1:25000).

The Ofanto Basin deposits occupy an elongate area (wide ~7,00 and long ~45,00 kms) along the Ofanto River from the Monte Vulture Volcano to Lioni village (fig. 1a), and are intensely deformed by synsedimentary Pliocene-Quaternary folding and faulting. To understand the age of the deposits and to define the sedimentary characters of the studied basin, several stratigraphic logs have been realised along two East-West transects positioned on the northern and southern boundaries of the basin, respectively (fig. 1b). Cross cutting of the various sections has allowed us to recognize that the Ofanto basin-fill can be divided into unconformity-bounded stratigraphic units. For every stratigraphic unit, facies variations and geometries of the sedimentary bodies have been studied, and the relationships between tectonics and sedimentation have been analyzed. Data have been used to propose a scheme of the tectono-stratigrafiphic evolution of the eastern sector of the basin.

The axes of the Ofanto basin syncline and of the contiguous positive morpho-structures strike roughly E-W, whereas the rest of the Campania-Lucania Apennine shows the well-known and rather regular NW-SE trend. In other word, the study area represents a relatively restricted bend-zone in the regional-scale geological structure. Several papers have treated in the past stratigraphic, tectonic, and morphological topics related to the Ofanto basin (HIPPOLYTE *et alii*, 1992, 1994; PATACCA & SCANDONE, 2001; GIANNANDREA, 2003). A recent synthesis, aiming to link the surface geometry with the deep structure is due to CASCIELLO *et alii* (2013).

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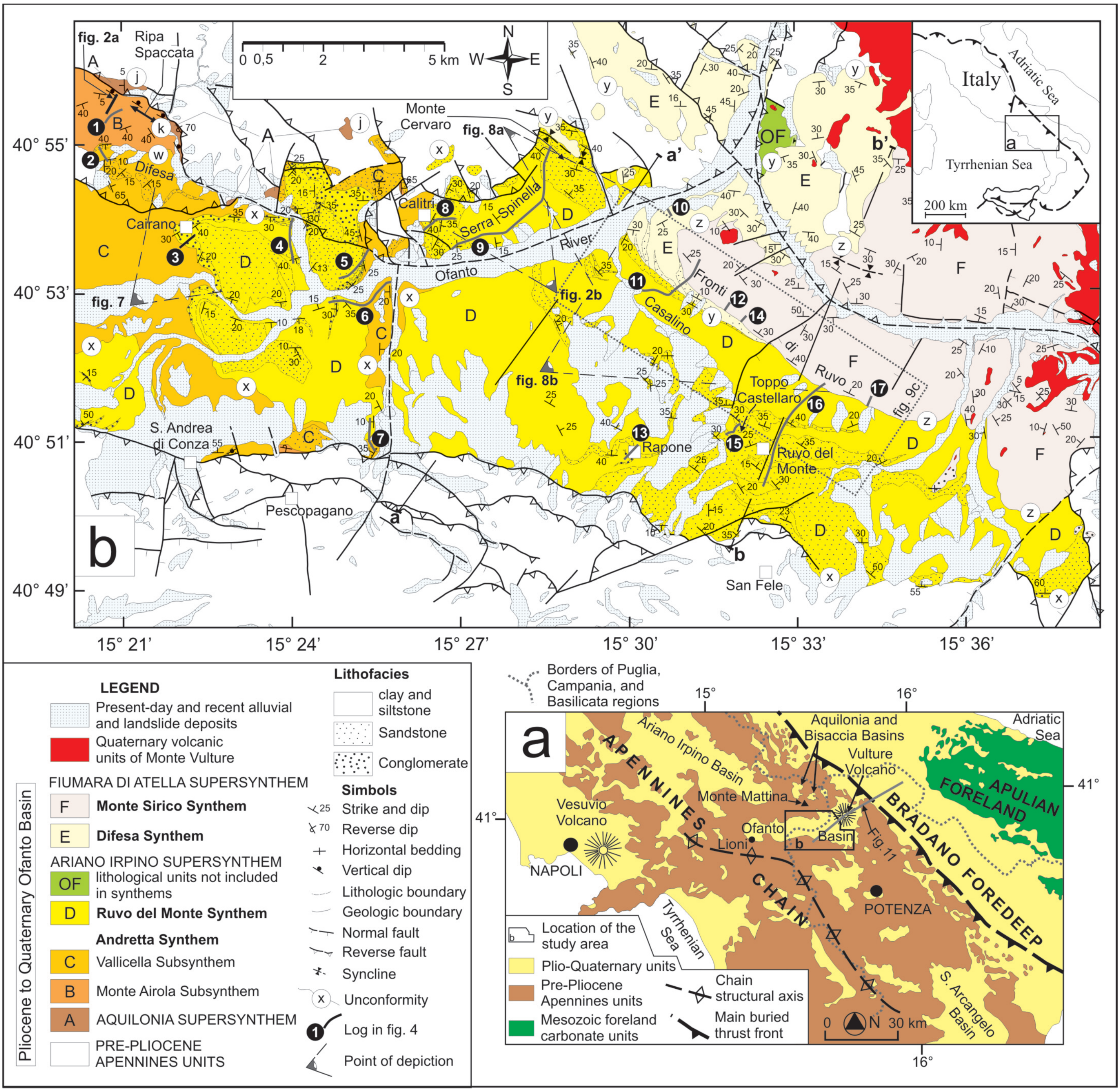

Fig. 1 - a) Schematic geological map of the southern Apennines and location of the study area; in this frame the trace of the tectono-stratigraphic scheme of fig. 10 is also indicated; *b*) Geological map of the eastern sector of the Pliocene to Quaternary Ofanto Basin, with *i*) traces of the cross-sections of fig. 5, *ii*) locations of the segments in which we performed the sampling for biostratigraphic analysis and collected sedimentological data (shown in fig. 4), and *iii*) points of depiction of the panoramic photos shown in figs. 2, 7 and 8.

REGIONAL SETTING

The Southern Apennines chain (fig. 1) was built on during a time-span ranging from the late Oligocene to the Pleistocene as a North-East-directed fold-and-thrust belt (e.g., MOSTARDINI & MERLINI, 1986; CELLO & MAZZOLI, 1998; PESCATORE *et alii*, 1999; MENARDI NOGUERA & REA, 2000; PATACCA & SCANDONE, 2007), evolved in a “collapsed” orogen characterised by low-angle extension (e.g., SCHIATTARELLA, 1998; FERRANTI & OLDOW, 1999; SCHIATTARELLA *et alii*, 2006) responsible for large-scale exhumation (e.g., ALDEGA *et alii*, 2005; SCHIATTARELLA *et alii*, 2006; GIOIA *et alii*, 2011a), and finally affected by block-faulting and uplift in Quaternary times (SCHIATTARELLA *et alii*, 2003, 2006; GIOIA *et alii*, 2011b). The Campania-Lucania sector of the Southern Apennines is made of both deep-sea sediments and shallow water carbonates, mainly Mesozoic in age. The latter units constitute the hanging-wall of a thrust system that characterise the entire axial zone of the chain. Pelagic units, on the other hand, represent the footwall of the same regional structure (Brienza-Paterno Thrust, after PESCATORE *et* *alii*, 1999). Both these tectonic features are locally covered by Miocene siliciclastic deposits, representing the synorogenic units of the fold-and-thrust system (foredeep deposits). Satellite basins, mainly upper Miocene and Pliocene-Pleistocene in age, are also arranged along the axis of the chain and lay on both the Miocene units and the Mesozoic bedrock. Transpressional to transtensional tectonics was responsible for the Pliocene to early Pleistocene evolution of the Southern Apennine chain (e.g., Catalano *et alii*, 1993; Schiattarella, 1998; Bonini & Sani, 2000; Monaco *et alii*, 2001; Benvenuti *et alii*, 2006), whereas extension, mainly associated to high-angle normal and strike-slip faults, took place in mid-Pleistocene times in the axial zone of the chain (Schiattarella, 1998; Schiattarella *et alii*, 2003). The main orientations of these high-angle strike-slip and normal faults are N 120±10°, N 150±10° and N 50±20°. The existence of recent to present-day tectonic activity of the front of the chain is still debated, but several data account for the persistence of a contractional or transpressional regime up to the middle Pleistocene (Pieri *et alii*, 1997; Schiattarella *et alii*, 2005).

On the Eastern front of the Southern Apennines chain, Pliocene to Pleistocene clayey, sandy and conglomerate deposits (Ariano Irpino Unit) unconformably lie on the wedge units and are extensively exposed (fig. 1a). These alluvial, deltaic and platform deposits are referred to different small sedimentary basins (Pescatore & Ortolani, 1973) distributed along the strike of the belt. They show a progressive southeastward migration of basin subsidence ages from ~4 to ~2.8 Ma (Ascione *et alii*, 2011). As a rule, these successions show cyclic sedimentation patterns of various orders due to sea level variations and to synsedimentary tectonics due to compression on moving thrust sheets (e.g., Roure *et alii*, 1991; Hippolyte *et alii*, 1992, 1994, 1995; Patacca & Scandone, 2007). The recognition and assessment of discontinuity-bounded bodies are prerequisites for the interpretation of basin-fill stratigraphy (e.g., Zavala, 2000; Basso *et alii*, 2002; Benvenuti *et alii*, 2006; Patacca & Scandone, 2007; Giannandrea, 2009; Servizio Geologico d'Italia, 2011).

The top of the belt is frequently characterised by the occurrence of remnants of an ancient flat landscape, uplifted and dismembered by Quaternary fault activity. Consequently, the erosional land surfaces are arranged in several superimposed levels (e.g., Schiattarella *et alii*, 2003, 2006; Gioia *et alii*, 2011b). The regional uplift hung the ancient erosional base level to which this palaeolandscape was related, triggering new morphoevolutionary stages. As a consequence of the former erosional stages, the paleosurfaces are low-relief and high-altitude relict geomorphological features.

The Ofanto Basin developed on the clayey-calcareous and arenaceous bedrock (Cretaceous-Miocene in age) of Lagonegro and Irpinian Units, and was interpreted as a piggy-back basin (e.g., Roure *et alii,* 1991; Hippolyte *et alii*, 1992, 1994; Patacca & Scandone, 2001), sensu Ori & Friend (1984). The basin-fill has been normally divided in two sedimentary cycles, Pliocene and Pliocene to Pleistocene in age (Vezzani, 1968; Pescatore & Ortolani, 1973). The youngest cycle crops out in the eastern sector of the basin (Hippolyte *et alii,* 1994), where it is covered by the mid- to late Pleistocene Vulture Volcano deposits (687±8 ka - 141±11 ka; e.g., Bonadonna *et alii,* 1998; Principe & Giannandrea, 2008; Villa & Buettner, 2009).

METHODS

Mapping and stratigraphy

This study is based on a detailed field survey which allowed the production of the attached geological map. The mapping of the eastern sector of the Ofanto Basin (performed from 1996 to 2000) has produced a map on a 1:25,000 scale, on the grounds of 1:10,000 scale survey. Sedimentological analysis of stratigraphic sections (for a total thickness of ~3,500 m) scattered in the whole basin area (fig. 1b) have been carried out on the largest outcrops. For every single bed, lithology, colour, composition, texture, palaeocurrent markers, and fossil contents have been described. Unconformity surfaces have been illustrated in details.

More than two hundreds samples have been collected in the silty-clayey marine facies and then analysed for the biostratigraphic age determinations. In order to establish the stratigraphic relationships among the Pliocene-Quaternary clastic deposits and to infer the subsurface geometries of the basin infill, the major natural outcrops have been studied and a published seismic profile (a-a' trace in fig. 1b) has been reinterpreted. All the stratigraphic unconformities recognized in the basin area have been physically tracked and mapped both in the field and by photogeological analysis.

The stratigraphic analysis has been mainly carried out through the recognition and description of discontinuity surfaces. Both abrupt facies changes and lithological contacts, in addition to the geometric relationships among the major geological bodies, have been used to recognize the discontinuities. The stratigraphic subdivision of the units confined by such discontinuities has been based on the criteria of the *Unconformity-Bounded Stratigraphic Units* (UBSU, Chang, 1975; Salvador, 1987, 1994).

In the eastern Ofanto Basin, the sedimentary succession shows local- and map-scale unconformities between both homogeneous and different rock-types. Tens to hundreds meters outcrop-scale growth structures have been also observed in several cases (fig. 2).

Chrono-biostratigraphy

Standard sample preparation techniques have been performed for calcareous plankton (nannofossil and foraminifera) investigations. Smear slides for calcareous nannofossil analysis were prepared according to Bown & Young (1998) and analyzed under a polarized light microscope at a magnification of 1000×. Foraminifera analyses were conducted at the stereomicroscope on the residue larger than 125 μm of the sediments previously dried and washed on a 63 μm sieve. Qualitative analyses were carried out on all calcareous plankton assemblages; however, quantitative investigations were also performed on samples of selected time intervals to accurately recognise the nannofossil biozones that are mainly established based on disappearance events of species.

Biostratigraphic scheme of Rio *et alii* (1990) was used for calcareous nannofossil biozonal attribution. Plank-

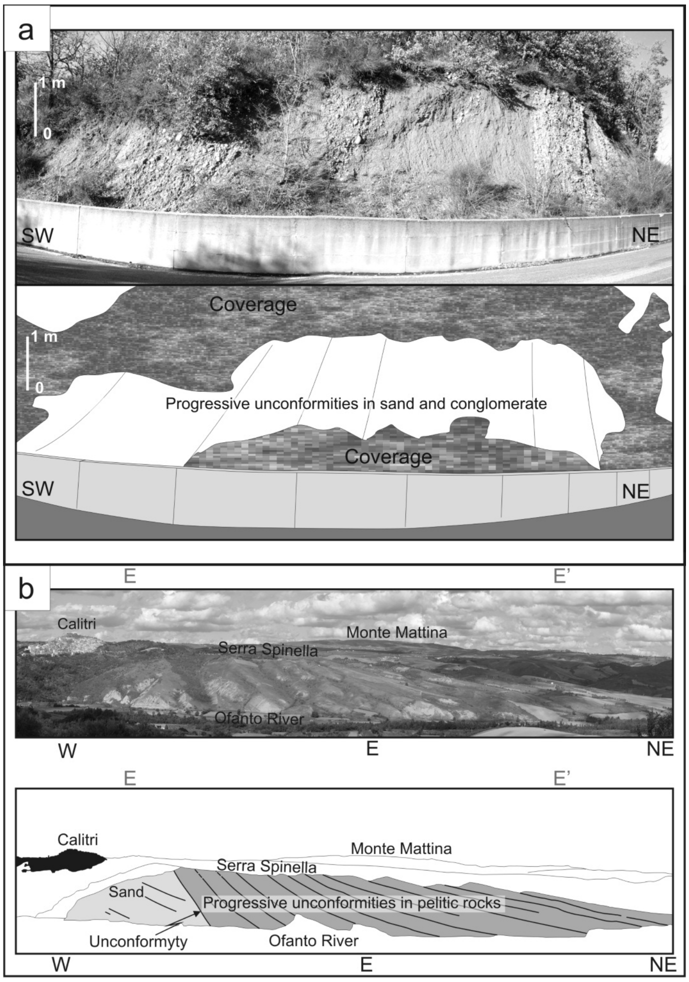

Fig. 2 - Photos and relative line-drawing showing outcrops and relative interpretations of progressive unconformities developed at two different scale in both alluvial (*a*) and marine (*b*) sediments.

tonic foraminifera biozones of CITA (1975, emended) for Piacenzian to Gelasian stages and of LOURENS *et alii* (2004) for Calabrian to present-day were adopted (fig. 3). Biozones are included in the chronostratigraphic scheme which refers to Pliocene-Pleistocene chronostratigraphy according to the current International Union Geological Sciences (IUGS) statement (June 30, 2009) and to the proposal of HEAD *et alii* (2008) and WALKER & GEISSMAN (2009) (see column Series* on the left of fig. 3). This new time scale transfers the upper Pliocene Gelasian Stage from the Neogene System and Pliocene Series to the Quaternary System and Pleistocene Series. In fig. 3 the Pliocene-Pleistocene chronostratigraphic scale of GRANDSTEIN *et alii* (2004) is also included in order to make possible the comparison between the present and previous chronostratigraphic schemes. Here we will refer to the Stage terms to indicate the time intervals recognised based on calcareous plankton assemblages.

BASIN STRATIGRAPHY

UNCONFORMITY SURFACES

The stratigraphic subdivision of the Ofanto Basin sedimentary succession through the record of unconformities has been recognised. This is a prerequisite to represent unconformity-bounded units in a geological map. In the study area six unconformity surfaces have been found: their traces have been mapped at the base and inside the Pliocene to Pleistocene succession, and labelled – from the oldest to the youngest surface – with the following acronyms: **j**, **k**, **w**, **x**, **y**, and **z** (figs. 1b and 4). The bi-dimensional unconformity geometries are reported in the cross-sections of fig. 6. In particular, the seismic section (fig. 5a) shows the unconformities **j**, **k**, **w**, and **x** bordering several geological bodies within the entire Pliocene-Quaternary succession, marked by both erosional truncations and local stratigraphic paraconformities (in the sedimentary basin depocentre), and also achieving the overlap of the clastic units on the pre-Pliocene bedrock.

The basal boundary of the succession (unconformity **j**) and the unconformities **k** and **w**, inside to the succession, are well-exposed on the western side of the study area, along the northern side of the basin (fig. 1b). The unconformity **j** is an erosive surface which cuts the pre-Pliocene sedimentary bedrock. The stratigraphic contact between clastic lower Pliocene (Zanclean) deposits and its bedrock is discordant and discontinuous. The contact is marked by conglomerate lying on both resedimented evaporitic sandstones, Messinian in age, and a chaotic or intensely deformed ("broken formation") succession constituted of clays and red, green, and grey marly clays, with interbedded calcarenites and marly limestone (*Gruppo delle Argille Variegate*, Cretaceous-Lower Miocene in age). The unconformity **k** separates two unconformably stacked conglomeratic successions (fig. 6). The boundary **w** is marked by an abrupt contact between marine clays and sandstones (at the top) and an alluvial conglomerate (at the bottom).

In the central portion of the Ofanto Basin, not far from Calitri and Cairano villages (fig. 1b), an abrupt contact (fig. 7) between sandy and sandy conglomerate (at the top) and marine clays (at the bottom), allows identifying and mapping the discontinuity **x**. Toward the south, the coarse-grained sediments cropping out at Cairano village laterally pass to silty clays, showing a clear example of interdigitated facies relationship. Here, the same geological contact becomes concordant and has been therefore mapped (fig. 1 and attached map) on the base of biostratigraphic data (fig. 4). At the southern boundary of the basin, the unconformity **x** is represented by an erosional truncation (fig. 5a).

The most recent unconformities (**y** and **z**) crop out in the eastern sector of the basin (fig. 1b). Near the localities of Casalino and Fronti di Ruvo, one can clearly observe conglomerates overlapping marine clays and sandstones (fig. 8), and the unconformity **z** cutting the unconformity **y** (figs. 4, 5b, 8c, and attached map). To the south of the Ofanto River, the unconformity **y** represents the depositional top of a deltaic sandy body, on which conglomerates with interbedded silty sandstones lie in downlap relationships (fig. 8c and attached map). At the North-eastern margin of the basin, these clastic deposits unconformably lie on both the older Pliocene clay and sandstones and the bedrock formations (figs. 1b and 5b, and attached map). Therefore, the boundary **y** has to be interpreted as an erosive surface shaped in a deformed portion of the basin, and precisely in the area of its ancient northern palaeo-

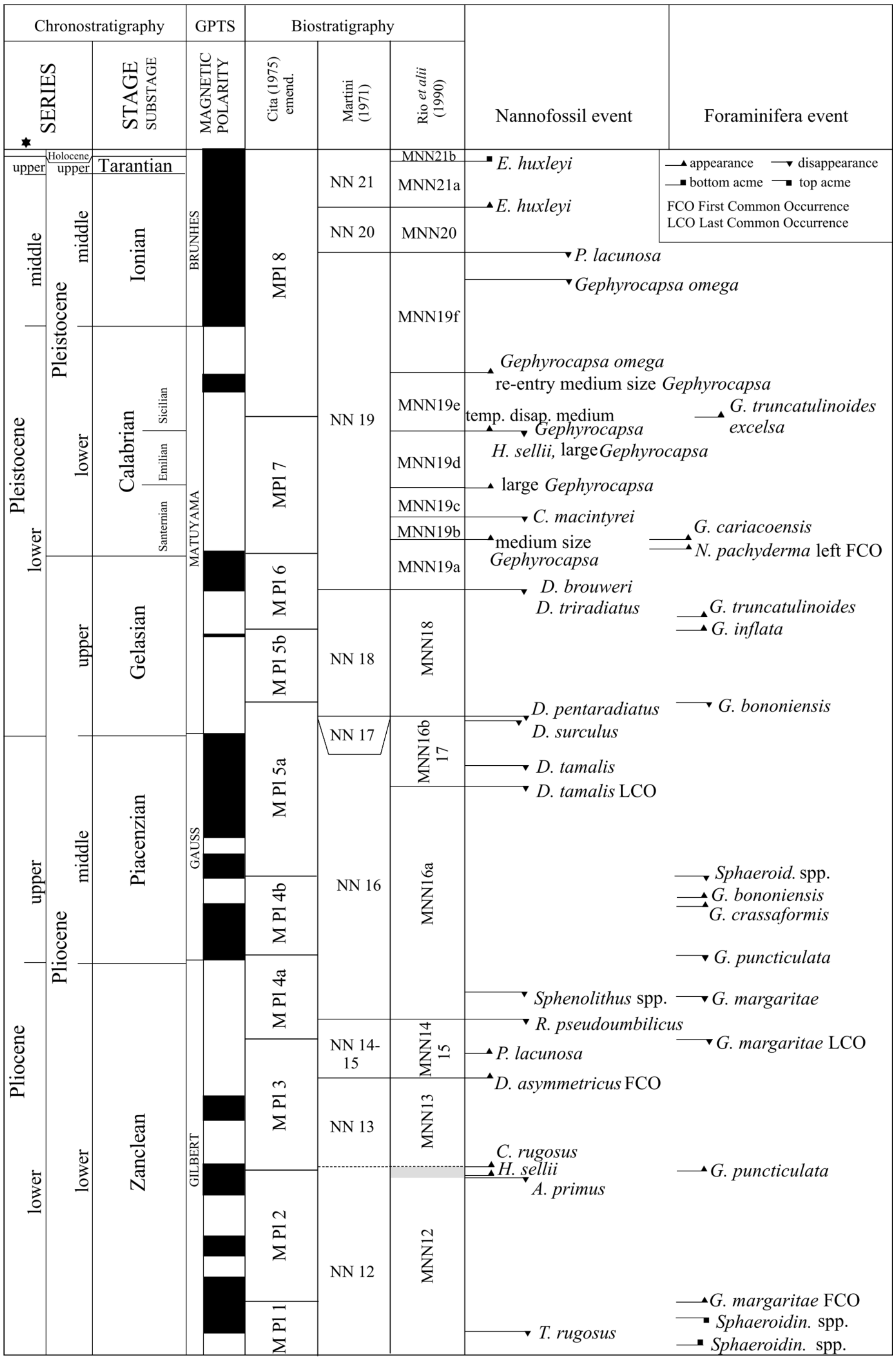

Fig. 3 - Chrono-biostratigraphic scheme of Pliocene and Pleistocene. The asterisk at the top of the first column on the left indicates the chronostratigraphic subdivision according to WALKER & GEISSMAN (2009).

margin, at the contact with the bedrock. The unconformity **z** has been identified in the field as a clear discordance between different lithological units (e.g. along the Fronti di Ruvo slope, cf. fig. 1 and attached map), or recognized by different attitude and facies of the units, when only conglomerate crops out (e.g. north-eastern sector of the attached map).

STRATIGRAPHIC UNITS

The six erosional surfaces corresponding to the mapped discontinuities have allowed us to divide the Pliocene-lower Pleistocene succession of the Ofanto Basin in six unconformity-bounded units (see geological map here attached) labelled in this paper with the letters **A**, **B**, **C**, **D**, **E** and **F** (fig. 1b).

*Units **A** and **B***

Units **A** and **B** crop out in Ripa Spaccata locality, along the north-western basin margin, where are bounded (from the bottom) by the unconformities **j**, **k** and **w**. Unit **A** is ~300 m thick and made by vertical fining-upward sequences (7-15 m thick) of massive or crudely bedded, clast-supported, rounded pebble to boulder (max 60 cm in size) conglomerates. These are organized in metric beds with horizontal and cross lamination. At the top of the sequences a 30-50 cm thick reddish

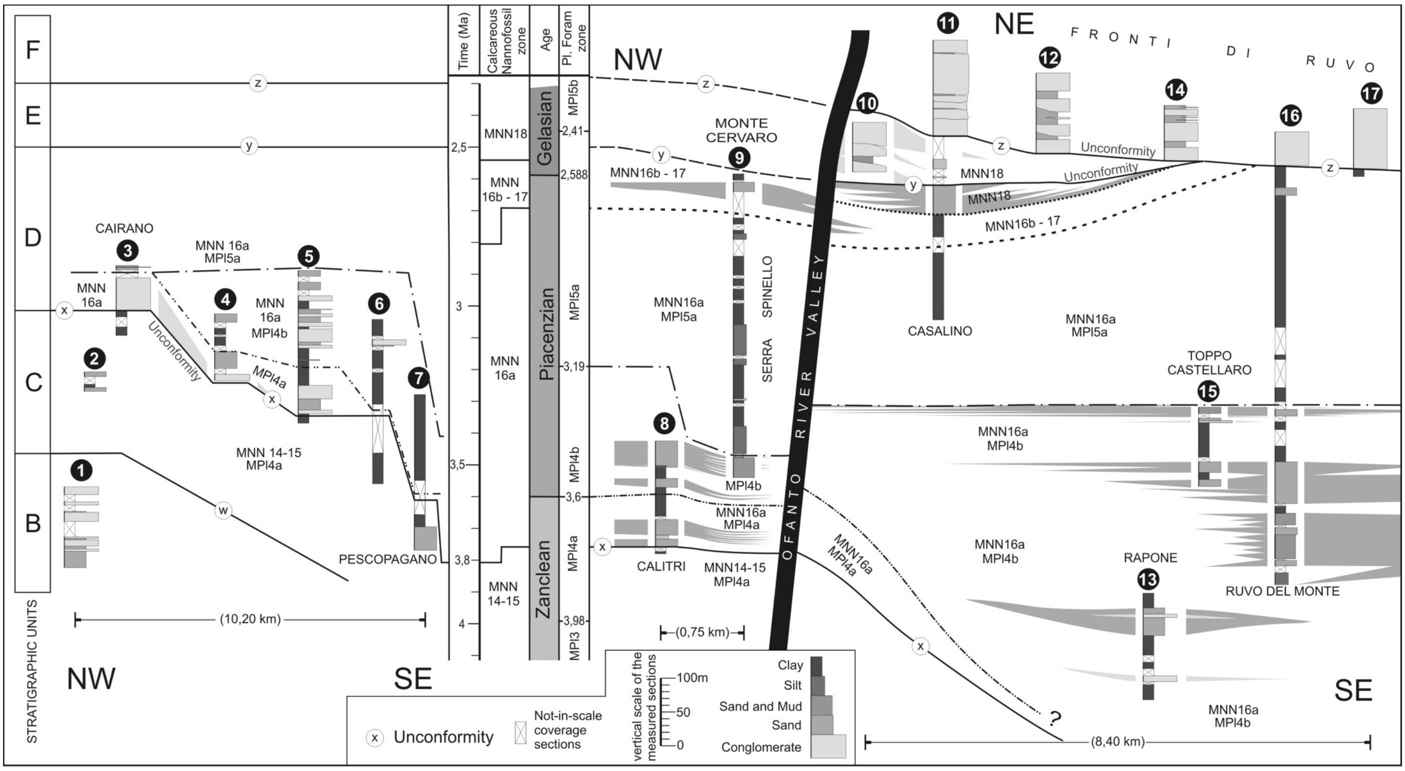

Fig. 4 - Stratigraphic correlation framework of the Ofanto basin fill, showing logs from the study area (location in fig. 1) and body geometries of the sandy and conglomerate deposits (see text for the explanation). Positions of biozonal and stage boundaries are in agreement with Lourens *et alii* (2004) and references therein.

palaeosol is always present. These sequences can be interpreted as an alluvial mid-fan (Stell & Gloppen, 1980), due to deposition of stratified gravels by not channelled upper-flow regime and, subordinately, channelled flows. Palaeocurrent markers measured thanks to the clast imbrication and the cross-bedding dip directions suggest a sedimentary supply from northeast.

Unit **B** (~300-400 m in thickness) unconformably overlies unit **A** and is composed of two stacked litofacies. From the base, these are clast-supported, massive, and planar cross-bedded brown conglomerates (clasts of max 50 cm in size) interbedded with thin-laminated sandstones, siltstones and clay; these deposits clearly show progressive unconformities (fig. 2a), with dip angles varying from vertical to ~5°. Beds (2-4 m in thickness) are characterised by lenticular geometry, with lateral continuity of some hundred meters. Reddish palaeosols are often present at the top of the sandy-pelitic beds. Palaeocurrents inferred by measures of cross-bedding dip directions suggest a northeast source. All the facies characters allowed us to interpret the conglomerate beds as debris flows and sieve deposits (Miall, 1996), forming wondering lobes of alluvial fan, whereas the thin-bedded fine facies represent overbank or waning flood (e.g., Walker, 1967; Van Houten, 1968; Besley & Turner, 1983; Miall, 1996; Benvenuti, 2003) linked to the channel abandonment, as a consequence of the migration of the coarse-grained flow in another zone of the fan. In the upper portion of the Unit **B** fine-grained deposits increase, and the coarse facies represent channelized deposits composed of clast-supported, cross- and horizontal-bedded, and imbricated brown conglomerates (clasts of max 50 cm in size). Such channels are NW-SE directed. Palaeocurrent measures, the abundance of fine-grained deposits, conglomerate facies (interpreted as longitudinal bar migrations and minor channel fills; Miall, 1996), the orientation of conglomerate channel-fill, and the presence of alluvial fan conglomerate at the base of the Unit **B** suggest palaeoflows from northwest and northeast, possibly by a bajada of alluvial fans, and permit us to hypothesize a sedimentary environment constituted by a N120-150°-directed subsident alluvial plain (see the north-western corner of the attached map).

Pebbles lithology of the units **A** and **B** is constituted by calcareous rocks (limestone, calcarenite, calcareous breccia, and cherty limestone, for a total of about 60 vol.%), sandstone (~35 vol.%), and – in a subordinate amount- marls, quartzite, siltstone, shale, and very rare cherty and granite elements. Clast composition and maturity demonstrate a prevailing sedimentary supply mainly from siliciclastic Miocene units and from Cretaceous to Oligocene pre-orogenic formations (*Galestri* Fm and *Gruppo delle Argille Variegate*), largely outcropping northwest of the basin.

*Unit **C***

Unit **C** crops out in the western part of the study area and to the west of Calitri village, forming a north-south directed narrow area. Its stratigraphic boundaries coincide with abrupt lithological changes, marked by the unconformities **w** and **x** (figs. 1b and 4). This unit is some hundred meters thick and constituted of massive or laminated grey-blue silty-clay with interbedded fine- to coarse grained sandstones with horizontal lamination, and thin-bedded sandstone, siltstone and clay in lenses up to 15-20 m

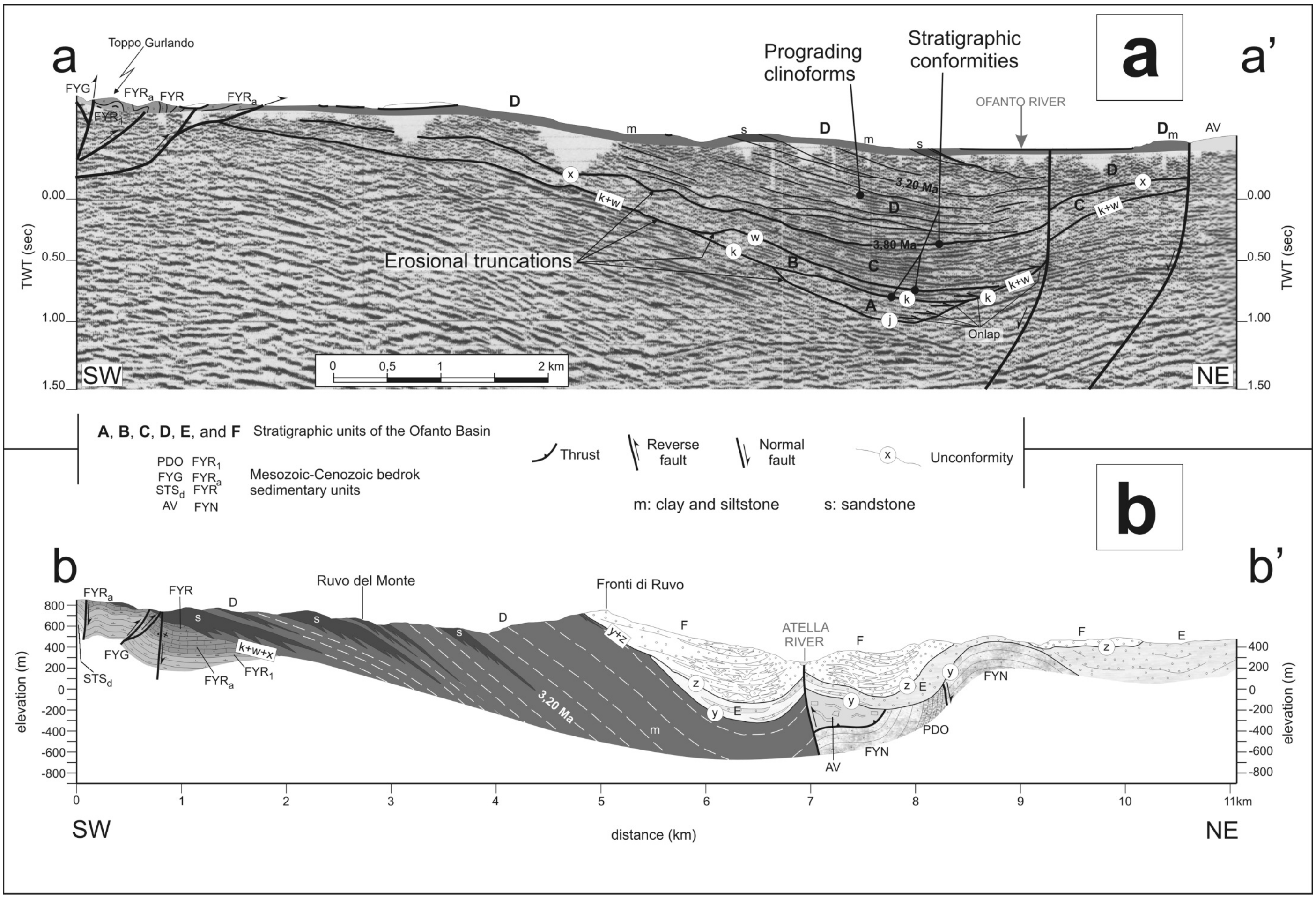

Fig. 5 - a) Interpreted seismic profile (seismic line after Roure *et alii*, 1991, also re-interpreted by Hippolyte *et alii*, 1994, and Patacca & Scandone, 2007), with additional surface data; *b*) geological cross-section through the Ofanto synform (location of the traces in fig. 1). The two sections show the bi-dimensional unconformity geometries of the mapped six stratigraphic units and the architecture of the depositional units. The ages of the surfaces derive from the stratigraphic scheme of fig. 4.

in thickness at different levels. Sandstone nodules of 10 to 80 cm in size are included in the sandy bodies distributed along the northern and southern margins of the basin, and absent in its central part (fig. 1b). The two litofacies contain marine molluscan shells, often fragmented.

Calcareous nannofossil assemblages mainly consist of *Reticulofenestra pseudoumbilicus*, *Sphenolithus abies*, *Pseudoemiliania lacunosa*, *Helicosphaera sellii*, *Discoaster asymmetricus*, *D. pentaradiatus*, rare *Discaoaster tamalis* and abundant small *Gephyrocapsa*. Assemblages are indicative of the late Zanclean Stage, specifically of the boundary between zone MNN14-15. Age assignment is consistent with planktonic foraminifera assemblages that are characterised by the presence of the marker species *Globorotalia margaritae* and *Globorotalia puncticulata* (MPL3/MPL4a zonal boundary).

Depositional environment of the unit **C** fine-grained deposits has to be referred to a prodelta or to a sea platform, whereas the sandy deposits should indicate a delta front. Clay beds have been sampled in order to establish the age of the unit by biostratigraphic analyses.

*Unit **D***

Unit **D** (thick up to ~1,700 m), bounded at the base by the unconformity **x** and by the unconformity **y** at its top, is the most compound stratigraphic unit because of its large distribution and facies lateral variations (figs. 1b, 4 and 5). The unit is composed of an eastward-dipping transgressive-regressive succession. The lithology is prevalently constituted by massive and laminated grey-blue silty clays and, subordinately, by sandstones and conglomerate arranged along the northern and southern basin margins. The sedimentary succession of this unit has been measured and sampled along two sections reconstructed on both the northern (between Calitri village and Mt. Cervaro, see enclosed MAP) and southern (between Ruvo del Monte village and Fronti di Ruvo, see enclosed MAP) sides of the basin. The conglomerate is widely represented by two coeval and coalescent bodies (Cairano and Calitri, see enclosed MAP) at the base of the unit, outcropping between Cairano and Calitri villages (figs. 1 and 7). Toward southeast, the conglomerate fringes into sandstones and clays. The Cairano body is a NW-SE-directed coarsening-upward sequence (up to 50 m thick and ~3 km laterally continuous). At the base of the sequence and at ~20 m in height, two 1.20 m thick layers of massive mud-supported conglomerate (facies c in fig. 7b) are present. They are mud and pebbles referred to high-viscosity debris flows (Miall, 1996). In the stratigraphic interval between these two bodies, the sequence is characterised by an about 16,70 m thick succession of

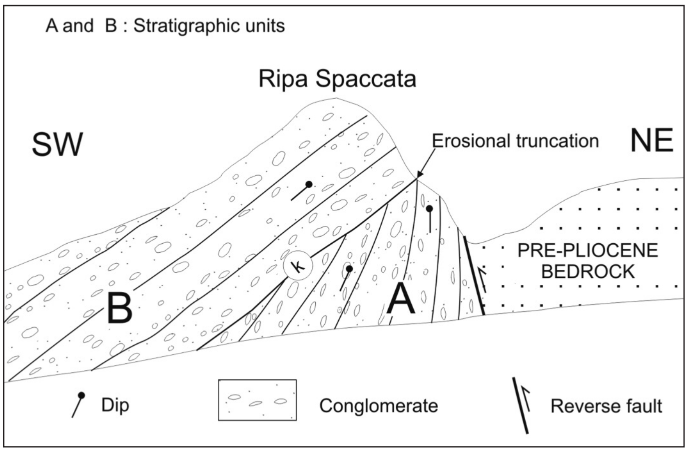

Fig. 6 - Not-in-scale cross section of the Ripa Spaccata site, showing the stratigraphic relationships between the units A and B.

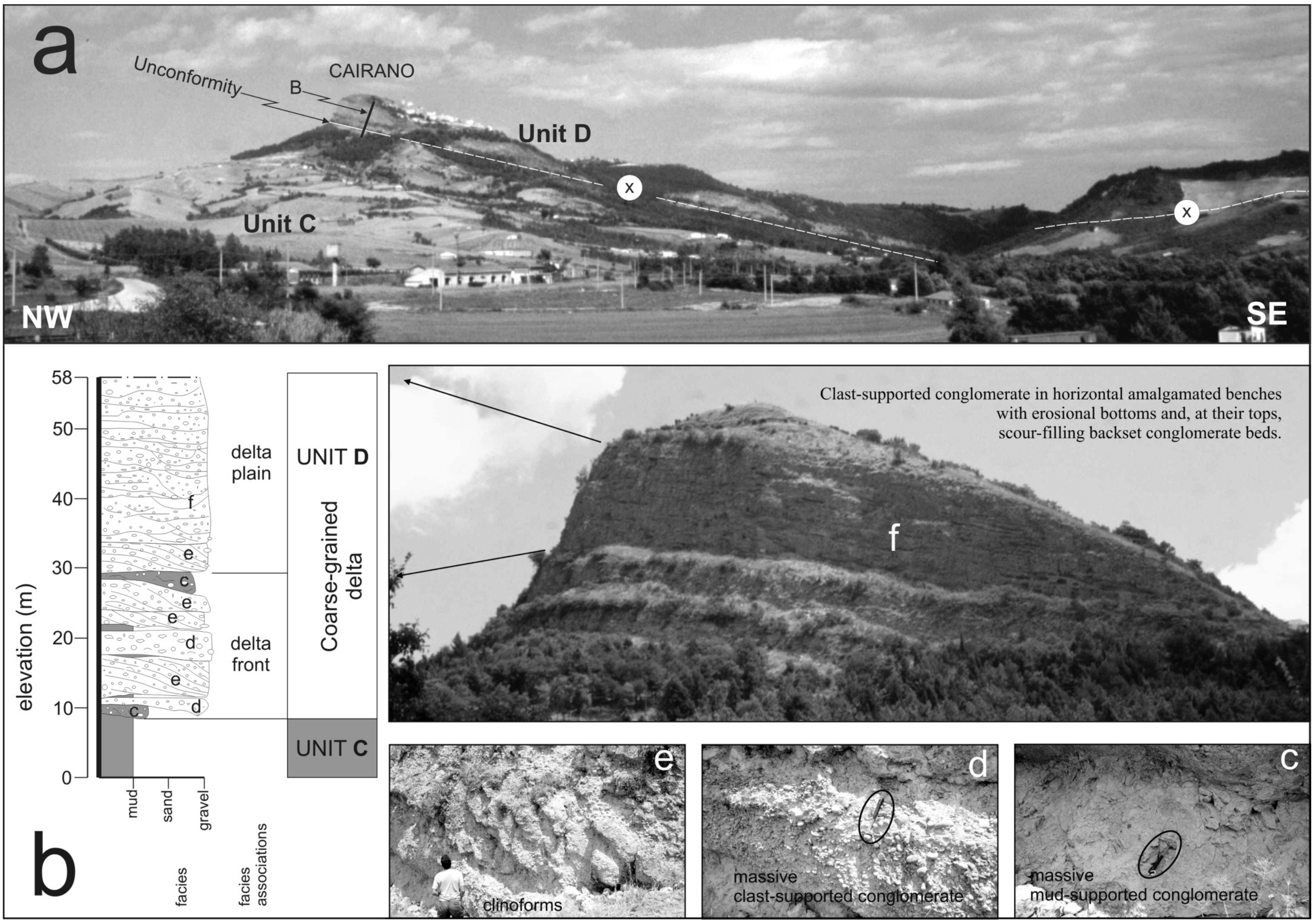

Fig. 7 - *a*) Panoramic view of Cairano village (see fig. 1 for location of the point of depiction) showing the unconformity **x** separating units C and D, and the location of the stratigraphic log reported in the frame *b*; note that the limit between the units is marked by an abrupt change in the gradient of the slope; *b*) stratigraphic log from the Cairano section displaying the relationships among the different facies (shown in the frames *c*, *d*, *e*, and *f*) and their associations.

topset (facies d in fig. 7b) and foreset (facies e in fig. 7b) units (1 to 6 m in thickness). Every single bed is formed by massive clast-supported conglomerate, which could be interpreted as a debris flow (MIALL, 1996) or as a hyperconcentrated flow (PIERSON, 1980; SMITH, 1986). The beds are amalgamated or separated by fine sediments, composed of massive or laminated silt with marine macrofossils, often fragmented. In the upper part of the Cairano body, the sequence is constituted by an about 32 m thick, massive, clast-supported conglomerate in horizontal amalgamated beds (with an average thickness of 5 m) with erosive base. At their top, some scour-filling backset conglomerate beds are present. This are interpreted as normal flow features. The pebbles (max 60 cm in size at the base of the sequence) are well-rounded and composed of sandstones (61 vol.%) and calcareous rocks (limestones, calcarenites, calcareous breccia and cherty limestones, for a total of ~35 vol.%), in a subordinate amount of marls, quartzites, siltstones, shales and cherts, and very rare granite clasts. Among the sandstone pebbles, are frequent those with a composition similar to the sandstone nodules of the Unit **C.** Palaeocurrent data indicate a northwest palaeoflow. Data collected for the other conglomerate bodies (cropping out in three small areas along the southern boundary of the Ofanto basin, and precisely at the western and eastern ends of the study area and near Rapone village; see attached map) are comparable to those described above, with the only difference

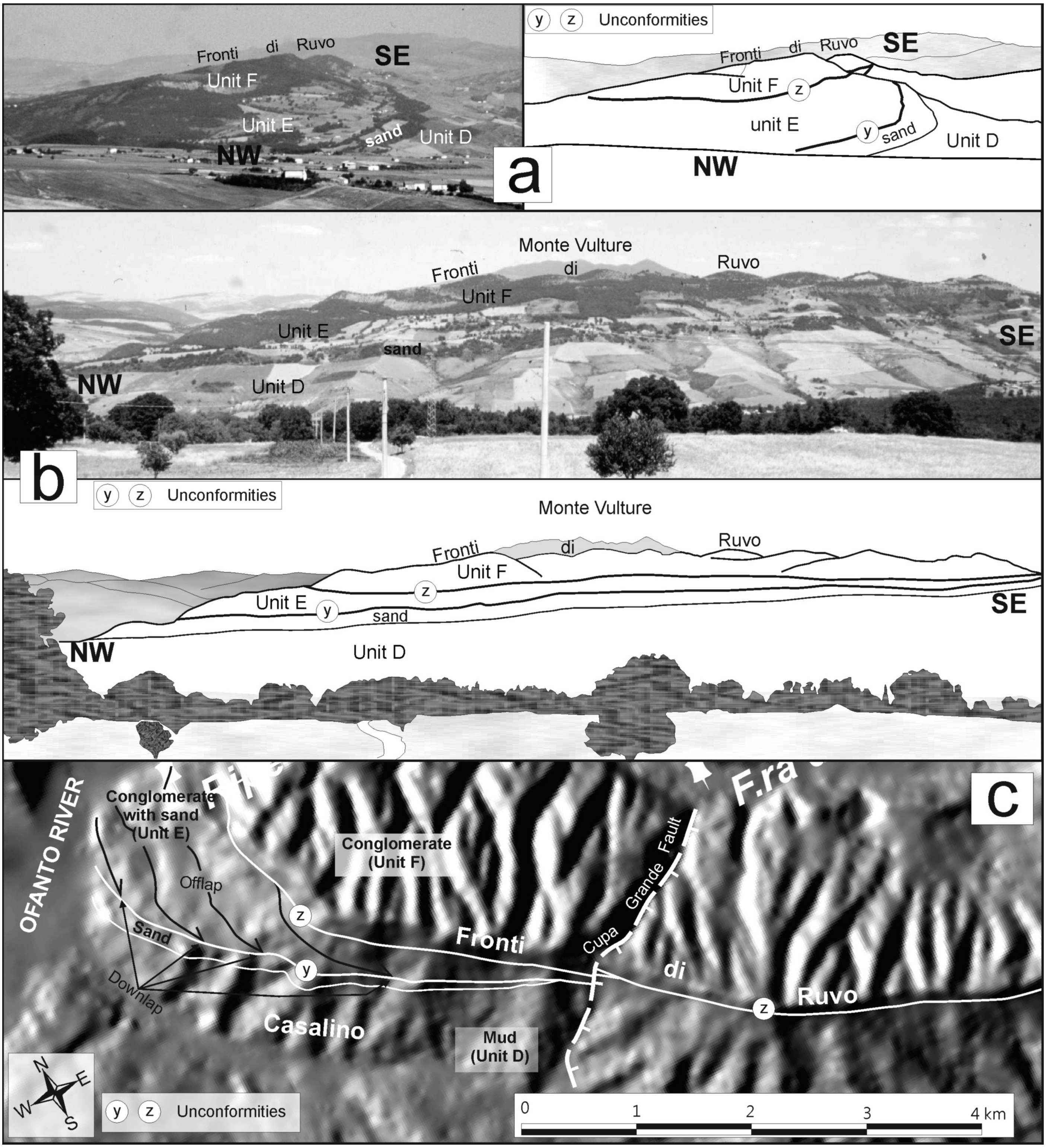

Fig. 8 - a) and *b*) Panoramic views and geological interpretations of the north-eastern portion of the basin (between Casalino and Fronti di Ruvo localities), showing the unconformities **y** and **z** separating the units D, E and F; *c*) line-drawing of the DTM of the same area displaying the morphological expression of the above explained relationships, due to the progradational fill of the unit E down-lapping on the unit D.

of the sedimentary sources. These deposits, in fact, derive from the erosion of southern source areas.

The sandy and pelitic facies have been studied in the Calitri, Ruvo del Monte, Fronti di Ruvo, and Monte Cervaro areas (see enclosed MAP). In the Cairano-Calitri area, they overlie the just described conglomerates (figs. 1 and 4). Between Calitri and Monte Cervaro, the reconstructed stratigraphic section shows a transgressive-regressive succession (logs 8 and 9 in fig. 4) made of silty-clayey sandstones (at the base and the top of the succession) and sandy-silty clay (in the middle portion of the succession and interbedded with the sandstones of the lower part). In the Calitri area, the bottom of the sandstones is marked by the unconformity **x,** whereas the top is truncated by a local unconformity mapped only in the Serra Spinella locality (fig. 2b). The sandstones are made up of three bodies, thick, from the bottom, respectively 40, 10 and 30 m; the sandy bodies are separated by two laminated clayey and silty bodies containing well-preserved macrofossils, thick, from the bottom, respectively 37 and 14 m (log 9 in fig. 4). The sandy bodies are fine- to medium-grained, yellow in colour, normal graded and organized in massive layers (from 0.20 to 1.90 m tick), with mud pebbles, bioturbations, and macrofossils both complete or in fragments. Toward south (i.e. to the basin depocenter), within ~750 m, the single sandy beds quickly decrease in thickness to few centimetres (fig. 4). The entire ridge of Serra Spinella (fig. 2b) is constituted of laminated grey to light blue silty-sandy clay organized in beds, prograding to the north-east, showing a progressive angular unconformity. At the top of the clay succession (Monte Cervaro locality), a regressive shoreface sandy body, composed of planar cross-stratified 3-5 m thick beds with common alignments of shells at the base of the foresets, has been surveyed. It is worth noting that foreset orientation and architecture of those sandy bodies (interbedded toward northeast and southeast with silty-clay facies; figs. 1b and 4) indicate an eastward clinoform migration.

The stratigraphic section reconstructed in the southern part of the basin, belonging to the same unit **D**, is about 620 m thick (log 16 in figs. 1 and 4) and is constituted by a NE-dipping succession of sediments (fig. 5b).

The lower part of the succession is composed of 235 m of fine- to medium-grained yellowish sandstone, in 0.10 to 1.6 m thick beds organized in four sequences. From the bottom, the first two sequences are formed by horizontally laminated sandstones with scattered fossils, both showing up to 10 m tick amalgamated beds, separated by an about 30 m thick stratigraphic interval constituted of sandstones interbedded with fossil-bearing laminated silty clays (0.20-2 m thick beds). To the top, the lower part of the succession shows massive or horizontally laminated (subordinately graded) sandy beds, interbedded with silty clay and sometimes characterised by scattered fossils and by erosive surfaces, ripples laminations, and trough cross beds at the top of the layers. The upper two sequences are formed by massive sandy beds with shelly basal lags, with thin interbedded layers of silty clay; the lower body is ~55 m thick, whereas the upper body reaches the thickness of ~10 m, and are separated by ~58 m of laminated silty clay.

All these sandstones, indeed, form up to 8 km laterally continuous lens-shaped bodies, which are northeastward dipping and progressively laterally shifted upward (i.e. to the north-west, cf. figs. 1b and 4). Locally (e.g. at Rapone village), up to 10 m thick bodies of amalgamated sandy layers with thin interbeds of massive clast-supported conglomerate, crop out.

The uppermost part of the Ruvo del Monte section is formed by 385 m thick beds made of massive or laminated grey-blue silty clay. Almost at the top of the section, up to 10 m thick massive fine-grained sandstones in amalgamated beds, locally with shelly basal lags, are present.

The top of the unit **D** (Casalino locality) is made of a 30 m thick lens-shaped sandy body, laterally extended up to ~4.5 km (figs. 1, 4 and 8). These fine-grained sandstones, yellowish in colour, form 60-70 cm thick beds with trough cross-beds; at the base of the channels, there is always a lag deposit of shells. The lower part of that body is constituted of 22 m thick amalgamated beds of sandstone with thin layers of laminated silty clays at their tops.

Samples of the unit **D** have been extensively collected in the basin, from the western (Calitri-Rapone localities) to the eastern outcrops which revealed to have younger age eastward (Casalino locality). Calcareous nannofossil assemblages have been analyzed quantitatively in order to provide accurate determination of the biozones which mainly base on the extinction events of *Discoaster* species. From the lower portions to the upper ones, the unit has been referred to the zones MNN16a, MNN16b/17, MNN18 (late Zanclean to Gelasian). Planktonic foraminifera assemblages are diagnostic of the same time interval, from the MPL4a zone (above the disappearance event of *Globorotalia margaritae*) in the lower part of the unit, to MPL5a zone (below the first occurrence event of *Globorotalia inflata*) at the top.

The above described facies characters allowed to argue that Cairano conglomerate body might represents Southeastward coarse-grained progradational marine delta system. The other conglomerate bodies, present in several small outcrops (fig. 1b), represent correlative facies of the Cairano conglomerate, forming a depositional system in which source variations of sedimentary supply may explain their arrangement and differences.

Sandy deposits outcropping in the Calitri and Monte Cervaro areas may be interpreted as river-dominated delta bars (Walker & James, 1992), whereas the sandstones outcropping in the Ruvo del Monte-Casalino area could represent Northeastward progradational river delta bars, weakly influenced by waves. In particular, the Calitri sandy deposits could be generated by material transported in suspension as a buoyant plume or as density underflows produced at the river mouth during high-discharge stages (Wright *et alii*, 1988). On the other hand, the presence of bioturbation is an indication of time-spaced sedimentary supplies, whereas the absence of wave structures suggests that the sedimentation surface had to be below the threshold of wave influence. The aggradational-type sand-clay lateral variations and the southward rapid decrease to some centimetres of the sandy beds are indicative of a subsident basin, bounded to the north by a steep slope, where the sedimentation rate is equal to the subsidence rate. Finally, the sandstones cropping out at Monte Cervaro are interpretable as a distributary mouth bar system (Bhattacharya & Walker, 1991).

Sandy bodies outcropping in the Ruvo del Monte-Casalino area are characterised by lateral continuity (4,5 to 8 km), suggesting an environmental setting of a shoreface on a gentle slope. The presence of reworked massive sandstone layers, characterised by cross-bed structures at the top and lag deposits of shells at the base, also marked by scour surfaces, indicates that deposition was most probably due to fluvial unconfined debris flows or sheet flows, later modified in marine environment so producing storm- or wave-generated sand ridge or storm-dominated shorface deposits (e.g. Johnson & Baldwin, 1986). The fine facies are interpreted as offshore sediments, whereas those interbedded with the sandstones as prodelta deposits.

Facies analysis allowed the attribution of the different sedimentary bodies to several Eastward wandering delta-systems distributed along the northern and southern margins of the basin. The unit **D** sediment sources have to be identified in both the sides of the basin, and precisely from the northern flank for the Cairano, Calitri, and Monte Cervaro delta-systems and from the southern sectors for the Ruvo del Monte delta-systems. At that time, the Ofanto Basin was an EW-striking elongated gulf (~7 km wide), open toward east.

*Units **E** and **F***

The last two units (**E** and **F**) crop out in the eastern sector of the basin (fig. 1b). The Unit **E,** bounded at the bottom and at the top respectively by the unconformities **y** and **z,** is a sedimentary wedge overlapping both the Ariano Supersynthem (fig. 8) and the pre-Pliocene bedrock, reaching ~400 m in thickness along the Ofanto River. The unit is composed of brown coarse-grained, clast-supported conglomerates interfingering toward southeast to silty-clay sandstones, with scattered shell fragments of marine molluscs (figs. 1b and 4). The conglomerate terminations, constituted by massive facies due to debris flows (MIALL, 1996) or iperconcentrated flows (PIERSON, 1980; SMITH, 1986), are in downlap onto the unconformity **y**. In the northernmost basin area, the Unit **E** conglomerate shows trough cross-bed structure (minor channel fills; MIALL, 1996), with rare lenses (up to 6 m in thickness and 15-20 m in width) of laminated marine silty-clay interbedded with thin horizontally laminated fine sandstones, yellowish in colour. The pebbles (up to 30 cm in size) are well-rounded and composed of sandstones, marly limestones and calcarenites. Palaeocurrent markers, measured along the cross-bedding dip direction, suggest palaeoflows from a Northwestern source.

Calcareous nannofossil assemblages are Gelasian in age. The MNN18 zone has been recognized on the basis of the occurrence of *Discoaster brouweri*, *Coccolithus pelagicus, Pseudoemiliania lacunosa, Calcidiscus leptoporus*, and the absence of other Pliocene discoasterids. Unfortunately planktonic foraminifera assemblages do not include taxa for reliable age assignment.

A SE-directed progradation is responsible for the sedimentation of the unit **E** conglomerates and interbedded silty sandstones; this unit has to be interpreted as a coarse-grained marine delta system.

Finally, the 550 m thick Unit **F** represents the uppermost portion of the Pliocene to Quaternary Ofanto Basin succession. This unit unconformably overlies the units **D** and **E,** and, on the eastern basin margin, directly the bedrock. Well-exposed outcrops allowed reconstructing a section of ~250 m in thickness, which represents the uppermost part of the unit **F**, being the rest of the unit buried by younger volcanic deposits (note that the whole thickness has been calculated on the grounds of the cross-section of fig. 5b). The lithological characters of the unit **F** permitted to split it into two heteropic facies associations. In a planimetric view, the conglomerate-prevalent facies association surrounds the sand-prevalent facies association, forming a sort of horseshoe-shaped arrangement (see the attached map).

The unit **F** conglomerates crop out along the Fronti di Ruvo slopes and edge the north-eastern and western basin margins (fig. 1b). In the Fronti di Ruvo area, the outcrops show ~80 m thick massive clast-supported dark-brown conglomerates, often characterised by trough/planar cross beds and subordinately by horizontal beds, interpreted as braided channels developed in an alluvial plain or fan (GIANNANDREA, 2003), dominated by flood deposits (e.g., ALLEN, 1981; TODD, 1989; MAIZELS, 1989, 1993) and bar-slipface deposition with bedload on bar surfaces (e.g., BAKER, 1973; HARMS *et alii*, 1975; BLUCK, 1980; STEEL & THOMSON, 1983). The pebbles/cobbles (clasts of max 60 cm in size) are mainly sub-rounded or tabular and consist of calcarenites, limestone with chert, calcisiltites, marly limestone, sandstones, and rare granites. At different stratigraphic levels there are lens-shaped intercalations (up to 5-6 m thick and up to 50 m wide) of sandstone, silt and mud with thin laminations (rapid fall-out from overbank flood; WALKER, 1967) and of massive and trough cross-bed yellowish sandstones, respectively associated with rapid fall-out from highly concentrated turbulent flows (SMITH, 1986) and with dune wandering (HARMS *et alii*, 1975) or scour fills (HARMS & FAHNESTOCK, 1965). In a minor amount, also thin layers of horizontally laminated beds are present in those lenses, as a product of an upper flow regime (PICARD & HIGH, 1973). These deposits generally contain plant remains and, locally (at about 19 m from the base of the Fronti di Ruvo outcrop), disarticulated bones of continental vertebrates.

The fine sediments occupy the core of the unit **F** outcrop area and are composed of an alternation of metric layers of thin laminated sandstone, siltstones and clay, and massive clay with plant remains and roots bioturbation. At several stratigraphic levels, channel-fills (0.5 to 5 m thick and 2 to 10 m wide) of massive and trough cross-bed clast-supported conglomerate are present as well. Fine facies are due to sedimentation linked to periodic floods of the alluvial plain or distal fans, whereas the conglomerates have to be interpreted as distributary channel-fills in a lacustrine or marshy floodplain (GIANNANDREA, 2003). Palaeocurrent markers in the conglomerate facies and channel directions in the fine facies suggest palaeoflows from south-west, north-west, and north-east with regard to the present-day outcrop area of the unit **F**. Facies relationships and radial palaeoflows remark the existence of an endorheic basin during the time-span early Gelasian-Calabrian?. This age has been obtained by the stratigraphic relationships among the unit **F** and the overlaying and underlying units: as a matter of fact, early Gelasian sediments (see unit **E**) lie below the unit **F**, whereas Monte Vulture volcanic rocks sutured the same unit.

UBSU INTERPRETATION

UBSU interpretation of the six stratigraphic units above described has been based on the lateral traceability and hierarchy of their discontinuity bounding surfaces. In this paper, according to UBSU nomenclature and rules, we assumed that the limits of synthems had to be recognisable in the whole Ofanto Basin, whereas the subsynthem limits had to be detectable in the entire synthem outcrop area in which they are included. The supersynthem rank is gained by units whose unconformities are identifiable across two or more adjacent basins (i.e. on a regional or sub-regional scale, cf. fig. 9). Aquilonia-Bisaccia and Ariano Irpino intra-chain-basins, respectively to the north and north-west, and the Bradano Foredeep Basin to the east (fig. 1a)

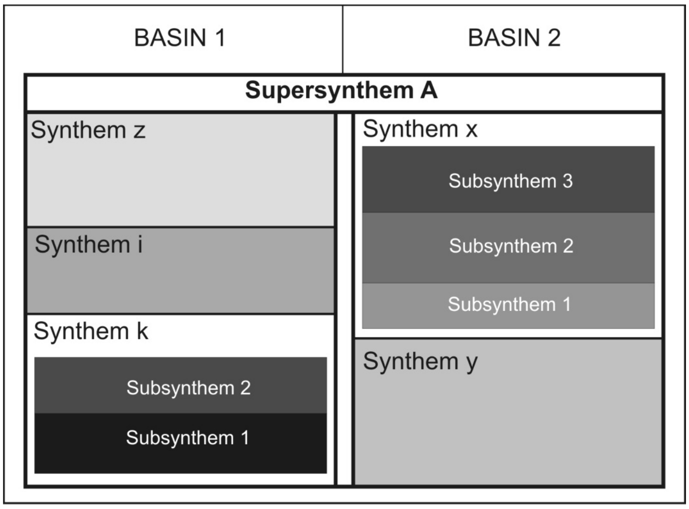

Fig. 9 - Conceptual scheme used in this paper to explain mutual and hierarchical relations among unconformity-bounded stratigraphic units outcropping in two adjacent sedimentary basins. In the same supersynthem may coexist quite different successions from distinct depositional realms.

are the closest, partly coeval, sedimentation areas with regard to the study area. Because of their regional spreading, we can assign the rank of supersynthem boundary to **j**, **k**, and **y** limits. The unconformity **j** crops out also in the Aquilonia-Bisaccia Basin, whereas the unconformities **k** and **y** are spread in the Ariano Irpino basin and Bradano Foredeep. On the basis of the biostratigraphic ages attributed to the deposits at the roof and at the bottom of the single unconformities, we can confidently constrain the unconformity **j** at ~4,5 Ma (Foglio 451 Melfi, scale 1:50,000, Carta Geologica d'Italia, 2010), the unconformities **k** at ~4 Ma, and the unconformity **y** at about 2,5 Ma (e.g., Balduzzi *et alii,* 1982a and b; Basso *et alii*, 2002; Patacca & Scandone, 2007).

Unconformities **x** and **z** are recognisable only in the Ofanto Basin area, so assuming a synthem-boundary rank. The unconformity **x** can be set at about 3.8 Ma on the grounds of biostratigraphic data (this paper). Finally, the unconformity **w**, outcropping just in a small area of the Ofanto Basin (Difesa locality; fig. 1b), takes the rank of subsynthem boundary. Therefore, the units forming the Pliocene to Quaternary sedimentary succession of the study area bounded by unconformities **j**, **k**, and **y** assumed the rank of supersynthems and named as Aquilonia, Ariano Irpino, and Fiumara di Atella supersynthems (fig. 10). The Aquilonia Supersynthem includes the alluvial conglomerates of the unit **A** (cf. § Stratigraphic units) and a marine-continental succession formed of conglomerates, sandstones, and clay cropping out in the Aquilonia-Bisaccia Basin. Such sediments testify the first Pliocene sedimentary syntectonic episode in the south-Apennines chain.

The Ofanto and Aquilonia-Bisaccia basins are separated by the flat-topped ridge of Monte Mattina (just at north of the mapped area, cf. Foglio 451 Melfi, scale 1:50,000, Carta Geologica d'Italia, 2010). Palaeocurrent measurements in conglomerates facies of both basins showed northeast provenance for the Ofanto Basin and a southern supply for the Aquilonia-Bisaccia Basin (Ciarcia *et alii*, 1998), so indicating that the present-day Monte Mattina area was the same sedimentary source for both the basins as an uplifted block.

The unconformities **k** and **y** bound the Ariano Irpino Supersinthem, including the units **B**, **C**, and **D**. Monte Airola and Vallicella subsynthems coincide respectively with **B** and **C** units, separated by the local unconformity **w**, and grouped in the Andretta Synthem. The unit **D**, which overlies the unconformity **x** and has been mapped at basin-scale, has been here named as Ruvo del Monte Synthem (fig. 10). The units **D** overlaps the unit **C**, that in turn covers the unit **B**, showing an eastward shift of the sedimentary depocenters (fig. 1b and attached map), i.e. a basinward relocation of depositional systems through the time. Such variations may reflect small changes in accommodation space and sedimentary supply during the tectonic evolution of the basin. The palaeocurrent data

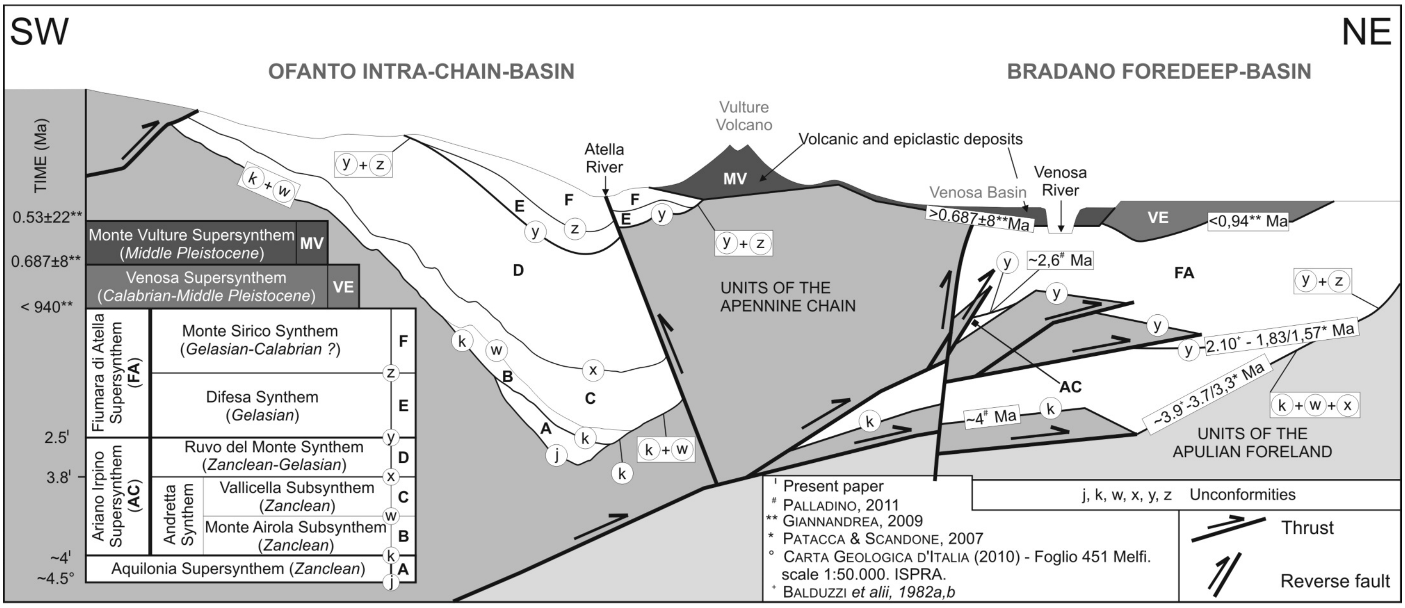

Fig. 10 - Tectono-stratigraphic scheme (location in fig. 1a) of a large area including the eastern Ofanto intra-chain basin and the western Bradano foredeep (see text for the explanation).

show that a palaeoflow from North-West was responsible for the sediment supply of the unit **B**, whereas palaeoflows from the North-Northwest and southern sectors indicate that the sediment source of the units **C** and **D** has to be identified in the present-day areas of Monte Mattina (at the North) and Pescopagano-San Fele (at the South). Further, the major basal unconformity **k** allows us to identify the original perimeter of the Ofanto palaeobasin. The later minor unconformities **w** and **x** cut both the Pliocene units and the bedrock. Both the transitions from Monte Airola to Vallicella subsynthems, and from Andretta to Ruvo del Monte synthems, are testified by abrupt, slightly discordant, contacts between quite different rocks, deposited in non-contiguous environments.

Also the Baronia and Sferracavallo synthems have been included in the Ariano Irpino Supersynthem (Basso *et alii*, 2002). They are composed of alluvial and marine conglomerates, sandstones, and clays cropping out in the Ariano Irpino intra-chain basin, and are correlative of a sandy-clayey-marly succession deposited in the Bradano Foredeep Basin (Balduzzi *et alii*, 1982a, b). In both the basins, the Pliocene deposits are bounded at the base by an unconformity cutting the bedrock. The age of this basal limit varies from ~4 Ma in the Ariano Irpino Basin (i.e. immediately before the debut of the MPl4a Biozone; Basso *et alii*, 2002) to 3.7-3.3 Ma in the Bradano Foredeep (Patacca & Scandone, 2007). The age of the upper unconformity of the Ariano Irpino Supersynthem in the homonymous basin has to be referred to ~2.46 Ma (i.e. the end of the zone MPl5a; Basso *et alii*, 2002), whereas in the Bradano trough the same limit has been identified at the base of the Apennines thrust wedge, which is incorporated in the Pliocene to Quaternary foredeep succession. The approximate age of this unconformity is 1.83-1.57 Ma (Patacca & Scandone, 2007). The ages of the unconformities which bound the Ariano Irpino Supersynthem in the tree basins above mentioned indicate a quasi-synchronous formation of erosional surfaces in the chain area, whereas the planation processes are diachronous in the Bradano Foredeep. There, a more recent age is recorded moving Northeastward. The lower discontinuity (i.e. the planation surface at the base of the supersynthem) is the product of erosional stages related to several unconformities (**k**, **w** and **x**); the upper discontinuity (i.e. the erosional surface generated at the top of the supersynthem) correspond to the sum of the erosional processes which lead to the formation of the unconformities **y** and **z** (fig. 10).

The Fiumara di Atella Supersynthem comprises the units **E** and **F**, separated from the unconformity **z** mapped at the scale of the Ofanto Basin. They have been defined, respectively, as Difesa and Monte Sirico synthems (fig. 10). The Difesa Synthem is composed of a wedge-shaped body of marine delta-system coarse-grained sediments which unconformably overlies both the Ariano Supersynthem and the bedrock (fig. 5b). Both the synthems covered a Southwest-verging high-angle back-thrust, which later cut the same units and the whole Pliocene succession of the Ariano Irpino Supersynthem. The Difesa Synthem palaeocurrent data indicate a northwest sediment source, from the Monte Mattina area. The geometry and the overlap relationships of the conglomerate bodies suggest a delta-system progradation toward the South-East. The Monte Sirico Synthem overlies the Difesa Synthem, showing a southeastward shift of the sedimentary depocenters (cf. § Stratigraphic units, *Units E and F*).

The Eastern location of the outcrop area of the Fiumara di Atella Supersynthem, together with the palaeocurrent data, besides its relationships with the oldest units, suggests that the transition from the Ariano Irpino to the Fiumara di Atella supersynthems is strongly controlled by a relevant tectonic stage that modified both the geometry and accommodation space of the Ofanto Basin. Such a change was so important to form a “new” basin with different sedimentary characters and shifting accommodation space. During this stage, the Apennines nappes were transported onto the mid-Pliocene foredeep succession. As a consequence, a ridge east to the Ofanto Basin started to grow. Such a structural high gradually separated the studied basin from the foredeep in Gelasian-Calabrian times, so furnishing new sedimentary supply to both the basinal areas.

DISCUSSION AND CONCLUSIONS

The comparison between the attached map of the eastern sector of the Ofanto basin and the same area in the official maps at 1:100,000 scale (Carta Geologica d’Italia, 1970a and b) shows the unquestionable increase in number of units and lithological distinctions. As well-known, the Ofanto basin grew on the top of stacked allochthonous tectonic units migrating toward the foreland (Patacca & Scandone, 2001, 2007). The detailed map here attached shows that the stratigraphic setting of the basin represents the effects of a tectonically-controlled deposition rather than the response of climate pulses. In other words, the fast tectonic processes acting in the study area overcame the rates of climate-induced changes. Yet, it is worth noting that some discontinuities have regional or sub-regional extent and, therefore, they have to be generated under peculiar climatic conditions that facilitated the genesis of huge erosional flat or gently dipping surfaces (see for example Gioia *et alii*, 2011a and b). It follows that such surfaces are diachronic and that the surfaces are progressively younger towards the zones reached later by the tectonic deformation (fig. 11 and tab. 1). Further, the ages of the main unconformities determined by accurate biostratigraphic analyses are in agreement with those obtained by Apatite fission track analysis and interpreted as the stages in which the regional palaeosurfaces formed (cf. Schiattarella *et alii*, 2012). Anyway, the correct mapping of unconformity-bounded units of clastic synorogenic basins may help to better relate the amount and the depositional modalities of the basin infill with the denudational stages featuring the bedrock of the source areas.

The boundaries among the units can separate both clastic bodies within the sedimentary basin and single units from the deformed bedrock on which they lay. For this reason, a discontinuity can represent in many cases the relic of a polyphasic (and maybe polygenic) erosional surface. In the study area and adjoining Bradano foredeep basin (fig. 10), the discontinuity that initially separated the oldest synthem from the bedrock has been repeatedly reworked and re-shaped as an erosional surface in its westernmost (Ofanto basin) and easternmost (foredeep area) sectors, whereas it was totally obliterated in the central area by the Monte Vulture Volcanic succes-

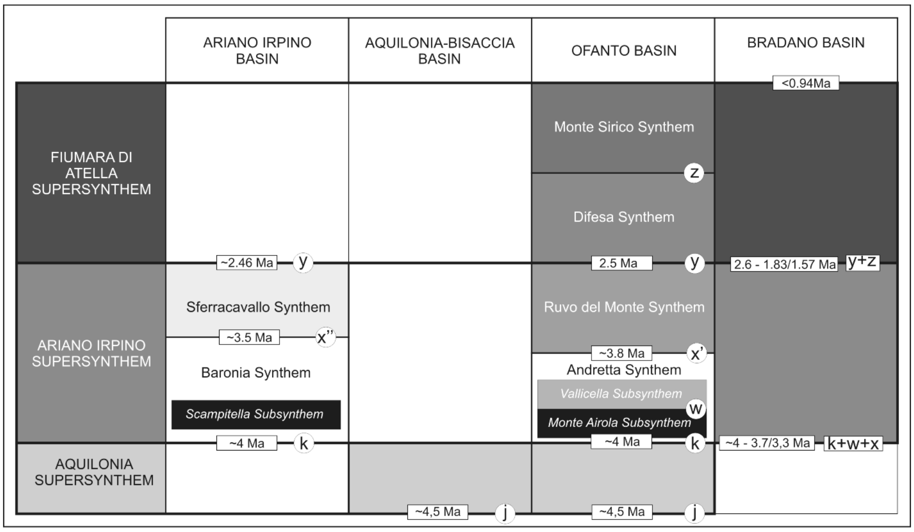

Fig. 11 - Stratigraphic and chronological scheme of correlation among unconformity-bounded stratigraphic units from the partly coeval Ariano Irpino, Aquilonia-Bisaccia, Ofanto, and Bradano adjacent sedimentary basins.

TABLE 1

Ages an ranks of the discontinuity surfaces from the Ariano Irpino, Aquilonia-Bisaccia, Ofanto, and Bradano basins.

Unconformity code	**Unconformity rank**	**Age (Ma)**	**Basin**	**References**
z	Synthem	-	Ofanto	Present paper and attached geological map. CARTA GEOLOGICA D'ITALIA (2010) - Foglio 451 - Melfi, scale 1:50000. ISPRA.
y	Supersynthem	~2,46 2.5 2.6-~2,1/1,57	Ariano Irpino Ofanto Bradano Foredeep	Present paper and attached geological map. PALLADINO (2011). CARTA GEOLOGICA D'ITALIA (2010) - Foglio 451 - Melfi, scale 1:50000. ISPRA. PATACCA & SCANDONE (2007). BASSO et alii (2002). BALDUZZI et alii (1982a and b).
x'' x'	Synthem	~3,5 ~3,8	Ariano Irpino Ofanto	Present paper and attached geological map. CARTA GEOLOGICA D'ITALIA (2010) - Foglio 451 - Melfi, scale 1:50000. ISPRA. BASSO et alii (2002).
w	Subsynthem	-	Ofanto	Present paper and attached geological map. CARTA GEOLOGICA D'ITALIA (2010) - Foglio 451 - Melfi, scale 1:50000. ISPRA.
k	Supersynthem	~4 ~4 ~4-3,7/3,3	Ariano Irpino Ofanto Bradano Foredeep	Present paper and attached geological map. PALLADINO (2011). CARTA GEOLOGICA D'ITALIA (2010) - Foglio 451 - Melfi, scale 1:50000. ISPRA. PATACCA & SCANDONE (2007). BASSO et alii (2002). BALDUZZI et alii (1982a and b).
j	Supersynthem	~4,5 ~4,5	Aquilonia-Bisaccia Ofanto	CARTA GEOLOGICA D'ITALIA (2010) - Foglio 451 - Melfi, scale 1:50000. ISPRA.

sion. Therefore, more denudational stages may superpose on the same morphological surface which is going to become an unconformity. Such a discontinuity, in fact, may be partly exposed for a long time ($N \times 10^5$) and it could experience further exogenic processes. Most part of the planation processes seems to occur during relatively cold periods within a progressive cooling trend (cf. LISIECKI & RAYMO, 2005), as suggested by sea-level negative oscillations between 4.0 and 3.8 Ma and before 2.5 Ma (between 3.0 and 2.8 Ma). As a matter of fact, the two major unconformities recorded in the sedimentary infill of the Ofanto basin are well-constrained by biostratigraphic data at about 4.0 and 2.5 Ma. It is worth noting that only long-lasting climate-induced erosional stages following relevant tectonic events are able to produce large flat or slightly undulate landscapes, whereas a continuous deformation that preserves the same structural setting on a regional scale (e.g. more basins separated by growing anticlines or thrust ramps) tends to generate intra-basinal unconformities and to retain the same morpho-structural scenario. Therefore, the unconformities which can be mapped on a regional or sub-regional scale and/or in different but contiguous basin-fills are the stratigraphic expression of quiet periods interposed between two regional tectonic events, assuming the rank of discontinuities separating supersynthems. In these cases, the units at the erosional interface generally show strong lithological and facies contrasts, well recognisable both in the field at the outcrop scale and in panoramic views (figs. 8a and 8b), and detectable also by photo-aerial, digital elevation model (fig. 8c), and remote sensing analyses.

The six stratigraphic units surveyed in the Ofanto basin are separated by discontinuities with different hierarchical ranks. The basal unconformity **j** and the subsequent **k** are supersynthem boundaries, delimitating the Aquilonia Supersynthem (figs. 10 and 11), constituted of alluvial deposits in the Ofanto basin (fig. 12a) and of conglomerate-sandy-clayey sediments in the Aquilonia-Bisaccia basin, dated at ~4.5 Ma (Zanclean, MNN13 Zone; Foglio 451 Melfi, scale 1:50,000, Carta Geologica d'Italia, 2010). In both cases, those sediments denote depositional areas characterised by fast accumulation, deformation, and erosion rates. In the Pliocene intra-chain basins and Bradano foredeep, the top unconformity **k** marks the beginnings of the sedimentation onto the Apennines allochthonous units at ~4 Ma, and onto the Apulian foreland at ~3.9 Ma (figs. 10, 11 and 12b).

During this stage, the Ofanto palaeobasin was most probably a 7-km-large open synform, bordered at its southern flank by gently dipping slopes and at its northern side by steeper slopes. A series of east-west striking and north-directed thrusts (fig. 1b) – controlling part of the Pliocene sedimentary history – characterised the southern basin side, whereas a strike-slip fault system deformed the northern basin boundary, also driving the stacked geometry of the upper Pliocene-lower Pleistocene deposits (i.e. Ruvo del Monte Synthem; cf. figs. 2b and 13). Such a trough was probably connected with the Bradano foredeep toward east and with the Ariano Irpino intra-chain basin toward its north-western termination. The unconformities **k** (age: ~4.0) and **y** (age: ~2.46/~2.5) respectively represent the lower and upper limits of the Ariano Irpino Supersynthem, cropping out in the Ariano Irpino, Ofanto, and Bradano basins (fig. 11). In the latter, the age of those unconformities have been respectively dated at 3.3 Ma and 1.57 Ma (fig. 10), so suggesting a progressive, east-directed, drowning of the Apulian carbonate platform, due to thrust propagation of the Apennines chain and related foreland underplating.

The unconformity **y** marks the erosional stage followed to the fill of the Ariano Irpino basin (Basso *et alii*, 2002), whereas the same discontinuity indicates a tectonic deformation in the Ofanto and Bradano areas, responsible for the relief growing between the two domains and their consequent separation (Giannandrea, 2003). The tectonic structures involving the pre-Pliocene bedrock are expressed by thrusts and back-thrusts forming a pop-up structure (fig. 10). The propagation of the west-dipping and east-directed thrust toward the foreland involved the Bradano foredeep successions, carrying out the allochthonous units over them (Balduzzi *et alii*, 1982a and b). To the south-west, back-thrusts cut the whole clayey-sandy sequence of the Ariano Irpino Supersynthem (fig. 12c), strongly modifying the previous geometry and sedimentary setting of the Ofanto palaeobasin. Synsedimentary tectonics was responsible also for the genesis of the unconformity **x**, partly sculptured as a marine erosional surface cutting both the Andretta Synthem and its western bedrock, previously modelled by other erosive stages (polygenic and polyphasic palaeosurface). This was, in fact, due to a growth anticline located near the present-day Calitri town which caused the formation of two distinct sedimentary depocenters inside the same basin during the sedimentation of the Ruvo del Monte Synthem (fig. 12b). It is worth noting that a correct palaeomorphological interpretation of the meaning of the stratigraphic unconformities (i.e. their identification as physical elements of the ancient landscape) would represent a powerful tool to better decrypt the complete geological history of complex basin in orogenic areas.

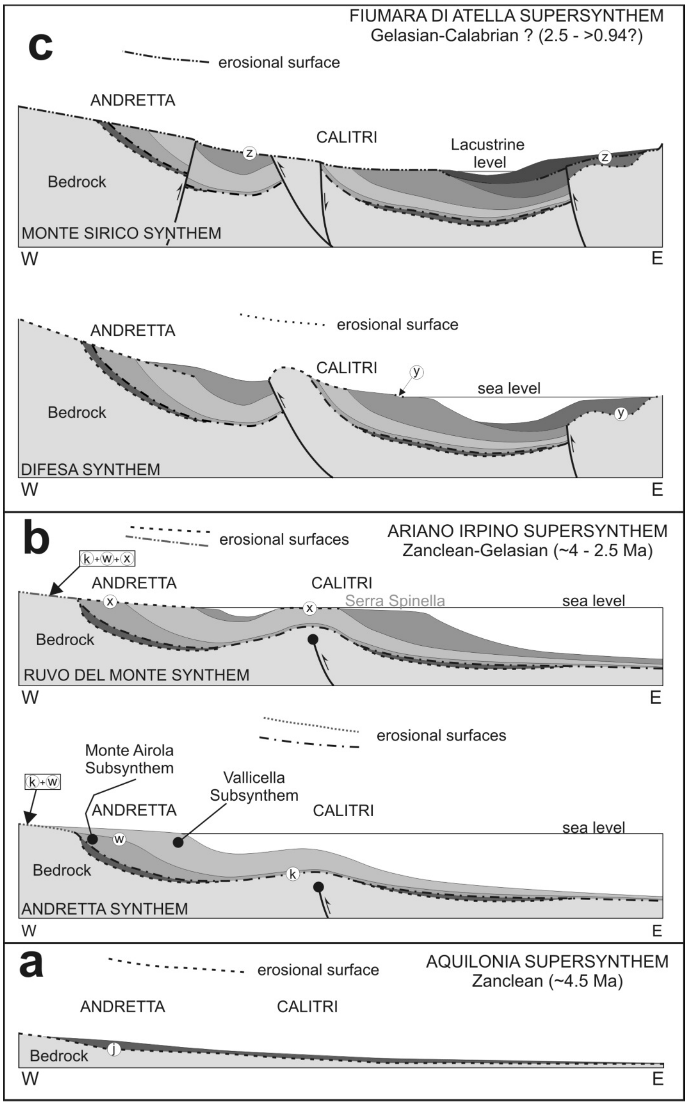

Fig. 12 - Morpho-tectono-sedimentary evolution of the study area, with particular reference to the northern margin of the Ofanto basin from the Zanclean to Gelasian-Calabrian (?): *a*) Embryonic basin formation associated to the sedimentation of the Aquilonia Supersynthem alluvial conglomerate on the erosive surface **j** (Zanclean); *b*) progressive anticline growth (Calitri village area) and sedimentation of the Ariano Irpino Supersynthem: note the synthemic subdivision based on the role of unconformities/erosional surfaces and on the development of the Calitri blind thrust, leading to the separation of the original sedimentary realm in two sub-basins; *c*) bedrock uplift of the eastern part of the area represented in the scheme, leading to the offset of the Pliocene Ofanto succession, modifying the basin geometry, and shifting toward east the depositional area.

The depocenter located to the west of Calitri town was characterised by lower subsidence rates, responsible for the progressive isolation and rapid fill of this sector. In the meantime, the Calitri growing anticline separated the eastern branch from the western one, determining the

Fig. 13 - Geometrical sketch of the Serra Spinella ridge. The progressive unconformities of the growth structure and the dip directions of the single sedimentary bodies are the result of an E-W oriented left-lateral strike-slip motion, as also shown by the complex fault association at the northern basin boundary.

eastward shift of its sedimentary depocenter and related depositional systems, as clearly shown by the local progressive unconformity in the Ruvo del Monte Synthem at Serra Spinella ridge (figs. 2b and 12b). Such a depositional geometry is the result of a left-lateral wrench faulting, which imposed a progressive counter clockwise rotation to the depositional system. This sense of shear has been deduced by the stacked sedimentary bodies, which grew eastward assuming a progressively "rotated" dip (fig. 13). In addition, the structural association of the north-bounding fault system of the Serra Spinella ridge clearly indicates a left-lateral kinematics acting along an E-W striking narrow zone. This deformational field may represent a surface effect, as a second-order fault association, of a deep-seated transfer structure, which might have subsequently controlled the activity of Vulture Volcano during Lower to Middle Pleistocene (e.g., SCHIATTARELLA *et alii*, 2005; GIANNANDREA *et alii*, 2006).

The Andretta Synthem (fig. 1b) is divided in two subsynthems by the unconformity **w**, which marks the contact between the marine sandy clay of the Vallicella Subsynthem on the underlying alluvial conglomerate of the Monte Airola Subsynthem, so implying a sharp palaeoenvironmental change (fig. 12b).

After the splitting of the major basin in two separate sub-basins, the sedimentary depocenter of the eastern one stabilizes in the easternmost sector of the Ofanto basin, close to the back-verging thrust of the Fiumara di Atella lower valley (figs. 5b, 10 and 12c), and is represented by the deposits belonging to the Fiumara di Atella Supersynthem. During this stage, a new deltaic depositional system developed (Difesa Synthem), constituted of SE-prograding conglomerate wedges (fig. 8c). At that time, the basin was likely still connected to the Bradano foredeep by a narrow sea-tongue. Such a linkage rapidly disappeared, causing the complete isolation of the Ofanto basin which became an alluvial floodplain whose fluvial channels drained toward south-east in a marshy area (Monte Sirico Synthem). Lateral sediment supply came from both south-western and north-eastern sides by fluvial transport. These streams mainly dismantled the Ariano Irpino Supersynthem, finally producing a significant but local erosional land surface. Such a morphological surface is stratigraphically expressed by the unconformity **z** (fig. 12c). The marshy area located at the eastern margin of the Ofanto basin was characterised by the sedimentation of fine-grained deposits, showing many flash-food overbank facies with set-apart channel-fill alluvial gravels. In such a scenario, more events of flood were alternated with relatively drier periods responsible for both the decrease in sedimentary supply and the areal reduction of the palustrine environment.

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