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32nd INTERNATIONAL GEOLOGICAL CONGRESS

PLIO-PLEISTOCENE STRATIGRAPHIC AND TECTONIC EVOLUTION OF THE FORELAND-FOREDEEP-CHAIN SYSTEM IN SOUTHERN ITALY

Leaders:
P. Pieri, L. Sabato, M. Tropeano

Associate Leaders:
S. Gallicchio, F. Loiacono, M. Schiattarella

Florence - Italy
August 20-28, 2004

Post-Congress **P35**

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Front Cover:
Nonna Carmela. Albano di Lucania
(southern Apennines, Basilicata).

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1. Introduction

P. Pieri, L. Sabato, M. Tropeano

The aim of this field trip is to illustrate the three main depositional areas of the Plio-Pleistocene Apennines foredeep system (foreland, foredeep *s.s.*, and satellite basins) in southern Italy and to discuss its evolution showing stratigraphic and sedimentologic features of tectonized to practically undeformed Plio-Pleistocene successions.

The Apennines foredeep (Italy) is the Upper Oligocene to present-day foreland basin developed on the flexured Adria Plate. Up to Pliocene time, the Apennines foredeep was a deep basin characterized mainly by turbidite sedimentation (Pescatore, 1978; Ricci Lucchi, 1986; Casnedi, 1988; 1991; Ori *et al.*, 1991), while the Quaternary Apennines foredeep is a basin characterized by: i) a subsiding overfilled sector (Po Plain); ii) a subsiding nearly filled sector (north-central Adriatic Sea); iii) an uplifted, exposed, and cannibalized sector (Bradanic Trough); iv) a deep-marine basin only in the southernmost part of the present-day foredeep (the Taranto Gulf in the Ionian Sea) (Tropeano *et al.*, 2002a, *and references therein*) (Figure 1).

Figure 1 - Schematic structural map of Italy showing the present-day location of the Apennines foredeep.

Oligo-Miocene deposits are today tectonized and added in the accretionary wedge. Younger (Plio-Pleistocene) foredeep deposits are less deformed and, in southern Italy, they are well exposed as a consequence of a severe Quaternary uplift which affected and affects the whole south-Apennines orogenic system (chain, foredeep and foreland settings). This allows us to observe, during our field trip, stratigraphic, sedimentologic, and tectonic features of Plio-Pleistocene successions of the whole south-Apennines foredeep system.

The field trip will develop between Apulia (evening of day 1) and Basilicata (days 2 to 5) regions (back cover and Figs. 7, 9, 28) and crosses a complete geological section of the Plio-Pleistocene foredeep system (Figure 2), beginning from the outer foreland ramp (Apulian Foreland - late evening of day 1 and day 2) as far as the younger thrusts of the Apennines (inner foredeep sector - day 3), through the foredeep *s.s.* (Bradanic Trough) (day 4) and the coeval satellite Sant'Arcangelo Basin (day 5) (Figure 3).

As regards field map references, we will refer to some geological maps of the Italian Geological Survey (Servizio Geologico d'Italia, sheets n°: 176 "Barletta"; 188 "Gravina"; 189 "Altamura"; 200 "Tricarico"; 201 "Matera"; 211 "Sant'Arcangelo"), and to other geological maps ("Carta Tettonica d'Italia" by Funiciello *et al.*, 1975; "Carta geologica dell'Appennino meridionale" by Bonardi *et al.*, 1988a; "Carta geologica delle Murge e del Salento" by Ciaranfi *et al.*, 1988). As regards road map references, we will refer to the "Grande carta stradale d'Italia 1: 200.000" made by the TCI (Touring Club Italiano – sheets: "Campania e Basilicata", and "Puglia").

2. Regional geological setting

P. Pieri, L. Sabato, M. Tropeano

The growth of the Apennines chain (Italy) started during Late Oligocene times (Boccaletti *et al.*, 1990), when the Adria Plate, characterized by both oceanic (Ionian sector) and continental (Apulia sector) lithosphere (Finetti, 1982; Catalano *et al.*, 2001), began to subduct back to the Alpine-Betic thrust belt; the Alpine-Betic back-thrust belt and the hinterland of the same Alpine-Betic orogen (the undeformed Adria) were progressively involved in this westward subduction (Doglioni *et al.*, 1998*, and references therein*).

The Apennines foredeep (Figure 1) is the foreland basin related to the Apennines thrust belt; its subsid-

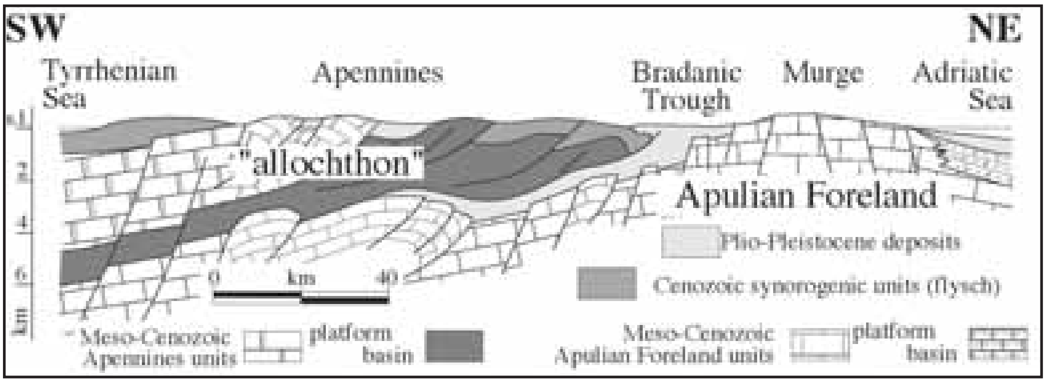

Figure 2 - Geological cross-section showing the main structural elements of the south-Apennines orogenic system (modified from Sella et al., 1988).

ence rate is higher than 1 km/Myr (Doglioni, 1994) and is induced by the eastward roll-back of the Adria Plate (slab pull and sinking, and/or opposition to relative eastward mantel flow) rather than by thrust-sheet loading (Royden *et al.*, 1987; Doglioni, 1991, *and references therein*). The Apennines foredeep depocenters moved towards the E-NE (Ricci Lucchi, 1986; Boccaletti *et al.*, 1990) following the fast Apennines arc migration, which has been calculated to be in the order of 700 km in southern Italy (*i.e.* Calabrian arc) (Patacca *et al.*, 1990; Gueguen *et al.*, 1997); this value linearly decreases moving towards the northern Apennines and, accordingly, both the amount and velocity of crustal shortening decrease from about 5-6 cm/yr to less than 1 cm/yr moving from south to north along the Apennines (Patacca and Scandone, 1989). The structural and sedimentary history of the Apennines foredeep records this progressive eastward migration of the orogenic system. Thrusting propagated within the foredeep, splitting it into an internal shallower basin (a piggyback area or a wedge-top basin) and an external deeper one (foredeep *s.s.*); high subsidence rates gradually involved more eastern sectors of the foreland (Ricci Lucchi, 1986; Boccaletti *et al.*, 1990; Ori *et al.*, 1991; DeCelles and Giles, 1996) (Figure 4). Moreover, the progressive eastward migration of the orogenic system induces the superposition of tensional and/or transtensional tectonic regimes back to the active piggyback area over chain sectors previously characterized by compressional regimes (the previous piggyback area) (Ricci Lucchi, 1986; Boccaletti *et al.*, 1990).

According to Patacca and Scandone (2001), two different styles of tectonic deformation characterize the central and southern Apennines. In the central Apennines, to the north of the Maiella Mountain and the Tremiti line, thrusts propagation mostly proceeded by imbricate fans development in piggyback sequences, which progressively involved the foreland (Bally *et al.*, 1986). In the southern Apennines, thrusts propagation mostly proceeded by long sheets (the "allochthon") which overthrust the south-Apennines foreland (the Apulian Foreland). Only after its underthrusting did thrusts propagate in the foreland (Mostardini and Merlini, 1986) and a large-scale duplex system form (Patacca and Scandone, 2001, *and references therein*) (Figs. 2, 4).

Therefore, two different styles of foredeep migration characterize the central and southern Apennines. In the central Apennines, the foreland sedimentary cover is directly involved in the thrust propagation and is predominantly added to the front of the accretionary wedge (Argnani *et al.*, 1991); in contrast, in the southern Apennines (from the Abruzzi-Molise southward up to the Basilicata region), foreland sedimentary cover is underthrust by the "allochthon" (Ciaranfi *et al.*, 1979) (Figs 2, 4, 5b). Moreover, the Apulian Foreland has been uplifting since Early-Middle Pleistocene times (Ciaranfi *et al.*, 1983). According to Doglioni *et al.* (1994) this uplift is related to the arrival of a thicker lithosphere in the south-Adriatic subduction hinge, which lowered subduction rates and caused the slab to buckle; northward and southward of Apulia the Apennines foreland continues to subside (Doglioni *et al.*, 1996).

In consequence of both uplift of the foreland and propagation of the duplex system in the south-Apennines chain, depositional successions belonging to different sectors of the Plio-Pleistocene south-Apennines foredeep system are today exposed and physically disconnected. Traditionally these disconnected successions were studied as deposited in different basins (or depocenters), but recently, according to

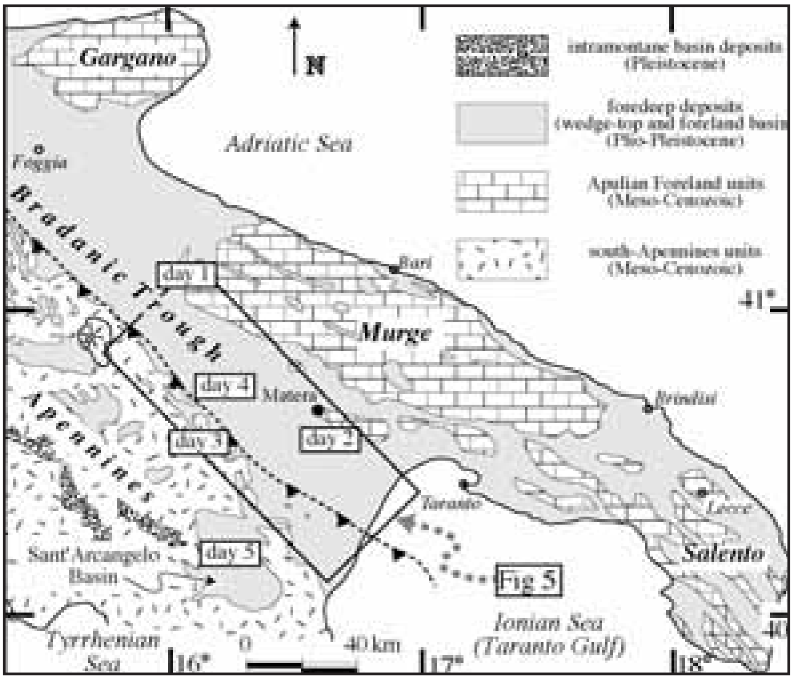

Figure 3 - Schematic geological map of southern Italy. The Bradanic Trough (foredeep) is located between the Apennines (chain) and the Murge (foreland) (modified from Pieri et al., 1997a).

biostratigraphic and structural constraints, Patacca and Scandone (2001) suggest a lithostratigraphic link between different successions of the whole foredeep systems, while, according to lithostratigraphic and sedimentologic constraints, Tropeano *et al.* (2002a) suggest a schematic depositional framework for the whole foredeep system (Figure 6).

2.1 The Bradanic Trough

The Bradanic Trough (Migliorini, 1937; Selli, 1962) is the Pliocene to Pleistocene south-Apennines foredeep sector, developed between the chain front and an exposed and flexured karstic foreland (the Apulian Foreland) (Ricchetti, 1980; Ricchetti and Mongelli, 1980) (Figure 3). The upper part of the in-fill successions crops out (up to about 600 m in thickness) and is mainly characterized by silty clay hemipelagites (the Argille subappennine Formation), which are either in transitional or in erosional contact with the overlying coarse-grained deposits (the "Regressive coastal deposits") (Pieri *et al.*, 1996a) (Figs 5, 22, 26). A carbonate unit (the Calcarenite di Gravina Formation) crops out in the outer margin successions onto the Apulian Foreland and below the Argille subappennine Formation (Iannone and Pieri, 1979; Tropeano and Sabato, 2000).

The in-fill of the Bradanic Trough began during late Early to Middle Pliocene times on a wide subsiding area of the Apulian platform (Ciaranfi *et al.*, 1979); foredeep deposits lie on a carbonate bedrock mainly exposed since Late Cretaceous time (Crescenti, 1975). The buried Pliocene to Lower Pleistocene succession is mainly characterized by a turbidite complex consisting of slope, fan and basin plain deposits (Casnedi, 1988; 1991) (Figure 5).

The inner part of the whole in-fill succession is characterized by the presence, above the turbidite deposits, of the so-called "allochthon", which emplaces predominantly pre-Pliocene deformed units (Mesozoic to Paleogene preorogenic units passing to Miocene synorogenic ones) over Pliocene to Lower Pleistocene foredeep deposits (Figure 2). The "allochthon" was considered a gravitational slide of the frontal part of the Apennines chain which moved towards the axis of the foredeep, but most recent data indicate that it represents a long thrust sheet system (as long along the dip as the Apennines chain is wide - Figure 2) which overthrusts the Apulian platform units and their foredeep cover (Mostardini and Merlini, 1986). According to Patacca and Scandone (2001), the buried front of the "allochthon" represents the tip line of the most external frontal ramp of the duplex system, active in earliest Pleistocene time (Santernian).

According to Pieri *et al.* (1994a; 1996a) and Tropeano *et al.* (2002a) three representative successions describe the Bradanic Trough in-fill. They are measured along WSW-ENE transects, perpendicular to the elongation of the trough (Figure 5) and their thickness depends on the inclination of the Apulian Foreland ramp: thicker successions, associated with both the "allochthon" and turbidites, developed on the inner foreland ramp, a sector of the trough with a highly inclined bedrock surface; thinner successions, not associated with the "allochthon" and turbidites,

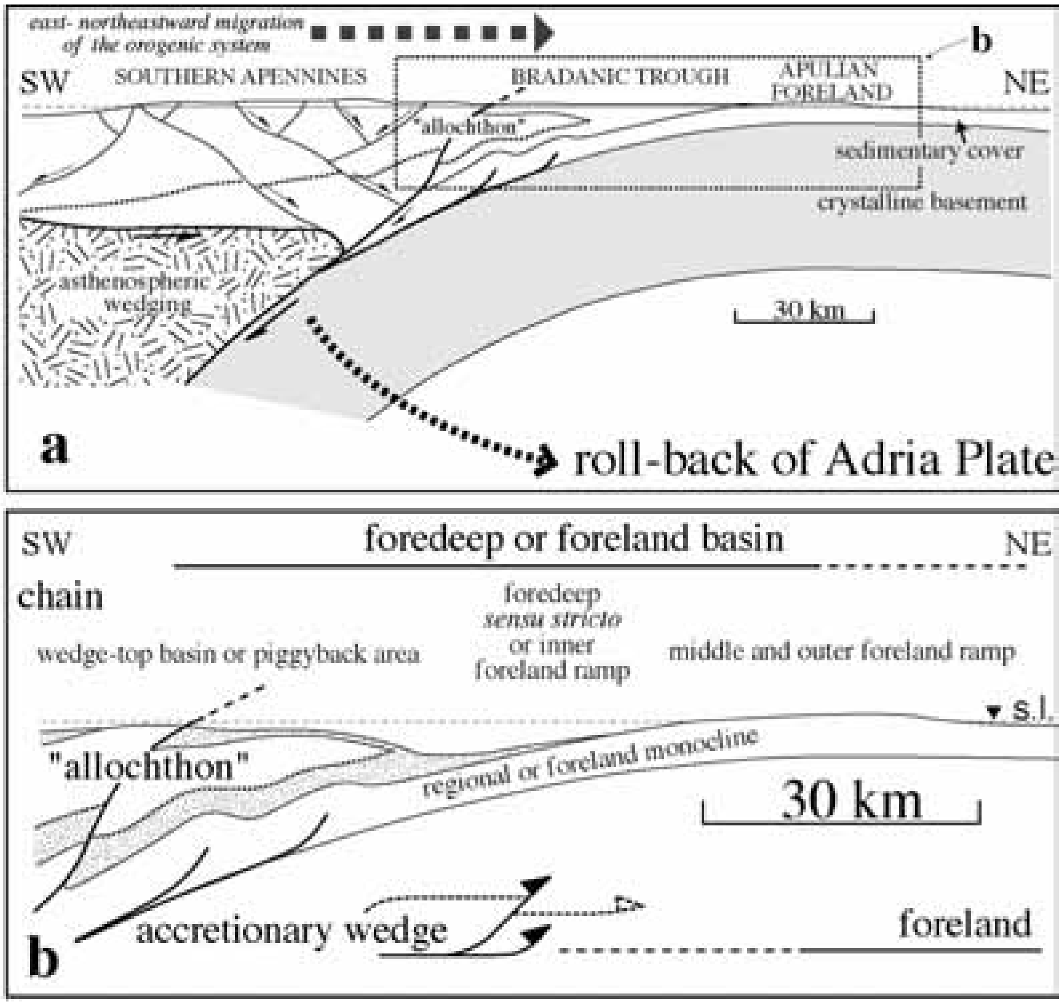

Figure 4 - a) Structural and geodynamic sketch of a section of the southern Apennines belt and its foreland basin (modified from Doglioni et al., 1994); b) detail of the section (a) (Tropeano et al., 2002a).

developed on the outer, less inclined, sector of the foreland ramp (pre-Murge and pre-Gargano plateaux) and around the highs of the exposed foreland. From the inner to the outer margins of the Bradanic Trough, these stratigraphic successions can be synthesized as follows:

i) inner successions (outer front of the wedge-top basin - succession A in Figure 5b) are composed of hemipelagites which pass upward into a thick pile of turbidites; the "allochthon" tectonically overlies the turbidite deposits. Hemipelagites (the Argille subappennine Formation), and subsequently, coarse-grained coastal and alluvial deposits (the "Regressive coastal deposits") cap the sequence on the wedge top. The whole thickness of this succession, including the "allochthon", is in the order of 3-4 km;

ii) thick depocenter successions (foredeep *s.s.* - succession B in Figure 5b) are adjacent to the front of the "allochthon", are up to 2 km thick and are composed of hemipelagites which pass upwards into a thick pile of turbidites which, in turn, are overlain by hemipelagites (the Argille subappennine Formation) and, finally, by coarse-grained coastal and alluvial deposits (the "Regressive coastal deposits"). Hemipelagites and coarse-grained deposits are laterally continuous with similar deposits formed both on the wedge top and on the outer margin of the trough;

iii) middle and outer margin successions (middle and outer foreland ramp) characterize a wide area of the presently exposed basin and have a variable thickness

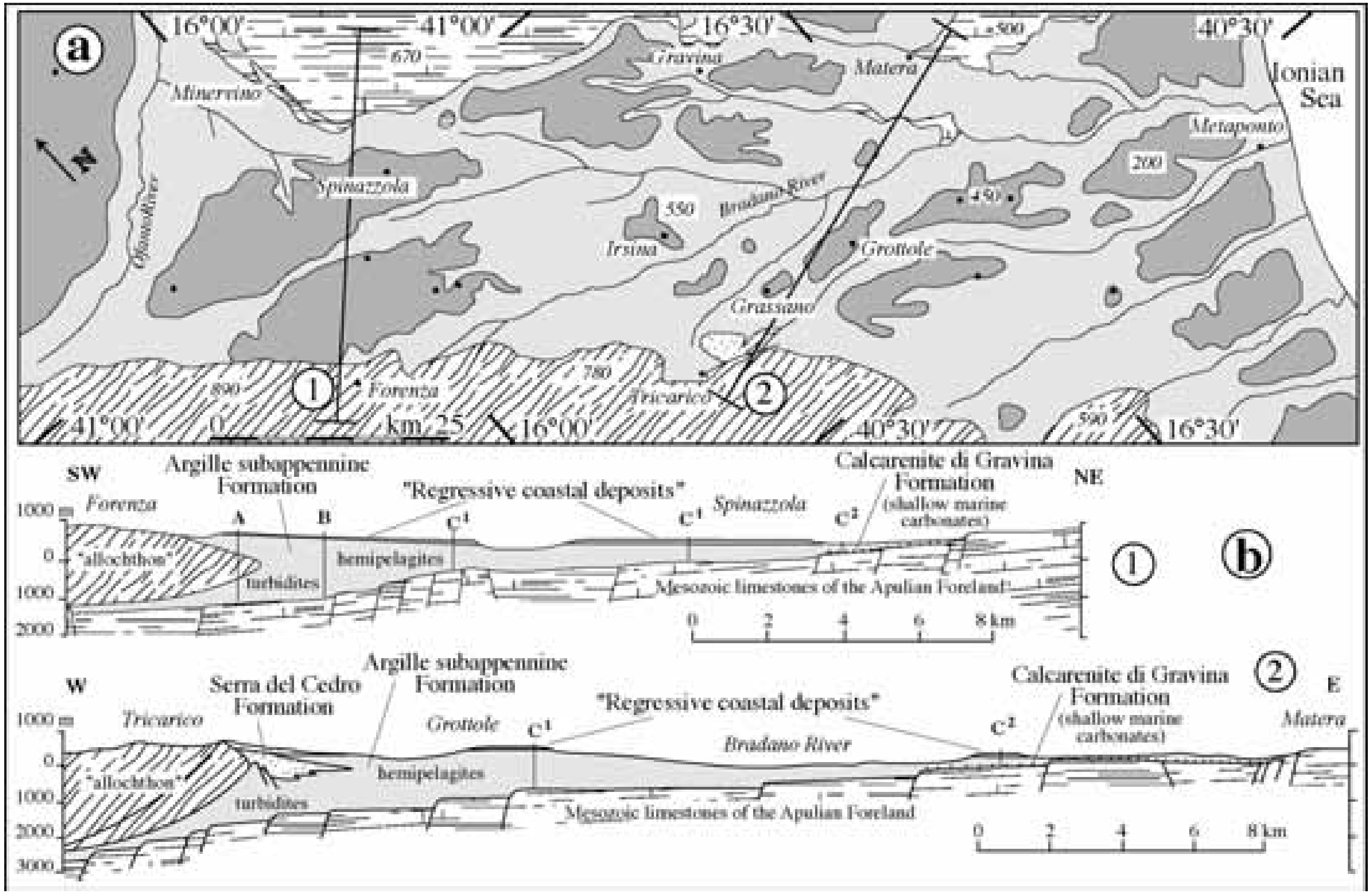

Figure 5 - a) Schematic geological map of the deposits outcropping in the Bradanic Trough (for location see Figure 3); b) geological cross-sections in which the structural features of the substratum and the distribution of the deposits filling the Bradanic Trough are shown; A, B, C^1 and C^2 indicate the most representative successions of the Bradanic Trough in-fill (modified from Pieri et al., 1994a; 1996a).

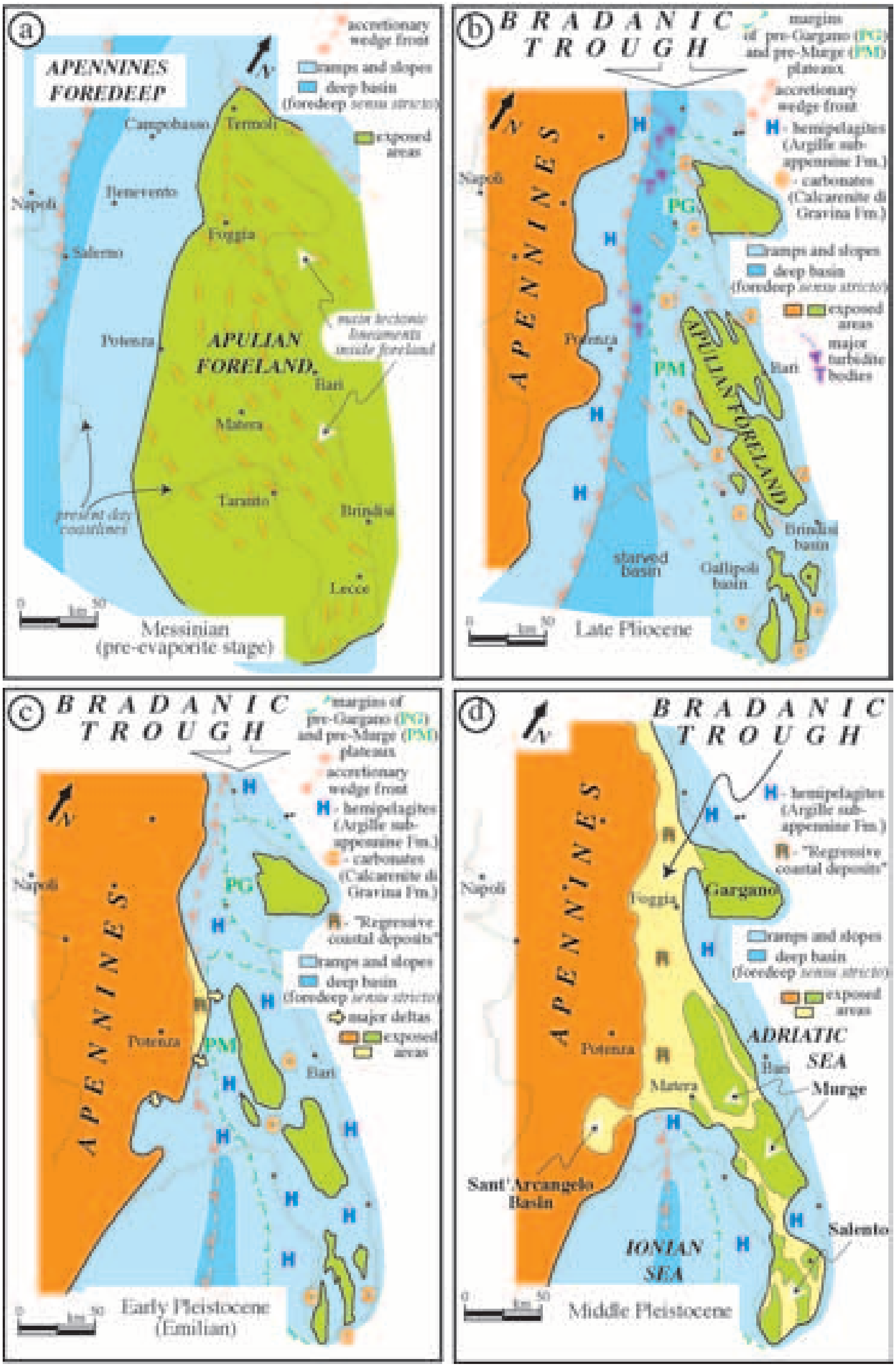

Figure 6 - Paleogeographies of the south-Apennines foreland basin system from Messinian to Middle Pleistocene (Tropeano et al., 2002a).

from a few tens of metres up to 1 km. They are mainly composed of hemipelagites (the Argille subappennine Formation) passing to coarse-grained shallow-marine and alluvial deposits (the "Regressive coastal deposits"). The relatively thicker successions (middle foreland ramp) are located in the central part of the basin (succession C^1 in Figure 5b). The thinner successions (outer foreland ramp) are located in the eastern part of the basin (succession C^2 in Figure 5b) with a basal unit of transgressive shallow-marine carbonates (the Calcarenite di Gravina Formation) overlain by hemipelagites (the Argille subappennine Formation) and finally by coarse-grained deposits (the "Regressive coastal deposits"). On the foreland side of the trough, these thin successions are completely exposed from the bedrock and also characterize some depressions inside the Apulian Foreland (*i.e.* the Murge grabens and the Brindisi basin).
It is important to underline that Lower to Middle Pleistocene shallow-marine and/or continental deposits (the "Regressive coastal deposits") covered the clay of the three types of succession; elevations of regressive deposits of up to more than 600 m and the incision of deep valleys clearly demonstrate the Quaternary uplift of the region (Pieri *et al.*, 1994a; 1996a; Tropeano *et al.*, 2002b).

3. Field itinerary

DAY 1

(no difficulty)

We will spend the morning of the first day travelling by bus from Florence to the area of interest.
The evening of the first day is dedicated to the description of stratigraphic, structural and geomorphological regional features of the Apulian Foreland in the Murge area (stops 1.1 and 1.2). In particular, a Pleistocene forced-regressive Gilbert-type delta that developed during foreland subsidence will be visited (stop 1.3), (Figure 7).

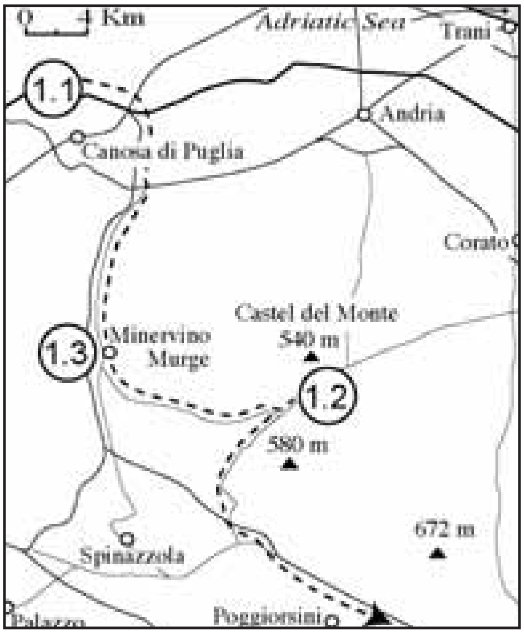

Figure 7 - Field trip itinerary of the first day.

3.1 The Apulian Foreland

M. Tropeano, P. Pieri, V. Festa , M. Moretti, L. Spalluto

The Apulian Foreland ("Avampaese apulo" of Selli, 1962) (Figs 2, 3, 4, 6) represents the south-Apennines foreland and is a sector of the Adria Plate characterized by a relatively thick lithosphere and by a weakly deformed and autochthonous sedimentary cover. It shows a uniform crustal structure with a Variscan crystalline basement and an approximately 6 km thick Mesozoic sedimentary cover overlain by relatively thin and discontinuous Tertiary and Quaternary deposits (Ricchetti *et al.*, 1988). The sedimentary cover was drilled by exploration wells and is composed of a syn-rift and passive-margin succession developed on metamorphic Hercynian rocks. This succession is composed of: Permo-Triassic red beds about 1 km thick and correlatable to the Verrucano Fm., evaporites, from about 1 to 2.5 km thick and correlatable to the Anidrite di Burano Fm., and well-bedded Jurassic-Cretaceous carbonates of generally restricted platform or back-reef facies, from about 3 to 5 km thick. This succession represents the Apulian carbonate platform succession.
Regionally the Apulian Foreland corresponds to a wide WNW-ESE trending antiform (Ricchetti, 1980; Ricchetti and Mongelli, 1980; Royden *et al.*, 1987) (Figure 2) which is obliquely oriented with regard to the south-Apennines subduction hinge (Casnedi, 1988; Doglioni *et al.*, 1994; Pieri *et al.*, 1996a). Large deformation zones, striking oblique or perpendicular to the main antiform trending, segment the outcropping portion of the Apulian Foreland in three main blocks with different degrees of uplift, from the higher Gargano and Murge to the lowland Salento towards the SE (Ricchetti *et al.*, 1988; Funiciello *et al.*, 1991; Doglioni *et al.*, 1994; Gambini and Tozzi, 1996) (Figs 3, 6).

As regards the Murge area (the foreland block crossed during our field trip), a 3-km-thick Cretaceous succession crops out, showing SW and SSW dip directions (Pieri, 1980; Ricchetti, 1980; Ciaranfi *et al.,* 1988; Ricchetti *et al.,* 1988). This succession, belonging to the Apulian platform, is mainly characterized by monotonous, well-bedded, restricted carbonate facies (Ricchetti 1975; 1980; Pieri, 1980; Ciaranfi *et al.,* 1988; Luperto Sinni, 1996). Two main formations were distinguished: the Calcare di Bari Fm. (Valanginian to Upper Cenomanian), about 2000 m thick and cropping out in the northern sector, and the Calcare di Altamura Fm. (Upper Turonian to Maastrichtian), about 1000 m thick and cropping out in the southern sector; a mild angular unconformity, marked by bauxites, green clays and/or marly sands, separates the Calcare di Bari Fm. from the Calcare di Altamura Fm. (Valduga, 1965; Pieri, 1980; Ciaranfi *et al.*, 1988; Luperto Sinni, 1996, *and references therein*). Discontinuous and thin Upper Pliocene-Quaternary deposits belonging to the Bradanic Trough sedimentary cycle overlie the Cretaceous succession of the Murge high. The latter is characterized by a large central NW-SE trending plateau (the "Murge Alte" plateau), about 15-20 km by 60-80 km and about 500-600 m above sea-level, flanked to the NE by fault-bounded displaced blocks that are up to 15-20 km by 60-80 km (the "Murge Basse" plateau and the Apulian Adriatic shelf). Between the blocks, two narrow and regionally elongated main grabens are present (Iannone and Pieri, 1982). In map view, faults and grabens show an arched shape with convexity towards the SW; according to kinematic indicators, the NW-SE trending fault surfaces reveal dip-slip movement while E-W trending fault surfaces reveal dextral transtensional movement (Festa, 2003). The shape is that of regional E-NE dipping listric faults which bound, through semigrabens, E-NE displaced blocks. Faults age ranges from Cretaceous to Pleistocene; amongst the most ancient structures, those located in the western side of the Murge area, at least Late Cretaceous in age, were cut during the Middle Pliocene-Early Pleistocene foreland subsidence by W-WS dipping normal faults. One of these younger faults bounds the Murge Alte plateau from the Bradanic Trough ("faglia della Valle del Bradano" of Martinis, 1961). The Plio-Pleistocene subsidence and transgression onto the Murge region is recorded by deposition of shallow-marine carbonates (the Calcarenite di Gravina Fm.).

The most recent faults cut or reactive ancient structures and cause the present-day low-energy seismicity of the Murge; they are likely related to the Quaternary uplift of the Murge induced by the buckling of the plate (Pieri *et al.*, 1997a; Tropeano *et al.*, 1997).

The buried foreland ramp, which represents the bedrock of the Bradanic Trough filling succession, is characterized by similar structural features (Sella *et al.*, 1988), mainly in the area adjacent to the Murge ("premurge plateau" in: Pieri *et al.*, 1994a; 1996a) (Fig 6a); as a whole, Murge and premurge plateaux correspond today to a horst and graben system (Tropeano *et al.*, 1997).

As regards the uplift of the Murge, this is testified by the presence of 16 orders of uplifted shorelines, recorded by paleocliffs, abrasion platforms, and/or by thin marine terraced deposits ("Depositi marini terrazzati") (Ciaranfi *et al.*, 1988). According to Late Pleistocene geochronological data, uplift rates are in the order of 0.2-0.3 mm/yr, whereas stratigraphic data suggest uplift rates of at least 0.5 mm/yr (Doglioni *et al*., 1996, *and references therein*).

Stop 1.1:
The Murge Alte plateau and the Bradanic Trough

A 150 m high and 30 km long scarp bounds towards SW the Murge Alte plateau from the Bradanic Trough. The scarp corresponds to a receded main normal fault ("faglia della Valle del Bradano") striking NW-SE and dipping SW. A Quaternary bajada develops along the scarp. Another scarp bounds towards W-NW the Murge Alte plateau from the Ofanto Graben.

Stop 1.2:
"Castel del Monte"

The top of the Murge Alte plateau is not flat, but is characterized by a series of gentle hills and depressions. Depressions, filled by *terra rossa*, represent tectono-karstic structures, some of which evolved as up to 200 m deep dolinas (locally called "puli", *i.e.* the "Pulo di Altamura" and the "Pulicchio di Gravina"). "Castel del Monte" is a small conical and isolated structural high where a castle was built in the Middle Ages by Federick II (depicted on the Italian 1 Euroecent coin).

3.2 The Calcarenite di Gravina Fm.
M. Tropeano

Subsidence of the Murge, induced by the eastward roll-back of the Adria Plate, produced a severe transgression onto the plateaux, except for the top of the highest one (the Murge Alte plateau). The Middle-Upper Pliocene to Lower Pleistocene Calcarenite di Gravina Fm. records this transgression (shallow-marine carbonates of Figure 5b and carbonates of Figure

6). This thin formation (no more than 70-100 m in thickness) derives from a mantle of bioclastic and/or lithoclastic carbonates deposited on the faulted rocks of the Apulian Foreland, and crops out on the outer margin of the Bradanic Trough and on the flanks of the Murge plateaux, from the present-day sea level up to more than 400 m in elevation (Iannone and Pieri 1979; Tropeano and Sabato, 2000).

The lower boundary of the Calcarenite di Gravina Fm. is a long-term ravinement surface abraded onto the bedrock. Carbonates of the formation were deposited in shallow-marine systems which regionally onlapped onto the Apulian Foreland highs (with a backstepping configuration), or covered the lower plateaux (Tropeano and Sabato, 2000; Pomar and Tropeano, 2001).

Skeletal grains are the basic components of the Calcarenite di Gravina Fm. and consist of abundant bivalves, echinoids, red algae, serpulids and benthic forams, fragments of barnacles, brachiopods, gastropods, bryozoans and rare planktonic foraminifera. This carbonate assemblage can be interpreted as a temperate-water deposit and is comparable to the molechfor facies of Carannante *et al.* (1988), typical of a temperate-water open shelf or ramp carbonate factory. A particular feature characterizes the lithology of the formation: the presence of terrigenous carbonate grains. The latter are mixed within bio-lithoclastic facies or may form either isolated bodies (stop 1.3), or, locally, may comprise the whole Plio-Pleistocene succession (stop 2.2). Terrigenous carbonate facies are commonly composed of coarse sand- and gravel-sized lithoclasts (calclithites and calcrudites) eroded from the Cretaceous bedrock of the Murge islands during transgression. Sedimentary structures are mainly indicative of deposition in wave- and/or storm-dominated environments.

From NW to SE and from W to E carbonate systems were diachronously covered by hemipelagites of the Argille subappennine Formation at progressively higher levels on the flanks of the foreland-highs (Pieri *et al.*, 1996a). A drowning unconformity bounds the top of the Calcarenite di Gravina Formation (Tropeano and Sabato, 2000).

As faulting of the Murge high mostly occurred prior to Plio-Pleistocene transgression (Figure 6a), the antecedent topography of the Murge area was an important control factor on the development of the Calcarenite di Gravina Fm. and, during drowning, the Murge region became an island archipelago (Figs. 6a, 6b). Horst-and-graben structures in the foreland controlled the distribution of emerged land, basins, islands and straits and, consequently, deposits of the Calcarenite di Gravina Fm. progressively onlapped the Murge paleoarchipelago by: i) aggradation against degraded fault scarps (stops 1.3, 2.1-2.4); ii) flooding of narrow shore platforms around paleoislands (horsts) or their tops (day 2); iii) drowning narrow straits (grabens) (Tropeano and Sabato, 2000).

Stop 1.3:
The Minervino Gilbert-type delta
L. Sabato

In the Minervino area, the western margin of the Murge Alte plateau, towards the Ofanto Graben, displays one of the best examples of a steep, fault-bounded paleocoastal relief where limestones of the Calcarenite di Gravina Formation, locally up to 40 m thick, onlap the Cretaceous substratum (Figure 8). Locally the Calcarenite di Gravina Fm. includes a conglomerate body (<12 m thick), interpreted as a terraced Gilbert-type delta (Sabato, 1996a). The delta, exclusively composed of rounded clasts of Cretaceous limestones, is situated adjacent to an up to 150-m-high major degraded N-S trending fault scarp, which represents the Pliocene to present-day structural boundary between the Murge Alte plateau (≈500-600 m in height) and the lower terraced surface (≈325 m in height). The modern relief is cut by steep karstic canyons (locally termed *gravine*).

The Minervino delta has a length of approximately 200 m, and its most proximal part sits unconformably on the Cretaceous bedrock and is comprised of *Lithophaga*-bored boulders (<0.7 m). Relief of the west-dipping delta foresets increases basinwards from a few tens of centimetres to 10 m, a thickening that is accompanied by a decrease of foreset dips from an angle of 30° to a few degrees. Beds are exclusively comprised of pebble-boulder grade limestone lithoclasts with large oysters (<0.2 m) colonizing bedding surfaces. Bottomsets beds are composed of matrix-rich coarse sands and interbedded conglomerates. A 2 m thick tabular gravelly unit rests with erosional unconformity on the truncated delta foresets and Cretaceous bedrock. This unit fines upward, and is comprised of conglomerates and coarse sands with a fine sand-grade matrix; it displays very low-angle (1°-2°) clinostratified beds, with bioturbations (echinoids), occasional faunas of small molluscs and imbricated clasts dipping both land- and seaward.

The Gilbert-type delta (Gilbert, 1885) at Minervino, was wave cut, terraced and overlain by a package that records upward deepening from shoreface to offshore environments. The supply of clastic sediment to the

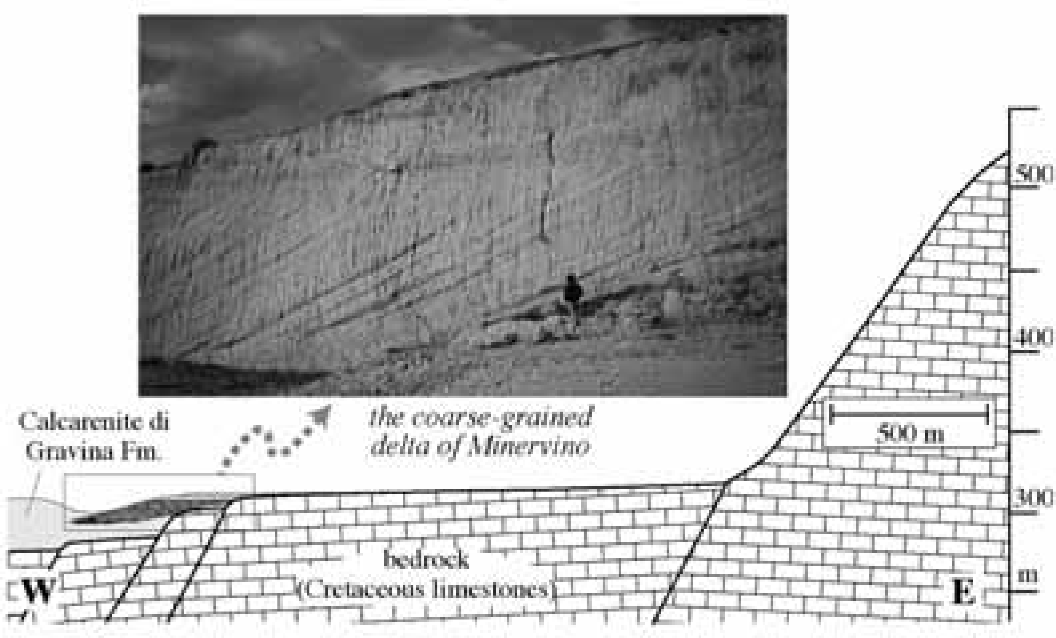

Figure 8 - Geological section showing the stratigraphic relationship between the Cretaceous substratum and the overlying Plio-Quaternary deposits close to Minervino. A terraced Gilbert-type delta is visible along the wall of a quarry (photo).

delta was probably via an ephemeral stream located within a karstic canyon, similar to the *gravine* (canyons) observed today in the Murge Alte karstic area. Indeed, a remnant of this feeder canyon is preserved in the delta apex where large boulders set in a sandy-conglomeratic matrix, fill and fossilize an erosional feature that cuts through the original, steep, coastal relief. Since the stream that fed the delta was apparently confined within the canyon, avulsion would have been impossible, so that the cessation of clastic supply was unlikely related to autocyclic processes (Sabato, 1996a, Tropeano and Sabato, 2000).

DAY 2

(low to middle difficulties)

During the second day some particular features of the Calcarenite di Gravina Fm., outcropping in the Matera area, will be discussed.
In the morning, coarse-grained, clinobedded coastal bodies, which backstepped on the flexuring foreland, will be observed (stops 2.1-2.4) (Figure 9).
In the afternoon, attention will be focused on the descriptions of growth structures and soft-sediment deformation structures (seismites) that developed in the Calcarenite di Gravina Fm. (stop 2.5) (Figure 9).

3.3 The Plio-Pleistocene transgression onto the small, drowning, Matera paleoisland

M. Tropeano, P. Pieri, L. Pomar

The Matera Horst (Murge di Matera) was a small island during Late Pliocene-Early Pleistocene times, which finally drowned during the regional subsidence-driven transgression. Towards the north, it was separated from the main Murge archipelago by a 6- to 7-km-wide graben (Viglione Graben). To the southwest, a seaway about 50 km wide (the Bradanic Trough) separated this small paleoisland from the Apennines highlands and connected the open Mediterranean (Ionian Sea) with the Adriatic Sea.
Structurally, the Matera Horst is located within the middle-outer foreland ramp, between the wider Murge area to the N-NE (in the Apulia Region) and the Bradanic Trough to the S-SE (in the Basilicata Region). Both the Murge area and the substrate of the Bradanic Trough are characterized by a horst and graben system and the Matera Horst, today partially exposed, is one of the most elevated horsts of the system. Today, the Matera Horst, a few tens of km^2 wide and up to 500 m in elevation, stands out from clays of

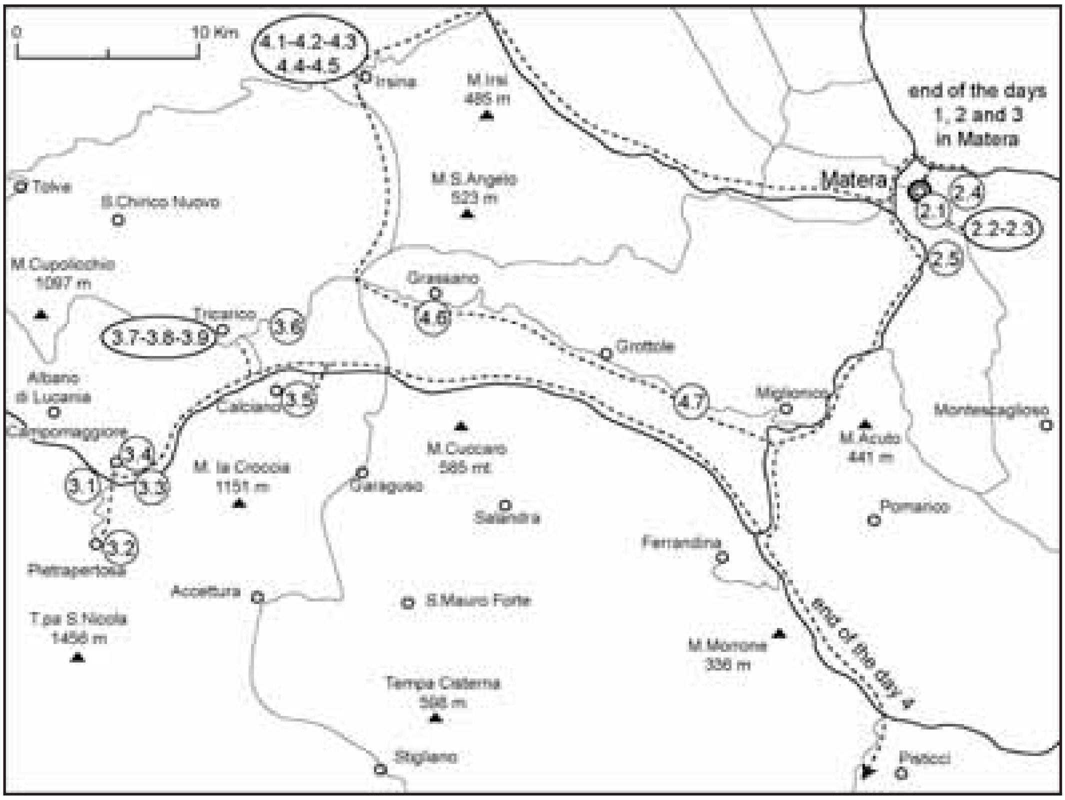

Figure 9 - Field trip itinerary of the second, third, and fourth days.

the Argille subappennine Fm., which filled both the Viglione Graben and the Bradanic Trough (Figure 10). A spectacular deep canyon, the "Gravina di Matera" (Figure 11), cuts the horst and widely exposes both the Cretaceous substrate of the foreland and the Plio-Pleistocene covers.
We will spend several nights in Matera. The old town was excavated in the Calcarenite di Gravina Fm. and is called "Sassi di Matera" (Figure 11), ("sassi" is the Italian word for stones). Since 1993 the Sassi di Matera have been on the World Heritage List with the following justification: "This is the most outstanding, intact example of a troglodyte settlement in the Mediterranean region, perfectly adapted to its terrain and ecosystem. The first inhabited zone dates from the Paleolithic, while later settlements illustrate a number of significant stages in human history".

Stop 2.1:
The Gravina di Matera canyon

The Gravina di Matera canyon offers some of the best exposed sections of the Calcarenite di Gravina Fm. Along the southern flank of the paleoisland these carbonates are mainly lithoclastic in origin with components derived from erosion of Cretaceous limestone. The spectacular coastal onlap onto the bedrock of the paleoisland is exposed near the town.

Stop 2.2:
Backstepping of accretional units at Lamaquacchiola

The southern margin of the Matera paleoisland was a moderately-inclined (up to 5°) rocky slope surface. Here the Calcarenite di Gravina Formation is composed of accretional units bounded by erosion surfaces. The accretional units are prism shaped, elongated in strike section and parallel to the paleocoast line. They provide continuous exposure of coarse-grained, gravel-dominated coastal systems and are composed of several lithofacies which are conglomeratic at the proximal end (rocky coast) and become progressively sandier basinward. Lithofacies range from shoreline to offshore, and are basically dominated by limestone gravel comprised of pebbles

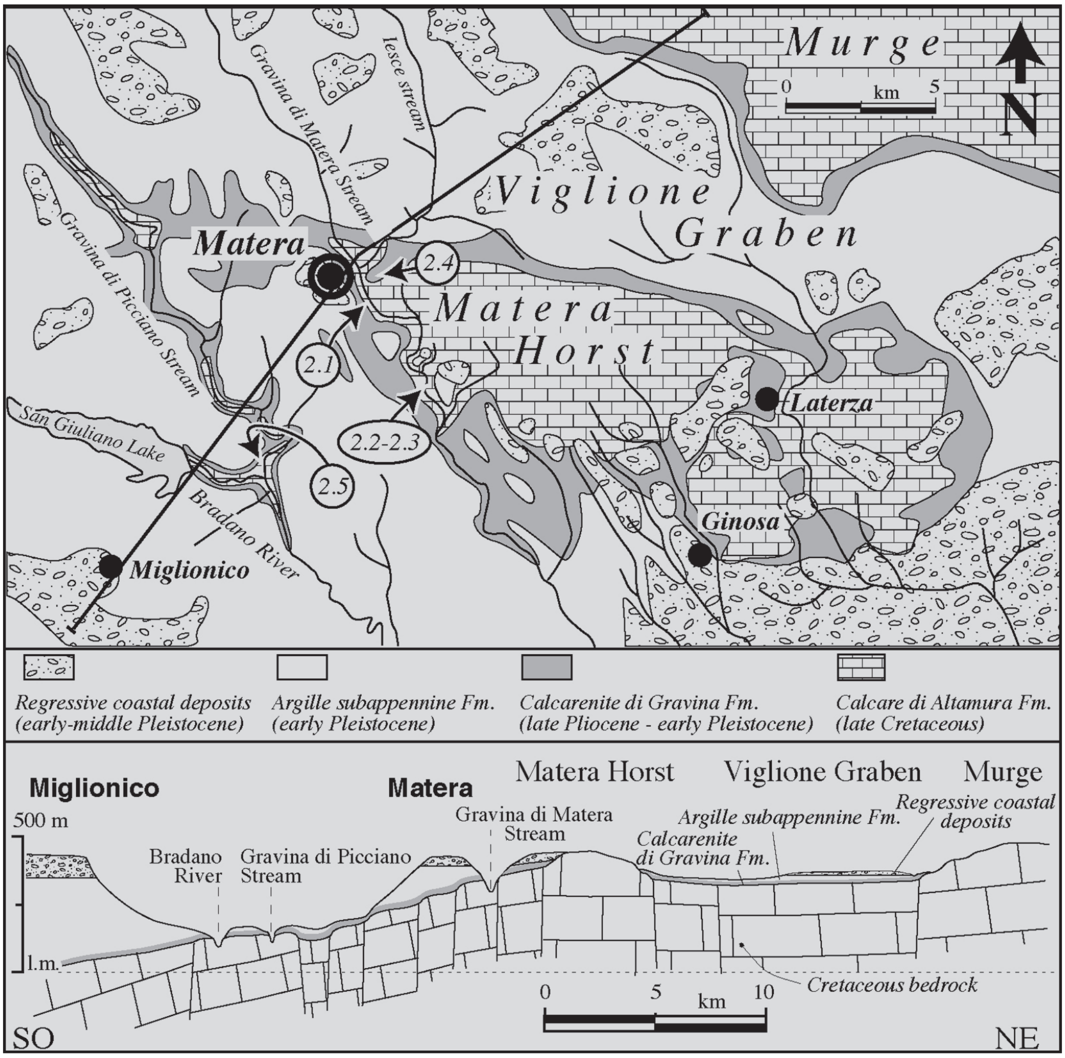

Figure 10 - Geological map and geological section of the Matera area (after Tropeano, 1992; Beneduce et al., 2004).

and granules. Carbonate sand, either lithoclastic or bioclastic, is only significant in offshore settings. Gravelly deposits developed in a wave-abraded coastal system; this setting is suggested by the abundance of erosion terraces (shore platforms) excavated into the intensely fractured limestone bedrock, and by the lack of significant alluvial/fluvial systems on the small calcareous paleoisland. Among facies, the most conspicuous and volumetrically important are the transition-slope deposits which form large-scale, high-angle, cross-bedded lithosomes (Figure 12). These are laterally extensive, parallel to the paleoshoreline and prograde seaward.

Accretional units are stacked in a backstepping configuration which resulted from a subsidence induced transgression that was punctuated by high-frequency cycles and stillstands of relative sea level.

Stop 2.3:

Depositional systems recorded in the accretional units

Four main depositional zones are differentiated in the accretional bodies (Figure 13):

- (a) the beachface: indicates the zone affected by breaking waves and wave-swash processes; (a') boulder wedges replace beachface on cliffed coastlines;

- (b) the shoreface: indicates the gently inclined zone dominated by wave traction and where, during large wave activity, sediments were swept seaward;
- (c) the transition slope: indicates the steep zone located seaward of the shoreface, just below the major wave-base level. Tractive flows, triggered by storm waves and wind-induced currents, swept the shoreface. At the storm wave base, the flows changed from tractive to gravity-driven, and depositional slopes developed as a result of sediment avalanche processes. The transition slope represents one sector of the coastal-equilibrium profile and migrates according to the evolution of the depositional system. The extensive lateral continuity of these lithosomes excludes an interpretation as wave-reworked, Gilbert-type deltas. Migration of large bedforms (*i.e.* sand ribbons or sand waves) are likewise excluded after considering the three-dimensional characteristics of the prograding lithosomes at Matera. Additionally, their basinward progradation also excludes other possible interpretations such as spits or other shore-parallel prograding bodies;
- (d) the offshore: indicates the area dominated by low

Figure 11 - Panoramic view of "Sassi" di Matera. The contact between the Cretaceous substratum and the Plio-Pleistocene Calcarenite di Gravina Fm. is located at the base of the city.

Figure 12 - Spectacular clinoforms of the transition slope (Lamaquacchiola).

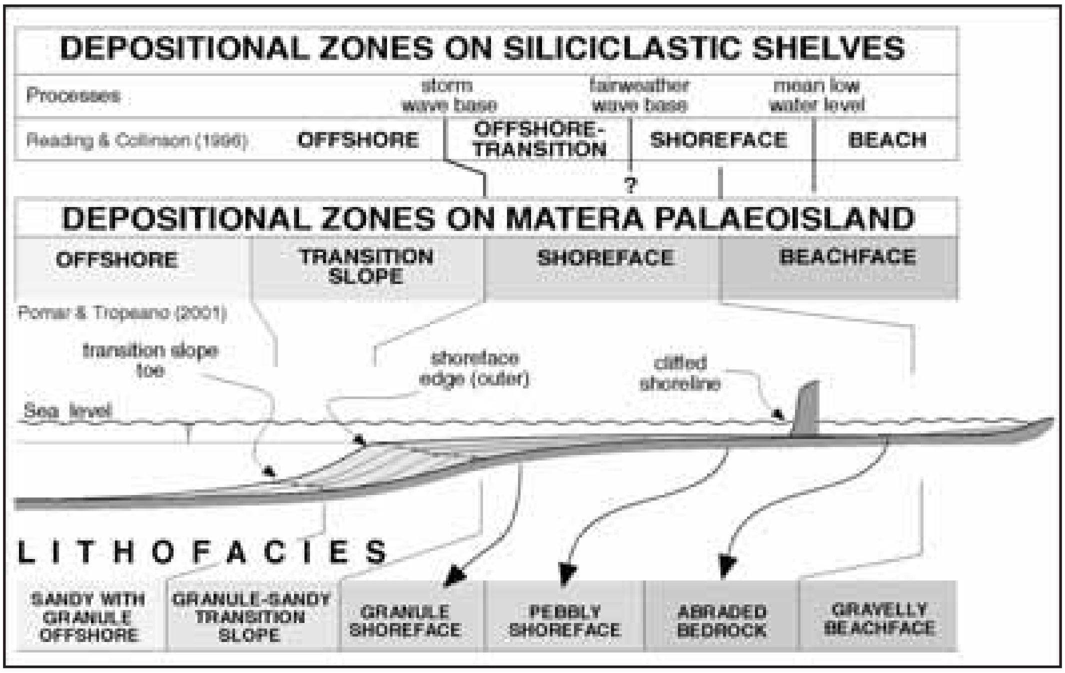

Figure 13 - Schematic depositional system of the coastal bodies developing on the Matera paleoisland (Pomar and Tropeano, 2001).

water-energy conditions and progressive seaward sediment starving, in which bioturbation was significant.

Stop 2.4:

The "Chiese Rupestri" panorama

At the western end of the paleoisland, the prism-shaped accretional units terminate and pass into large westwardly-prograding fan-like bodies. On the northern flank of this paleo-cape a steeper slope (up to 20°) existed and a set of successive fan-shaped bioclastic bodies formed. These fan bodies cover the inclined northern flank of the corner of the paleoisland.

3.4 Growth and soft-sediment deformation structures in the Calcarenite di Gravina Fm.

M. Tropeano, V. Festa , M. Moretti, P. Pieri

Spectacular outcrops along the "Bradano" and "Gravina di Picciano" canyons show the occurrence of tensional and transtensional growth faults in limestones belonging to the Calcarenite di Gravina Fm. Basically, where the Cretaceous substratum of the premurge plateau outcrops, the foreland ramp is characterized by a complex horst and graben system, with structures ranging from kilometric to metric scale (Tropeano *et al.*, 1994). These structures show a pre-, syn- and post-depositional activity referred to the Upper Pliocene- Lower Pleistocene outcropping formations. Some of the structures grew during the sedimentation of the Calcarenite di Gravina Fm., but others completely cut these very deposits, recording at least a Middle Pleistocene tectonic activity (Tropeano *et al.*, 1994; 1997).

Locally, in the lower part of the Calcarenite di Gravina Fm., an up to 2-3-m-thick horizon of contorted beds occurs (Figure 14). The geometry of the contorted beds and their confinement in a horizon within undeformed beds allow us to refer them to a soft-sediment deformation. Regarding the geometry, these soft-sediment deformation structures show convoluted and distorted beds with decimetric folds. No preferential vergence (typical of slumps) has been found; folds indicate mainly vertical rather than horizontal movements. Moreover, the limestone succession was developed on top of a small horst which during Late Pliocene times became an isolated carbonate platform, up to a few km wide and long. Beds are few decimetres thick and are made up of an alternation of grainstones and packstones. On the sea bottom, during the sedimentation, this alternation constituted a multilayer unstable system with reverse density gradients (a potential driving force system for the origin of soft-sediment deformation structures) (*i.e.* Anketell *et al*., 1970). The occurrence of synsedimentary faults and the lateral extension of the deformed horizon (which may be followed for more than 1 km) allow us tentatively to refer the trigger of the deformation to a seismic shock.

Stop 2.5:

"Gravina di Picciano" canyon at Mandolalena

The small graben at Mandolalena is one of the best examples of tectonic structures which grew during the sedimentation of the Calcarenite di Gravina Fm. At the base of the formation, a 2-m-thick horizon characterized by soft sediment deformation structures may be observed (Figure 14).

DAY 3

(low to medium difficulties)

The morning of the third day is dedicated to the descriptions of the main tectonic units and structures of the Apennines frontal imbricate fan (stops 3.1-3.6); the evening is dedicated to the description of the satellite deposits in the Tricarico area (stops 3.7-3.9) (Figure 9).

We will discuss the relationship between tectonics and sedimentation in a thrust-top basin context (Figure 4).

3.5 Satellite successions near the front of the Apennines (the Tricarico example)

L. Sabato, S. Gallicchio, P. Pieri, M. Tropeano

Within the south-Apennines chain, from the Abruzzo-Molise regions to the Basilicata region, Upper Tortonian to Lower Pleistocene siliciclastic and, subordinately, carbonate deposits unconformably rest on older and previously deformed chain units. These deposits developed onto the moving "allochthon" (thrust-top basin) and, according to their age, fall within the Villamaina, Altavilla or Ariano units (Ippolito *et al.*, 1975; Bonardi *et al*., 1988). They crop out discontinuously and, despite their age correlations, they were considered as having been deposited within different satellite sub-basins (*i.e.* Ofanto, Benevento, Potenza, Calvello basins). The Ariano Unit represents the most recent (Early Pliocene to Pleistocene) and the most external of these units, and forms a discontinuous belt of some tens of kilometres in width near the outer margin of the south-Apennines chain

Figure 14 - Detail of the soft-sediment deformation structures displayed in the Calcarenite di Gravina Fm. (Mandolalena).

(Figure 3). Two sedimentary cycles, bounded by an unconformity surface and both showing syntectonic sedimentary features, have been distinguished within the Ariano Unit successions (Maggiore and Walsh, 1975; Caldara *et al.*, 1993; Sabato and Marino, 1994; Ciarcia *et al*., 2003, *and references therein*).

Near the chain front these successions were successively cut by several tight thrust planes, the youngest of which (the Stigliano ramp) developed around the Early-Middle Pleistocene boundary (according to Patacca and Scandone, 2001).

Before observing the satellite succession of the Ariano Unit, we will discuss some features of the chain, mainly in the "Dolomiti lucane" relief.

3.6 Regional tectonics of the south-Apennines chain

M. Schiattarella

The southern Apennines are a NE-verging orogenic wedge accreted from Late Oligocene-Early Miocene to Pleistocene. The chain is composed of a Mesozoic-Cenozoic sedimentary cover derived from the deformation of several paleogeographic domains (*i.e.* the Ligurian oceanic crust and the western passive margin of the Adriatic plate) and of the Neogene-Pleistocene piggyback basin and foredeep deposits of the active margin. Recent shortening occurred at the belt front deforming Pleistocene sediments and volcanics (Pieri *et al.*, 1997b) whilst widely documented extension is still active along the south-Apennines axial zone and Tyrrhenian side (Brancaccio *et al.*, 1991; Ortolani *et al.*, 1992; Amato and Montone, 1997).

The average trend of the chain axis is about N150°, corresponding to the strike of the main thrusts and coaxial normal faults. The belt is largely affected by Plio-Quaternary strike-slip faults, mainly oriented according to N120°±10° and N50-60° trends (Schiattarella, 1998, *and references therein*).

In a regional cross-section, from the Tyrrhenian Sea to the Adriatic (Apulian) foreland, and from the top to the bottom of the accretionary wedge, the following tectonic units are observed (Prosser *et al.*, 1996) in Figure 15: (1) Jurassic to Oligocene polydeformed ophiolitic units (Knott, 1987, Mauro and Schiattarella, 1988; Monaco and Tortorici, 1995), unconformably covered by syntectonic deposits, Early Miocene in age (Ligurian units, Bonardi *et al.*, 1988b); (2) a carbonate platform unit (Campania-Lucania platform), the age of which ranges from Late Triassic to Early Miocene (D'Argenio *et al.*, 1975); (3) several units mainly composed of deep-sea sediments, ranging from Early Triassic to Lower-Middle Miocene (Lagonegro units, Scandone, 1967; Miconnet, 1988; Mazzoli, 1992); (4) a frontal imbricate fan made up of Cretaceous to Lower Miocene deep-sea marls, shales and sandstones (Pescatore *et al.*, 1999) covered by Middle to Upper Miocene flysch deposits (Pescatore, 1988); (5) Pliocene to Pleistocene foredeep clastic deposits (Pieri *et al.*, 1996a); (6) the Apulian carbonate platform, which has been partly incorporated at the base of the accretionary wedge and which forms towards the east the less deformed foreland area (Mostardini and Merlini, 1986).

A conservative shortening up to 100% (corresponding to about 200 km) has been calculated for the orogenic wedge, excluding the internal deformation of the Ligurian units (Schiattarella *et al.*, 1997). Due to the relevant shortening and the time span of the south-Apennines orogeny (about 20 Ma), a very high strain rate can be inferred (about 1 cm/yr). The average uplift rate of the entire chain during Quaternary times can be estimated at 1 mm/yr (Schiattarella *et al.*, 2003).

Stop 3.1:
Stratigraphic and tectonic relationships between

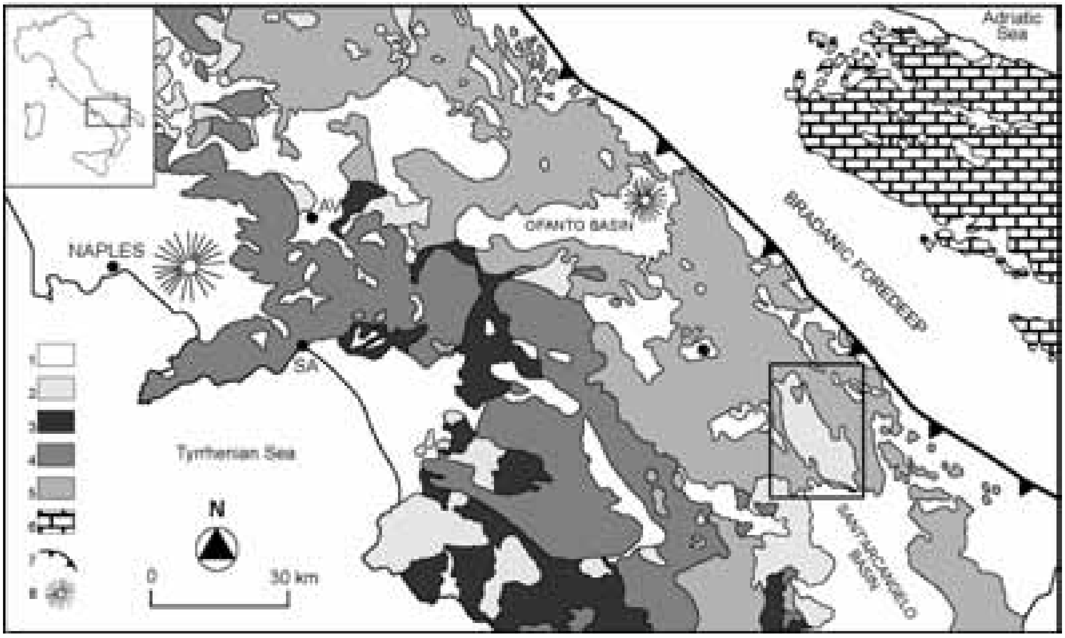

Figure 15 - Geological sketch map of southern Apennines. Legend: 1. Plio-Quaternary clastics and Quaternary volcanics; 2. Miocene syntectonic deposits; 3. Cretaceous to Oligocene ophiolite-bearing internal units (Ligurian units); 4. Meso-Cenozoic shallow-water carbonates of the Campania-Lucania platform; 5. Lower-Middle Triassic to Miocene shallow-water and deep-sea successions of the Lagonegro, Numidian and Irpinian basins; 6. Meso-Cenozoic shallow-water carbonates of the Apulian platform; 7. Thrust front of the chain; 8. Volcanoes. Black frame indicates the area of the "Dolomiti Lucane".

flysches and pre-orogenic units. At this stop-site the general structure of the whole area can be easily observed (Figure 16). The beds of the Gorgoglione Flysch unconformably lie on Cretaceous to Oligocene shales (Pescatore and Tramutoli, 1980), representing the pre-orogenic succession severely deformed by the older tectonic stages. This flysch, towards the east, thrusts on the Numidian sandstone (Patacca *et al*., 1992; Pescatore *et al.*, 1992), a well-known Lower to Middle Miocene quartzarenite turbidite formation largely outcropping from Maghreb to southern Spain and Italy (Flysch Numidico Fm. in Ogniben, 1963).

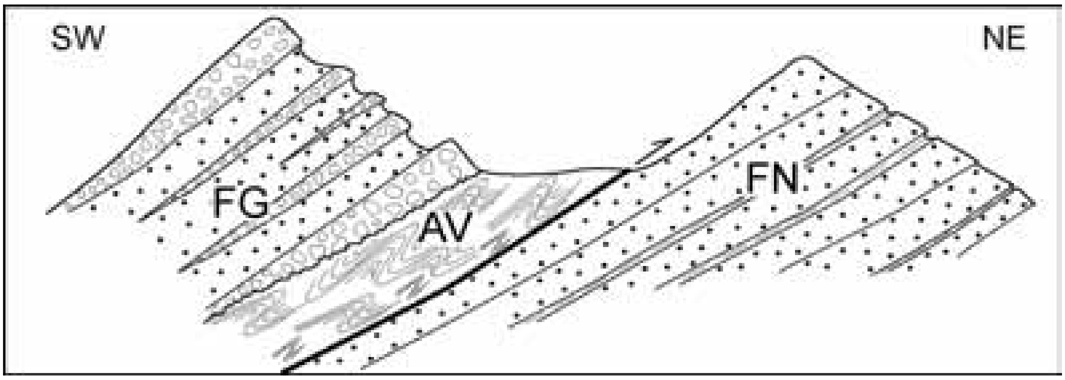

Figure 16 - Schematic cross-section of the "Dolomiti Lucane" area (not in scale). FG = Gorgoglione Flysch (Upper Miocene); FN = Numidian Sandstone (Lower-Middle Miocene); AV = "Argille varicolori" (Upper Cretaceous – Oligocene).

3.7 The "Dolomiti lucane" relief

M. Schiattarella

The "Dolomiti lucane" relief is a sharp NW-SE-trending ridge located in the external belt of the Lucanian Apennine, a segment of the Neogene chain forming the geological backbone of southern Italy (Figure 15). The "Dolomiti lucane" area is included in the unit 4 (frontal imbricate fan). Accordingly, its structural style has been mainly imposed by thrust tectonics of the external sector of the chain. The "Dolomiti lucane" ridge emerges from the surrounding landscape in a marked and startling way, due to the clear contrast between the less erodible rocks of the ridge and the other outcropping formations, basically made of marly-clayey or arenaceous-pelitic successions. The ridge is in fact mainly constituted by an alternation of well-cemented and thick-bedded conglomerates and sandstones with subordinate pelitic layers, forming a 1500 m thick succession characterized by regressive trend and channel facies (Pescatore *et al.*, 1980).

These rocks are part of the Gorgoglione Flysch, an Upper Miocene synorogenic succession of the Irpinian realm (Pescatore, 1978). Specifically, the Irpinian trough represented the entire Miocene foredeep of the southern Apennines, in which several silici- and calcareous-clastic successions deposited (*i.e.* Serra Palazzo Formation, Faeto Flysch, Castelvetere Formation), whilst the Gorgoglione Flysch (Ogniben, 1969) is currently interpreted as a piggyback basin succession (Pescatore, 1988; Pescatore *et al.*, 1999).

From a geomorphological standpoint, one can observe in the "Dolomiti lucane" area, besides the above-mentioned strongly morpho-selected landscape, the effects of the superimposition phenomenon of the Caperrino River, a tributary of the Basento River, which deeply cuts the Gorgoglione Flysch carving major gorges and narrow minor channels that are responsible for the beautiful exposition of most of the succession. Rock pinnacles and needles - generated by fracturing coupled with erosion processes, sometimes promoting rock falls by seismic triggering - complete the spectacular landscape of the "Dolomiti lucane".

Stop 3.2:

The "Dolomiti lucane" relief.

This stop shows the stratigraphic and tectonic features of the Gorgoglione Flysch succession, forming a SW-dipping monocline affected by both growth strata structures and thrusts (Figure 17).

We will walk to the unique panoramic view towards the Castelmezzano village, surprisingly rooted on the sharply dipping conglomerate and sandstone beds.

3.8 The frontal imbricate fan of the south-Apennines thrust belt

S. Gallicchio

The main stratigraphic and structural characters of the frontal imbricate fan of the Lucanian Apennine can be observed along the deep and wide valley of the Basento river; these features mostly constrained the paleogeography and the evolution of the Plio-Pleistocene foredeep in its inner sector.

In this area the chain consists of several Cretaceous to Pliocene lithostratigraphic units, belonging to different and diachronous sedimentary basins which developed on the western margin of the Adria Plate (Lagonegro Basin; Numidian Basin, Irpinian Basin and Bradanic Trough, *i.e.* Pescatore *et al*., 1999, *and references therein*). These units were split into different thrust systems from the Late Oligocene - Early Miocene to the Pliocene, and, during the Early Pleistocene, overthrust the foredeep deposits of the Bradanic Trough ("Argille subappennine" and "Conglomerato di Serra del Cedro" Fms.). Furthermore, in the Plio-Pleistocene the front of the chain was affected by breaching thrusts and extensive strike-slip faults.

Along the Basento valley, the frontal imbricate fan is represented by three main superimposed tectonic units. From the top to the bottom they are informally called: the Pietrapertosa, Vaglio di Basilicata, and San Chirico tectonic units (PTU, VBTU, SCTU in Figure 18), (Gallicchio *et al*., 1996; Sabato *et al., in press* a).

The Pietrapertosa tectonic unit is represented by the Gorgoglione Flysch, and by its severely deformed substratum, represented by the argille varicolori unit, Cretaceous to Oligocene pelagic deposits, and by the Tufiti di Tusa Formation, an Upper Oligocene-Lower Miocene volcanoclastic turbidite succession (*i.e.* Ogniben, 1969). The Pietraperosa tectonic unit was superimposed onto the Vaglio di Basilicata tectonic unit in the Early–Middle Miocene, during the deposition of the Gorgoglione Flysch.

The Vaglio di Basilicata tectonic unit is represented by a continuous and conformable Cretaceous to Lower-Middle Miocene succession, belonging to the Lagonegro basin, and is made up of: a) the "argilliti e radiolariti di Campomaggiore" unit (Early–Middle Cretaceous); b) the "calcareniti e argilliti di Fontana Valloneto" unit (Late Cretaceous-Early Miocene); c) the Flysch Numidico Fm, (Early-Middle Miocene). This tectonic unit is mainly arranged in an east-verging thrust sequence of Early-Middle Miocene age and is tectonically superimposed on the San Chirico

Figure 17- Panoramic view of the "Dolomiti lucane".

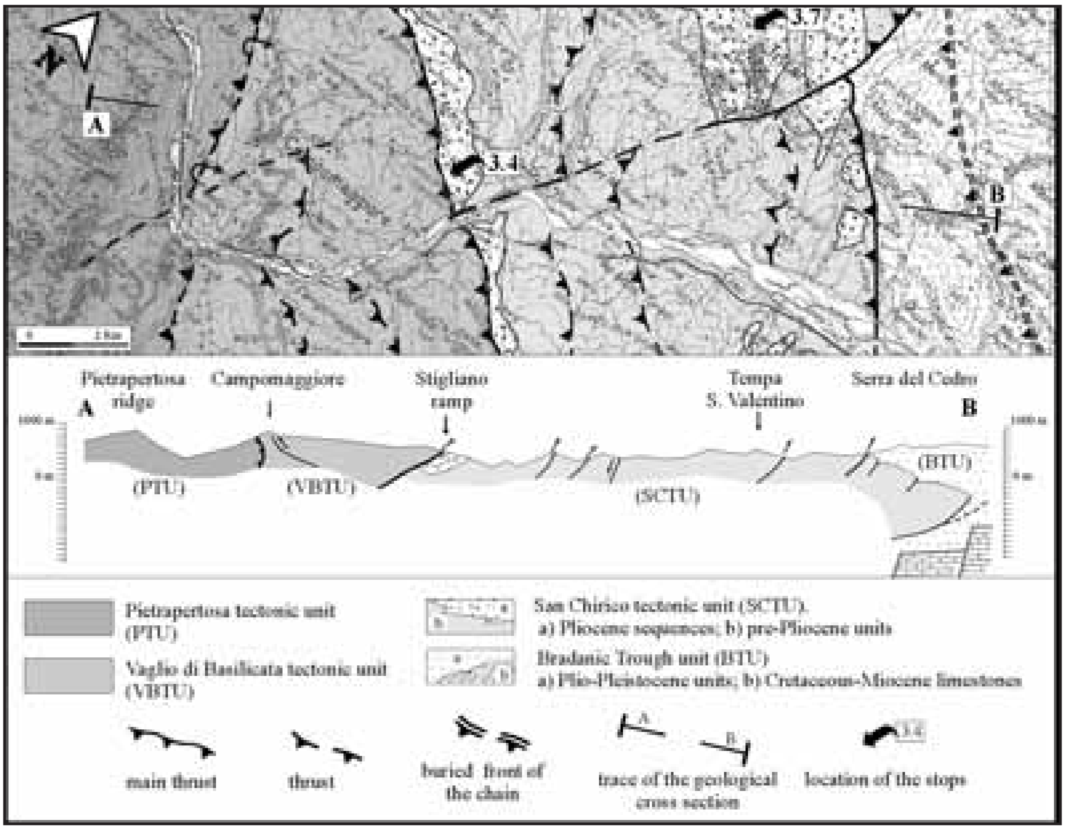

Figure 18 - Geological map showing the main stratigraphic and structural features of the frontal imbricate fan of the south-Apennines thrust belt, between the villages of Campomaggiore and Tricarico.

tectonic unit by a breaching thrust which was active during the Middle-Late Pliocene. This structure, the Stigliano ramp in Patacca and Scandone (2001), outcrops in the Basilicata region from Mt. Vulture to Stigliano village.

The San Chirico tectonic unit is made up of a continuous Cretaceous to Miocene succession, on which Pliocene wedge-top deposits unconformably lie. The pre-Pliocene succession is represented by: a) the “argilliti e radiolariti di Campomaggiore” unit; b) the “calcareniti e argilliti di Fontana Valloneto” unit; c) the Flysch Numidico Fm; d) the Serra Palazzo Fm, an arenaceous turbidite succession deposited in the Miocene south-Apennines foredeep (*i.e.* Gallicchio and Maiorano, 1999, *and references therein*); e) the Marne Argillose del Toppo Capuana Fm. (Crostella and Vezzani, 1964), an Upper Miocene muddy unit. The Pliocene covers rest unconformably on these pre-Pliocene units and show a depositional arrangement characterized by angular unconformities and growth structures.

The San Chirico tectonic unit tectonically overlies the Plio-Pleistocene foredeep *s.s.* deposits of the Bradanic Trough either along a wide east-verging subsurface thrust (*i.e.* Patacca and Scandone 2001, *and references therein*) or along an outcropping breaching Quaternary thrust (Oppido Lucano-Tricarico ramp) which has NW-SE strike and NE vergence.

Stop 3.3:

The Stigliano ramp

In this stop the breaching thrust that superimposed the Vaglio di Basilicata tectonic unit on the San Chirico tectonic unit can be clearly observed (Figure 19). This structure can be correlated to the Stigliano ramp which was considered, by Patacca and Scandone (2001), active until the Early-Middle Pleistocene boundary. In this area the Stigliano ramp affects a Middle-Upper Pliocene wedge top succession.

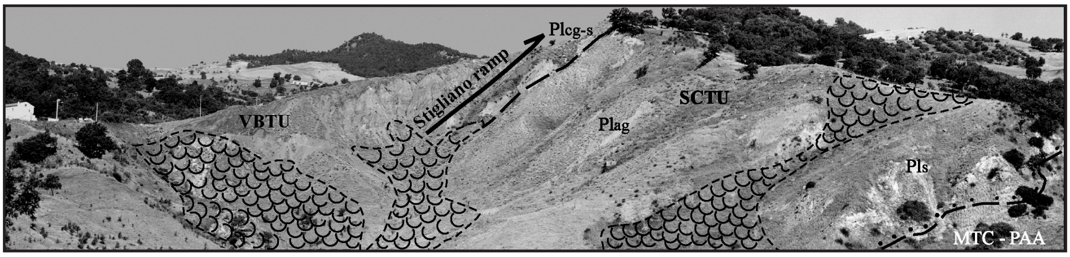

Figure 19 - Overview of the Stigliano ramp along the Basento valley. VBTU: Vaglio di Basilicata tectonic unit; SCTU: San Chirico tectonic unit; MTC: Marne argillose del Toppo Capuana Formation; PAA: Serra Palazzo Formation; Pls: Pliocene sandstones; Plag: Pliocene clays; Plcg-s: Pliocene conglomerates and sandstones.

Stop 3.4:

Campomaggiore Vecchio
(close-up view of the Stigliano ramp)

In this area a Middle-Upper Pliocene wedge top succession unconformaby overlies the Serra Palazzo and the Marne argillose del Toppo Capuana Fms. (San Chirico tectonic unit). Through the Stigliano ramp this tectonic unit is underthrust by the "argilliti e radiolariti di Campomaggiore" (Vaglio di Basilicata tectonic unit). Here, the Stigliano ramp is cut by Quaternary NW-SE trending transtensional faults.

We will cross the ruins of Campomaggiore Vecchio (the old Campomaggiore village), the abandonment of which occurred during the spring of 1885, when part of the village slid down the flank of the mountain. The landslide followed an earthquake which hit central-southern Italy. All the structures, which included the Duke's castle, were in ruins. Village people decided to build Campomaggiore Nuovo (the new Campomaggiore village) on its original site by extending it around the other side of the summit (away from the side that fell down).

3.9 The Quaternary front of the chain

P. Pieri, S. Gallicchio, L. Sabato, M. Tropeano

In the most external part of the Lucanian Apennine chain, the San Chirico tectonic unit overthrusts the Lower Pleistocene foredeep deposits represented by clays of the Argille subappennine Fm. In the latter, adjacent to the most external outcropping ramp, a thick conglomerate body, the "Conglomerato di Serra del Cedro" Fm. (Gambassini, 1967; Loiacono and Sabato, 1987), is enclosed (Figure 5b). This coarse-grained body is composed of a lower deltaic part and an upper alluvial one, separated by a clayey lens. It outcrops for about 500 m and its thickness progressively decreases eastward. However, drilling data reveal a total thickness of about 1500 m in its proximal part. The activity of the emerged thrust ramp during the Early Pleistocene is testified by the presence of this thick, coarse-grained body. The ramp was the boundary between emerged lands and the foredeep *s.s.* area when a wedge-top basin did not exist (Tropeano *et al*., 2002). The gravelly body was successively affected by Middle Pleistocene backthrusting, induced by a younger and more external blind thrust (Pieri *et al*., 1997b).

Stop 3.5:

Panoramic view from Calciano village

From this view-point the structural and stratigraphic relationship between the San Chirico tectonic unit and the Pleistocene foredeep unit, along the Basento valley, are clearly visible (Figure 20).

3.10 Sedimentary evolution of the "Conglomerato di Serra del Cedro" Formation

F. Loiacono

Three main stratigraphic units, each representing a depositional system, can be distinguished from the bottom to the top in the outcropping succession belonging to the Conglomerato di Serra del Cedro Fm. (Loiacono and Sabato, 1987). A proximal sector and a distal sector are recognized inside each system.

- *Lower unit (subaqueous fan delta system)*

The proximal part (western sector) of the lowest depositional system is composed of well stratified conglomerates (C3) and, locally interbedded, thin lenticular sandstones (S1), passing upward to cross-bedded conglomerates bodies that include well sorted sandstones (C2, C4). This facies association, several tens of metres thick, is interpreted as a delta front. It is enclosed in disorganized matrix-supported conglomerates with clays, that are interbedded, containing marine fossils and bioturbations; this facies association is referred to a delta slope. Thick beds of clast- or matrix-supported conglomerates, well cemented and locally cross-stratified (C4), overlie,

through a sharp contact, the slope deposits. Thickness of these tabular-shaped beds decreases towards the east. These features suggest reworking in shallow water during low stand episodes. In association with slope deposits (C1), concave-upward conglomerate beds (C2) and heterolithic facies (S2) are observed; these deposits are probably referable to the channelled part of the slope.
In the distal part (eastern sector), the conglomerate facies are less thick than in the proximal one; pebbly mudstones (A2) are interbedded to fine grained prodelta facies. The delta front facies overlie well stratified thin beds organized in broad-shallow channelled bodies or lenticular convex-up coarse grained bodies (C2, C3, S2). These deposits are probably referable to the interdistributary bays of a delta plain.
- *Middle unit (shelf system)*
With a sharp contact, clay facies overlie the delta plain deposits. These clayey sediments, whose thickness increases towards the east, contain marine fossils and are interpreted as shelf deposits (Argille subappennine Fm.).
- *Upper unit (alluvial plain system)*
Conglomerate facies, up to 150 m thick, unconformably overlie the shelf sediments; they are well visible in the western sector, where they are mainly composed of disorganized bodies (C1) with interbedded massive clays. These facies are referable to an alluvial fan system. Eastward, well-stratified conglomerate facies are arranged into decimetric beds (C2 and C3), associated to thinly bedded, lenticular-shaped, and fine-grained facies. These features suggest a lateral evolution of the alluvial fan to a braid plain, characterized by stream and sheet flows.
Three sedimentary stages characterize the evolution of the Conglomerato di Serra del Cedro Fm:
i) the infilling of a structural depression. Sedimentation was controlled by strong subsidence, as suggested by the remarkable thickness of the conglomerate body. The architecture of the fan delta system in its outcropping part shows that the delta front and delta slope facies are assembled in a complex vertical and lateral architecture, probably related to either recessional or progradational trends. Both fining and shallowing upward evolution of the system is indicated by the delta or coastal plain facies at the top of the lowest unit;
ii) a transgressive phase (marine flooding), indicated by the shelf facies overlying the delta system;
iii) the activation of a terrigenous system, represented by alluvial coarse facies unconformably overlying the marine sediments.

Facies
C1= disorganized conglomerates; debris flow. *C2*= lenticular bedded conglomerates; stream flow. *C3*=

Figure 20 - Panoramic view showing Cretaceous to Miocene deposits belonging to the San Chirico tectonic unit which overthrust the Pleistocene deposits of the Bradanic Trough: the Argille subappennine Fm. below, and the Conglomerato di Serra del Cedro Fm. above.

horizontal well-stratified conglomerates; sheet flow. *C4*= thick or very thick cross-bedded conglomerates with interbedded well-sorted sandstones, reversely to normally graded; reworking and traction. *S1*= graded to laminated sandstones, including scattered pebbles or lenticular gravels, associated to C3 and C4. *S2*= thinly bedded sandstones which alternate with clays, locally bioturbated and showing load-deformation and tractive structures. *A1*= massive clays, bioturbated and rich in organic material and marine fossils. *A2*= disorganized clays containing coarse sand and scattered pebbles.

Stop 3.6:

Appia road (km 512-513), near Tricarico village

Along the road some outcrops show well-bedded, coastal plain facies including horizontally laminated sandstones and tabular conglomerates; transgressive shelf clays (middle unit) overlie the shallow marine deposits with a sharp contact; finally, braid plain facies of the upper unit overlap, with an erosional surface, both the shelf and transitional sediments.

3.11 The Pliocene sequences and tectonic structures in the Tricarico area

L. Sabato, S. Gallicchio, P. Pieri, M. Tropeano

In the Tricarico area a Lower Pliocene to Upper Pliocene succession crops out (stop 3.7). The succession lies on tectonized Cretaceous to Miocene units (stop 3.9). It belongs to thrust-top basin deposits of the Ariano Unit and is composed of two depositional sequences bounded by an angular unconformity (Sabato and Marino, 1994) (stop 3.8). Both the Pliocene sequences show unconformities and growth structures, and are affected by Quaternary (post-depositional) tensional and transtensional faults.

The two sequences are mainly preserved in two east verging asymmetric synclines with NW-SE trending axis (the Tricarico and Fronte Pizzuta synclines - TS and FPS in Figure 21). Both synclines are genetically linked to the growth of two east verging anticlines (the Tricarico and Fronte Pizzuta anticlines – TA and FPA in Figure 21). The Pliocene deposits are southward bounded by a major SW-NE striking transtensional structure (Figure 21); other minor transtensional structures, with either NW-SE or SW-NE strikes, are also observed.

The first sequence is Early Pliocene in age and has a variable residual thickness which ranges between some tens of metres up to 150 m. Since the lithologic, sedimentologic and geometric features of the sequence are very variable and the outcrops not physically connected, it is very difficult to correlate not-adjacent sections. The sequence is made up of conglomerates, sandstones and claystones belonging to coastal to marine facies; it begins with some metres of conglomerates, sometimes channelled and normally or normally-to inverse graded, clast-supported, and with well-sorted sandy matrix. Lenses and layers of sandstones are very frequent, whilst the occurrence of thin layers of clay is rare. Clasts consist of rounded and well rounded pebbles to boulders, mainly arenaceous in composition; siliceous, granitic and carbonate clasts are also present. Carbonate clasts often show borings by Lithophaga and attached oysters and *Balanus*; scattered pectinids, oysters and *Balanus* are also visible. Very frequent is the occurrence of soft-sediment deformation structures (load casts). Upward the sandstones became prevalent, and crop out for some tens of metres. They are often arranged in a monotonous series of several-metres-thick banks, sometimes amalgamated; normally, each bank shows an erosional base and an inverse gradation, and contains up to some decimetres thick conglomerates layers. They bear pectinids, oysters, Vermetus, *Ditrupa* and are parallel- or low angle cross-laminated. Rapidly the sandstones pass to some tens of metres thick bedded claystones and silty claystones with rare layers of gravels, containing macro (lamellibranchs) and microfossils (foraminifers and nannoplancton). The facies characteristics suggest coastal (deltaic) to marine (prodelta-shelf deposits) environments.

The second sequence lies disconformably either on the deposits of the first sequence (stop 3.8) or on older Apenninic units (stop 3.9). It is represented mainly by hybrid arenites and secondly by calcarenites (about 60 m thick) which pass to claystones (30 m thick). The sequence begins with some decimetres-thick conglomerates made up of well-rounded, Lithophaga-bored cobbles and boulders. The hybrid arenites and calcarenites are organized in up to 2–m-thick beds, and show parallel, trough-cross, or hummocky-cross laminations. The upper part of these deposits is represented by S-SW 30° dipping clinoforms. The clinobeds are characterized by the alternation of siliciclastic (quartz and feldspar) and carbonate layers. The latter are rich in macrofossils, either unbroken or fragmented (red algae, lamellibranchs, bryozoans, echinoids, *Balanus*), and benthic foraminifers (Textularia, Rotalia, Cibicides, Elphidium, Lenticulina). The bioturbation, which is very intense, is present throughout the arenaceous succession. The facies analysis allows us to refer this part of the sequence to high-energy shallow-marine environments.

Stop 3.7:

Panoramic view from the Saracen tower in Tricarico village

The Saracen tower is located on the eastern limb of the Tricarico syncline. Looking east, in front of you, you can observe several main structures of the more external part of the frontal imbricate Apennines fan. The core of the Fronte Pizzuta anticline, represented by the lower part of the succession of the San Chirico tectonic unit, crops out; the fold plunges towards the NW. The western limb of the asymmetric and east-verging Fronte Pizzuta syncline may also be observed; it is represented by sands and conglomerates. The out of sequence thrust (Figure 21), which superimposed the San Chirico tectonic unit on the Pleistocene deposits of the Bradanic Trough (Argille subappennine and Conglomerato di Serra del Cedro Fms.), crops out in the middle of the hill.

Moving to the north (on the left) we can observe the upper part of the second succession, characterized by the occurrence of up to 1-2 m thick sets of clinoforms, which are often separated from each other by erosional surfaces. Each set of clinoforms shows either

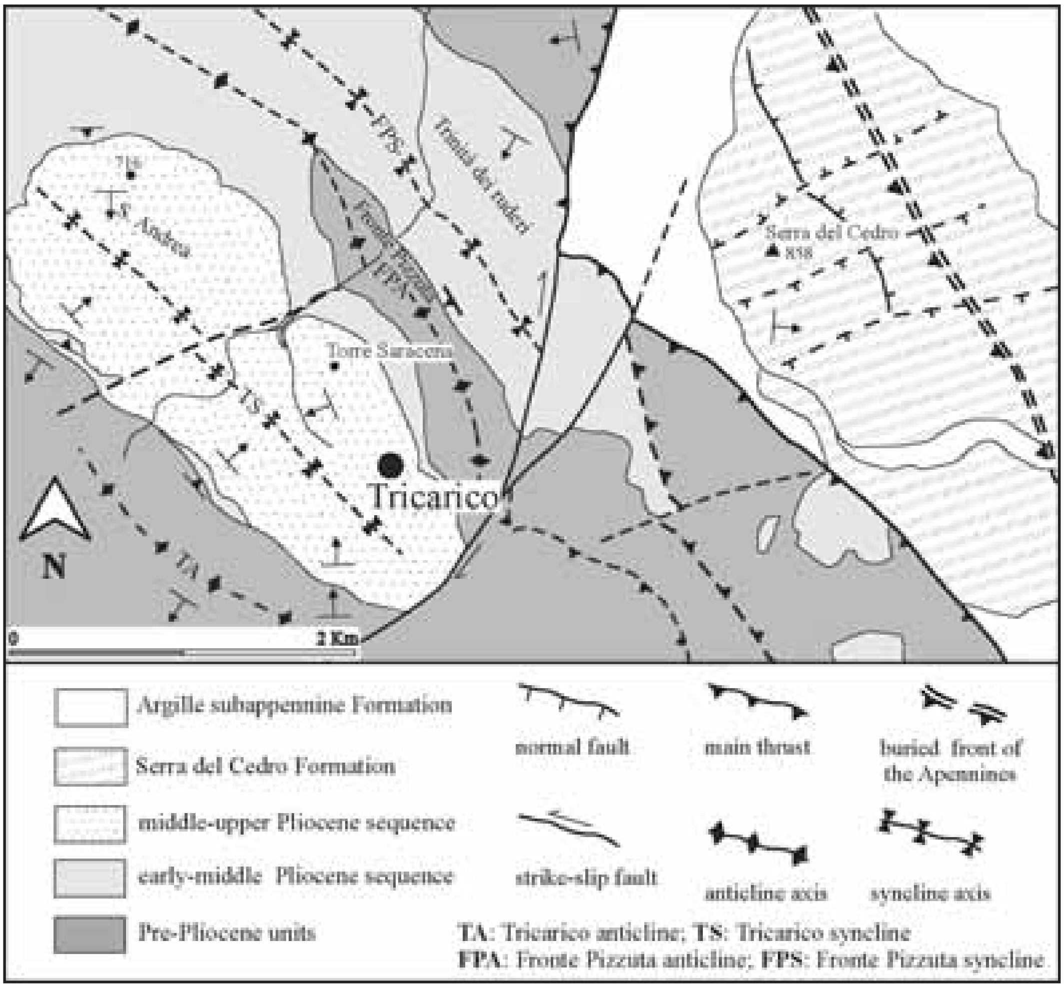

Figure 21 - Schematic geological map of the Tricarico area; VBTU: Vaglio di Basilicata tectonic unit; SCTU: San Chirico tectonic unit; MTC: Marne argillose del Toppo Capuana Formation; PAA: Serra Palazzo Formation; Pls: Pliocene sandstones; Plag: Pliocene clays; Plcg-s: Pliocene conglomerates and sandstones.

an angular or a tangential base; sometimes the first type passes to the second one in the same set. Along the outcrop we can also observe diverse tectonic structures which affected the deposits during and after their sedimentation.

Stop 3.8:

Relationships between the two Pliocene sequences

At Tricarico village, the second sequence overlies the first one through an angular unconformity. The first sequence is represented by subvertical (up to 80° NE) sandstone banks with thin conglomerate layers. The overlying hybrid arenites show at the base some centimetres thick conglomerates with well–rounded, Lythophaga-bored pebbles to cobbles, representing a lag deposit during a trangression. Locally, a growth structure (a progressive unconformity?) characterizes the second sequence, demonstrating Pliocene syn-depositional tectonics.

Stop 3.9:

Relationship between the substratum and the Pliocene succession

In Tricarico village, the second Pliocene sequence lies on the Miocene Serra Palazzo Fm. through an angular unconformity. The Miocene deposits dip 35° towards N while the onlapping Pliocene sequence dips 20° towards NE.

DAY 4

(low to medium difficulties)

The fourth day of the excursion (Figure 9) is dedicated to the observation of the different geometries and sedimentary features of the "Regressive coastal deposits".

In the morning we will visit the deposits outcropping in the neighbourhood of Irsina village, an area located in the central-western sector of the Bradanic Trough (stops 4.1-4.5). Here, the deposits overlie the hemipelagites of the Argille subappennine Fm. either transitionally or erosionally.

In the afternoon we will visit the Regressive coastal deposit well outcropping in Grassano village and in the Miglionico area (stops 4.6 and 4.7).

3.12 The Regressive coastal deposits of the Bradanic Trough

L. Sabato, P. Pieri, M. Tropeano

The Regressive coastal deposits represent the upper part of the Bradanic Trough in-fill succession and lie on the Argille subappennine Fm. (Figs. 5, 6, 22, 26). The latter is represented by hemipelagites cropping out extensively either in subhorizontal or monoclinalic arrangement, with a dip of a few degrees towards the NE; the cropping thickness is variable, but it is up to a few hundreds of metres, and the age (Late Pliocene to Middle Pleistocene) becomes younger from NW to SE and from W to E. A shallowing upward trend characterizes the Argille subappennine Fm., from offshore environments (*i.e.* Ciaranfi *et al*., 1996) passing upward to shallow shelf and to lower shoreface environments (*i.e.* Sabato, 1996b).

The Regressive coastal deposits overlie the hemipelagites of the Argille subappennine Fm. either transitionally (stops 4.1, 4.6, 4.7) or erosionally (stop 4.3) (Figs. 22, 26). These coarse-grained coastal deposits represent the top of the foredeep successions and are mainly shallow-marine in origin (Irsina and Grassano examples, stops 4.1-4.4, 4.6), secondly continental in origin (Miglionico example, stop 4.7). Thicknesses vary from a few metres up to over 100 metres, and facies belong to paralic, deltaic and/or alluvial environments (Massari and Parea, 1988; 1990; Pieri *et al.*, 1994a; 1996a; Sabato, 1996b; Lazzari and Pieri, 2002).

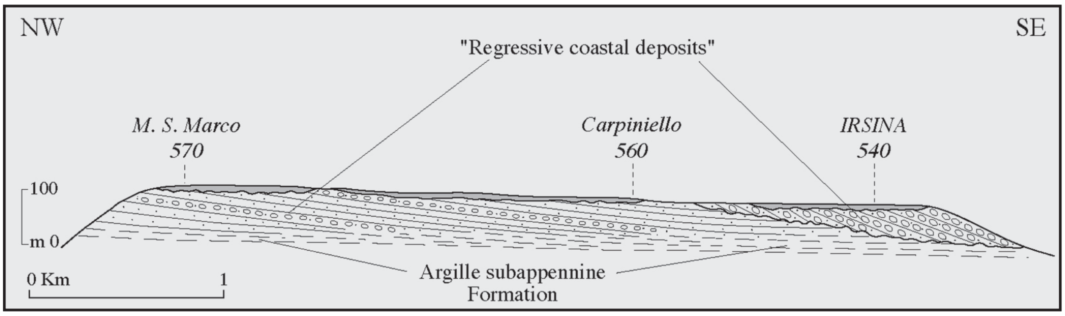

Figure 22 - Depositional scheme of the "Regressive coastal deposits" outcropping in the Irsina area. Modified from Sabato (1996a).

The highest and oldest Regressive coastal deposits are Sicilian in age and prograde towards the E-NE (Pieri *et al.*, 1994a; 1996a) whilst the younger Middle and Upper Pleistocene deposits prograde either to the N (towards the central Adriatic coast), to the E (towards the Manfredonia Gulf) or to the SE (towards the Taranto Gulf) (Tropeano *et al.*, 2002b) (Figure 6). These deposits are mainly siliciclastic in origin and of Apenninic provenance, but locally, near the foreland highs, they may be carbonate or mixed in origin. According to Pieri *et al.* (1996a), these coarse-grained deposits are arranged into prograding wedges, often characterized by wave-dominated Gilbert-type bodies, whose top depositional surface progressively falls in elevation along the progradation dip. The erosionally based wedges, commonly characterized by gravelly delta deposits (*i.e.* Massari and Parea, 1990; Sabato, 1996b), alternate with transitionally based ones, characterized mainly by aggrading deposits which from bottom to top pass from offshore-transition facies of the Argille subappennine Fm. up to shoreface, beach and, in some places, to alluvial facies (Sabato, 1996b).

3.13 The Pleistocene Regressive coastal deposits in Irsina village

L.Sabato

In the Irsina area we have the opportunity to compare the different types of relationships with the Argille subappennine Fm. that the Regressive coastal deposits offer (Figure 22). In fact, in the northern zone, sandy and sandy-conglomeratic offshore-transition to foreshore sequences form transitionally based wedges, whilst in the southern zone, conglomerate deltaic sequences erosively overlie the underlying Argille subappennine Fm. (Sabato, 1996b). Both examples are represented by a group of sandy-conglomeratic deposits, 60 m in thickness, having lithostratigraphic and facies characteristics laterally and vertically variable. Internally, this group of sediments shows a progradational geometry, with NW-SE trending, low-and high angle foreset beds.

The northern zone

The base of the offshore-transition to foreshore sequences, some metres in thickness, is composed of thinly-stratified, intensely-bioturbated, and parallel laminated clays and silty clays; erosive-based sandstones, parallel- and planar-cross laminated, are interlayered. Macro and microfossils and plant remains are abundant. This portion of the sequences represents offshore-transition environments. The middle portion of the sequences, 25-30 m in thickness, is formed by parallel- swaley- and ripple-laminated fine-grained sandstones commonly displaying hummocky-cross bedding, and characterized by the occurrence of frequent erosional surfaces draped by thin layers consisting of unbroken or fragmented fossils (lamellibranchs, gastropods, oysters, *Ditrupa*) and discontinuous clays and marls intensely bioturbated (echinoids), and often subjected to fragmentation into mud clasts and clay chips. This portion of the sequences can be related to lower shoreface environments. The upper portion of the sequences, up to 15 m thick, is characterized by remarkable variability in the lithologic features. It can be represented either by conglomerates with sandstones interlayered (stop 4.1), or by sandstones deposits with rare conglomerates layers (stop 4.2).

The southern zone

In the southern zone of the Irsina area a mainly conglomerate erosionally-based body outcrops (Figure 23). It is represented by a wave-dominated Gilbert-type delta in which bottomset, foreset and topset are distinguished. The foreset unit mainly consists of clinostratified conglomerates with sandy interlayers (stop 4.4). The thickness ranges between some metres in the proximal area, where the sequence is incomplete because of lack of bottomset beds, and 40 m in the distal one, where sandy interlayers increase, and bottomset beds gradually appear. Furthermore, in the proximal area the foreset beds lie at a high angle (up to 30°) over the underlying unconformity surface (Argille subappennine Fm.), while distally they become tangential. Foreset beds occur often arranged into groups of beds with different dipping, separated by erosional surfaces. Foreset beds are sigmoidal-shaped, some decimetres thick, reverse or reverse-normal graded. They are mainly clast-supported, with sandy-matrix; locally, matrix-supported beds are present. The rare interlayered sands are laminated and contain gravel layers. Clasts (up to 30 cm in size) are well rounded and often the smaller ones show imbrication indicating paleoflows from N-NW. Upwards, 1-m-high, channelled, sandy-conglomerate bodies occur. Bottomset beds are mainly represented by sandy layers bearing microfossils (foraminifers). The topset unit has a maximum thickness of 10 m; it lies with an erosional contact on the foreset beds (Figure 24) (oblique geometry) in the proximal area and gradually passes into the foreset unit in the distal one (sigmoid geometry). Topset beds are made up of

Figure 23 - Sandy-conglomeratic deltaic deposits erosively overlie the clay deposits of the Argille subappennine Formation.

conglomerates with frequent sandy interlayers; clasts are smaller than those of the foreset unit and show a well-developed seaward imbrication.

Either on the offshore-transition to foreshore or on deltaic sequences, a reddish sandy-conglomeratic deposit unconformably lies through an erosional surface (Figure 25). It is an up to 10 m thick continental deposit showing different facies (lagoonal, alluvial, palustrine). The better exposed facies are related to alluvial environments and are represented by crudely stratified, sometimes low-angle clinostratified, matrix-supported conglomerates, with abundant clayey matrix, and organic-rich layers and manganesifer crusts. The imbricated clasts, up to 10 cm in size, indicate paleoflows from N.

Stop 4.1:

Upper portion of the offshore-transition to foreshore sequences in the northern zone of the Irsina area.

Here, in the lower part (upper shoreface) of the sequences we can observe sandstone/conglomerate couplets; the sandstones show onshore and offshore dipping planar cross-lamination; the conglomerate layers dip 10°. Upward, the sequences (beachface) are dominated by conglomerates organized into some decimetres thick and often coarser-graded beds; they are clast-supported, and some layers show openwork fabric; the matrix is represented by well sorted coarse sand. Clast sizes range between some centimetres up to 15 cm; they are well rounded and the smaller are mostly disc-shaped, and show a dominant seaward dipping imbrication. Attached or scattered oysters are frequent. Clasts composition is mostly arenitic and carbonate.

Stop 4.2:

Upper portion of the offshore-transition to foreshore sequences in the northern zone of the Irsina area.

Here, the deposits of the upper portion of the sequences are represented by sandstones whose facies are indicative of upper shorefaces environments. The sandstones occur in 1-2 m thick beds, are medium-coarse grained, well-sorted, bioturbated and rarely show planar-cross-laminations. Upwards, layers or lens-shaped conglomerates are found; clasts are 2-3 cm up to 10 cm in size. Frequent is the occurrence of hummocky-cross bedding. Scattered or along surfaces *Ditrupa*, lamellibranchs, gastropods and oysters are found. The sequences are sometimes represented by foreshore facies with some metres thick conglomerates beds, inversely graded, with well developed seaward imbrication, and with interlayered sandstones.

Stop 4.3:

The base of the delta.

To the south of Irsina village, we can observe the Gilbert-type delta sequences erosionally overlying the hemipelagites of the Argille subappennine Fm. (Figure 23)

Stop 4.4:
Conglomerates of the Gilbert-type delta sequences in the southern zone of the Irsina area.
Here, it is possible to observe the conglomerates topset unit erosively overlying the conglomerates foreset beds (Figure 24)

The sequences begin with about 15-m-thick, fine and well-sorted sandstones arranged into some decimetres-thick bioturbated (echinoids) packages which alternate with low-angle, cross- and parallel laminated sandstones beds; lamination is often underlined by fragmented silty layers. Seldom thin conglomerates layers and hummocky-cross stratification occur; high-angle cross-lamination is also observable. At different heights some lenses of laterally continuous claystones are visible. This portion of the sequences can be related to offshore-transition to lower shoreface environments.
The sequences follow for about 10 m with sandstones, generally medium-coarse grained and bioturbated, showing longshore-directed (N-S) trough-cross bedded sandstones and pebbly sandstones, grouped in sets of about 10-20 cm thick. Upwards, wedge-shaped conglomerates alternate with wedge-shaped sandstones; both wedge out seawards and are offshore dipping (5°-6°); planar cross-stratification occur in sandy wedges. Conglomerate wedges sometimes pass distally to sandstone ones. This portion of the sequences can be referable to lower shoreface-transition

Figure 24 - Oblique geometry of the foreset beds at their upper boundary. Irsina village.

Stop 4.5:
Continental deposits erosionally overlying the Regressive coastal deposits in Irsina village.
Here, the continental deposits, erosively overlying the Gilbert-type delta sequence, outcrop on the foreset beds, for a thickness of about 6 m (Figure 25).

<u>3.14 Regressive coastal deposits in Grassano area</u>
L. Sabato M. Tropeano
In the afternoon we will arrive at Grassano village, where at Cinti, the good exposure of a vertical section allows Regressive coastal deposits to be investigated. Here, the regressive succession is formed by 30-35-m-thick sandstones and sandy-conglomerates offshore- transition to deltaic sequences, transitionally lying on the Argille subappennine Fm. (Figure 26).

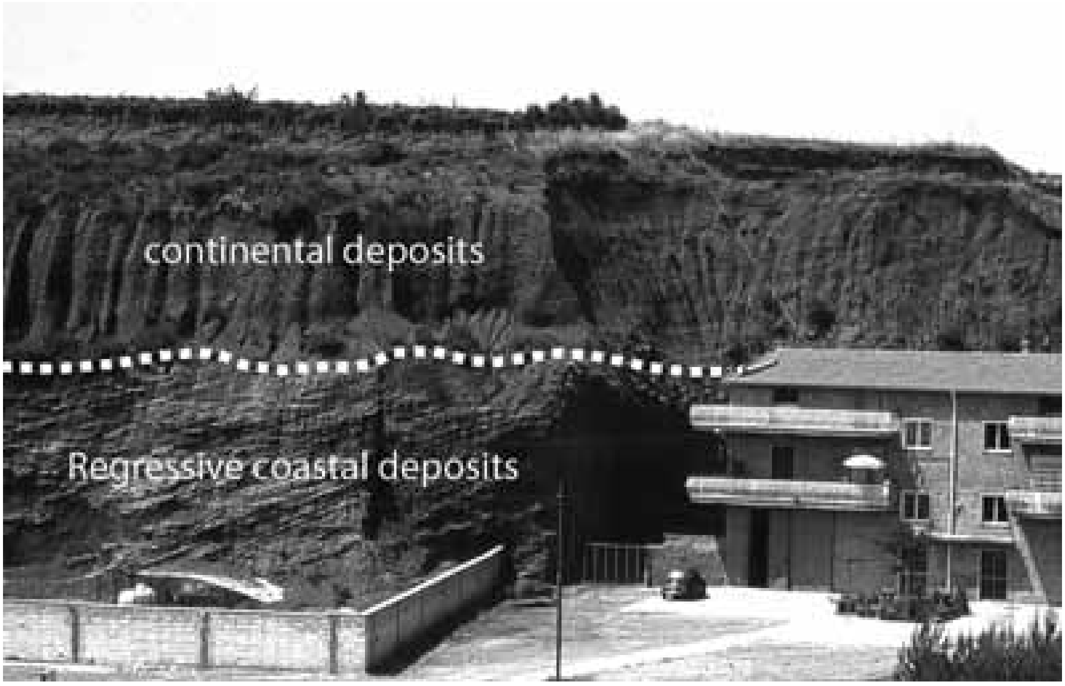

Figure 25 - Alluvial deposits erosively overlie the Gilbert-type delta sequence in Irsina area.

to offshore environments.
Through an erosional and very gently inclined seawards surface, a mainly conglomeratic body lies on the previous deposit. It has a thickness of about 6 m, and internally it is possible to distinguish a foreset unit and a topset one. The foreset unit has a wedge-shape and its thickness decreases from 5 m to 2.5 m basinwards. The northeast-dipping coarse-grained foresets decrease basinward from 17° to 5°. Foreset beds are some decimetres up to 1 m thick, have an angular and/or tangential base and display a wedge-shape; furthermore, they alternate with a few-decimetres-thick sandy beds, which disappear upwards (Figure 27). The sandy foresets display a high angle cross-lamination dipping onshore. Commonly the coarse-grained beds are clast-supported and normally graded, with scarce, coarse-grained sandy matrix; in many cases it is possible to observe a downslope increase in clast grain-size (mainly where the foresets height is less), from some cm up to 60 cm. The foreset beds show well-rounded arenitic, granitoid and carbonate clasts and subangular siliceous clasts with an average diameter of 7-8 cm; frequent is the occurrence of attached oysters, mainly at the base of the foreset unit. The arenitic clasts are also disc-shaped and show dipping seaward and landward imbrications. Some foreset beds are very well sorted, with disc-shaped pebbles showing an eastward paleoflow. The foreset beds show at the upper boundary a complex oblique/sigmoid geometry, suggesting a series of high-frequency sea level fluctuations. The foreset/topset boundary is evidenced by a drop in the clast size, which have an average diameter of 3-4 cm. The topset unit is formed firstly by 1.4-m-thick conglomerates arranged into about 20-cm-thick horizontal beds showing a seaward low-angle cross lamination; the matrix is composed of coarse sand, and the clast imbrication indicates a paleoflow towards the NE. The following 2 m are composed of better sorted conglomerates; the disc-shaped pebbles (average diameter of 6-7 cm) show a seaward dipping imbrication. An up to 2-m-thick matrix-supported conglomerate lies on the underlying topset unit. This part of the succession can be interpreted as a wave-influenced Gilbert-type delta passing upward to shoreface and beachface environments and finally to an alluvial one. Distally the delta grades into sandstones lower shoreface-transition to offshore deposits.
Finally, the succession is capped by fine-gravel deposits, matrix-supported and alluvial in origin. Though not well visible here, they have the same significance as the more clearly observable continental deposits overlying the Regressive coastal deposits in the Irsina

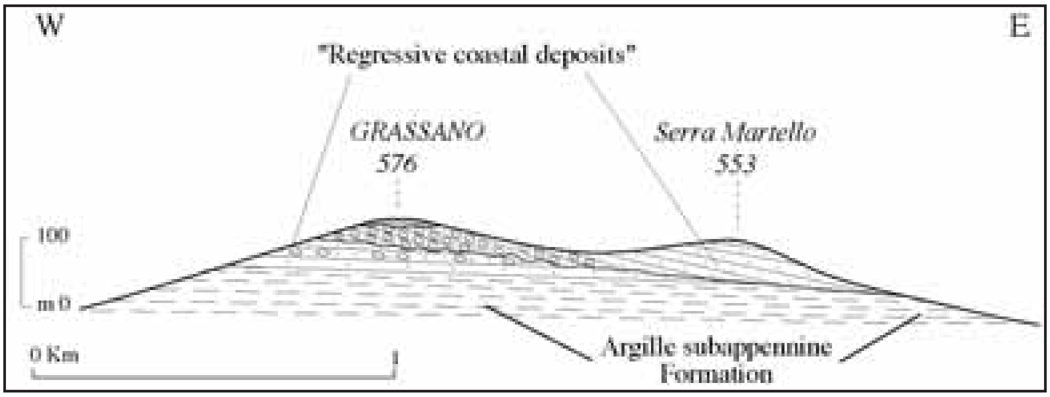

Figure 26 - Depositional scheme of the "Regressive coastal deposits" outcropping in the Grassano area. From Tropeano et al., 2002.

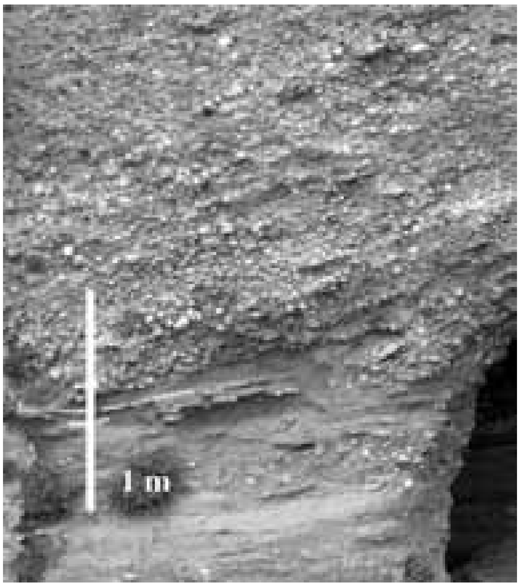

Figure 27 - Detail of the conglomerate foresets of the Regressive coastal deposits outcropping at Cinti, near Grassano.

area, which we observed during stop 4.5.

Stop 4.6:
Regressive coastal deposits at Cinti, near Grassano village

Stop 4.7:
Transitionel fecies pessing upward to continental ones.

In other areas, the "Regressive coastal deposits" are made up of transitional facies passing upward to a continental one. Such deposits can be seen along the road from Grassano to Miglionico. The road cuts into deltaic conglomerates passing to lagoonal-palustrine clays (50-60 m in all).

In the evening, we will travel towards east, crossing well developed badlands (called "calanchi").

DAY 5
(low to middle difficulties)

During the fifth day we will visit the northern (in the morning, stops 5.1-5.4) and the southern (in the afternoon, stops 5.5 and 5.6) part of the Sant'Arcangelo piggyback Basin (Figure 28).
It will be possible to discuss tectonics and sedimentation relationships in a piggyback context. Particular attention will be turned to the progressive unconformities characterizing the piggyback sequences and to the description of lacustrine deposits that developed in a tectonically controlled sub-basin. Furthermore, the relationships between the substratum and the infill deposits of the basin will be observed.

3.14 The wide Sant'Arcangelo Basin
P. Pieri, L. Sabato

The Pliocene to Pleistocene Sant'Arcangelo Basin (Figure 29) is a satellite basin, located back to the front of the south-Apennines thrust belt. The Sant'Arcangelo Basin in-fill, up to 5 km in thickness (Mostardini and Merlini, 1986; Merlini and Cippitelli, 2001), is basically marine in origin, although in the upper part of the succession Lower and Middle Pleistocene continental deposits occur (Vezzani, 1967;

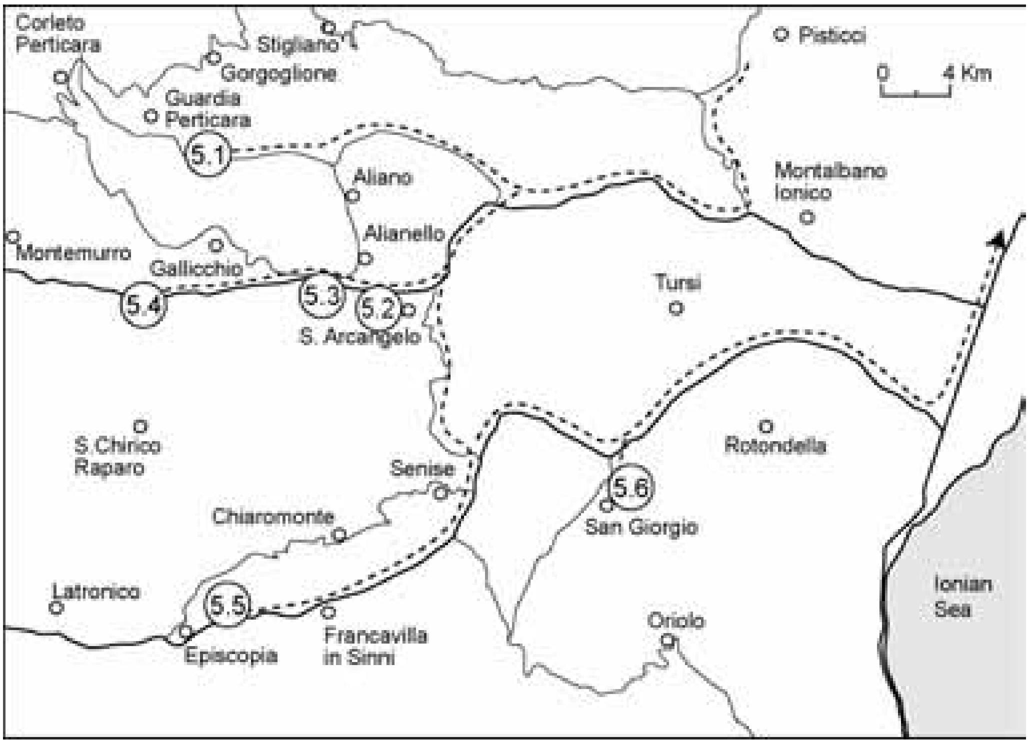

Figure 28 - Field trip itinerary of the fifth day.

Caldara *et al.*, 1988).
The Sant'Arcangelo Basin was interpreted as:
- a piggyback basin, by Caldara *et al*. (1988), Casero *et al*. (1988), Roure *et al*. (1991), Hippolyte *et al*. (1994);
- a pull-apart basin, by Turco *et al*. (1990);
- a depression associated with basic magmatic intrusion or mantle bulging at the front of the chain, by Merlini and Cippitelli (2001);
- part of the thrust-top basin succession which was passively folded, by Patacca and Scandone (2001).

According to Pieri *et al.* (1996b), marine deposits accumulated onto a large moving thrust sheet during the Pliocene and Early Pleistocene (open piggyback stage), while continental deposits accumulated when the thrust front began to uplift (closed piggyback stage). The uplift was caused by thrusting and transpression that occurred in the Apulian units which previously had been overthrust by the large sheet (Roure *et al.*, 1991; Hippolyte *et al.*, 1994; Bonini and Sani, 2000; Patacca and Scandone, 2001) (Figure 29C). During the Middle Pleistocene, thrusting in the Apulian units caused the complete emergence of a ridge (ridge 2 in Figure 29B), leading to the physical separation of the Sant'Arcangelo Basin from the foredeep *s.s.* (the Bradanic Trough, Figs. 29B, 29C) and the end of deposition within the basin. Present-day, according to structural data, normal and transcurrent faults occur in the basin area (Pieri *et al.*, 1997b), while thrust faults still affect the chain front (Doglioni *et al.*, 1996) (Figure 29C).

The Sant'Arcangelo Basin in-fill contains four siliciclastic, Upper Pliocene to Middle Pleistocene, depositional sequences (**A**-**D** in: Pieri *et al.*, 1996b). Each sequence is bounded by unconformities, some of which are progressive in origin. The lower two sequences are mainly composed of deltaic to shelf systems; the third sequence developed in two different and adjacent sectors of the basin and consists of deltaic to shelf systems in the eastern sector and fluvio-lacustrine systems in the western sector (San Lorenzo Cycle); the fourth sequence unconformably overlies the older ones and is composed of alluvial sediments.

These sequences were mainly affected by NW-SE oriented folds and faults that were active during sedimentation as suggested by the presence of growing structures (Caldara *et al.*, 1988; Pieri *et al.*, 1994b;

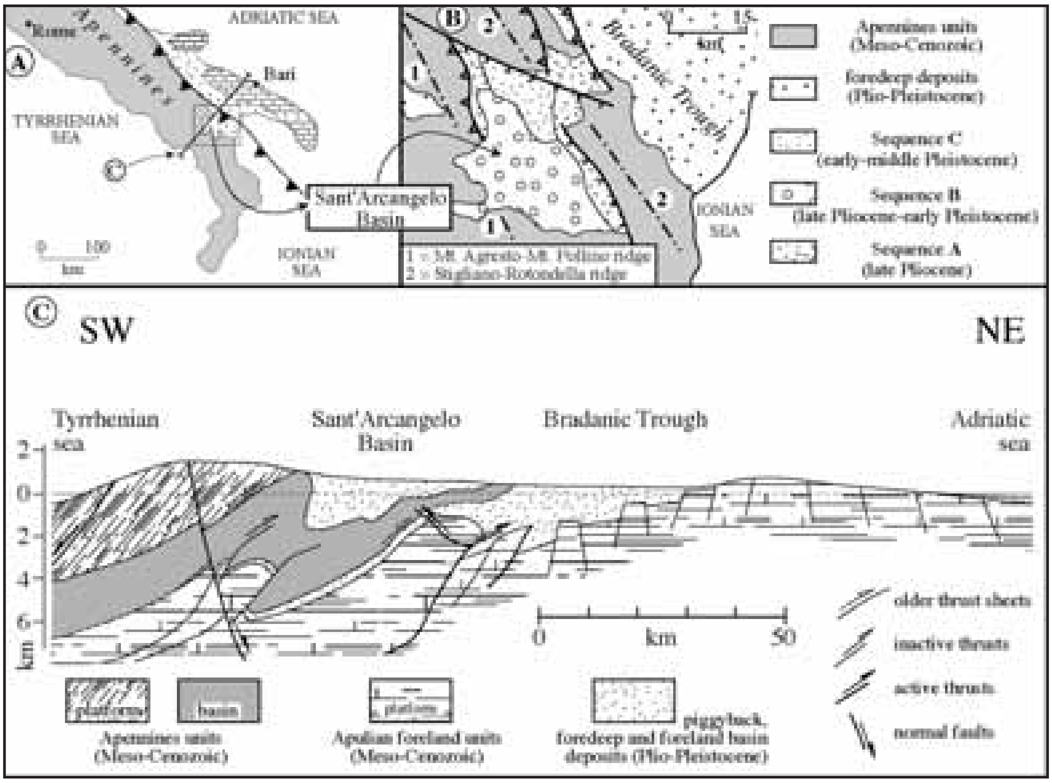

Figure 29 - (A) Schematic structural sketch of southern Italy; (B) location of the Sant'Arcangelo Basin and its main structural and stratigraphic elements; (C) schematic cross-section through the area from SW to NE. Modified from Sabato (2000).

Vitale, 1996; Zavala, 2000) and by paleogeographic change through time.

The first sequence (**A**; Caliandro Cycle in Pieri *et al.*, 1994b) was deposited during the Late Pliocene. This sequence lies unconformably on the deformed pre-Pliocene units and is made up of conglomerates, sandstones, and marly claystones representing a complete sedimentary marine cycle with transgressive and regressive deposits. It has a wedge-shape with maximum thickness (1000 m) towards the west, in the proximal area. The dip angle of beds progressively decreases from the lower part of the sequence (75°) to the upper part (35°). Its sedimentologic features suggest that the basin can be recognized in this stage as an open piggyback (Pieri *et al.*, 1996b).

Sequence **B** (Agri Cycle in Pieri *et al.*, 1994b) lies on sequence **A** with a syntectonic unconformity; it developed in the Late Pliocene-Early Pleistocene and is composed of silty claystones, sandstones, and conglomerates, forming a marine fan delta system up to 1000 m thick and prograding north-eastwards.

Sequence **C** lies unconformably on sequence **A** and through a syntectonic unconformity on sequence **B**. The development of the sequence **C** had been controlled by the growth of a fault propagation fold (the Alianello anticline, Figure 30), NW-SE trending, which divided the basin into two parts during the Early Pleistocene (Pieri *et al.*, 1996b). In the eastern part, which maintained a connection with the Bradanic Trough conserving the characteristics of an open piggyback basin, marine sedimentation carried on until the Middle Pleistocene (Sauro Cycle in Pieri *et al.*, 1994b, Figs. 29B, 30), and a fan delta system, prograding east-southeastwards, was deposited. This sequence is composed of silty claystones, sandstones and conglomerates, up to 1300 m thick. On the contrary, the western part was separated from the sea and assumed the characteristics of a closed piggyback basin; here continental sediments, composed of 500 m thick silty claystones and conglomerates deposited

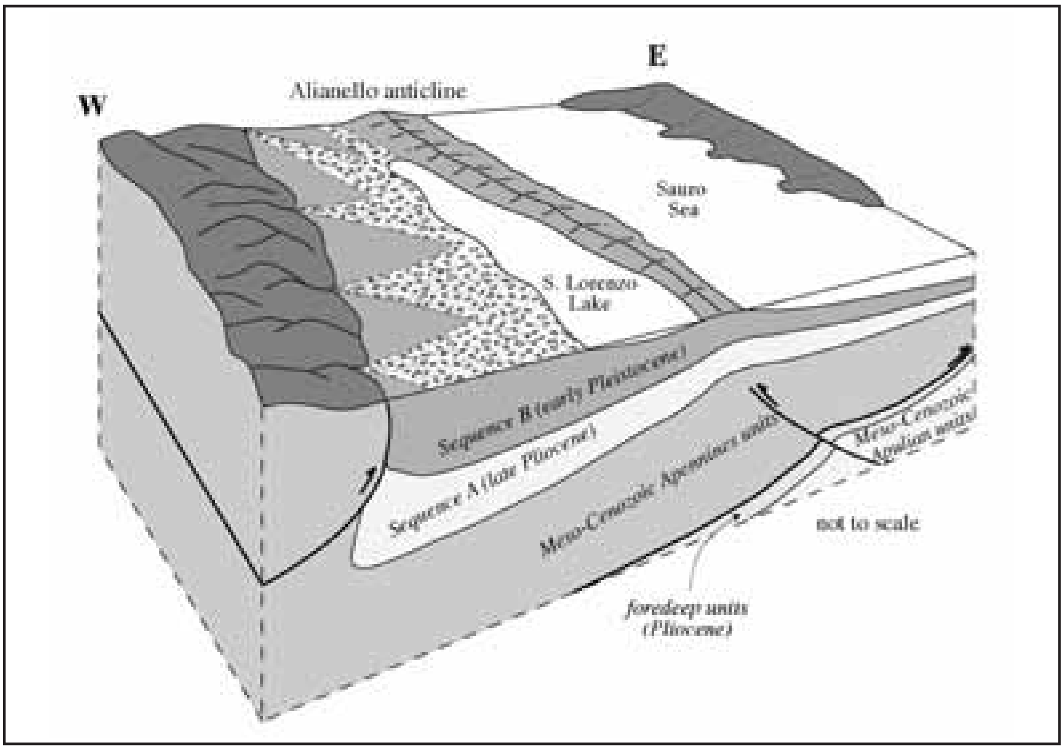

Figure 30 - Block diagram showing the dissection, in the Early Pleistocene, of the Sant'Arcangelo Basin into two sectors as a result of the growth of a ramp fold (the Alianello anticline).

(San Lorenzo Cycle in Pieri *et al.*, 1994b).
The fourth sequence (sequence **D**; Sabbie e Conglomerati di Serra Corneta in Pieri *et al.*, 1994b), continental in origin (Vezzani, 1967; Loiacono, 1983) and Middle Pleistocene in age, lies unconformably on the previous sequences; it is made up of silty sandstones and conglomerates about 150 m thick and is interpreted as alluvial fan deposits. This sequence represents the last evolutionary stage of the basin and was brought about by the emergence of an outer thrust (ridge 2 in Figure 29B) which caused the physical isolation of the basin from the rest of the foredeep, in which sedimentation continued for the entire Pleistocene. According to Pieri *et al.* (1996b), only in this last stage can the entire Sant'Arcangelo Basin be defined as a closed piggyback basin.

3.15 The northern part of the Sant'Arcangelo Basin
L. Sabato, P. Pieri

Stop 5.1:

The relationship between sequence B (Agri Cycle) and sequence C (Sauro and San Lorenzo cycles)
Along the left side of the Sauro valley, we can observe the conglomerates belonging to the San Lorenzo cycle (sequence **C**) faulted by a normal fault, in contact with the deltaic sandstones belonging to sequence **B** (Agri Cycle). On the latter, the alluvial conglomerates of sequence **C** (Sauro Cycle) overlie with a syntectonic unconformity. Note the decreasing of the dipping in the deposits of both sequences **B** and **C**.

Stop 5.2:

Stratigraphic and structural features of sequence C
From this panoramic view you can make out the different stratigraphic developments and arrangements of sequence **C** to the east (Sauro Cycle) and to the west (San Lorenzo Cycle) of the Alianello anticline (Figure 30). Furthermore, looking towards the west, the sandstone and conglomerate deposits of sequence **B** can be observed.

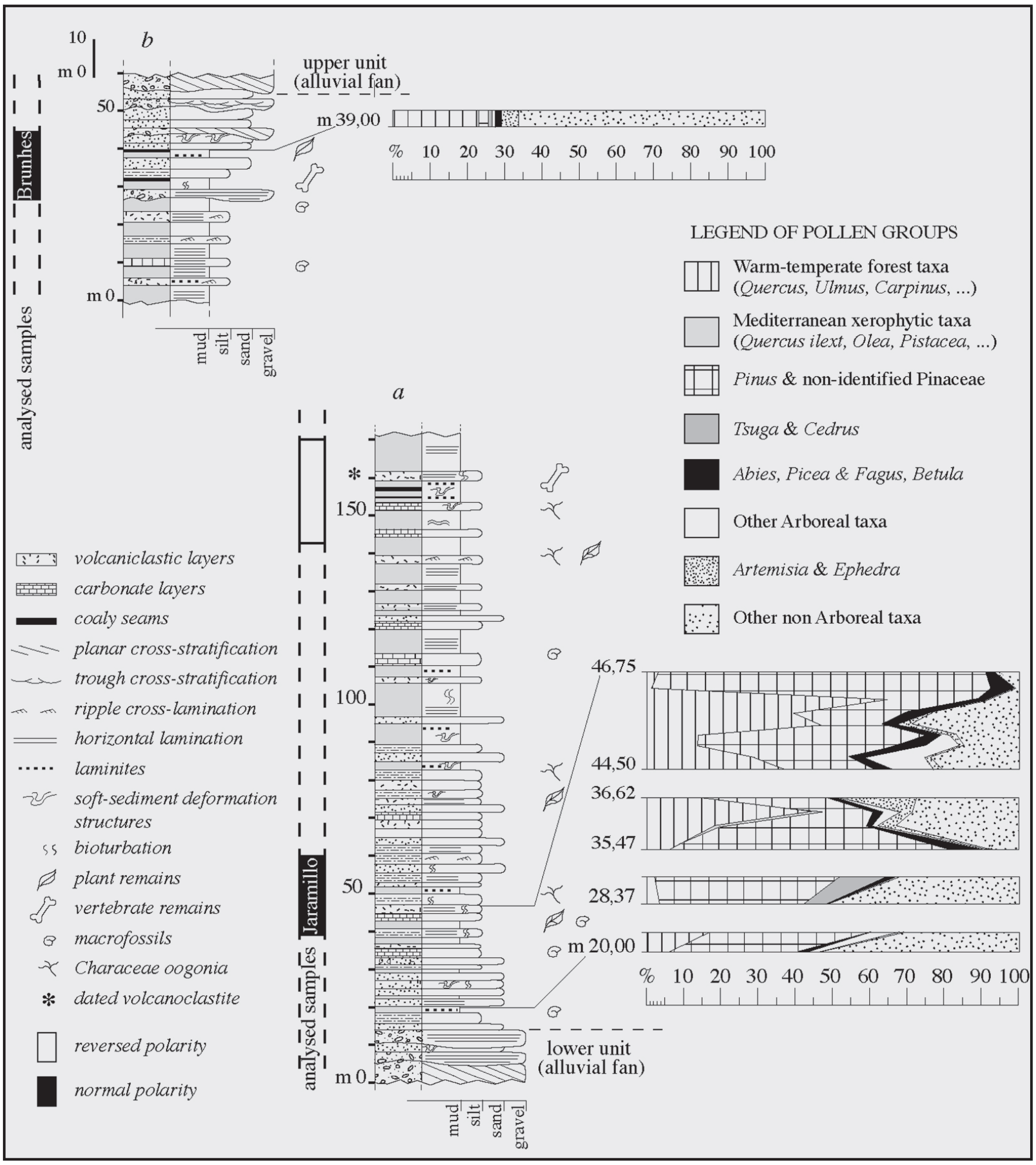

Figure 31 - The two measured lithostratigraphic logs within the lacustrine unit of the San Lorenzo Cycle in the Sant'Arcangelo Basin: log a was measured in the depocentral area, log b in a marginal area (3,5 km to the NW of log a). The three recognized magnetic polarity intervals and the palynological spectra are shown.

3.16 Lacustrine deposits of sequence C (San Lorenzo Cycle)

L. Sabato, A. Albianelli, A. Bertini, F. Masini, M. Moretti, G. Napoleone, P. Pieri, M. Tropeano, C. Lombardi

The lacustrine deposits are variable in thickness, with a maximum of over 200 metres, and are generally composed of thinly bedded claystones and silty claystones, interbedded with sandstones, calcareous and volcanoclastic interlayers. To the west it is possible to observe sandstones and conglomerates that are interlayered with claystones. Measurements of paleocurrents indicate major paleoflow direction towards the SE; transverse paleocurrent directions along the western side towards the east have also been measured. The volcanoclastic layers, phonolitic in composition, from the upper part of the succession, indicate an age of 1.1 ± 0.3 Ma (Caggianelli *et al*, 1992), obtained by K-Ar radiometric measurements (Figure 31, log *a*). In the synthetic columns (Figure 31, log *a* in the central part, and log *b* in the northern marginal part of the lacustrine deposits) three magnetic polarity intervals are also shown, as a result of detailed magnetic measurements of reversed polarity stratigraphy. The reversed polarity contains the dated volcanoclastites, whose range of confidence confirms the latest Matuyama chron assigned to this magnetozone. The basal normal polarity is therefore the Jaramillo chron (0.99 – 1.07 Ma), and the upper one the Brunhes (0 – 0.78 Ma). In a profile of up to 200 m in thickness, these time limits suggest a quite high sedimentation rate. The upper normal polarity (upper part of log *b*) includes the layers in which a vertebrate fauna (rare reptiles, amphibians, rare remains of a medium sized deer and a fairly diversified small mammal assemblage) was found. The occurrence among small mammals of *Mimomys savini* allows us to refer the fauna to the Biharian Mammal Age; the presence of some faunal elements such as *Microtus* (*Terricola*) *arvalidens, Microtus* (*Iberomys*) ex gr. *huescarensis - brecciensis,* and *Macroneomys* cf. *brachygnathus* restricts the age of the assemblage to the latest part of this Mammal Age. Therefore, the obtained age for the lacustrine succession is Early to Middle Pleistocene.

Palynological data individuated alternations between steppe-dominated phases and forest taxa from 20 m to 47 m of log *a* and the upper part of log *b* (Figure 31, Sabato *et al.,* in press b). Steppe-dominated phases contain Poaceae and Chenopodiaceae, and are characterized by the occurrence of *Artemisia* and *Ephedra*; scarce finds of deciduous tree pollen contribute to attribution of conditions to an arid climate. In contrast, the forest flora is dominated by deciduous trees, mainly *Quercus* followed by *Carpinus, Ulmus* and *Zelkova*, which are taxa of a warm and relatively humid climate. Palynological analyses, in progress, from the middle to upper part of the succession complete the record of the vegetational (herbaceous vs. arboreal pollen assemblages) and climatic changes which are correlatable with the Early to Middle Pleistocene glacial/interglacial phases.

Along the entire succession charophytes (Characeae oogonia), freshwater ostracods and gastropods (*Planorbis* sp.), as well as plant and vertebrate remains are found. A very distinctive feature of this lacustrine succession is the occurrence of soft-sediment deformation structures. They show a wide morphological variability (deformed lamination, load-structures, large vertical water escape structures and neptunian dykes). The analyses carried out on these structures (Moretti and Sabato, *in prep.*) show that they occur at different times (during or after sedimentation, and during compaction) and with different mechanisms of deformation. Slumps provide evidence of a paleoslope dipping towards the axis of the syncline.

Facies analysis of the depocenter sediments indicates that they were deposited in a distal zone of a terrigenous-dominated fresh water lake; the facies observed in the proximal area are interpreted as the distal part of a fan delta, at the transition of a proximal lacustrine environment into the overlying distal lacustrine environment (Sabato, 1997; 2000).

Stop 5.3:

The fluvio-lacustrine deposits of the San Lorenzo Cycle

From this viewpoint, the lacustrine deposits belong-

Figure 32 - Field view, along the Agri valley, of sequence C (the San Lorenzo Cycle). The lacustrine deposits (on the left) lie on a small anticline that developed within the lower alluvial deposits, belonging to the same C sequence.

ing to the San Lorenzo Cycle (sequence **C**), can be observed lying on the alluvial deposits, which belong to the same sequence (Figure 32). In the distance, it is possible to make out the alluvial conglomerate unit which overlaps the lacustrine deposits and closes sequence **C**. The lower unit forms a small anticline, and has a thickness of about 150 m; it is composed of poorly-sorted and well-stratified conglomerates, which locally contain decimetre thick clayey beds and massive sandstone layers. The lacustrine deposits onlap onto the flank of the fold, showing a progressive unconformity; this, together with other sedimentary features, confirms its sedimentation during the Alianello anticline's growth

Stop 5.4:
Unconformity between the substratum and sequence A

Along the Agri valley we can observe conglomerates and sandstones, belonging to sequence **A**, which dip about 50°-55° towards E-NE. They unconformably overlie the deformed Miocene Gorgoglione Flysch, which dips about 70° towards NE.

3.17 The southern border of the Sant'Arcangelo Basin

M. Schiattarella

The southern border of the Sant'Arcangelo Basin is located to the north of the Pollino Massif, a mountainous area with elevations up to 2200 m a.s.l. representing the junction between the southern Apennines and the Calabrian arc and which is constituted by Meso-Cenozoic platform carbonates overthrust by Ligurian (*i.e.* internal ophiolite-bearing) units. The carbonate ridge is sharply interrupted toward the NW by the Mercure River structural depression, a lacustrine basin filled by mid-Pleistocene sediments (Schiattarella *et al.*, 1994).

The average trend of the carbonate Pollino Ridge axis is about N120°, corresponding to the strike of the main transcurrent and normal faults. The ridge is in fact bordered by Plio-Pleistocene strike-slip faults re-activated as normal faults starting from Middle Pleistocene times (Schiattarella, 1998).

In a schematic cross-section from SW to NE (*i.e.* from the bottom to the top of the tectonic stack), the following units can be observed: (1) a carbonate platform unit (Alburno-Cervati-Pollino Unit, corresponding to the back-reef bulk of the Campania-Lucania platform), the age of which ranges from Late Triassic to Early Miocene (D'Argenio *et al.*, 1975), paraconformably covered by Lower-Middle Miocene pre-flysch deposits (Bifurto Formation); (2) Jurassic to Oligocene polydeformed ophiolitic units (Ligurian units, Bonardi *et al.*, 1988b; see also Knott, 1987, Mauro and Schiattarella, 1988; Monaco and Tortorici, 1995), unconformably covered by syntectonic deposits, Early Miocene in age (Albidona Formation); (3) Lower Pleistocene satellite basin clastic deposits (Caldara *et al.*, 1988; Pieri *et al.*, 1994b), corresponding to the upper part of the thick Sant'Arcangelo succession, covered by mid-Pleistocene alluvial deposits with reddish matrix (Sabbie e Conglomerati di Serra Corneta Fm.).

Stop 5.5:
Contact zone between bedrock and basin succession

In this stop the tectonic setting of the entire area can be observed. Along the frontal part of the northern sector of Pollino Ridge, Meso-Cenozoic limestones are thrust onto the Bifurto Formation. A comparison between the attitude of the NW-dipping carbonates in the northern sector and the attitude of the NE-dipping limestones outcropping in the central area suggests that the frontal thrust developed by anticlockwise rotation of blocks bordered by left-lateral strike-slip N120° trending faults and right-lateral strike-slip N-S trending faults, since the basic orientation of the ridge is NW-SE. Owing to the transversal streams cutting the hanging wall, it has been possible to estimate a thrust motion of at least 1.5 km (Schiattarella, 1996; 1998). However, it is likely that the moderate thrusting due to block rotation re-activated an inherited out-of-sequence thrust related to the earlier Pliocene contractional tectonics. The propagation of a deeper thrust under the Pollino structure may be responsible for the growth strata and general architecture of the southern zone of the Sant'Arcangelo Basin. As a matter of fact, growth structure expanding towards the NE in the southern flank of the basin and NW-SE trending transpressional structures have both been observed in the Plio-Pleistocene clastics.

In this site we can also observe the contact zone between Pleistocene clastics and the pre-Pliocene bedrock. Conglomerate and sand beds are visibly tilted and affected by eye-catching faults. The panorama also allows us to view both the growth structures in the Sant'Arcangelo Basin strata and its Quaternary stratigraphic setting.

3.18 The southern part of the Sant'Arcangelo Basin

Figure 33 - Sandstone lobes in the delta front of the Senise Synthem.

F. Loiacono

The stratigraphic succession outcropping in the southern part of the Sant'Arcangelo Basin, along the Sinni valley and its main tributaries (Sarmento and Serrapotamo rivers), is up to 2500 m thick, and has been subdivided into three, unconformity bounded, supersynthems (Monte Cotugno, Sinni and Serrapotamo).

The Monte Cotugno Supersynthem

The lower unit, the Monte Cotugno Supersynthem (Upper Pliocene), unconformably lies on the pre-Pliocene substratum at the southeastern margin; it is composed of an up to 900-m-thick pelitic succession which, through a sharp contact (marine flooding) overlies a-few-metres-thick, coarse-grained deposits, alluvial or deltaic in origin. This unit shows, in the upper part, two small-scale T-R pulses, probably of eustatic origin, which occurred before the sandy supply increased in the plain. Thus, in this unit, a small-scale cyclicity, probably of eustastic origin, can be identified (in the context of a regressive phase of a higher order).

The Sinni Supersynthem

The following unit, the Sinni Supersynthem, is composed of two alluvial and deltaic synthems (Senise and Noepoli) which correlate to important stages in the basin evolution linked to the uprising and to the mobility of the southern and eastern margins. The migration of the Apenninic frontal thrust formed a roughly N-S elongated top basin. Longitudinal and transversal supply, due to very active alluvial systems, fed deltaic marine systems in a strongly subsident regime.

The Senise Synthem is represented by an up to 1000-m-thick succession of marine delta sandstone bodies (Figure 33), organized into two main systems:

i) the S. Giorgio delta system, about 450 m thick, is composed of several sandstone bodies, 10 to 100 m thick, interbedded to thick fine-grained facies whose origin is referable to a sharp cyclic decrease in alluvial supply. This system had a point source from the southeast. The causes of the cyclicity may most likely be related to structural barriers in the source areas and/or to Early Pleistocene eustatic oscillations;

ii) the Roccanova system, up to 350 m thick, is composed of delta front sandstone lobes with overlying alluvial conglomerates facies. Its stacking pattern reveals western provenance (linear and transverse source) as well as a N-S elongated subsiding depocenter.

The Noepoli Synthem, up to 400 m thick, corresponds to the most important paleogeographic change in the basin. This sedimentary stage was controlled by the uplifting of the Valsinni ridge that separated to the east the Sant'Arcangelo Basin from the foredeep. In the Sant'Arcangelo Basin the sedimentary succession is represented by prograding coarse grained facies of a marine fan delta underlying fine grained facies of shallow marine systems (nearshore or lagoon). The overlying alluvial and lacustrine facies record the overall evolution to continental depositional environments.

In the foredeep depocenter, the development of marine delta systems (Lower-Pleistocene Tursi Sandstones) is the result of the eastward migration of the alluvial deposition through the superimposition of hydrological channels on the rising outer thrust.

The Serrapotamo Supersynthem

The Serrapotamo Supersynthem, composed of lacustrine and alluvial systems up to 300 m thick, follows the last compressional phases which restricted the sedimentation area along the western margin. On a gentle syncline, lacustrine and alluvial systems (the Francavilla Synthem) developed. Most of the supply came from the internal areas (western sides); fining upward sequences attest to periods of increase in subsidence that confined the coarse detritus in the proximal areas of the basin, in accordance with models proposed by Blair and Bilodeau (1988), Heller *et al.* (1988), Paola (1988), and Hartley (1993).

The Chiaromonte Synthem records the extension of the braided plain towards the N-NW, on the area previously dominated by lacustrine sedimentation (the Francavilla Synthem), and is indicative both of an increase in erosion, transport and sedimentation as well as of a decrease in subsidence.

The overlying paleosol and the following cutting and alluvial phases recorded in the uppermost unit (Sabbie e Conglomerati di Serra Corneta), represent successive events in which the climatic variations, the regional rising, and the various phases of cutting and terracing in the hydrographic networks marked the subsequent history of this region (Giannandrea and Loiacono, *2003*).

Stop 5.6:
the Sarmento valley and San Giorgio village

The Sarmento valley offers a panoramic view and a noticeable cross section of the southern sector of the Sant'Arcangelo Basin. San Giorgio village is located on extensive outcrops of the San Giorgio delta system (the Sinni Supersynthem) and offers an almost 360° panorama: to the E and NE, the Valsinni Structure, composed of pre-Pliocene units, is observable (northeastern margin of Sant'Arcangelo Basin); to the SW, the highest mountains of the southern Apennines (Pollino, Alpi, and Raparo) are visible. Furthermore, to the west, marine prodelta and shelf mudstones of the Monte Cotugno Supersynthem (Upper Pliocene), delta front sandstone lobes of the San Giorgio system (Early Pleistocene), fan delta and lacustrine systems of the Noepoli synthem (Lower Pleistocene), lacustrine mudstones and alluvial sheetlike conglomerates of the Francavilla and Chiaromonte synthems (Lower Pleistocene), are visible. Finally, at the top of the westernmost outcrops, alluvial facies including paleosols (Sabbie e Conglomerati di Serra Corneta, Middle Pleistocene) may be observed.

In the evening we will cross an important archeological area, along the Ionian coast, where it is possible to visit remains of Magna Graecia. During the 7th century BC, Greek settlers began to disembark on the shores of southern Italy, establishing primitive outposts. Successively, traders, farmers and craftsmen founded Sybaris, Poseidonia (Paestum), Crotone and, maybe, Naples. The artefacts they have left behind are clearly Hellenic, yet marked with their own "provincial" themes and shapes. Locally it is possible to observe remains of Heracleia and Metapontum Hellenic villages, represented by temples - as the 6th century BC Tavole Palatine temple - walls and columns; near the villages of Policoro and Metaponto two rich archeological museums are present.

The field trip will end in Bari, where we will arrive in the night, after dinner.

Acknowledgments

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field trip itinerary
with location of the stops

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