# STRATIGRAPHY AND SEDIMENTARY HISTORY OF THE PLIO-PLEISTOCENE SANT'ARCANGELO BASIN, SOUTHERN APENNINES, ITALY

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*Riassunto.* Definito come un bacino di piggy-back, il bacino Plio-Pleistocenico di Sant'Arcangelo è uno dei più recenti bacini sedimentari dell'Appennino Meridionale. Un ampio studio di terreno ha consentito di reinterpretare la stratigrafia del bacino in un modo più semplice e significativo. Sono stati distinti 5 gruppi di unità a limiti inconformi.

(1) Gruppo Catarozzo (Pliocene superiore) che copre in discordanza le unità pre-Mioceniche, ed è composto da sistemi di delta-conoide marini dominati da eventi alluvionali (C1) e da sistemi marini a circolazione ristretta, delimitati da un contatto netto e con uno spessore totale sino a 650 m.

(2) Gruppo Aliano (Pliocene superiore-Pleistocene inferiore), che comprende una successione potente sino a 1.400 m di sistemi deltizi dominati da eventi di piena, con facies che spaziano da conglomerati alluvionali scarsamente organizzati, delimitati da discordanze regionali, che mostrano passaggi bruschi da condizioni marine più aperte (A1) a condizioni marine a circolazione ristretta (A2).

(3) Gruppo Tursi (Pleistocene inferiore e medio) che raggiunge lo spessore di 500 m. E' costituito da 2 sotto-unità, corrispondenti a sistemi di conoide alluvionale (T1) e di delta-conoide (T2) rispettivamente. Le facies alluvionali del (T2) (conglomerati) affiorano estesamente nel bacino di Sant'Arcangelo, con lobi equivalenti di arenarie di piattaforma dominate da eventi alluvionali, presenti nell'area di Tursi (bacino di Metaponto).

I Gruppi (4) Profico e (5) Montalbano Ionico (Pleistocene medio) sono in parte isocroni. e sono sviluppati sui due lati della struttura di Valsinni, che divideva il precedente più vasto bacino di Sant'Arcangelo in due sottobacini, l'attuale bacino di Sant'Arcangelo e il bacino di Metaponto. Il Gruppo Profico ha uno spessore sino a 300 m ed è costituito da livelli lacustri che ricoprono in discordanza angolare l'Allogruppo di Tursi nell'attuale bacino di Sant'Arcangelo. Il Gruppo di Montalbano Ionico invece consiste di strati marini a granulometria fine, spessi sino a 300 m, che ricoprono in discordanza il Gruppo di Tursi nel bacino di Metaponto. Tutte le unità considerate mostrano una chiara influenza di tettonica sinsedimentaria.

*Abstract.* Defined as a piggyback basin, the Plio-Pleistocene Sant'Arcangelo basin is one of the more recent onshore sedimentary basin of the Southern Apennines. Extensive field studies allow to reinterpret the whole stratigraphy of the basin in a more simple and significant way. Five unconformity-bounded units ("groups") have been recognised :

The (1) Catarozzo Group (late Pliocene) unconformably overlies pre-Miocene units, and it is composed of a flood-dominated fan-delta marine (C1) and restricted-marine (C2) systems bounded by a sharp contact with a total thickness up to 650 meters.

The (2) Aliano Group (late Pliocene - early Pleistocene) includes an up to 1,400 meters thick succession of flood-dominated fan-delta systems, with facies ranging from poorly organised alluvial conglomerates in the west to massive marine mudstones in the east. Two sub-units have been recognised, bounded by a regional unconformity, which shows an abrupt passage from marine (A1) to restricted-marine (A2) conditions.

The (3) Tursi Group (early-middle Pleistocene) reaches a thickness of 500 meters. It is composed of two sub-units, corresponding to alluvial fan (T1) and fan-delta (T2) systems. The alluvial facies of T2 (conglomerates) outcrop extensively in the Sant'Arcangelo basin, with equivalent flood-dominated shelfal sandstone lobes broadly developed in the Tursi area (Metaponto basin).

The (4) Profico and (5) Montalbano Jonico groups (middle Pleistocene) are partially time equivalents, and were developed in both sides of the Valsinni structure, which divided an early, broader Sant'Arcangelo basin into two sub-basins, the present "Sant'Arcangelo" and "Metaponto" basins. The Profico Group has a thickness of up to 300 m and consists of lacustrine strata overlying in angular unconformity the Tursi Allogroup in the "Sant'Arcangelo basin": The Montalbano Jonico Group on the other hand is made up of up to 300 m of fine-grained marine strata unconformably overlying the Tursi Group in the "Metaponto basin". All the units considered display clear evidences of synsedimentary tectonics.

## Introduction.

The southern Apennines is a complex Neogene thrust belt, made up of tectonostratigraphic units deriving from the deformation of distinct pre-Miocene paleogeographic domains which have been piled up since the Oligo-Miocene age and are still moving (Ogniben, 1969; D'Argenio *et al.*, 1973; Knott, 1987). The structural evolution of this orogenic belt during Pliocene and Pleistocene times led to the formation and infilling of marine and lacustrine basins located in the back of an active frontal thrust system (satellite or piggyback basins in the sense of Ori & Friend, 1984). The Sant'Arcangelo basin (see location in Fig. 1) is the largest and most recent onshore piggyback basin (Caldara *et al.*, 1988; Casero *et al.*, 1988; Hippolyte, 1992). This basin was

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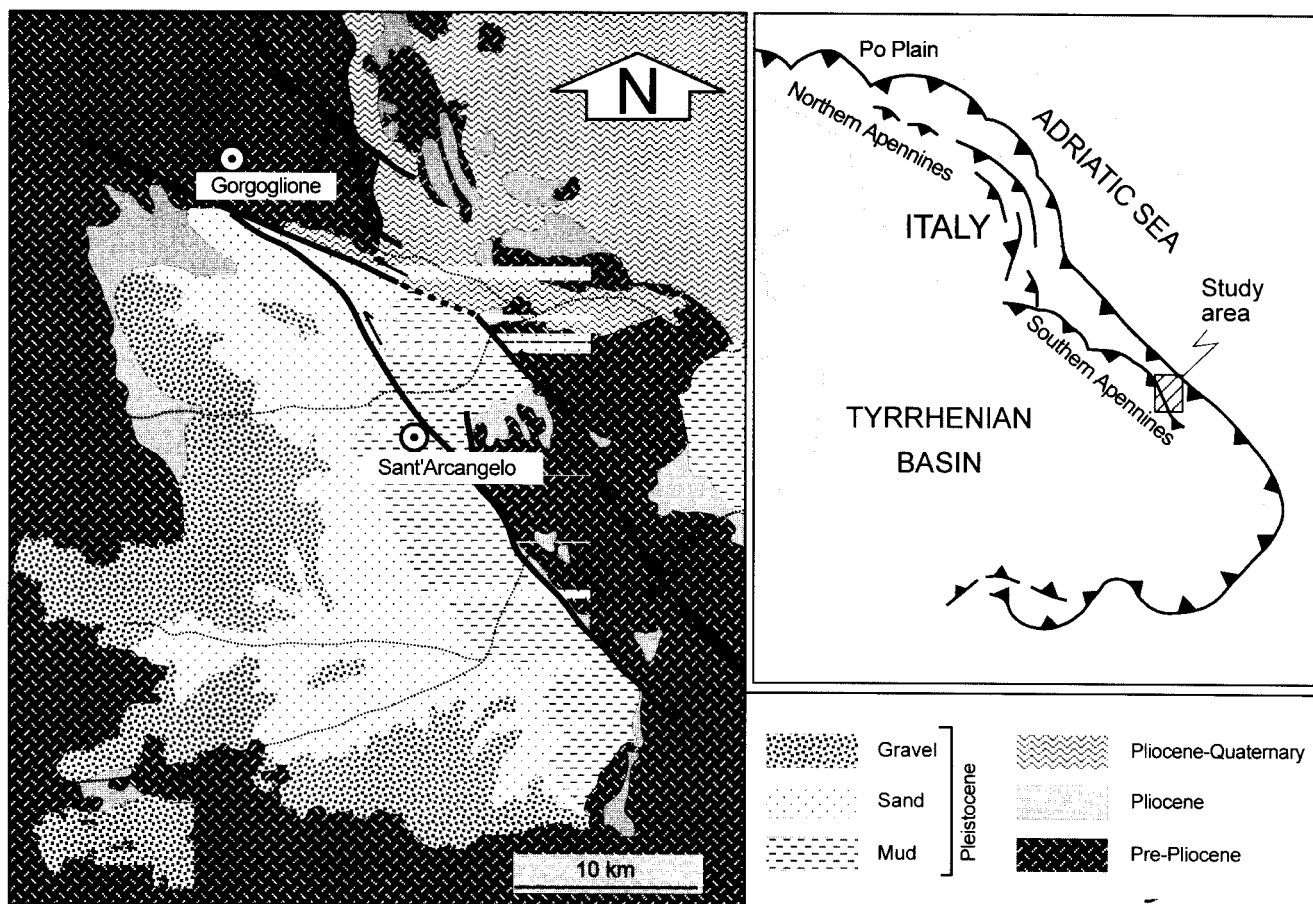
Fig. 1     - Location map of the Sant'Arcangelo Basin.

filled by huge volumes of siliciclastic sediments ranging from alluvial conglomerates in the west to marine shelfal mudstones in the east. These sediments appear to have been strongly affected by synsedimentary tectonism (Hippolyte et al., 1994; Pieri et al., 1994; Zavala & Mutti, 1996).
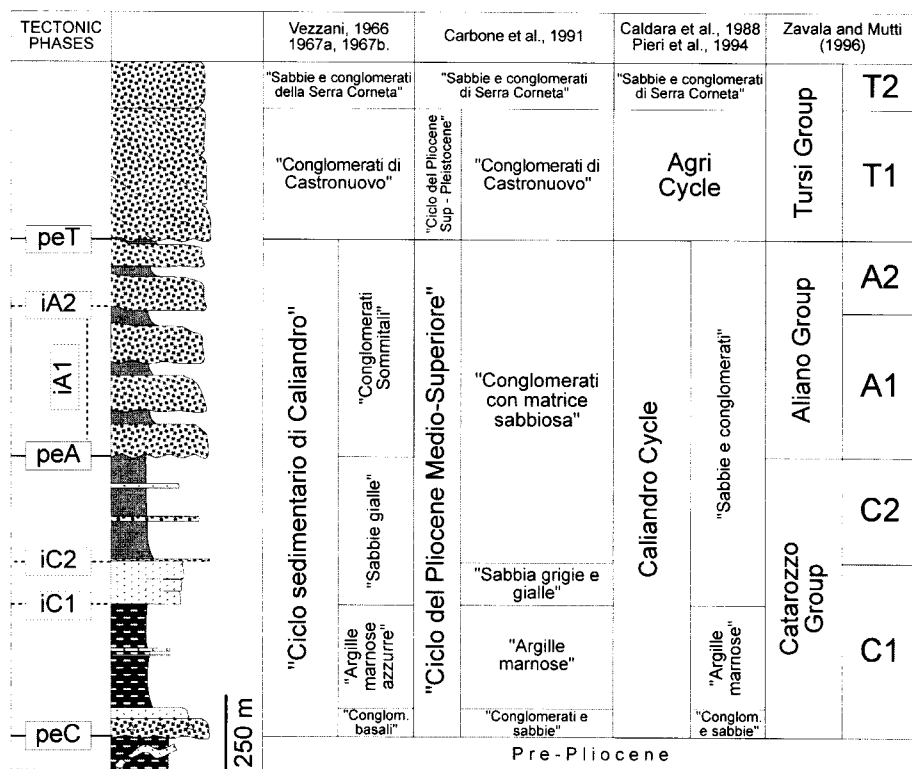
This paper deals with the Pliocene and Pleistocene sedimentary sequences that constitute a more than 3,000 meters thick siliciclastic succession. The study is based on an extensive field work on stratigraphy and facies, supported by more than 7,000 meters of detailed stratigraphic sections. Field studies have been integrated as much as possible with aerial photographic mapping carried out over most of the study area. The criteria used for physical stratigraphic correlations is based on the recognition and detailed mapping of unconformity-bounded units or allogroups (hereafter abbreviated into groups). The results of these studies have led to substantial departures from the previously proposed stratigraphic schemes (Zavala & Mutti, 1996).

The purposes of this paper are to (1) introduce new stratigraphic scheme and analyse the sedimentary evolution of the Sant'Arcangelo Basin and (2) to briefly discuss the relationships between tectonics and sedimentation.

## General geological setting.

The Southern Apennines thrust belt is the geological consequence of the Africa-Europe continental collision during Neogene-Quaternary times (Ogniben, 1969; D'Argenio et al; 1973; Knott, 1987). The post-Messinian geologic evolution of the southern Apennines is related to the interplay between two main geologic elements: the Apennine chain and the Apulian foreland. The Apennine chain is composed of Mesozoic - early Cenozoic units resulting from the deformation of Afro-Adriatic paleomargins, piled up since the Oligo-Miocene (Ogniben, 1969; D'Argenio et al., 1973; Knott, 1987; Cello et al., 1989). The Apulian foreland on the other hand comprises a thick meso-cenozoic carbonate succession belonging to the Adriatic Promontory. The particular geological settings of these pre-Pliocene units will not be discussed here, and the reader is instead referred to fundamental papers published by Ogniben (1969), Lentini (1979), Casero et al. (1988), Carbone et al. (1988; 1991), and Cello et al. (1990).
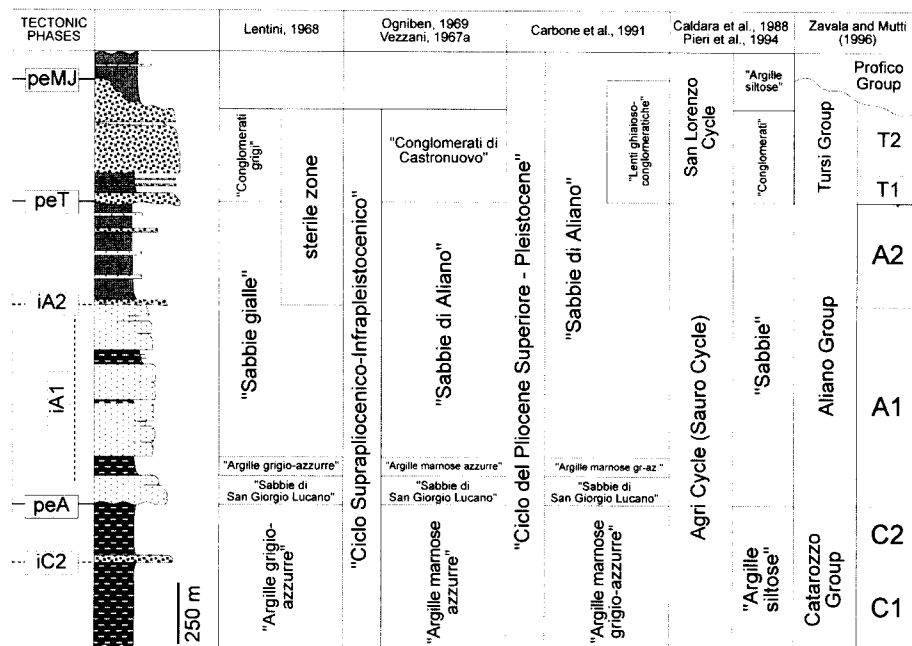
After the Messinian, the Apennine chain overthrusted the Apulian foreland, thus configuring the Plio-Pleistocene Adriatic foredeep and related satellite basins such as the Sant'Arcangelo Basin. Regional sub-

| TECTONIC PHASES | | Vezzani, 1966 1967a, 1967b. | Carbone et al., 1991 | Caldara et al., 1988 Pieri et al., 1994 | Zavala and Mutti (1996) | |
|---|---|---|---|---|---|---|
| | | "Sabbie e conglomerati della Serra Corneta" | "Sabbie e conglomerati di Serra Corneta" | "Sabbie e conglomerati di Serra Corneta" | Tursi Group | T2 |
| peT | | "Conglomerati di Castronuovo" | "Ciclo del Pliocene Sup.-Pleistocene" / "Conglomerati di Castronuovo" | Agri Cycle | | T1 |
| iA2 | | | "Conglomerati Sommitali" | | Aliano Group | A2 |
| iA1 | | "Ciclo sedimentario di Caliandro" | "Ciclo del Pliocene Medio-Superiore" / "Conglomerati con matrice sabbiosa" | Caliandro Cycle | | A1 |
| peA | | | | | "Sabbie e conglomerati" | |
| iC2 | | | "Sabbie gialle" | | Catarozzo Group | C2 |
| iC1 | | | "Sabbia grigie e gialle" | | | |
| | | | "Argille marnose azzurre" / "Argille marnose" | | "Argille marnose" | C1 |
| peC | | "Conglom. basali" | "Conglomerati e sabbie" | | "Conglom. e sabbie" | |
| | | | Pre-Pliocene | | | |

250 m

Fig. 2 - Stratigraphy of the Plio-Pleistocene deposits in the Sant'Arcangelo Basin, exposed in the Armento, Nascefro and Racanello areas. The scale is indicative.

surface data indicates that the foredeep axes have progressively migrated from north-west to south-east. In the Abruzzo zone, the Adriatic Foredeep begins to be activated in the early Pliocene, while the southern Lucanian foredeep was configured during the late Pliocene (Casnedi et al., 1982). Subsurface data also indicate that in this area the Apulian foreland was probably subaerially exposed during the early Pliocene (Casnedi et al., 1982; Casnedi, 1988).

According to its interior position in the thrust belt relative to the frontal thrust sheets of the Apennine chain, the Sant'Arcangelo Basin has been interpreted as a piggyback basin (Caldara et al., 1988; Casero et al., 1988; Hippolyte, 1992; Hippolyte et al., 1994). This interpretation was given mainly from the analysis of regional seismic lines. Strike-slip tectonics probably have played a fundamental role in thin-skinned and thick-skinned deformation, as documented from field data (Catalano et al., 1993). From a general kinematic model, other authors have also proposed a pull-apart origin for the Sant'Arcangelo and other Plio-Pleistocene related basins (Turco et al., 1990).
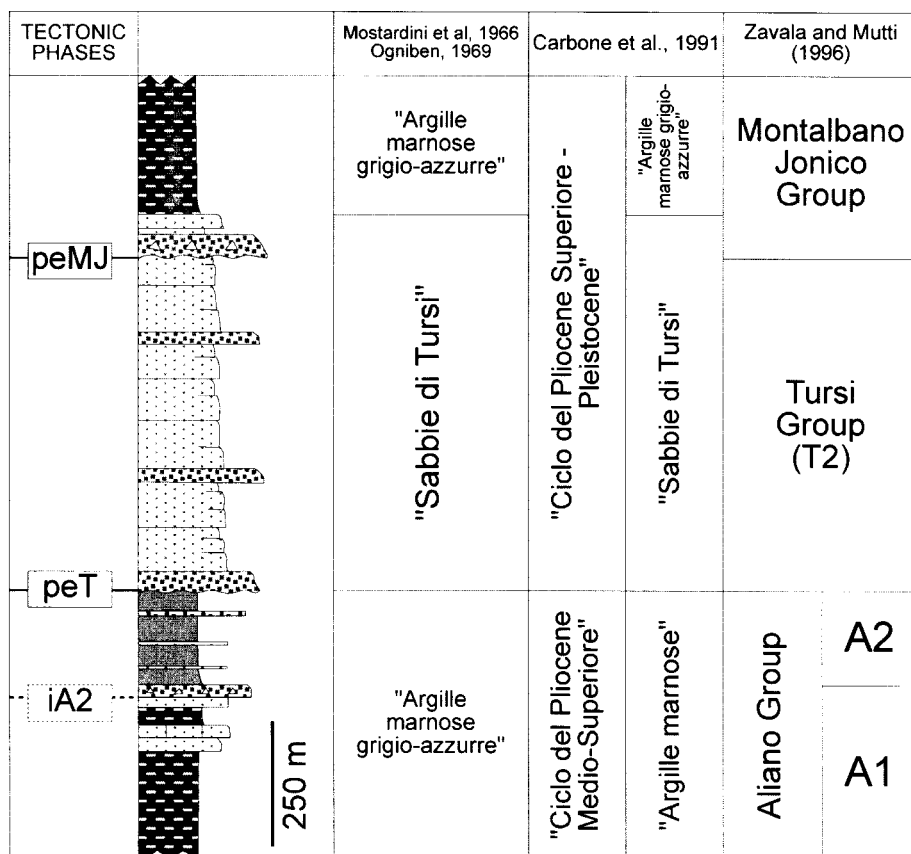
| TECTONIC PHASES | | Lentini, 1968 | Ogniben, 1969 Vezzani, 1967a | Carbone et al., 1991 | Caldara et al., 1988 Pieri et al., 1994 | Zavala and Mutti (1996) | |
|---|---|---|---|---|---|---|---|
| peMJ | | | | | "Argille siltose" | Profico Group | |
| peT | | "Conglomerati grigi" / "sterile zone" | "Conglomerati di Castronuovo" | "Lenti ghiaioso-conglomeratiche" | San Lorenzo Cycle | Tursi Group | T2 / T1 |
| iA2 | | "Sabbie gialle" | "Ciclo Suprapliocenico-Infrapleistocenico" / "Sabbie di Aliano" | "Ciclo del Pliocene Superiore - Pleistocene" / "Sabbie di Aliano" | | Aliano Group | A2 |
| iA1 | | | | | Agri Cycle (Sauro Cycle) | "Sabbie" | A1 |
| peA | | "Argille grigio-azzurre" / "Sabbie di San Giorgio Lucano" | "Argille marnose azzurre" / "Sabbie di San Giorgio Lucano" | "Argille marnose gr-az." / "Sabbie di San Giorgio Lucano" | | | |
| iC2 | | "Argille grigio-azzurre" | "Argille marnose azzurre" | "Argille marnose grigio-azzurre" | | "Argille siltose" | Catarozzo Group | C2 / C1 |

250 m

Fig. 3 - Stratigraphy of the Plio-Pleistocene deposits in the Sant'Arcangelo Basin, exposed in the Aliano, Alianello, Sant'Arcangelo and San Giorgio Lucano areas.

| TECTONIC PHASES | | Mostardini et al, 1966 Ogniben, 1969 | Carbone et al., 1991 | | Zavala and Mutti (1996) |
|---|---|---|---|---|---|
| | | "Argille marnose grigio-azzurre" | "Ciclo del Pliocene Superiore - Pleistocene" | "Argille marnose grigio-azzurre" | Montalbano Jonico Group |
| peMJ | | "Sabbie di Tursi" | | "Sabbie di Tursi" | Tursi Group (T2) |
| peT | | | | | |
| iA2 | 250 m | "Argille marnose grigio-azzurre" | "Ciclo del Pliocene Medio-Superiore" | "Argille marnose" | Aliano Group A2 / A1 |

Fig. 4 - Stratigraphy of the Plio-Pleistocene deposits in the Metaponto Basin, exposed in the Tursi area.

## Stratigraphy.

The Plio-Pleistocene sedimentary succession of the Sant'Arcangelo Basin is composed of up to a 3,000 meter thickness of siliciclastic deposits, ranging from massive continental conglomerates in the west to shelfal mudstones in the east (Fig. 1). Because in the work being presented here a substantial modification of the basin's stratigraphic subdivision is proposed, it is considered necessary to briefly discuss previous stratigraphic schemes in three different positions of the basin (Fig. 2, 3 and 4).

The early knowledge and stratigraphic subdivision of the basin derives from Vezzani (1966; 1967a; 1967b; 1968), Amore (1967), Ogniben (1969), and Lentini (1967; 1968). Vezzani (1966, 1967a, 1967b) recognised two sedimentary successions bounded by a regional unconformity. The first, known as "Ciclo sedimentario di Caliandro", was assigned to the middle to late Pliocene, and was defined as a sedimentary cycle with transgressive and regressive intervals (Fig. 2). The second succession, assigned to the late Pliocene - early Pleistocene, was recognised as an essentially regressive cycle, where proximal fluvial conglomerates ("Conglomerati di Castronuovo") grade downcurrent into marine sandstones ("Sabbie di San Giorgio Lucano" and "Sabbie di Aliano") and shelfal mudstones ("Argille marnose azzurre") (Fig. 2 and 3). All the above authors agree with these stratigraphic relationships, with the sole exception of Lentini (1968, table I) who indicates a

possible sharp contact between the sandstone and conglomerate units ("Sabbie gialle" and "Conglomerati grigi" respectively, see Fig. 3).

More recently Caldara et al. (1988) and Pieri et al. (1994) recognised in the Plio-Pleistocene succession four sedimentary cycles, extending from late Pliocene to middle Pleistocene (Fig. 2 and 3). The two first cycles (Caliandro and Agri cycles) are essentially the same recognised in early works. The Sauro and San Lorenzo cycles were proposed to resolve specific stratigraphic problems found in the northern portion of the basin, where the definition and general applicability of these last two units remain unclear.

Detailed field analysis allowed the reinterpretation of the stratigraphy of the Sant'Arcangelo basin in a substantially different way. The criteria for stratigraphic subdivision and correlation included facies analysis, physical stratigraphy, detailed photostratigraphic mapping and the existing background on biostratigraphy. The volumetrically largest proportion of the basin fill is composed of coarse to fine grained, graded beds related to the downstream dilution of subaerially derived gravity flows. The importance of these flood-dominated systems in the stratigraphic record has recently been reviewed in detail by Mutti et al. (1996). Proximal deposits consist of poorly organised alluvial conglomerates that were deposited by hyperconcentrated flows (Fig. 5A and 5B). These deposits can be physically traced into shallow and shelfal marine (or marine
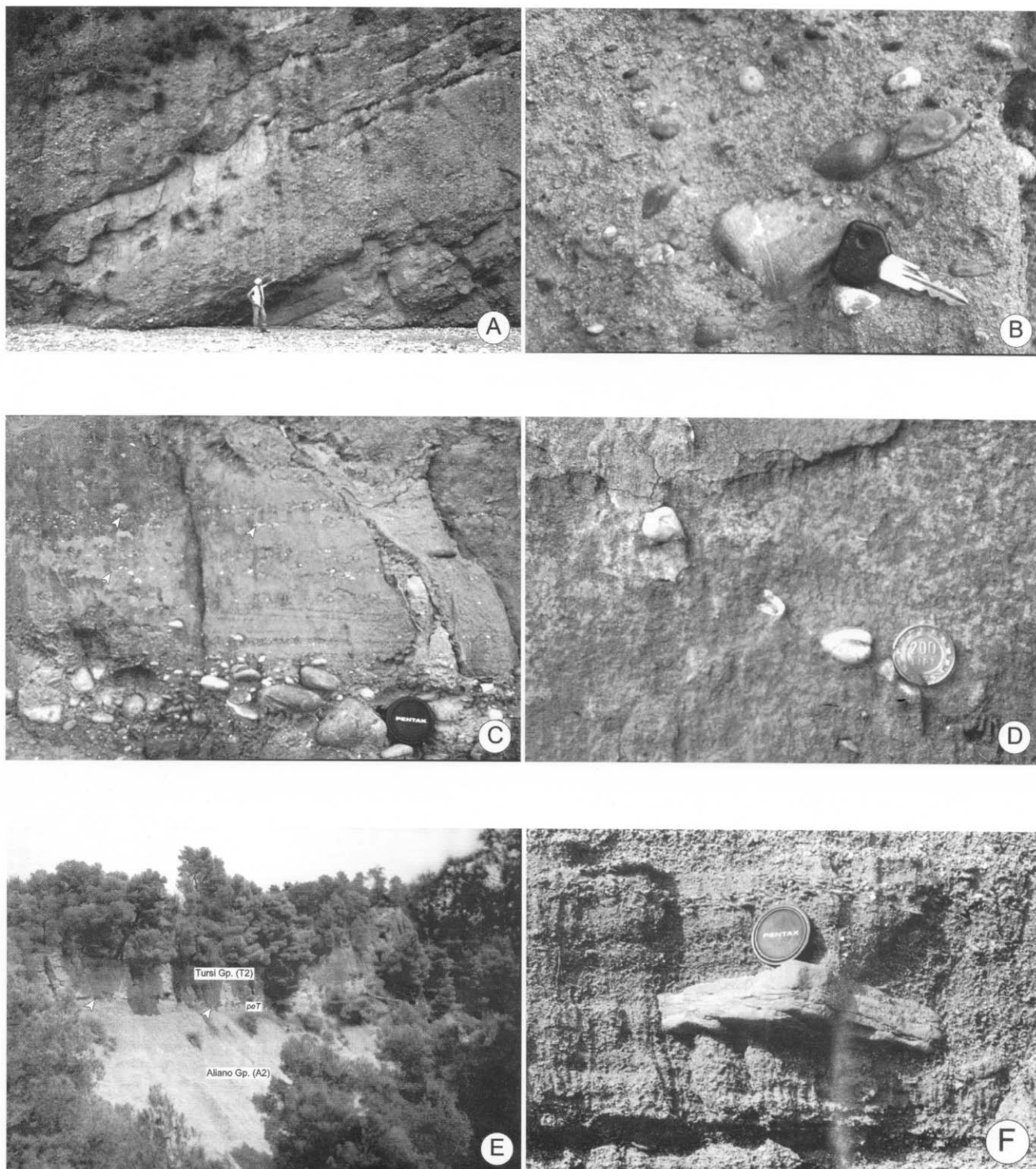
Fig. 5 - (A) Proximal conglomerates, related to hyperconcentrated flows (HCF) associated with flood episodes in fluvial environments. Aliano Gp. (A2) at Cerrito creek (section 3 in Fig. 8). (B) Textural characteristics of HCF deposits. Note that large clasts appear "floating" in a coarse-grained sandy matrix. (C) Typical facies from the fluvio-marine transition. These facies are related to the downstream transformation of a fluvial-derived HCF in a gravelly high-density turbidity current (GHDTC) marine underflow. Shell debris (arrows) suggests submarine erosion processes (bulking) in coastal areas. (Aliano Gp., sect. 15 in Fig. 8). (D) Detail of the occurrence of some bivalves (*Glycymeris* sp.) in shelfal sandstone lobes (SSL). These marine fossils appears frequently with articulate valves, and located near the base of thick (up to 10 m) graded tabular sandstone beds interbedded with offshore mudstones. The last characteristics suggest flood-related erosion, transport, and deposition of huge volumes of coastal sandstones and their associated living communities. (Aliano Gp., sect. 19 in Fig. 8). (E) Particular of restricted-marine mudstones of the Aliano (A2) Group unconformably overlaid (*peT*) by coarse-grained SSL of the Tursi Group (for location see sect. 25 in Fig. 11). (F) Presence of large angular clasts in the basal coarse-grained (foreshore) deposits of the Montalbano Jonico Group. These blocks are derived from the erosion of pre-Pliocene units exhumed during the *peMJ* tectonic phase at the Valsinni area (road to Rabatana, surroundings of Tursi town, Fig. 11).

Fig. 6    - (A, B) Flood-generated shelfal sandstone lobes (delta-front deposits) of the Aliano Group (A1) outcropped in the surroundings of
          Aliano town. Note the good lateral continuity and the near-tabular geometry of individual sandstone beds (sect. 19 in Fig. 8). (C) Gen-
          eral view of lower delta-front deposits. These distal lobes grade basinward into a monotonous mudstone succession. (Aliano Gp. sect.
          20 in Fig. 8).

restricted) strata made up of graded, pebbly sandstone (Fig. 5C and 5D) and sandstone facies with hummocky cross-stratification (HCS), that were deposited by progressively more dilute turbidite currents containing an oscillatory component. These sandstone beds are essentially tabular, and integrate shelfal sandstone lobes (Fig. 6A and 6B), the most genuine expression of delta front deposits. The final element of these extended fluvio-deltaic systems (Fig. 6C) is composed of a monotonous succession of prodelta mudstones. A synthesis of the main facies and their arrangement in their facies tract is given in Fig. 7.

Five flood-dominated complex systems bounded by unconformities (groups) can clearly be recognised in the Sant'Arcangelo basin (Fig. 2, 3 and 4, see also map of Fig. 8), ranging in age from late Pliocene to middle Pleistocene.

### Catarozzo Group (late Pliocene).

This group is entirely exposed in the western margin of the basin, along the Nascefro creek (section 4 in Fig. 8), and in outcrops located eastward of Sant'Arcangelo town (Fig. 8). It unconformably overlies pre-Pliocene units, and consists of a lower open-marine unit (C1) sharply overlain by a restricted-marine unit (C2) (Fig. 2).

The type-section is located in the Nascefro creek area (Fig. 8), where the C1 sub-unit corresponds to a flood-dominated fan-delta marine system up to 500 meters thick. It is comprised of a basal matrix-supported conglomerate unit evolving into coarse grained shallow-marine deposits with *Ostrea* sp., *Mytilus* sp., *Chlamys* sp. and *Pecten* sp.. These deposits are followed by a thick succession of prodelta mudstones, ending with shelfal sandstone lobes with *Glycymeris* sp., *Cardium* sp., *Pinna* sp., *Venus multilamella*, *Cerastoderma edule*, *Chlamys* sp., and *Ditrupa arietina*. The C2 sub-unit is mainly fine-grained, composed of gray siltstones with thin intercalations of gravelly sandstones, reaching a total thickness up to 150 m. This sub-unit displays a drastic reduction in the macrofossil content with respect to the C1 sub unit. Rare *Cerastoderma edule* and other
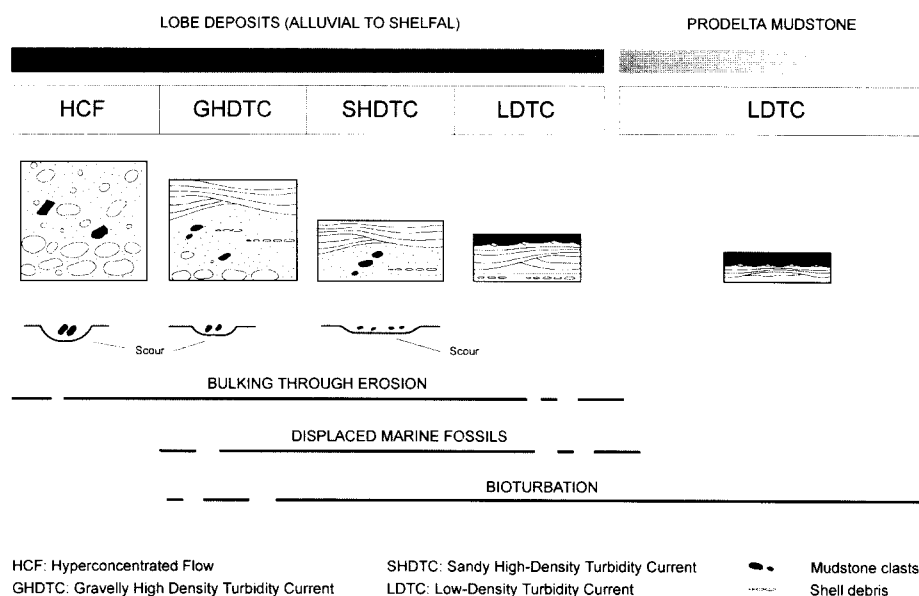
Fig. 7 - Elements, basic facies tract and inferred depositional processes characteristic of flood-dominated fan-delta systems. (after Mutti et al., 1996).

LOBE DEPOSITS (ALLUVIAL TO SHELFAL)     PRODELTA MUDSTONE

| HCF | GHDTC | SHDTC | LDTC | LDTC |

BULKING THROUGH EROSION

DISPLACED MARINE FOSSILS

BIOTURBATION

HCF: Hyperconcentrated Flow
GHDTC: Gravelly High Density Turbidity Current

SHDTC: Sandy High-Density Turbidity Current
LDTC: Low-Density Turbidity Current

Mudstone clasts
Shell debris

macrofossils from restricted-marine environments (Dominici, pers. comm.) have been found only in the basal levels. The C2 sub unit is interpreted as deposited in a flood-dominated, fan-delta, restricted-marine system.

This group is also widespread in outcrop to the east of Sant'Arcangelo and Alianello towns (Fig. 3 and 8), and is composed of a monotonous succession of distal marine mudstones up to 600 meters thick (Lentini, 1968). The boundary between the C1 and C2 sub-units recognised in proximal positions is here difficult to be established from lithological criteria. It is interpreted that this boundary coincides with the decrease in the foraminiferal abundance and diversity noted by Marino (1994, p. 345) for the upper portion of the mudstone succession in the San Giorgio Lucano area. Similar conditions of restriction, interpreted as a salinity decrease related to a fast shallowing episode, have been pointed out by Lentini (1968, p. 280-281) from micropaleontological data in the last 100 meters of the mudstone unit ("argille grigio-azzurre", see Fig. 3) that outcrops below the town of Sant'Arcangelo.

In the Alvaro creek area, fine grained deposits of the Catarozzo Group have been recognised below the basal levels of the Aliano Group outcropping in the Masseria Celli (section 7 in Fig. 8). In this position, the boundary between the C1 and C2 sub-units is marked by a 4 meters thick pebbly sandstone unit with *Glycymeris* sp., *Venus multilamella*, and *Cerastoderma edule*, which is interbedded between predominantly mudstone deposits. The C2 sub-unit in this position is composed of a 80 m thick mudstone succession with minor laminated, fine-sandstone beds, where no macrofossils were found.

The Catarozzo Group is partially equivalent to the Caliandro Cycle of Vezzani (1966) with the difference that in this work the upper conglomeratic unit ("Con-

glomerati sommitali") of this cycle has been segregated and assigned to the next group (Aliano Group) (see Fig. 2). This is because in the Nascefro creek area (section 5 in Fig. 8, Masseria Rinaldi), a 20 degrees angular unconformity can clearly be recognised bounding these conglomerates (up to 600 meters in thick) with the C2 sub-unit. In the Armento area (section 1 in Fig. 8), these continental deposits occur in-angular unconformity directly over the Miocene Gorgoglione Formation. This angular unconformity is also evident in the geologic sketch introduced by Vezzani (1966, fig. 1, p. 198).

Previous studies interpreted the Nascefro (Caliandro Cycle) and lower Sant'Arcangelo - San Giorgio Lucano fine-grained sections as belonging to two different and diachronous sedimentary cycles (Vezzani, 1967; Ogniben, 1969; Pieri et al., 1994). Vezzani (1966) assigned his Caliandro Cycle to the early - middle Pliocene from foraminiferal data, while Lentini (1968), based on micropaleontological data, proposed a late Pliocene - early Pleistocene age for the mudstones resting below the "Sabbie di San Giorgio Lucano" (Fig. 3).

Biostratigraphic studies performed by Marino (1994) through calcareous nannofossils and foraminifera support the present stratigraphic interpretation. The C1 sub unit sampled at the Racanello stream area was assigned in that work to the late Pliocene (*Discoaster tamalis, D. pentaradiatus* and *D. brouweri* Zones according to calcareous nannofossils, and *Globorotalia crassaformis* Zone of Foraminifera). The mudstone succession outcropping below the "Sabbie di San Giorgio Lucano" (here interpreted as corresponding to both the C1 and C2 sub units of the Catarozzo Group) was also assigned to the late Pliocene (*Discoaster pentaradiatus, D. brouweri*, and *D. productus* zones of calcareous nannofossils, and *Globorotalia crassaformis* and *G. inflata* zones of Foraminifera) (Marino, 1994).
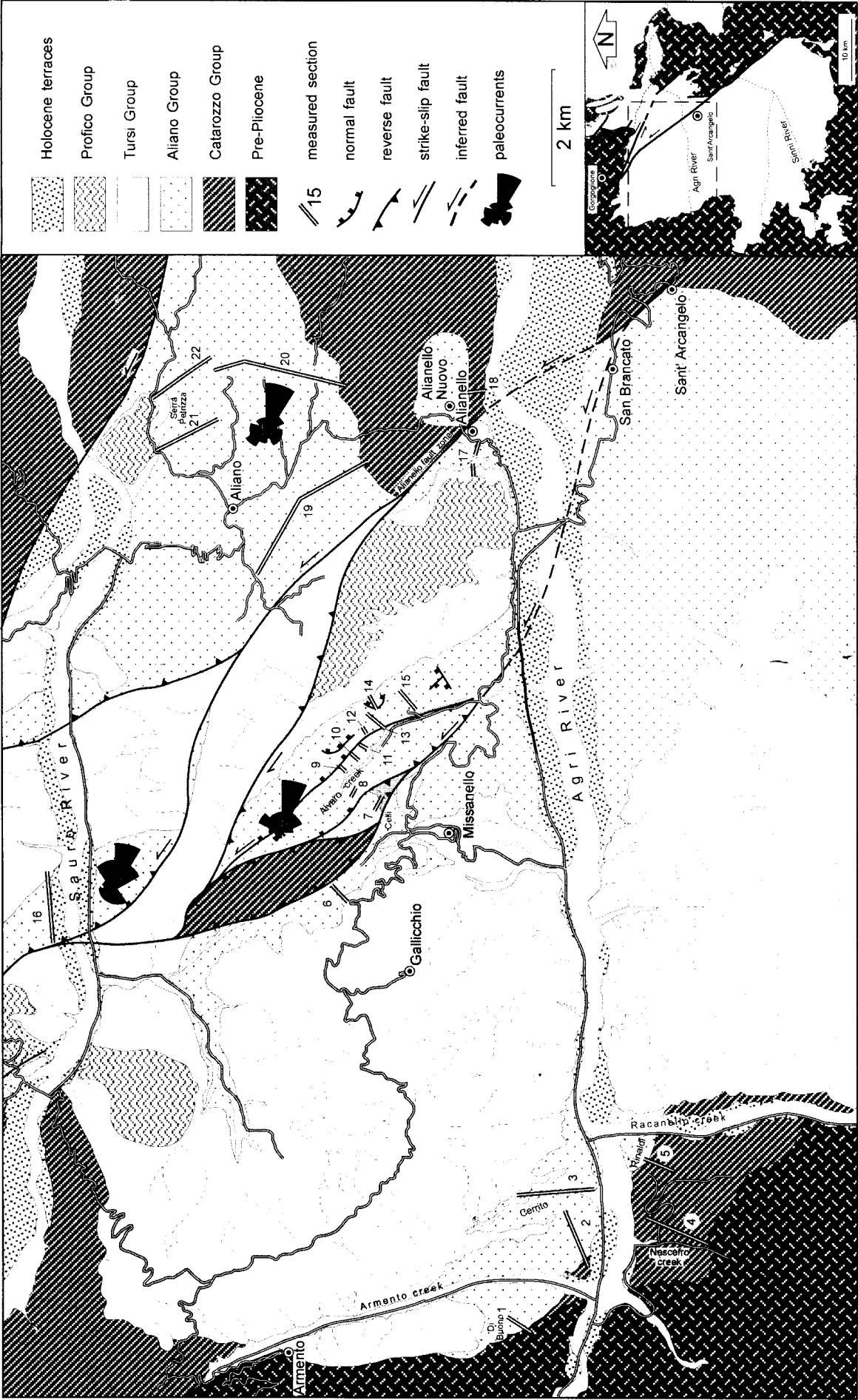
Fig. 8   - Geologic map of the northern portion of the Sant'Arcangelo Basin.

## Aliano Group (late Pliocene - early Pleistocene).

These deposits include a succession up to 1,400 meters thick ranging from poorly organised, reddish, alluvial conglomerates and siltstones in the west to massive open marine and restricted-marine mudstones in the east (Fig. 8 and 9). The type-section of this group is located at the surroundings of the Aliano town (Fig. 6A and 6B). In proximal positions, the Aliano Group overlies the Catarozzo Group and pre-Pliocene units through an angular unconformity (Fig. 10). An irregular, up to 20 meters thick, basal chaotic level has locally been observed over the basal unconformity (section 1 in Fig. 8, Masseria Di Buono).

Two distinctive sub-units bounded by a regional unconformity have been recognised within the Aliano Group, which show evidence of an abrupt passage from open marine (A1) to restricted-marine (?) (A2) conditions (Fig. 3 and 9). The A1 sub-unit comprises a flood-dominated, fan-delta marine system (cf. Mutti et al., 1996.). Proximal deposits crop out near the Agri river, between the Armento and Cerrito streams (sections 2 and 3 in Fig. 8, see also Fig. 2), and are composed of cyclically stacked, reddish conglomerates and siltstones (Fig. 5A and 5B), the last with pedogenic features. In the Alvaro creek area (Fig. 8), these deposits display the transition from continental to marine conditions, and they are composed of residual conglomerate facies with shell debris (Fig. 5C), coarse to fine grained sandstones with HCS, and massive marine mudstones (Fig. 9). The main depositional area of this sub-unit outcrops near the town of Aliano, and consists of flood-dominated shelfal sandstone lobes and mudstones (see Fig. 8 and 9). Shelfal sandstone lobes are composed of graded and commonly amalgamated fine-grained, sandstone bodies 0.5 to 10 meters thick, with HCS (Fig. 6A and 6B). In more distal positions (east of Aliano and in the Tursi area, Fig. 4 and 11), the A1 sub-unit is represented by prodelta mudstones with minor sandstone intercalations (Fig. 6C).

Macrofossils are locally abundant, including *Acanthocardia tuberculata*, *Amyclina semistriata*, *Aporrhais pespelecani*, *Aporrhais uttingeriana*, *Arcularia gibbosula*, *Bittium reticulatum*, *Cerastoderma edule*, *Cerithium vulgatum*, *Chama* sp., *Chamelea gallina*, *Aequipecten opercularis*, *Corbula gibba*, *Dentalium sexangulum*, *Ditrupa arietina*, *Flabellum* sp., *Glycymeris insubrica*, *Hinia reticulata*, *Narona hirta*, *Naticarius tigrinus*, *Neverita josephinia*, *Ostrea edulis*, *Sphaeronassa mutabilis*, *Venus multilamella*, *Truncolariopsis* sp., and *Turritella vermicularis* (Stefano Dominici identifications). Biostratigraphic studies based on calcareous nannofossils and foraminifera (Marino in Pieri et al., 1994) indicate an early Pleistocene age for these strata (*Calcidiscus macintyrei* - *Pseudoemiliana lacunosa*, and *G. cariacoensis* - *H.*

*balthica* zones of calcareous nannofossils and foraminifera respectively).

In the Fig. 9, a stratigraphic cross-section of the Aliano Group can be seen. Syntectonic depositional geometries are evident, and will be discussed later.

The A2 sub-unit corresponds to a flood-dominated fan-delta restricted-marine system up to 300 meters thick. Facies and sediment distributions are essentially similar to those of the previous sub-unit with the difference that flood-dominated shelfal sandstone lobes are poorly developed, and these deposits lack marine macrofossils. The basal boundary of this sub-unit is characterized by the presence of a regional coarse grained bed which physically marks the disappearance of macrofossils. This level also constitutes an optimal key-bed for local to regional correlations ("datum" in Fig. 9). In the Alvaro, Sauro and Aliano areas (Fig. 8), this bed is composed of conglomerates and pebbly-sandstones up to 11 meters in thickness. In the eastern Tursi outcrops (sections 23-25 in Fig. 11), the A2 sub-unit is represented by up to 80 meters of black siltstones with minor intercalations of conglomeratic beds (Fig. 5E), containing an oligotypic fossil association (*Cerastoderma edule*), characteristic of restricted-marine conditions (Fig. 4). This sub-unit begins with a 1 to 3 meters conglomerate level with angular clasts derived from pre-Pliocene units and displaced marine fossils, which sharply overlies fine grained marine deposits of the A1 sub-unit, here with an outcrop thickness of more than 150 meters. The A2 sub-unit coincides with the barren interval documented by Lentini (1968) for the upper levels (more than 300 meters) of his yellow sands ("Sabbie gialle", see Fig. 3) in the area between Sant'Arcangelo and Roccanova (Lentini, 1968; p. 282, see also table I).

Stratigraphic evidence indicates that the deposits assigned to this group may have been misinterpreted in previous works because (1) in proximal areas (Fig. 2) the conglomerate deposits were included in the upper conglomerate succession of the Caliandro Cycle of Vezzani (1966); (2) in the Alvaro creek area, coeval sandstone deposits were assigned to the Agri Cycle (Fig. 3) and correlated with the Castronuovo Conglomerates (Tursi Group); and (3) in the Aliano area (Fig. 3) these deposits were interpreted as belonging to the Sauro Cycle (Pieri et al., 1994). The stratigraphic cross-section of Fig. 9 displays the good lateral correlativity of deposits previously interpreted as corresponding to three different and diachronous stratigraphic units.

## Tursi Group (early Pleistocene).

This group reaches a thickness of more than 500 meters, and since this unit crops out in angular unconformity above previous stratigraphic units with evidences of a widespread basin widening (Fig. 8), repre-

sents the sedimentary expression of an important paleo-geographic change in the Sant'Arcangelo basin. The key-section of this group is located near the town of Tursi (Fig. 11), where it is composed of an impressive succession of stacked shelfal sandstone lobes with an aggregate thickness in excess of 500 meters (Mostardini et al., 1966; Ogniben, 1969) (Fig. 4). Two depositional sub-units can be recognised in the Tursi Group (Fig. 10). The first one (T1) is well-developed in the western portion of the basin (Fig. 2), and it is composed of poorly organised foreset-dipping conglomerates, grading in a down-stream direction to genetically related, fine-grained, lacustrine deposits. The presence of these basal deposits is limited to the sedimentary infill of a large scale ero-sional depression (Fig. 10). In the Armento area, a large paleovalley is recognised incising both the Aliano and Catarozzo groups. This first sedimentary succession displays syntectonic activity, and no marine equivalents have been found. This sub-unit reaches its maximum thickness in the surroundings of Armento town, and progressively pinches-out in a downstream direction, where it is strongly truncated by the more regional tab-ular upper sub-unit (T2). The origin of this unit (T1) is here thought as related to the prograding toe of "nor-mal type" alluvial fans.

The T2 sub-unit is composed of massive tabular conglomerates grading eastward into equivalent sand-stone and mudstone marine deposits. In proximal areas (Armento stream) this sub unit reaches a thickness of about 200 meters, and unconformably overlies the frontal-foreset conglomerates of the T1 sub-unit. In the Alvaro, Missanello, and Aliano areas (Fig. 8), the basal unconformity of this sub-unit directly overlies the Aliano Group with a drastic facies change, putting into contact fine-grained delta front and prodelta restricted-marine deposits of the A2 sub-unit with poorly organ-ised meter-thick tabular conglomerates and siltstones, the last with pedogenic features. These fluvial conglom-erates, widely developed in the Sant'Arcangelo Basin, grade basinward into shallow marine strata, recognised where they start to incorporate marine macrofossils in the area surrounding Oriolo town (Vezzani, 1967a, p. 217). Equivalent flood-dominated shelfal sandstone lobes are well developed in the Tursi area (Fig. 4 and 11), with a total thickness of up to 500 meters. These strata are composed of graded meter-thick amalgamated sheet sandstone bodies with HCS and minor cyclically-stacked tabular conglomerates. The basal deposit is integrated by a 20 meters thick conglomerate unit unconformably rest-
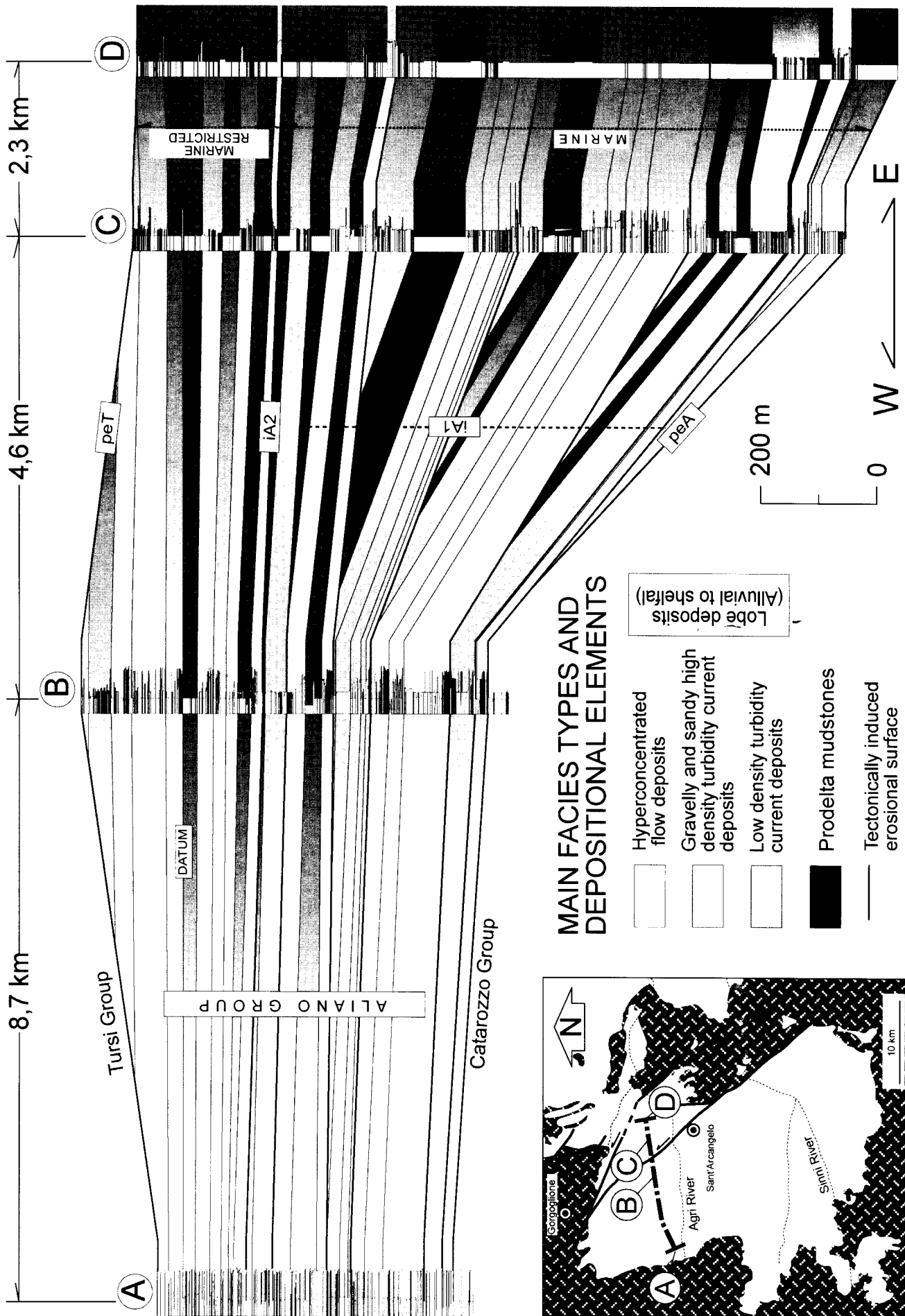
ing over fine-grained marine restricted deposits of the Aliano Group (A2 sub-unit)(Fig. 5F). This mainly sand-stone unit grades eastward into marine prodelta mud-stones with minor sandstone intercalations.

The stratigraphy of these deposits has been diversely interpreted in previous literature (Caldara et al., 1988; Pieri et al., 1994), because (1) in the Armento stream area (Fig. 8) they were assigned to the Agri Cycle (Fig. 2), (2) in the Sauro river area they were included in the Sauro Cycle, and (3) in the Alianello area they were interpreted as part of the San Lorenzo Cycle (Fig. 3). On the other hand, the sandstone succession out-cropped in the Tursi area has been correlated with the "Sabbie di San Giorgio Lucano" (base of Aliano Group) (Lentini, 1967; Vezzani, 1967a, Ogniben, 1969; Carbone et al., 1991). One of the problems derived from this last correlation was pointed out by Ogniben (1969, p. 642) in the sense that all the regressive units outcropping in the Sant'Arcangelo basin, with about 2,000 meters in thickness ("Sabbie di Aliano", "Conglomerati di Cas-tronuovo" and "Sabbie e conglomerati della Serra Cor-neta", see also Fig. 3 and 4) seem to not have been devel-oped in the Tursi and Montalbano Jonico areas, were the possible equivalent deposits are represented by a monot-onous succession of marine mudstones. Another point contrary to this interpretation is the fact that the "Sab-bie di San Giorgio Lucano" (located upcurrent in this scheme) is thinner and composed of fine sands, finer that the "Sabbie di Tursi", which displays at their base (and in different levels within) the presence of 5-15 meters thick conglomeratic beds. Recent chronostrati-graphic data support the interpretation given in this work because both the proximal conglomerate unit out-cropping in Alianello and the sandstone unit outcrop-ping at Tursi are followed by fine grained deposits con-taining volcaniclastic levels displaying similar radiometric ages (Caggianelli et al., 1992; Capaldi et al., 1979, see later).

### Profico and Montalbano Jonico groups (middle Pleis-tocene).

The deposition of these groups (partially time equivalent) has been controlled by the tectonic uplift of the Valsinni structure, which has divided an early and broader Sant'Arcangelo basin into two contemporane-ous sub-basins, the Pleistocene "Sant'Arcangelo" and "Metaponto" basins (Fig. 12). The Profico Group con-sists of up to 300 m of fine-grained lacustrine strata (Caggianelli et al., 1992) overlying in angular unconfor-

Fig. 9    - Cross-section of the lower Pleistocene Aliano Group. Sections A to C are composed of the following measured sections indicated in
        Fig. 8: A) sections 1, 2 and 3; B) sections 7, 9, 10, 13, 16; C) sections 19, 21; D) sections 20, 22. Tectonic phases: peA: pre- and early
        Aliano; iA1: intra-Aliano 1; iA2: intra-Aliano 2; peT: pre- and early Tursi. See text for details.
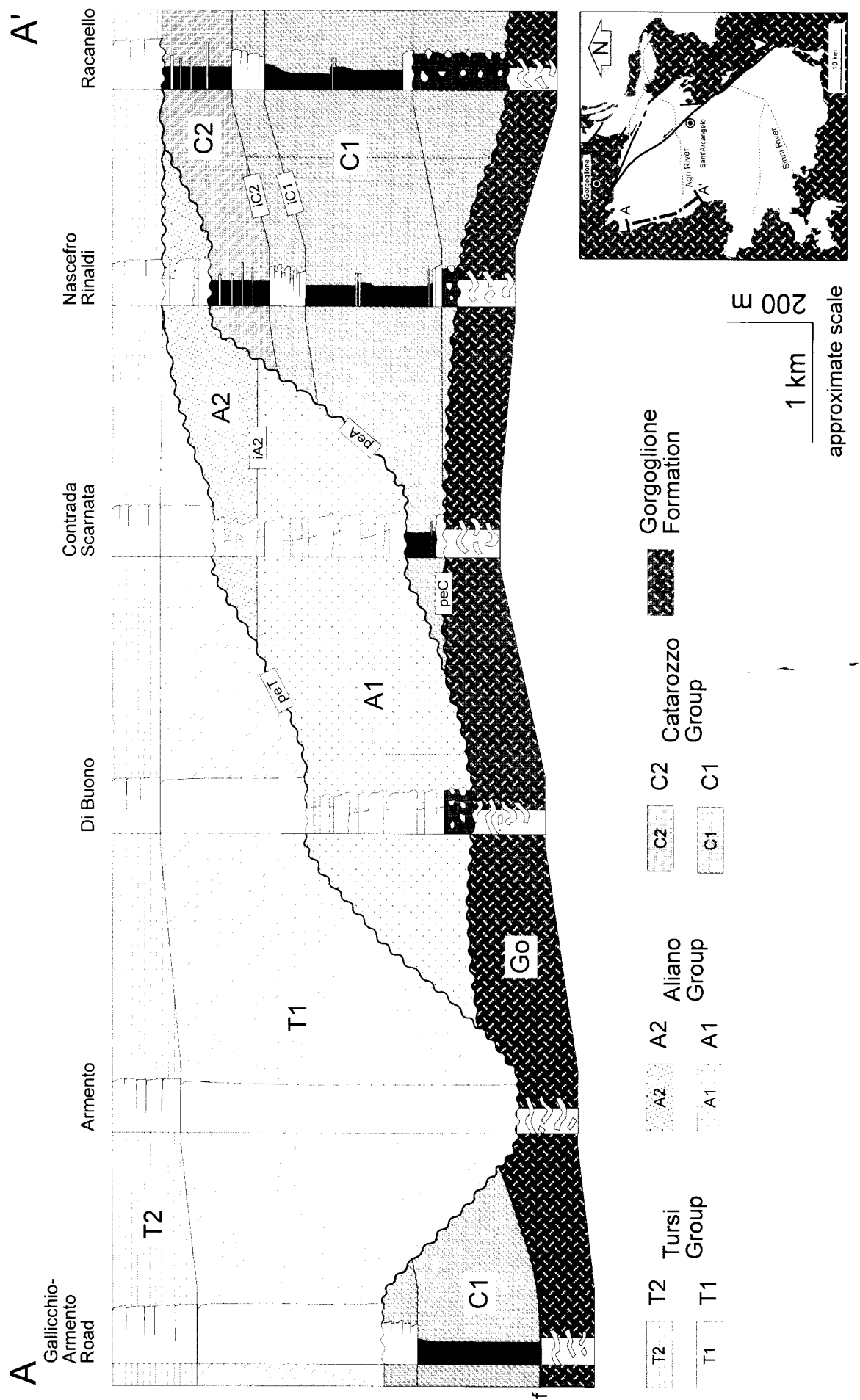
MARINE
RESTRICTED

MARINE

peT

iA2

iA1

peA

DATUM

Tursi Group

ALIANO GROUP

Catarozzo Group

E

W

200 m

0

8,7 km

4,6 km

2,3 km

A

B

C

D

## MAIN FACIES TYPES AND DEPOSITIONAL ELEMENTS

Hyperconcentrated flow deposits

Gravelly and sandy high density turbidity current deposits

Low density turbidity current deposits

Prodelta mudstones

Tectonically induced erosional surface

Lobe deposits
(Alluvial to shelfal)

N

Gorgoglione

Agri River

Sant'Arcangelo

Sinni River

10 km

A

B

C

D

Fig. 10 - Schematic cross-section in the Armento-Raccanello area.
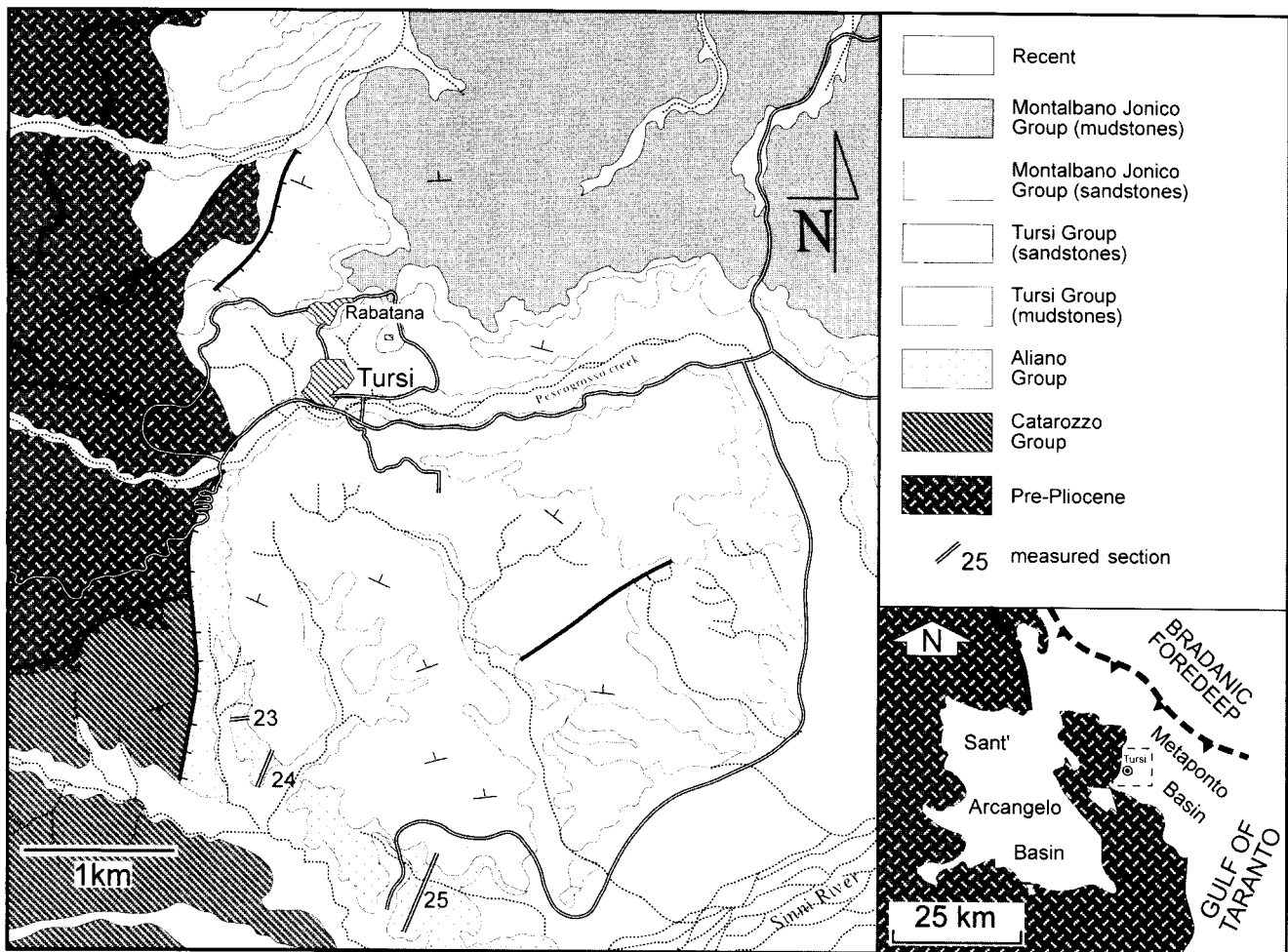
Fig. 11 - Geologic map of the Tursi Area (modified from Carbone *et al.*, 1991).

mity the Tursi Group in the "Sant'Arcangelo basin". These deposits are partially equivalent to the San Lorenzo Cycle of Pieri et al. (1994), with the difference that in this cycle the conglomerates of the Tursi Group were included as a basal conglomeratic sub-unit (Fig. 3).

The Montalbano Jonico Group is made up of up to 300 meters of fine-grained marine strata overlying in angular unconformity the Tursi Group in the "Metaponto basin" (Fig. 4, 11 and 12). The basal levels include a 20 meters thick conglomerate with angular clasts (Fig. 5F) derived from the pre-Pliocene units (flysch and carbonate blocks). Vertically, this group evolves in poorly developed, shelfal sandstone lobes (up to 40 meters thick) and finally a thick and monotonous succession of prodelta mudstones, indicating the deactivation of the flood-dominated system as a consequence of the subaerial exposure of pre-Pliocene rocks in the Valsinni structure.

K\Ar dating of volcaniclastic levels in the lacustrine Profico Group indicates an age of 1.1±0.3 Ma (Caggianelli et al., 1992). A similar dating (1.14±0.09 Ma) was obtained from volcaniclastic levels intercalated within marine mudstones of the Montalbano Jonico

Group (Capaldi et al., 1979). These data reinforce the hypothesis of a synchronous origin of these groups, and also allows correlation of the overlying conglomerates and shelfal sandstone lobes of the Tursi Group (see above) on the basis of their position in the sequence.

**Remarks on the relationship between tectonics and sedimentation.**

In tectonically active basins, medium to large scale stratigraphic cycles recorded in depositional areas are the result of Davisian-type cycles, which are characterized by repeated episodes of uplift/denudation mainly affecting source areas (Mutti et al., 1996). The area of geologic preservation of these sedimentary cycles is mainly controlled by the long term cumulative difference between tectonic-induced uplift and basin subsidence. Even with a net effect of subsidence, longer periods of basin subsidence are punctuated by relatively short periods of rapid uplift. High-frequency vertical movements, especially uplift, operate in the frequency band of eustatic cycles. Being an order of magnitude
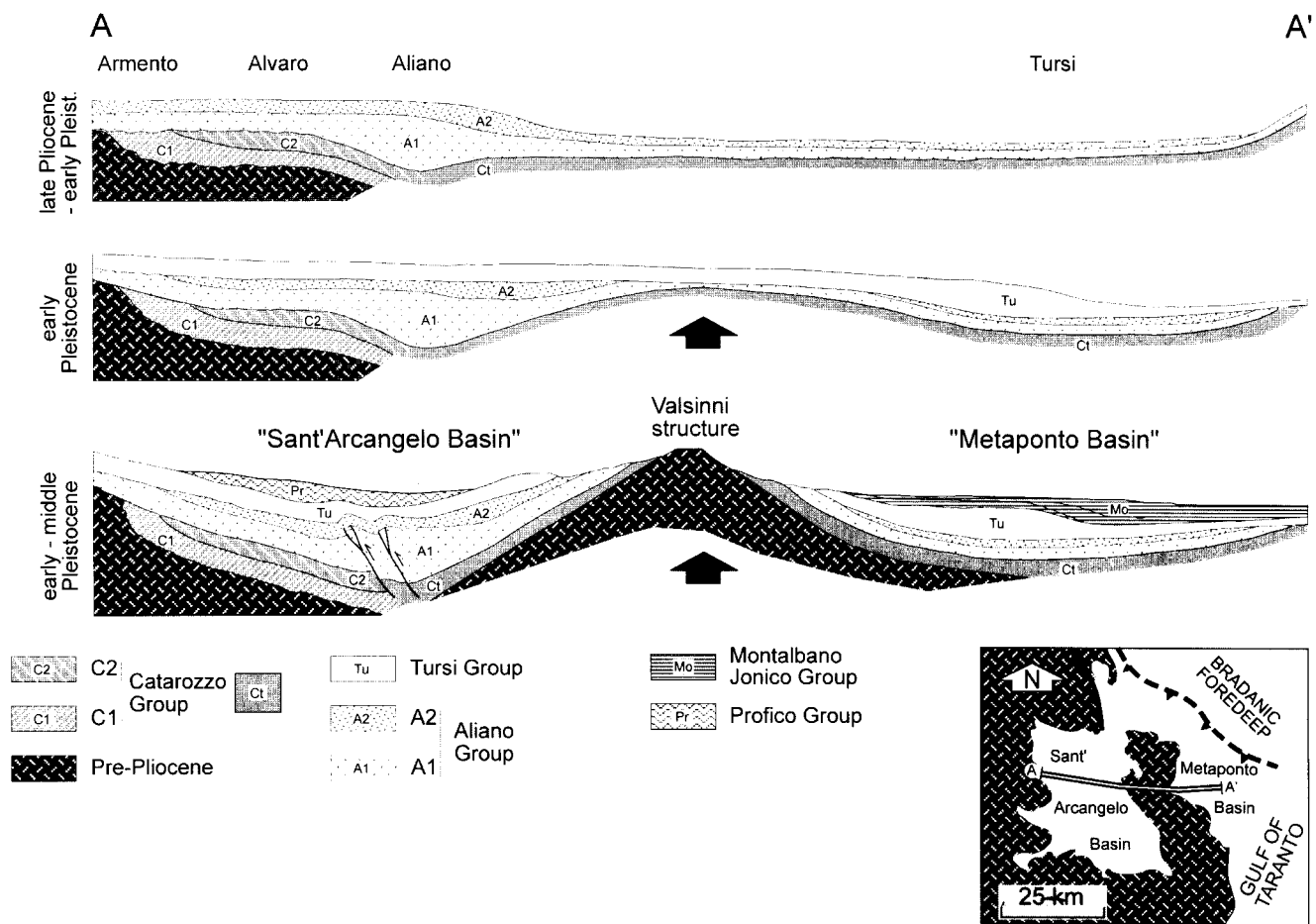
Fig. 12 - Inferred basin and stratigraphic evolution of the Sant'Arcangelo basin during the late Pliocene - middle Pleistocene. The horizontal
length is about 50 km. Slightly modified from Zavala and Mutti (1996).

larger in vertical extent, tectonic changes and their timing rather than eustatics will, however, determine major unconformities (sequence boundaries) in these areas during the orogenic period (Fortuin & De Smet, 1991).

High-resolution stratigraphic analysis reveals that several tectonic episodes occurred during the sedimentary infilling of the Sant'Arcangelo Basin. Major tectonic episodes define group boundaries and are characterised by the development of regional unconformity surfaces. The nature and regional characteristics of these tectonic phases will be briefly discussed below.

### Pre-and Early Catarozzo tectonic phase (peC).

This deformational phase coincides with the early configuration of the Sant'Arcangelo basin. It is dominated by a widespread subsidence regime characterised by the accumulation of immature cohesive debris flow deposits with very irregular thickness, followed in a fast transition by offshore prodelta mudstones indicative of rapid basin deepening and the initiation of starved basinal conditions. Deposits of this phase are well exposed along the Nascefro creek and the Racanello stream areas (section 4 in Fig. 8, see also Fig. 2).

### Intra Catarozzo tectonic phases.

Two tectonicly induced surfaces can be interpreted from the stratigraphic record. The first one ($iC1$) is evidenced by the rapid passage from distal prodelta mudstones to proximal shelfal-sandstone lobes (Fig. 2) and is interpreted as the consequence of a moderate compressive tectonic deformation affecting landward portions of the basin. Spectacularly exposed outcrops of this surface can be seen in the Nascefro creek and Armento areas. The second tectonically induced surface ($iC2$) marks the sharp boundary between open marine shelfal sandstone lobes and the mainly fine grained, restricted-marine succession of the upper Catarozzo Group (Fig. 2). This surface is exposed in Masseria Rinaldi, in the Catarozzo area (section 5 in Fig. 8), and in the Armento stream area. It is interpreted as related to the seaward shift of the deformational zone, thus partially separating the early Sant'Arcangelo Basin from the open marine conditions of the Bradanic Foredeep.

### Pre-and Early Aliano tectonic phase (peA).

This tectonic phase is characterized by a widespread basin widening accompanied by transgressive

sequences. In the Armento area (Masseria Di Buono, section 1 in Fig. 8), the Aliano Group displays a basal deposit up to 20 meters thick composed of cohesive debris flow, directly overlying the Miocene Gorgoglione Flysch within an angular unconformity (see also Fig. 10). In the Masseria Rinaldi and Racanello stream area (section 5 in Fig. 8), the basal deposits of the Aliano Group lack this chaotic basal unit, starting with tabular red conglomerates of proximal lobe deposits found in a 30° angular unconformity above the restricted-marine facies of the Catarozzo Group. In distal positions (*i.e.* Alianello, Sant'Arcangelo, San Giorgio Lucano), this tectonicly induced surface bounds restricted-marine mudstones of the Catarozzo Group, with wave-dominated marine deltaic deposits ("Sabbie di San Giorgio Lucano", Lentini 1968) (Fig. 3) evolving in a vertical succession to shelfal sandstone lobes and prodelta mudstones.

### Intra Aliano tectonic phases.

Two main tectonic phases have affected the evolution of the Aliano Group. The first tectonic phase (*iA1*) was responsible of the sedimentary expansion shown in the section of Fig. 9. This expansion is here related to localised and punctuated tectonic uplift episodes affecting the landward portion of the basin within a context of a regional subsidence regime. During such periods of local tectonic activity, the thrust induced uplift exceeded the regional subsidence rate, resulting in truncation of previously accumulated deposits. In these conditions, periods of relative thrust quiescence are characterised by a quasi-tabular correlation pattern.

The second tectonicly induced surface (*iA2*) marks the sharp boundary between open marine and restricted-marine conditions. This surface has a regional significance and has been recognised all over the study area. In the Sauro (section 16 in Fig. 8), Armento (sections 13 and 15) and Aliano (sections 21 and 22) areas, the boundary is marked by a 1 to 5 meters thick polymictic conglomerate unconformably lying over open marine shelfal sandstone lobes of the A1 sub unit. These residual conglomerates are followed with barren, mainly fine-grained strata of the A2 sub unit. This barren interval has also been documented by Lentini (1968) (Fig. 3). In the Tursi area, a two meters thick conglomerate with angular blocks of the pre-Pliocene units has been recognised bounding open marine prodelta mudstones of the A1 sub-unit containing fine grained restricted marine facies with *Cerastoderma edule*. This surface is here related to a compressive tectonic regime affecting the seaward limit of the basin. As in the Catarozzo Group, it is interpreted that the restriction in the Sant'Arcangelo Basin is linked to the presence of an off-shore uplifted structure which partially separated the basin from the Bradanic Foredeep.

Fig. 9 illustrates that during the *iA1* tectonic phase, the uplift rates (proportional to the volume of missing sediments) have increased during deposition of the first half of the Aliano Group. The two last unconformities show a decrease in the uplift rates, ending with the *iA2* tectonic phase who marks the rapid passage to restricted-marine conditions. The restricted-marine strata show a quasi-tabular correlation pattern, indicating that no tectonically-induced uplift episodes occurred landward. This change in the deformational pattern of the Aliano Group is here interpreted as a consequence of the seaward shift of the active thrust front.

### Pre-and Early Tursi tectonic phase (peT).

This tectonic phase is characterised by a widespread extensional tectonic regime. This phase also coincides with a regional widening of the basin as shown by deposits of the Tursi Group being regionally disposed over the pre-Pliocene units. Evidence of this extensional tectonic phase is also present in the Alvaro creek area where NW-SE and NE-SW oriented, high-angle normal faults affected the Aliano Group, with vertical displacements of about 100-200 meters (see the geologic map of Fig. 8).

### Pre-and Early Montalbano Jonico tectonic phase (peMJ).

This tectonic phase was responsible of the uplift and related subaerial exposure of the pre-Pliocene units at the Valsinni area (Fig. 12), probably associated with a positive flower structure (Catalano et al., 1993). The sedimentary consequence of this tectonic uplift was the division of the Sant'Arcangelo basin in two isochronous sub-basins, one located inland and dominated by a fluvio-lacustrine sedimentation (Profico Group), the other open to the Bradanic Foredeep and therefore affected by marine fine-grained sedimentation (Montalbano Jonico Group). In the Alianello area, the preceding Tursi Group appears folded and shows a subaerial erosion surface on top, onlapped by the lacustrine deposits of the Profico Group (Fig. 13). Similar relationships can be seen in the Serra Petrizza area (sections 21 and 22 in Fig. 8), where the Profico Group overlies the Tursi Group with an angular unconformity. In the Tursi area along the road to Rabatana (Fig. 11) this tectonic phase is expressed by a 20 meters thick conglomerate and pebbly-sandstone level containing angular pebbles and blocks (up to 0,5 meters in diameter) derived from pre-Pliocene flysch and carbonate units (Fig. 5F). Facies analysis suggest the occurrence of small flood events strongly modified by wave diffusion processes, with sediments sourced by small and high-gradient drainage basins possible located at the west side of the exhumed pre-Pliocene units at the Valsinni structure. This level is assigned to the basal
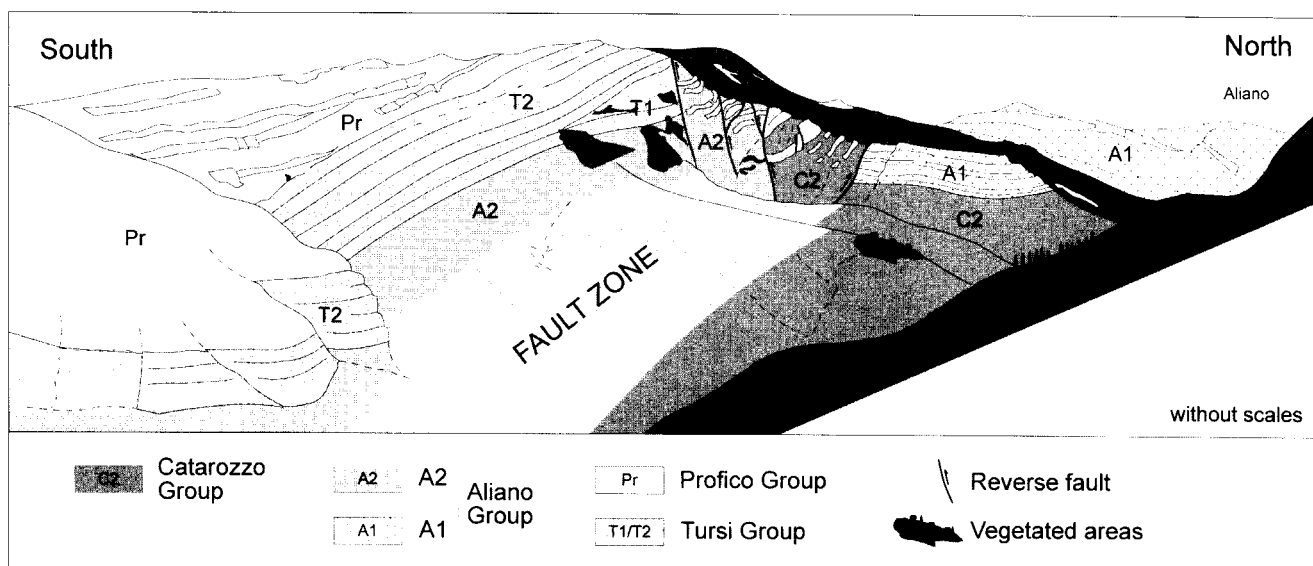
Fig. 13 - Geological sketch of the Alianello fault zone, as observed from the Alianello own towards the NW (for location see Fig. 8).

deposit of the Montalbano Jonico Group (Fig. 4), which rests in angular unconformity over more than 500 meters of shelfal sandstone lobes of the Tursi Group. Another evidence of this tectonic uplift derives from the fact that these basal deposits are followed by few meters of highly burrowed receding shelfal sandstone lobes which evolve into a thick and monotone succession of prodelta mudstones, spectacularly exposed between the Tursi and Montalbano Jonico towns. This vertical transgressive succession is here related to starved basinal conditions generated by a gradual interpose of a physical barrier who limited flood-generated sedimentary yield from the extensive drainage basins located westward. As stated by Allen et al. (1986), uplifting thrust fronts may no act as major sediment suppliers but may instead from barriers to basinward sediment transport.

### Post Montalbano Jonico tectonic phase (pMJ).

This last tectonic phase recognised in the study area is responsible for the generalised emergence that began after middle Pleistocene times. The left-lateral, strike-slip and related oblique thrust faults shown in the geologic map of Fig. 8 probably resulted from inversion of older structures and are here linked to this tectonic episode. An excellent example of one of these complex, high-angle, strike-slip faults is spectacularly exposed in front of the Alianello town (Fig. 13) where the stratigraphy indicates a complex vertical displacement in excess of 1,500 meters. Detailed photostratigraphic mapping, accurate control on the stratigraphic thickness, and field measurements also allowed construction of a regional cross-section across the Sant'Arcangelo Basin (Fig. 14), where a series of high-angle reverse faults can be recognised. The steeply dipping nature and

general appearance of these structures strongly suggest a positive flower structure, which appears very similar in orientation and age to those described by Catalano et al. (1993). This flower structure affect the pre-Pliocene units in the North Pollino, Satanasso, Valsinni, and Stigliano fault zones, and developed as a response to a deep-seated, steeply dipping, strike-slip fault (Naylor et al., 1986). Probably, this structure could be a NW propagation of the strike-slip Valsinni Fault Zone, related to the internal deformation of a left-lateral, transpressive, crustal shear zone running along the main boundary between the Apulian block and the Apennine chain (Dewey et al., 1989 ; Catalano et al., 1993).

### Conclusions.

(1) High resolution stratigraphic analysis performed in the Plio-Pleistocene deposits of the Sant'Arcangelo Basin indicates that the stratigraphy of these deposits can be interpreted in a more simple way that in previously proposed stratigraphic schemes.

(2) Facies, inferred depositional processes, and geometry of conglomeratic and sandstone bodies indicate that catastrophic flooding is the main depositional mechanism in controlling the fill of the Sant'Arcangelo basin. Facies analysis supported by more than 7,000 meters of detailed measured sections indicates that flood-related deposits constitute more than 90 % of the Plio-Pleistocene succession of the Sant'Arcangelo Basin. Spectacularly exposed outcrops make it possible to analyse the complete facies transition between continental and marine deposits, allowing correlation of huge volumes of distal shelfal sandstone lobes exhibiting HCS, with proximal tabular conglomerates deposited by hyperconcentrated flows.
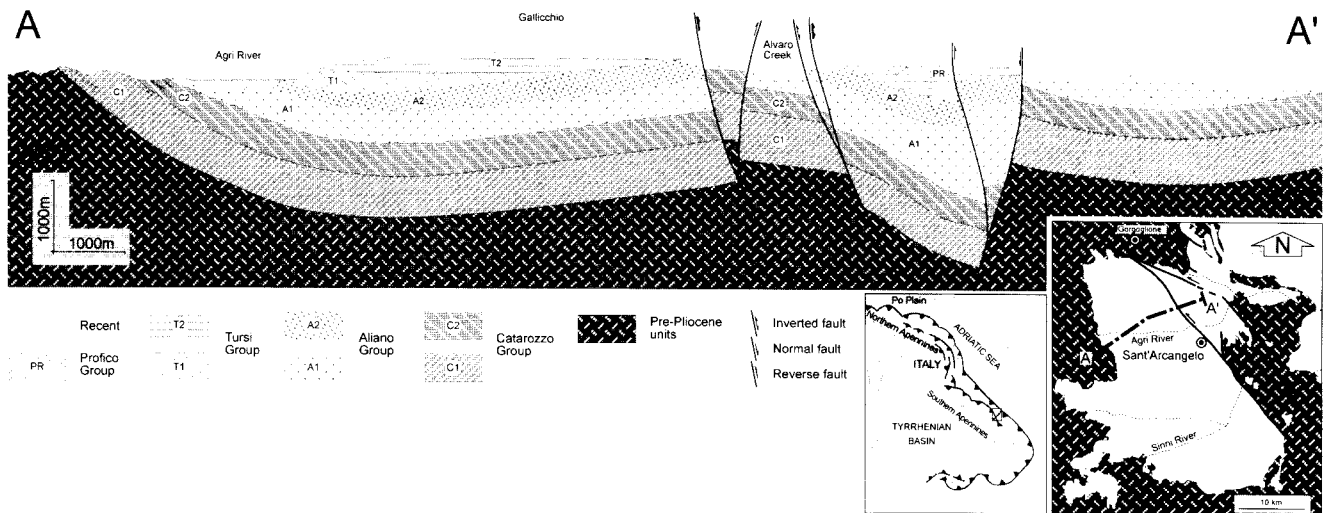
Fig. 14 - Regional cross-section across the Sant'Arcangelo basin, based on surface data. The thickness of the units have been controlled by detailed stratigraphic sections and regional mapping. Dip and strike of faults and beddings were controlled during fieldwork.

(3) Detailed correlations support the syntectonic deposition of the Aliano Group. A local differential subsidence appears to be the main mechanism responsible for controlling the geometry of this group. This study indicates the existence of high frequency episodes of tectonic uplift, that are directly related to increasing sedimentary yield towards the basin. The last supports the importance of the Davisian-type cycles proposed by Mutti *et al.* (1996) in controlling at least part of the high frequency cyclicity.

(4) Stratigraphic and sedimentologic evidence strongly supports the hypothesis of a common early origin for the "Sant'Arcangelo" and "Metaponto" basins. As shown in Fig. 12, the Valsinni structure seems to have been activated in early-middle Pleistocene times, thus dividing the Sant'Arcangelo basin into two sub-basins.

(5) If we agree that an adequate stratigraphic subdivision should precede successful structural studies, then our knowledge of the structural geology of a certain area could be no better than our advances in stratigraphy. The application in the Sant'Arcangelo basin of a new and more significant stratigraphic subdivision has resulted in the identification of a number of tectonic structures (see Fig. 8, 13 and 14), many of which have never before been described (compare for example with the contributions of Carbone et al., 1991; Pieri et al., 1994; Hippolyte et al., 1994). While these structures were accurately identified and mapped in the field (also with the aid of aerial photographs), their study exceeds the scope of this contribution. Future structural studies incorporating the new stratigraphic subdivision herein proposed are considered essential to properly assess the importance of strike-slip tectonics in the evolution of the Sant'Arcangelo Basin.

REFERENCES

Allen P.A., Homewood P. & Williams G.D. (1986) - Foreland basins: an introduction. In: P.A. Allen & P. Homewood (Eds.), Foreland Basins. *International Association of Sedimentologists*, Special Publication 8, pp. 3-12, Oxford.

Amore T. (1967) - La sezione plio-pleistocenica di Senise (Potenza). *Riv. It. Paleont. Strat., Mem. 13*, pp. 65-127, Milano.

Caggianelli A., Dellino P. & Sabato L. (1992) - Depositi lacustri infrapleistocenici con intercalazioni vulcanoclastiche (Bacino di Sant'Arcangelo, Basilicata). *Il Quaternario*, v. 5, pp.123-132, Napoli.

Caldara M., Loiacono F., Morlotti E., Pieri P. & Sabato L. (1988) - I depositi Pliopleistocenici della parte Nord del Bacino di S. Arcangelo (Appennino Lucano): Caratteri geologici e paleoambientale. *Mem. Soc. Geol. It.*, v. 41, pp. 391-410, Roma.

Capaldi G., Civetta L., Lirer L. & Munno R. (1979) - Caratteri petrografici ed età K/Ar delle cineriti intercalate nelle

formazioni argillose pleistoceniche della Fossa Bradanica. *Geol. Appl. e Idrogeol.*, v. 14, pp. 493-501,

Carbone S., Catalano S., Lentini F., & Monaco C. (1988) - Le unità stratigrafico strutturali dell'alta Val d'Agri (Appennino Lucano) nel quadro dell'evoluzione del sistema catena-avanfossa. *Mem. Soc. Geol. It.*, v. 41, pp. 331-341, Roma.

Carbone S., Catalano S., Lazzari S., Lentini F. & Monaco C. (1991) - Presentazione della carta geologica del Bacino del fiume Agri (Basilicata). *Mem. Soc. Geol. It.*, v. 47, pp.129-143, Roma.

Casero P., Roure F., Endignoux L., Moretti I., Müller C., Sage L. & Vially R. (1988) - Neogene geodynamic evolution of the Southern Appennines. *Mem. Soc. Geol. It.*, v. 41, pp. 109-120, Roma

Casnedi R. (1988) - La Fosa Bradanica: Origine, sedimentazione e migrazione. *Mem. Soc. Geol. It.*, v. 41, pp. 439-448, Roma.

Casnedi R., Crescenti U. & Tonna M. (1982) - Evoluzione della Avanfossa Adriatica Meridionale nel Plio-Pleistocene, sulla base di dati di sottosuolo. *Mem. Soc. Geol. It.*, v. 24, pp. 243-260, Roma.

Catalano S., Monaco C., Tortorici L. & Tansi C. (1993) - Pleistocene strike-slip tectonics in the Lucanian Apennine (southern Italy). *Tectonics*, v. 12, pp. 656-665, Washington.

Cello G., Tortorici L., Martini N. & Paltrinieri W. (1989) - Structural style in the frontal zones of the southern Apennines, Italy: An example from the Molise district. *Tectonics*, v. 8, pp. 753-768, Washington.

Cello G., Lentini F. & Tortorici L. (1990) - La struttura del settore calabro-lucano e suo significato nel quadro dell'evoluzione tettonica del sistema a thrust sud-appenninico. *Studi Geologici Camerti*, Volume speciale, pp. 27-34, Camerino.

D'Argenio B., Pescatore T. & Scandone P. (1973) - Schema geologico dell'Appennino meridionale. *Atti Acc. Naz. Lincei*, v. 183, pp. 49-72.

Dewey J.F., Helman M.L., Turco E., Hutton D.H.W. & Knott S.D. (1989) - Kinematics of the western Mediterranean. In: Coward M.P., Dietrich D. & Park R.G. (Eds.), Alpine Tectonics. *Geol. Soc. Spec. Publ.*, , v. 45, pp.265-283, London.

Fortuin A.R. & De Smet M.E.M. (1991) - Rates and magnitudes of late Cenozoic vertical movements in the Indonesian Banda Arc and the distinction of eustatic effects. In : D.I.M. Macdonald (Ed.), Sedimentation, Tectonics and Eustasy, Sea-Level Changes at Active Margins. *International Association of Sedimentologists*, Special Publication 12, pp. 79-89, Oxford.

Hippolyte J.C. (1992) - Tectonique de l'Apennin méridional: structures et paléocontraintes d'un prisme d'accrétion continental. Unpublished Ph.D. thesis, Université P. et M. Curie, Paris.

Hippolyte J.C., Angelier J., Roure F. & Casero P. (1994) - Piggyback basin development and thrust belt evolution: structural and palaeostress analyses of Plio-Quaternary basins in the Southern Apennines. *Journ. of Struct. Geology*, v. 16, pp. 159-173. Amsterdam.

Knott S.D. (1987) - The Liguride complex of Southern Italy-A Cretaceous to Paleogene accretionary wedge. *Tectonophysics*, v. 112, pp. 217-226, Amsterdam.

Lentini F. (1967) - Le successioni stratigrafiche plio-pleistoceniche sui due lati della dorsale Nocara-Colobraro (Matera). *Atti Acc. Gioenia Sc. Nat.*, v. 18, pp. 181-206, Catania.

Lentini F. (1968) - Stratigrafia micropaleontologica dei terreni plio-pleistocenici di Sant'Arcangelo (Potenza). *Atti Acc. Gioenia Sc. Nat.*, v. 19, pp. 255-344, Catania.

Lentini F. (1979) - Le unità sicilidi della Val d'Agri (Appennino Lucano). *Geol. Romana*, v. 18, pp. 215-225, Roma.

Marino M. (1994) - Biostratigrafia integrata a nannofossili calcarei e foraminiferi planctonici di alcune successioni terrigene Pliocenico-superiori del bacino di Sant'Arcangelo (Appennino Meridionale). *Boll. Soc. Geol. It.*, v. 113, pp. 329-354, Roma.

Mostardini F., Pieri M. & Pirini C. (1966) - Stratigrafia del Foglio 212, Montalbano Jonico. *Boll. Serv. Geol. d'It.*, v. 87, 89 p., Roma.

Mutti E., Davoli G., Tinterri R. & Zavala C. (1996) - The importance of ancient fluvio-deltaic systems dominated by catastrophic flooding in tectonically active basins. *Mem. di Scienze Geologiche*, v. 48, pp. 233-291, Padova.

Naylor, M.A., Mandl G. & Sijpesteijn C.H.K. (1986) - Fault geometries in basement-induced wrench faulting under different initial stress state. *Journ. of Struct. Geology*, v. 8, pp. 737-752, Amsterdam.

Ogniben L. (1969) - Schema introduttivo alla geologia del confine Calabro-Lucano. *Mem. Soc. Geol. It.*, v. 8, pp. 453-763, Roma.

Ori G.G. & Friend P.F. (1984) - Sedimentary basins formed and carried piggyback on active thrust sheets. *Geology*, v. 12, pp. 475-478, Denver.

Pieri P., Sabato L., Loiacono F. & Marino M. (1994) - Il bacino di piggyback di Sant'Arcangelo: evoluzione tettonico-sedimentaria. *Boll. Soc. Geol. It.*, v. 113, pp. 465-481, Roma.

Turco E., Maresca R. & Cappadona P. (1990) - La tettonica plio-pleistocenica del confine calabro-lucano: Modello cinematico. *Mem. Soc. Geol. It.*, v. 45, pp. 519-529, Roma.

Vezzani L. (1966) - La sezione stratigrafica di Caliandro nel Pliocene medio-inferiore della Val d'Agri (Lucania). *Riv. Ital. Paleont. Strat.*, v. 72, pp. 461-489. Milano.

Vezzani L. (1967a) - Il bacino pliopleistocenico di S. Arcangelo (Lucania). *Atti. Acc. Gioenia Sc. Nat. s.* VI, 18 (Suppl. Sc. Geol.), pp. 207-227, Catania.

Vezzani L. (1967b) - La sezione stratigrafica pleistocenica di Castronuovo di S. Andrea (Potenza). *Riv. It. Paleont. Strat., Mem 13*, pp. 11-59, Milano.

Vezzani L. (1968) - Geologia della tavoletta "Castronuovo di S. Andrea" (Prov. di Potenza, F. 211 IV-SE), *Atti. Acc. Gioenia Sc. Nat. s.* VI, 19 (Suppl. Sc. Geol.), pp. 9-108, Catania.

Zavala C. & Mutti E. (1996) - Stratigraphy of the Plio-Pleistocene Sant'Arcangelo Basin, Basilicata, Italy. Riunione annuale 1996 del Gruppo Informale di Sedimentologia, Atti, pp. 279-282. Catania, (Italia) 10-14 Ottobre 1996.