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NEOGENE GEODYNAMIC EVOLUTION OF THE SOUTHERN APENNINES

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ABSTRACT

Combined surface and subsurface studies have been used here to present an up-to-date structural synthesis of the southern Apennines. Six parallel sections crossing the southern Apennines from the Adriatic coast westward to the Tyrrhenian coast are presented, and help to correlate the surface and subsurface structures between the Abruzzi Mtns and the Gulf of Taranto.

Four tectonostratigraphic units are actually stacked in this Neogene accretionary wedge, developped above a south-west dipping A-subduction of the Apulian continental lithosphere. It includes: (1) an ophiolitic upper unit, the Liguride, which derives from the Neotethyan paleo-ocean; (2), (3) and (4) the western platform, the Lagonegro-Molise basin and the eastern platform, three distinct units derived from the Mesozoic Apulian continental margin. Timing of the deformation is well constrained by the shallow to deep water transition observed in the sedimentary facies of the platform domains when they enter the flexural trough in front of the wedge. Deformation and accretion of the basinal units into the Apenninic prism is outlined by the basal unconformity of the piggy-back basins where syntectonic deposits have been trapped. High fluids pressures related to dewatering processes in the accretionary wedge led to the occurence of melanges and broken formations along major thrusts, and to the decollement of the upper part of the Lagonegro Molise basin to form far travelled plastic nappes (the «argille varicolori» of previous authors).

In order to balance the large amount of shortening in the sedimentary cover and to fit the flexed Moho geometry, we propose here a basement involved solution for the deep structure of the belt. Normal faulting, erosion and syntectonic sedimentation in piggy-back basins are the major elements which help to maintain the critical taper of the prism.

KEY WORDS: *Apennines, accretionary wedge, tectonic melange, argille varicolori.*

RIASSUNTO

Lo studio integrato di dati di superficie e di sottosuolo (pozzi, linee sismiche, dati gravimetrici, ecc.) ha permesso di elaborare una sintesi strutturale aggiornata dell'Appennino meridionale.

Vengono presentati sei profili geologici regionali, sub-paralleli, trasversali all'orogene, dalla costa tirrenica a quella adriatica, spaziati tra l'Abruzzo meridionale e il Golfo di Taranto.

Quattro grandi unità stratigrafico-strutturali sono attualmente impilate in un prisma di accrezione sviluppatosi nel Neogene sopra la litosfera continentale apula in subduzione di tipo A verso sud-ovest.

Il prisma include: (1) un'unità superiore ofiolitica, Unità Liguride, che deriva dal paleo-oceano neo-tetide; (2), (3) e (4) rispettivamente la Piattaforma appenninica occidentale, l'unità del Bacino lagonegrese-molisano e l'unità della Piattaforma orientale, unità derivanti dalla deformazione di tre domini paleogeografici contigui ma distinti del margine continentale apulo.

Nei domini di piattaforma la cronologia della deformazione è ben definibile dall'età dei sedimenti pelitici di transizione a bacino che coprono le sequenze carbonatiche quando le piattaforme stesse sono integrate nell'avanfossa al fronte del prisma. L'età di deformazione e di integrazione nel prisma di accrezione appenninico delle unità di bacino è definita dalla discordanza basale dalla sequenza sinorogena dei bacini di «piggy-back». Fenomeni di sovrapressione connessi ai processi di espulsione dell'acqua nelle argille hanno condotto alla formazione di «melanges» e/o «broken formations» lungo i piani di sovrascorrimento principali, e allo scollamento della parte superiore della sequenza del bacino lagonegrese che va a formare falde plastiche alloctone («argille varicolori» Auct.).

In ordine all'esigenza di bilanciare gli importanti valori di raccorciamento della copertura sedimentaria e di rispettare la geometria piegata della Moho, si propone il coinvolgimento del basamento nella struttura profonda della catena. Faglie normali (listriche), erosione e sedimentazione sinorogena nei bacini di piggy-back sono gli elementi primari che concorrono a mantenere il «critical taper» del prisma.

TERMINI CHIAVE: *Appennino, prisma di accrezione, melange, argille varicolori.*

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INTRODUCTION

The Apennines orogenic belt reflects Neogene deformation along the western border of the Apulian promontory of the African plate during the northward convergence of Africa and Europe (AMODIO MORELLI *et alii*, 1976; GRANDJACQUET & MASCLE, 1978; BOCCALETTI *et alii*, 1984; DERCOURT *et alii*, 1985; HILL & HAYWARD, 1988). This orogenic belt constitutes the back-bone of the Italian Peninsula, a 1000 km long fold belt that links the Alps and the Sicilian-Calabrian arc (fig. 1). The present study deals only with the southern part of the Apennines, an area encompassing the Abruzzi Mtns to the north and the Gulf of Taranto to the south (fig. 2). Unlike the northern Apennines, where most of the Mesozoic carbonate architecture remains apparent in the landscape, the southern Apennines are characterized by the wide extension of superficial tectonic melanges or chaotic formations (Bradanic allochthon) which mask the fundamental geometry of the underlying overthrust belt (fig. 4) (IPPOLITO *et alii*, 1973; 1974; PESCATORE & ORTOLANI, 1973; SCANDONE, 1967; D'ARGENIO *et alii*, 1973).

Nonetheless, conventional seismic reflection lines, exploration wells and field studies enable us to interpret major stratigraphic and structural boundaries (fig. 3). Additionaly, new paleontological data (Coccolithoforids) provide the timing of deformational events. Stratigraphic and structural data constrain regionally balanced geologic sections across the entire orogenic belt, from the Adriatic to the Tyrrhenian coast (Plates II and III). As a result of thin-skin tectonics, these geological sections show a major shortening in the sedimentary cover, which creates a «room» problem for the basement, that is what is the fate of the missing basement? To address this question, we have integrated the surficial geologic cross-sections with informations regarding the geometry of the Moho. From this, we are able to propose an overall crustal model of the southern Apennines, accounting for crustal shortening which evidently includes both thin and thick-skinned thrusting (ENDIGNOUX *et alii*, 1989).

I. PRESENT TECTONOSTRATIGRAPHIC UNITS GERMANE TO THE MESOZOIC PALEOGEOGRAPHY

Due to the recent (post-Tortonian) opening of the Tyrrhenian sea, parts of the initial Apenninic edifice have probably been «left behind» along west margin of Tyrrhenian sea, and are now missing from the onland cross-sections presented here (REHAULT, 1981; REHAULT *et alii*, 1987). Instead, the cross-sections depict deformed parts of the ancient Apulian continental margin, including both platform and basinal Mesozoic units, and a few fragments of the more internal oceanic domain (Ligurian ophiolitic units). The cross sections do not show the exotic continent terrane involving the Calabrian units. To study more accuratly these internal nappes (Liguride and Calabride), one has to look elsewhere, either to the south (Calabria) or to the north (Toscane). We shall describe the various tectono-stratigraphic units involved in the Apenninic deformations from east to west, and concentrating on the upper part of the structural pile:

The Ligurian ophiolitic unit (Neotethyan oceanic unit): well exposed to the south in the Monte Polino-Monte Alpi area (fig. 2), the Liguride represents the upper-most unit of the southern Apenninic structural pile, as shown on the sections E and F (plate III). It consists in a dilascered late Jurassic ophiolite (which forms a tectonic melange at the base of the nappe), on which rest a thick Cretaceous to Paleogene terrigenous sequence. Two major unconformities shall be discussed (fig. 3). The first one, in the Middle-Late Eocene, results from alpine deformations. The second (VEZZANI, 1975; ZUPPETTA *et alii*, 1984), which postdates Aquitanian deposits, is outlined by the progressive transgression of Langhian to Serravalian coarse grained deposits in piggy-back basins. This second event marks the accretion of this ophiolitic terrane into the Apenninic wedge, in Late Aquitanian to Middle Burdigalian times, during the collision between Europe (Calabria) and Apulia (REHAULT, 1981; ROURE *et alii*, 1988).

The units derived from the Apulian continental margin: from east to west, and from bottom to top, we distinguish three additional tectonostratigraphic units in the Apenninic wedge, all of them deriving from distinct domains of the Apulian continental paleomargin (fig. 3).

The eastern platform: the Puglia foreland extends from the Apenninic thrust front to the Adriatic coast. The same autochthonous beds

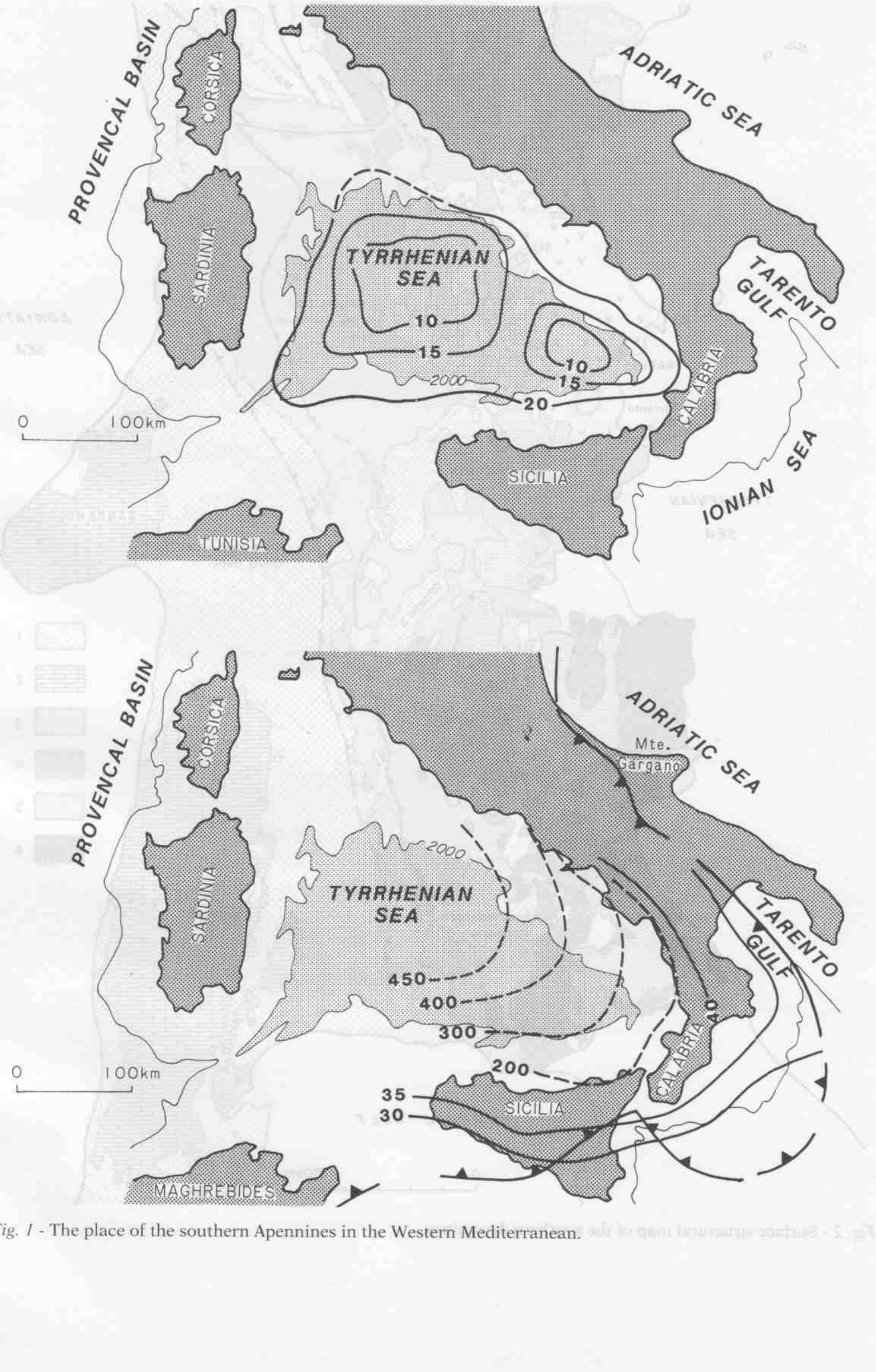

Fig. 1 - The place of the southern Apennines in the Western Mediterranean.

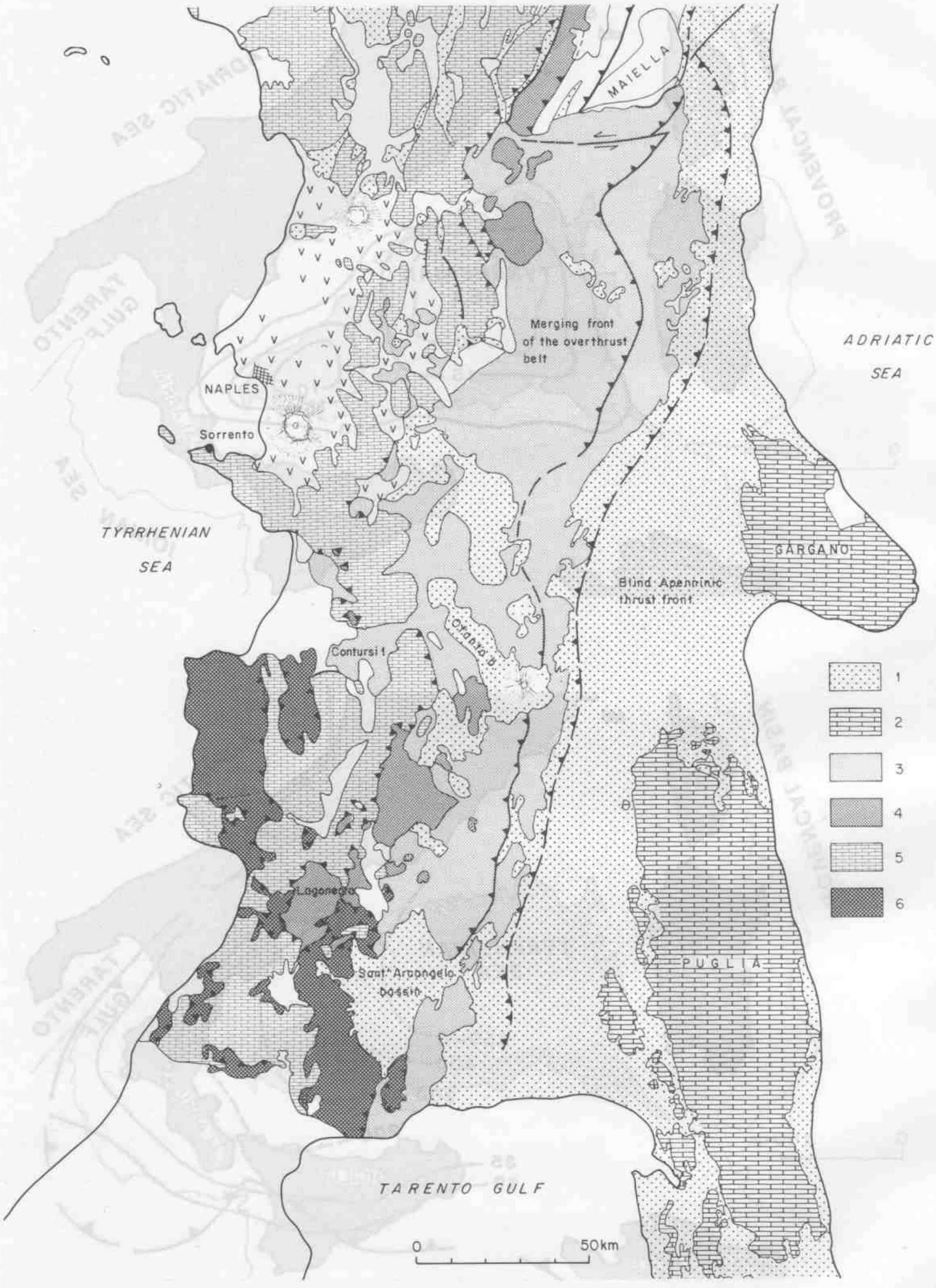

Fig. 2 - Surface structural map of the southern Apennines.

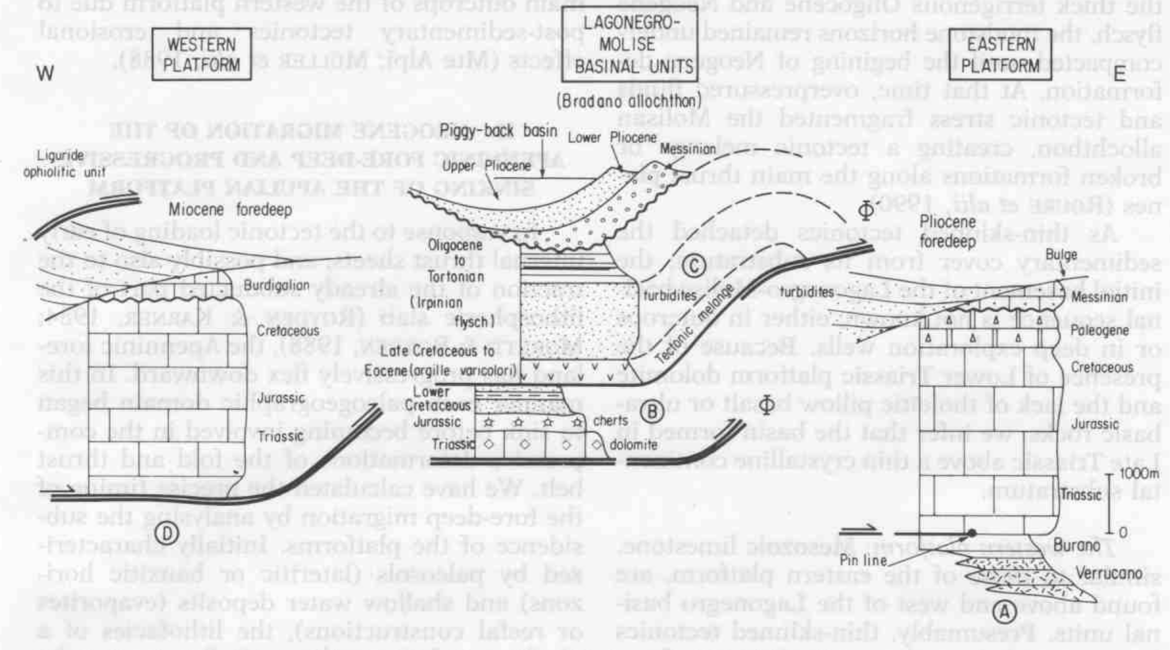

Fig. 3 - Synthetic columns of the southern Apennines. Tectono-stratigraphic units.

underlie the Bradanic allochthon in the Apenninic foredeep, and the overthrust belt is also made of thrust slices of Mesozoic platform limestone, each 4 to 7 km thick, and belongs to the same original paleogeographic setting (fig. 3 and Plates II and III). The upper part of Paleozoic substratum of the eastern platform is preserved in the area of foreland, where it consists of thick volcaniclastic strata of Permian age. Toward the west, in the Apennines, Triassic evaporites or bituminous dolomitic levels acted as decollement during the late Tertiary compression. In the region, Mesozoic sedimentary strata are no longer attached to their basement.

The Lagonegro-Molise basin: the Bradano trough, a complex geologic domain which separates the calcareous mountains of the western Apennines (Matese, Monte Raparo, Monte Alpi) from the thrust front and the Puglia foreland (fig. 2), comprises two sets of lithostratigraphic units, the Lagonegro nappes and the Molisan allochthon. Once supposed to have been originated in two distinct domains (SCANDONE, 1967; D'ARGENIO *et alii*, 1973), these basinal units are now regarded as complementary portions of a single stratigraphic sequence (fig. 4), from which the upper part has been detached and translated farther to the east during later deformations (MOSTARDINI & MERLINI, 1986; CASERO *et alii*, 1988).

The 1 km-thick Mesozoic basinal sequence is restricted to the Lagonegro nappes (SCANDONE, 1967; MICONNET, 1983; WOOD, 1981). It includes Triassic dolomites and Jurassic chert and cherty limestones, that pass upward to Lower Cretaceous terrigenous deposits. The Cenozoic part of the sequence is located in the Molisan allochthon, where stratigraphic thicknesses of 2 or 3 km are due to voluminous Oligocene and Neogene turbiditic deposits (the socalled Numidian and Irpinian flysch).

The Upper Cretaceous to Eocene red and green argillite units («red flysch» or «argille varicolori») are found structurally either at the top of the Lagonegro sequence or at the bottom of the Molise allochthon. Their pervasive slatty cleavage («argille scagliose») and their common association with massive indurated limestone blocks, lead us to consider these «argille varicolori» as the principal decollement level which effectively separates the upper sequence from the lower sequence of the basin. Due to the rapid sedimentation of the thick terrigenous Oligocene and Neogene flysch, the mudstone horizons remained undercompacted until the begining of Neogene deformation. At that time, overpressured fluids and tectonic stress fragmented the Molisan allochthon, creating a tectonic melange or broken formations along the main thrust planes (ROURE *et alii*, 1990).

As thin-skinned tectonics detached the sedimentary cover from its substratum, the initial basement of the Lagonegro-Molise basinal sequence is not known, either in outcrops or in deep exploration wells. Because of the presence of Lower Triassic platform dolomite and the lack of tholeïtic pillow basalt or ultrabasic rocks, we infer that the basin formed in Late Triassic above a thin crystalline continental substratum.

The western platform: Mesozoic limestone, similar to those of the eastern platform, are found above and west of the Lagonegro basinal units. Presumably, thin-skinned tectonics has removed the sedimentary horizons from their crystalline basement. The initial thickness of this platform sequence is rarely, if ever, preserved due to listric normal faulting which also accounts for the frequent occurence of younger-over-older tectonic contacts (Plate II, section B). Transitional facies (slope deposits) occur locally along the eastern border of the western platform. These slope strata occur as intermediate tectonic slices, pinched between the western platform units and the Lagonegro-Molise basinal units (Sannio Mtns for example, fig. 2 and section B). These transitional facies preclude the previously held concept of single platform domain. Thus, we suggest that the Lagonegro-Molise basinal units should be tectonically restored to a position between two platformal domains; in this reconstruction, the Bradanic allochthon has an external (more continentalward) origin, relative to the western platform. Other models (SGROSSO, 1983) involving an intermediate platform between the Lagonegro and Molise basinal sequences are not argumented by subsurface (seismic and wells) data, neither by structural field studies. Fragments of platform previously attributed to this questionable intermediate domain (Monte Alpi or Matese Mtns, fig. 2 and sections B and F) clearly derive from the remaining western platform, being either still directly in connexion with it (Matese) or being nowadays isolated from the main outcrops of the western platform due to post-sedimentary tectonics and erosional effects (Mte Alpi; MÜLLER *et alii*, 1988).

II. NEOGENE MIGRATION OF THE APENNINIC FORE-DEEP AND PROGRESSIVE SINKING OF THE APULIAN PLATFORM

In response to the tectonic loading of early internal thrust sheets, and possibly also to the traction of the already subducted part of the lithospheric slab (ROYDEN & KARNER, 1984; MORETTI & ROYDEN, 1988), the Apenninic foreland has progressively flex downward. In this manner each paleogeographic domain began to sink before becoming involved in the compressive deformations of the fold and thrust belt. We have calculated the precise timing of the fore-deep migration by analysing the subsidence of the platforms. Initially characterized by paleosols (lateritic or bauxitic horizons) and shallow water deposits (evaporites or reefal constructions), the lithofacies of a platform change dramatically once the platform domain passes from the flexural bulge into the progressively sinking foredeep (Plates II and III). Marly limestones and pelagic oozes overlie the platformal beds, and these in turn are covered by submarine fan sequences once the tectonic front has reached the area (COCCO & PESCATORE, 1975; PESCATORE, 1978; CASNEDI & BALDUZZI, 1984; CASNEDI *et alii*, 1984).

Unlike the platforms, the Lagonegro basinal strata do not accurately constrain the timing of the foredeep migration for the following reasons:

Firstly, the turbiditic sequences are not necessarely related to the Apenninic deformations. Most, if not all, of the Oligocene and early Miocene flysch (Numidian and Irpinian formations) could represent coarse grained, thick bedded submarine fans derived from a distal African source similar to today where the Nile transports terrigeneous materials into the eastern Mediterranean domain.

Secondly, basinal units such as the Lagonegro-Molise basin may be early inverted in response to the flexing of the Apulian lithospheric plate. The upper sedimentary contents of the basin («argille varicolori» and Irpinian flysch) would be expulsed to form plastic nappes emplaced on to the bordering platforms, and therefore, the linkage between the deformation front and basin subsidence becomes confused.

The results of paleontologic analyses show a west to east migration of the subsidence, a consequence of the eastward advance of the fore-deep (fig. 3) (MÜLLER *et alii*, 1988). Best data are given by the marly pelagic limestone which rests directly above platform carbonate. The overlying turbidite usually reworks older sediments remobilized from internal nappes, and is thus of poor help to date the sinking of the foreland. On the geological section (Plates II and III), platform sinking is thus Langhian to Serravalian to the west in the Matese Mtns (pelagic formations), but only Pliocene on the Puglia foreland to the east (ORTOLANI, 1978). In addition, ages of subsidence differ systematically form north to south, which reflects obliquity in the onset of Apenninic deformation. On the western platform, the earliest flysch is Messinian in the Abruzzi to the north (Montagna Grande), but Tortonian farther south (Matese Mtns). Southward, dating the subsidence of the western platform becomes difficult because of frequent absence of marly pelagic limestone and common tectonic contacts between the Neogene terrigenous allochthon and the Mesozoic platform carbonates. At any case, platform conditions are attested everywhere until Burdigalian, which is the younger age found for the calcarenite of the western platform to the south (Monte Alpi, Monte Raparo) (GRANDJACQUET, 1962; 1971; MÜLLER *et alii*, 1988).

At the southeastern border of the western platform anyway, the Neogene section of the Monte Alpi is more complete and gives good constraints for the timing of both platform subsidence and thrusting. There, Messinian ages have been obtained for autochthonous marly limestones which rest between the Burdigalian calcarenite and a thick turbidite which only reworks Langhian fauna (ORTOLANI & TORRE, 1971; MÜLLER *et alii*, 1988; SCANDONE, written communication, 1989). The space-time advance of the deformational front, post Early Messinian in the Monte Alpi, post Late Tortonian in the Matese and probably only Pliocene (post Messinian evaporite) in the Abruzzi, is well expressed along the entire Apennine. The actual segmentation of the fore-deep probably also reflects paleogeographic discontinuities, well expressed lateraly by the abrupt meridional limit of the Puglia platform south of the Taranto Gulf, and by the east-west platform to basinal facies transition of the Maiella (fig. 2).

III. BASIN INVERSION, NAPPE EMPLACEMENT AND MELANGE FORMATION: CONCEPTS REGARDING THE ORIGIN OF THE «ARGILLE VARICOLORI»

The origin of the «argille varicolori» and related sequences from the southern Apennines have been the focus of major controverses. If most of these strata are associated with the Apenninic fore-deep in the Molise area (Bradanic allochthon), some occur as isolated patches of «argille varicolori» found in the proximal submarine fan facies which overlie the western platform (Petraroia Tortonian Formation in the Matese Mtns for example). Beside similar facies are locally interbedded to the south within the Ligurian paleoceanic sequences thrust onto the western platform (fig. 3 and Plate III), this internal occurence has been used to infer a complex paleogeography, according to which the locus for the initial sedimentation of the «argille varicolori» as a whole was neither the Lagonegro or Molise external basinal domains, but a paleo-tyrrhenian basin located west of the western apenninic platform (the Sicilian units). This classical model implies successive jumps across platforms for the Bradanic allochthon: from the paleo-tyrrhenian to the Lagonegro basin across the western platform, and then from the Lagonegro to the Molise basin, across an hypothetical intermediate platform (SGROSSO, 1983; SCANDONE, 1967).

For numerous reasons exposed here, we favor an other model which considers that part of the «argille varicolori» (those from the Bradanic allochthon) do have an external origin:

- as mentioned above, Molise and Lagonegro sedimentary facies probably represent a single paleogeographic domain;
- there is no clear argument for an intermediate platform;
- the internal «argille varicolori» associated with the Ligurian units derive from an alpine domain, first tectonized in Late Cretaceous and Upper Eocene times. Paleogene unconformities are obvious in the internal sequences, whereas they are completely missing here in the Bradanic allochthon;
- the Cenozoic stratigraphic column of the «argille varicolori» found in the Bradanic

allochthon is directly complementary with the Mesozoic Lagonegro sequence (fig. 3).

In such an hypothesis (MOSTARDINI & MERLINI, 1986; CASERO *et alii*, 1988), the internal occurrence of «argille varicolori» on top of the western platform (Matese Mtns) is better explained by the early inversion of this single external Lagonegro-Molise basin, or by wedging (Plates II and III), parts being expulsed toward the west as well as toward the east. Indeed, the typical melange fabric for the plastic Bradanic allochthon, its diverticulation and detachment from the underlying cherts and cherty limestone, are the result of high fluids pressure in undercompacted sediments which aided this style of expulsive tectonics. None of the more indurated basal sequences of the Lagonegro basin has ever been found on top of the western platform, the remaining part of this external basinal domain being tectonized later, when the area was reached by the Apenninic eastverging thrusts.

A still more external origin has been recently proposed for the origin of parts of the Bradanic allochthon (MOSTARDINI & MERLINI, 1986). In this last model, the Late Miocene Irpinian flysch would have been deposited in an eastern Apulian basin located between the tectonized and the undeformed parts of the eastern (Puglia) platform (between the overthrust belt and the foreland). This model is unlikely because of constraints involving the time migration of fore-deep subsidence and thrusting. Flexure and deformation occurred in post-late Tortonian, probably Messinian times, in the above mentionned Bradanic allochthon, but not until Lower Pliocene in the overthrust belt, precluding any external (Apulian) origin for the «argille varicolori».

Timing of deformation of the «argille varicolori» found in the Bradanic allochthon is relatively well constrained to Messinian-Pliocene by two sets of data:

- the «argille varicolori» occur usually at the sole of nappes, and represent tectonic melanges emplaced above Late Tortonian flysch of the western platform (Pietraroia, section B) or younger Messinian turbidite of the Molise sequence (Nusco, Mte Forcuso, section C);
- the syntectonic deposits which infill the piggy-back basins developped above the Bradanic allochthon during its deformation are always post-Tortonian (usually Messinian to Pliocene, fig. 3, plates II and III), and rest unconformably above already structured strata. In Anzi, coarse grained sandstones at the base of the piggy-back sequence are usually referred as Langhian, even if the finer grained overlying turbidite is Pliocene. According to this old age at the base of the piggy-back, and to its structural position, we consider the Anzi sequence as a part of a Ligurian klippe now directly resting on top of the Lagonegro Molise units, as shown on sections E and F (Plate III).

IV. EFFECTS OF SUPERPOSED TECTONICS ON EARLY STRUCTURES

Both the western platform and the Lagonegro Molise basin were affected by the Apenninic thrust front by Messinian or Lower Pliocene times. But it was not until the Middle Pliocene that these internal nappes were underthrust by the eastern platform. The correlative shortening of the eastern (Puglia) platform in the overthrust belt (substratum of the previous tectonic wedge) lead to a remobilisation of the previous units, which were thus tectonized for second time. They currently exhibit complex geometries due to superposed tectonics. Best seen with seismic data, examples of these structures are shown in our cross-sections (Plates II and III).

Pliocene thrust planes involving the eastern platform (Puglia) generated ramp anticlines in the carbonates of the lower unit. Such a structure is presently exposed north of the Bradanic trough, in the Maiella, where the overthrust belt locally merges with the allochthon (section A). Elsewhere, folding of the overthrust belt created nappes anticlines (Monte Alpi, Monte Caldarosa, sections B to F). These structures are often the only surficial evidence for the Pliocene deformation of the Puglian substratum. Locally, erosion may dissect these young structures, exposing tectonic windows of the underlying nappes (TURCO, 1976). The Monte Raparo and Monte Alpi area (fig. 2) are examples of nappes anticlines where three superposed nappes are exposed (Ligurian units, western platform and Lagonegro-Molise basin) above a still unexposed ramp anticline of the overthrust belt (MÜLLER *et alii*, 1988, section F).

Superficial nappes synclines or Plio-Quaternary piggy-back basins also occur in the

Bradanic allochthon above the flats of the thrusts which emerge from the underlying overthrust belt (Plates II and III). As deformation in the southern Apennines still progressed from west to east during the Pliocene, and even during the early Quaternary to the south near the Gulf of Tarento, younger tectonic slices were progressively accreted to the base of the tectonic wedge, with a resulting uplift and tilting of the previous and more internal thrust-sheets. Pliocene and Quaternary deposition in the piggy-back basins (Sant'Arcangelo, fig. 2, section F) evince these recent deformations; the sedimentation axis of each individual basin migrated westward due to progressive underthrusting and accretion beneath the eastern margin of the piggyback basin.

In response to the regional uplift and to the opening of the Tyrrhenian sea, Plio-Quaternary listric normal faults affected the western part of the southern Apennines (BOUSQUET & PHILIP, 1987; D'ARGENIO *et alii*, 1986). These normal faults are particularly well expressed in the western platform where they have reorganized the landscape, creating prominent tilted blocks; each is mainly rotated toward the south or west (Abruzzi Mtns, Matese, Monte Pollino, sections A, B and F). Younger-over-older tectonic contacts are also common which explains the frequent thinning of the internal nappes (Contursi well, section D). Superficial thrust planes are locally cut by these recent distensive structures, but seismic data clearly show that the thrusts become rapidly listric at depth, and branch on deeper thrust planes which are thus reactivated as detachment surfaces during the extension. The important superficial rotation of the tilted blocks agree for such a relatively shallow level of decollement. Antithetic normal faults are locally rotated to an apparent reverse geometry, where gliding progressed sufficiently on a major underlying detachment (tilted graben of Guardaregia for example, ROURE *et alii*, 1988). The synchronism between Apenninic compression to the east and peri-tyrrhenian distension to the west remain to be explained (SCANDONE, 1979; MALINVERNO & RYAN, 1986). Nevertheless, most normal faults in the Apennines appear where the uplift has been very active (Plates II and III), and may thus result from a topographic effect, that is gravity sliding occurring along previous west-dipping thrust planes.

V. GLOBAL GEODYNAMICS AND MOUNTAIN BUILDING PROCESSES

The post-Tortonian shortening of the southern Apennines seems directly related to the deformations of the Apulian continental margin. Balanced cross-sections (Plates II and III) reveal approximately 120 km of shortening in the sedimentary cover: Messinian flysch linked to the eastern platform lies in Contursi well beneath the allochthon 50 km west of the thrust front (fig. 2 and section D), near the Tyrrhenian coast (DONDI & PAPETTI, 1965), and additional shortening is observed in the eastern platform (overthrust-belt) (ENDIGNOUX *et alii*, 1989).

Field data do not show directly the involvement of basement in thrusting, nonetheless the amount of shortening determined for the sedimentary cover must also occur in the basement. Refraction studies reveal deepening up to 50 km of the Apulian Moho toward the west beneath the southern Apennines (LETZ *et alii*, 1978; SCHÜTTE, 1978; MORELLI *et alii*, 1975; NICOLICH *et alii*, 1981). Shortening in the sedimentary cover is therefore in part compensated by a thickening of the crust. Additionally, earthquakes focal mechanisms indicate a Benioff zone that extends to a depth of 400 km beneath the Calabrian-Sicilian arc (GASPARINI *et alii*, 1985). Because of the length of the descending slab, the descending plate is probably essentially oceanic lithosphere, but the amount and effect of continental subduction is not constrained by these data.

Seismic reflection data indicate that the Puglia platform is flexured toward the Apennines (fig. 4 and Plates II and III) and gravimetric data corroborate this flexure. A large positive anomaly is situated on the high topography, about 100 km east of the trench; these relations can be explained by a mechanical model, the topographic high may be considered as the flexed bulge of the subducting plate (MORETTI & ROYDEN, 1988). In such a model, the simple loading of the emergent allochthonous nappes as well as crustal overthrust that thickens the crust by another 10 km is not sufficient to explain the bending of the lithosphere. The traction or pull of a subducted lithospheric slab remains necessary to account the observed geometry of the foreland.

The timing for the change from oceanic subduction to the more recent continental subduction remains uncertain. Some authors suggest even the occurrence at depth of a subducted fragment detached from the Adriatic plate (PANZA *et alii*, 1980). By knowing the thickness of the sedimentary cover and the subsidence history, it is possible by using mechanical models (KARNER & WATTS, 1983) to have a first estimate of the rigidity and thus, of the type of the subducted crust (MORETTI *et alii*, in prep.). More directly, the isostatic desequilibrium due to the subduction of the light continental crust explains the large Quaternary uplift of the Apennines. The amount of this uplift during the last My. is as much as 1000 m in the central part of the chain. The change from oceanic to continental subduction may also induce some variations in the velocity of the subduction. Such variations should again produce vertical movement in both the overriding and the subducted plates. The quantification of these coupled phenomena is not the matter of this paper, nevertheless combining these geological and geophysical data allow us to propose an overall geodynamical model to account for the observed structures of the southern Apennines. We consider here the post-Tortonian history of the belt as a result of the continental subduction of the Apulian lithosphere beneath the pre-Messinian Apennines. This subduction of the eastern platform is synchronous with the oceanic opening of the Tyrrhenian sea, which detached the present Apenninic tectonic wedge (accretionary prism) from a former continental block (including Corsica and Sardinia since early Miocene, after their suture and collision with Apulia) (REHAULT, 1981; DERCOURT *et alii*, 1985; ROURE *et alii*, 1988).

In the Sant'Arcangelo basin (fig. 2, Plate III), marine Quaternary (Calabrian) sedimentary rocks crop out at elevations as high as 600 m above sea level. This recent uplift of the southern Apennines is directly linked to the occurence of the proposed continental subduction of the Apulian lithosphere. Subducted continental crust is too light to descend into the mantle; alternatively, the descending crust becomes thickened due to thrust imbrications. The recent mountain building is linked to isotatic reequilibration of this thickened crust.

CONCLUSION

The post Tortonian geodynamic evolution of the southern Apennines result from continental subduction of the Apulian lithosphere. Measured horizontal shortening of the sedimentary cover of the eastern platform is compensated by shortening and thickening of the crust; this process involves progressively deeper parts, towards the west, of the Apenninic basement (Plates II and III). The continental subduction and consequent crustal thickening also induces a regional flexure of the lithosphere within the still autochthonous part of the crust (MORETTI & ROYDEN, 1988; ROYDEN, *et alii*, 1987).

Earthquake hypocenters define a clear Benioff plane 400 km long (GASPARINI *et alii*, 1985) beneath the Calabrian-Sicilian arc. One must imagine therefore that the current continental subduction followed a more typical phase of oceanic subduction, which lead to the disappearence of the paleo-thyrrhenian (Ligurian) oceanic crust and to the early Miocene accretion of an exotic continental block (Calabria-Corsica and Sardinia) with Apulia.

The post-Tortonian of the eastern platform is a continuation of the earlier (i.e. Langhian to Tortonian) shortening of inner parts of the western platform. Thus, last phase of subducting the paleo-tyrrhenian oceanic crust was most likely in the Aquitanian or early Burdigalian, as evinced by the basal unconformity of the Late Burdigalian to Serravalian piggyback sequence found on top of the paleo-oceanic Ligurian sequence (fig. 3), which was deposited at a time where all the neoethys oceanic crust had already been subducted, or accreted in the paleo-Apenninic accretionary prism.

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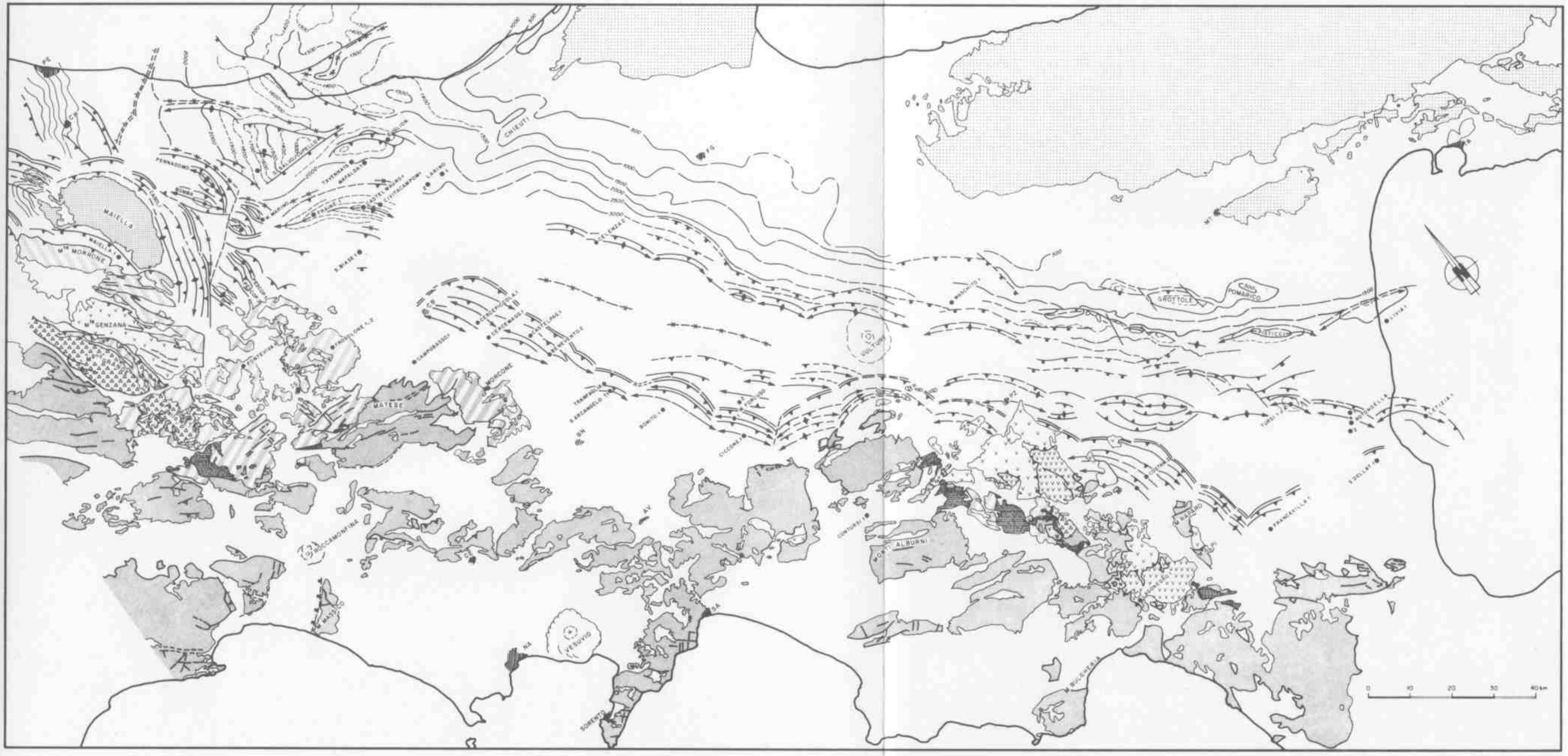
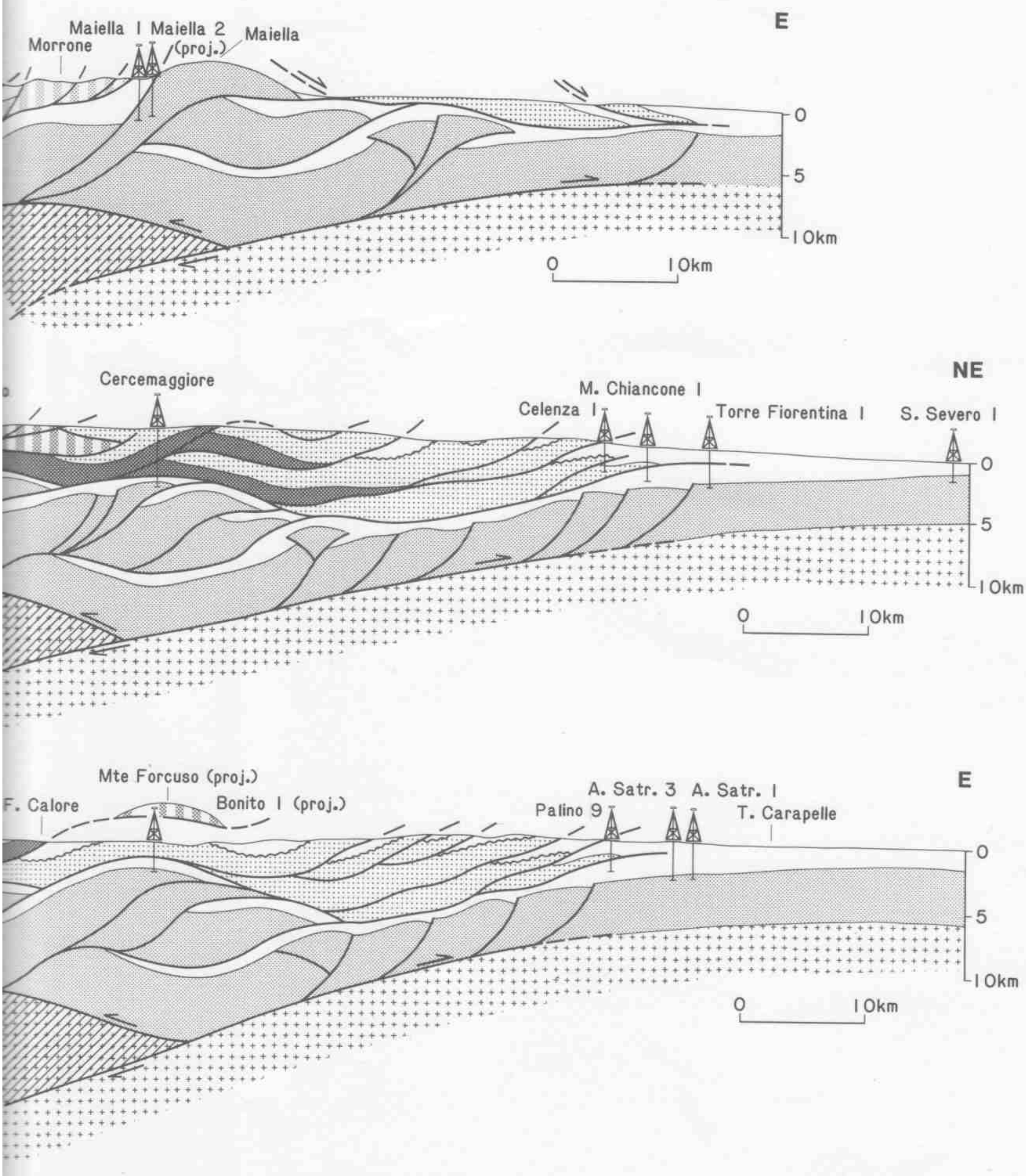


Subsurface structural map of the Southern Apennines



Geologic cross sections of the southern Apennine. For location, see fig. 2. Comments in the text.
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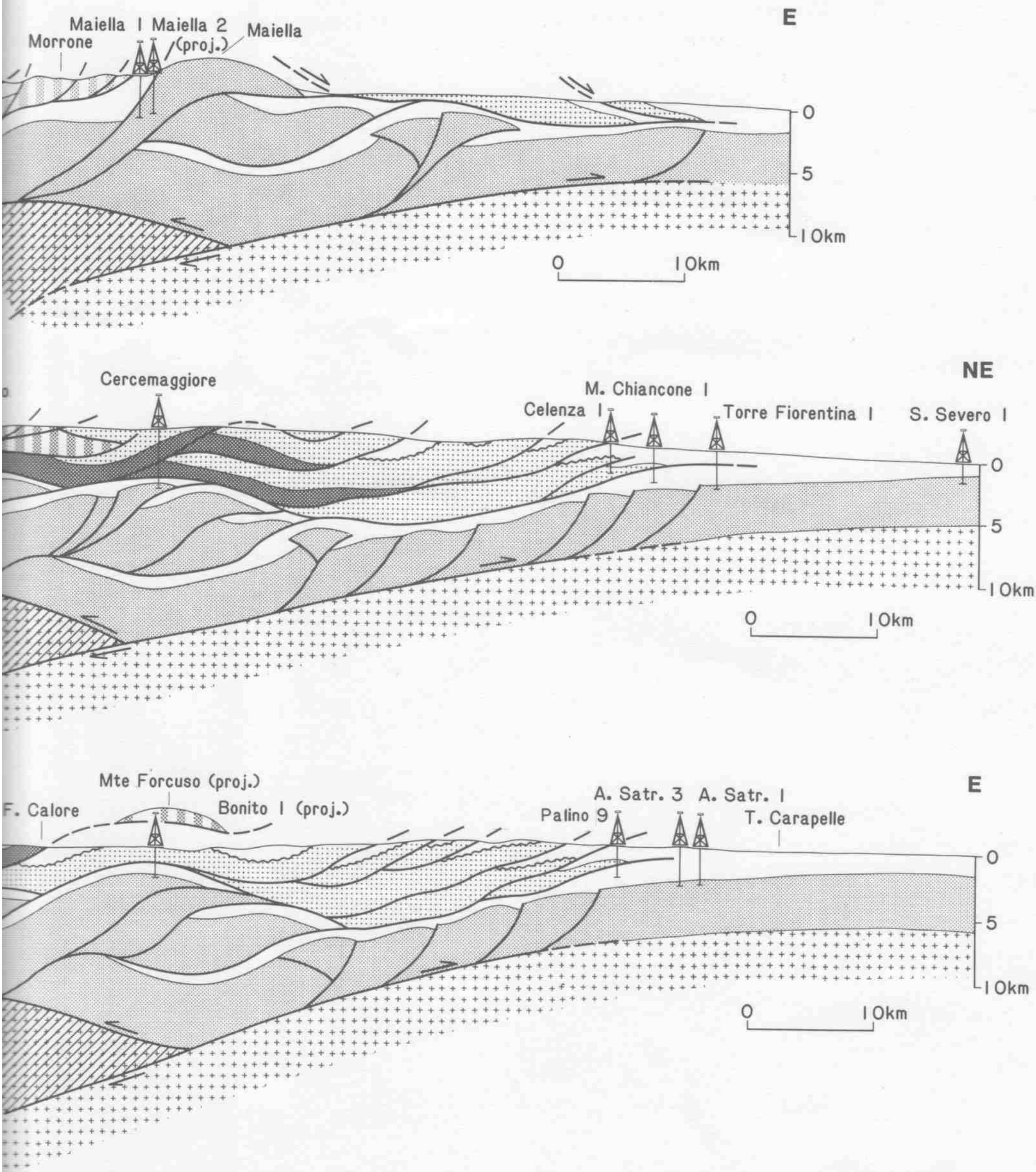

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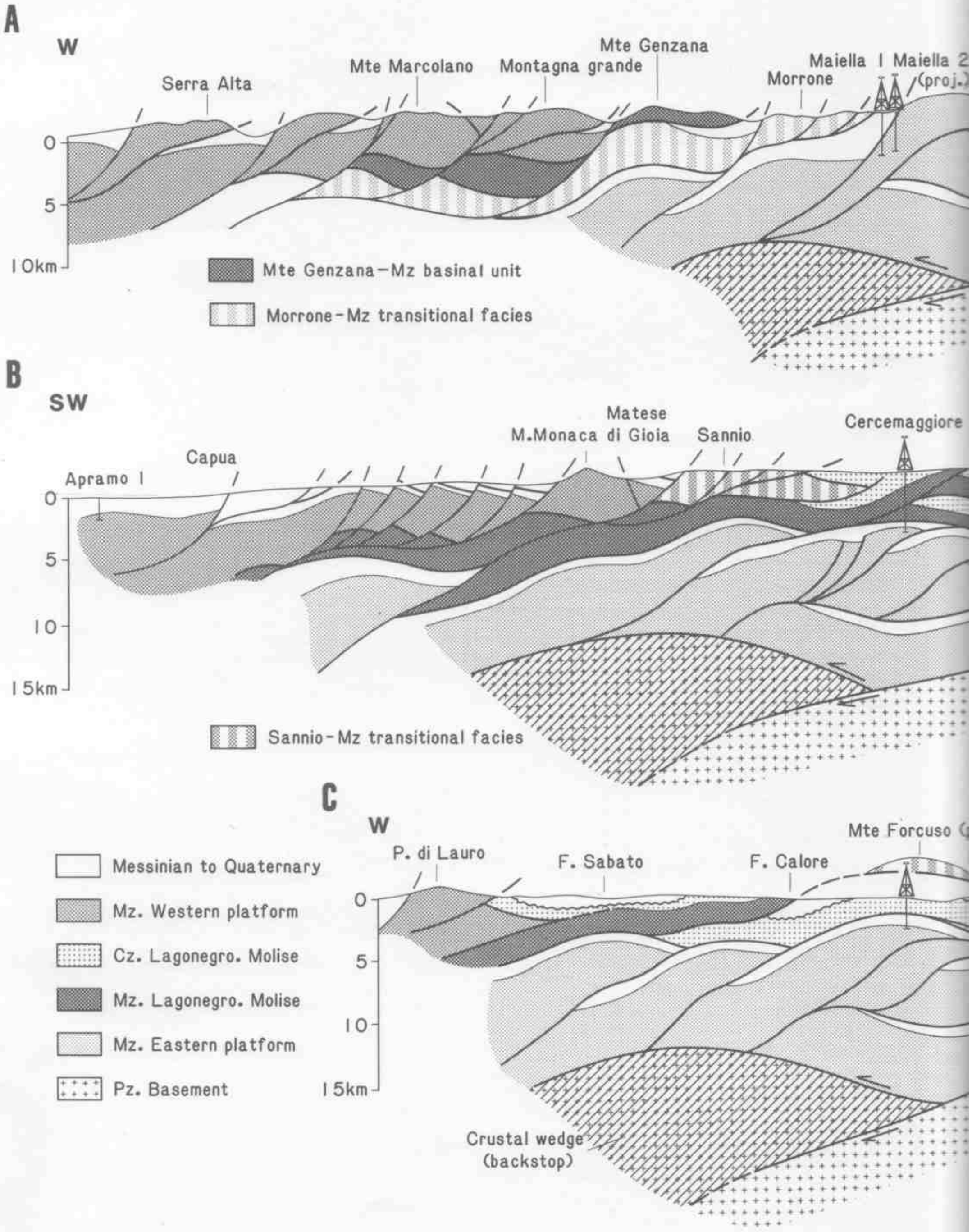

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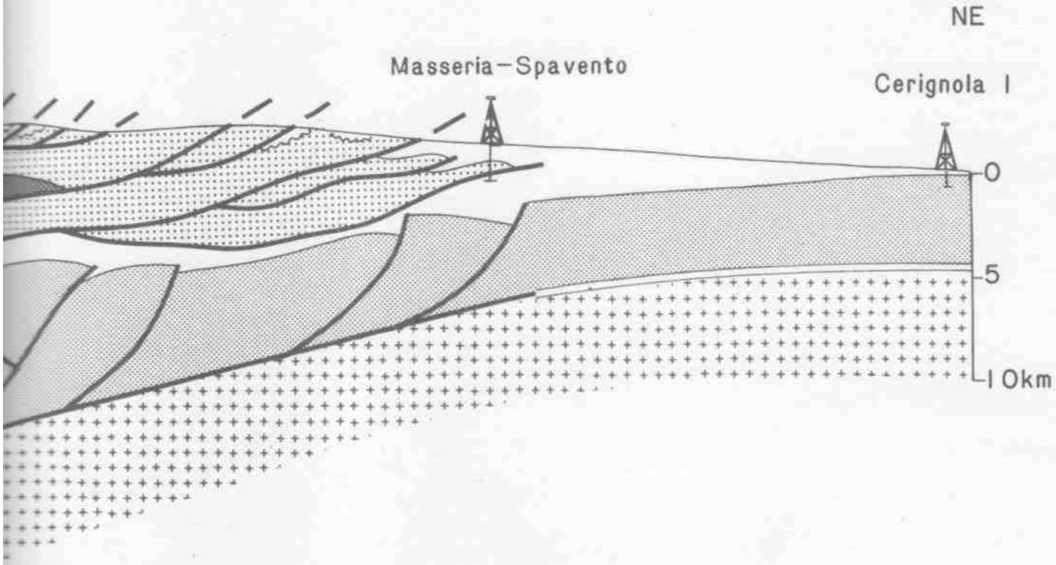
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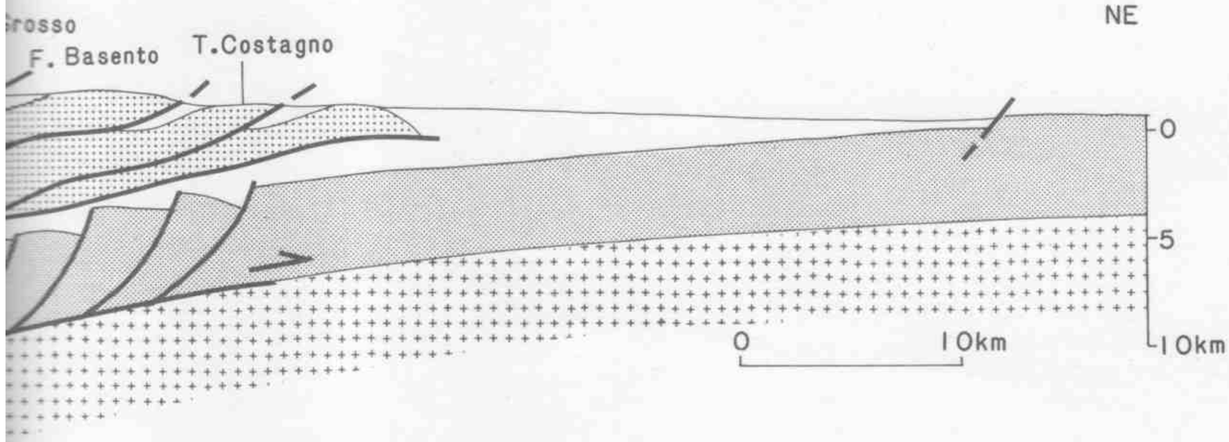
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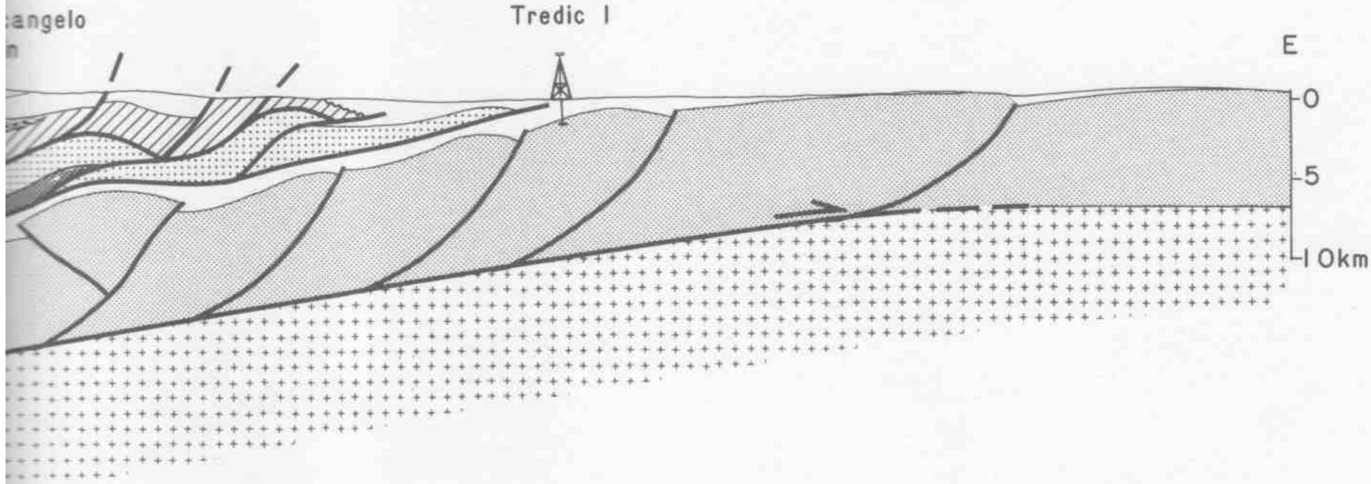
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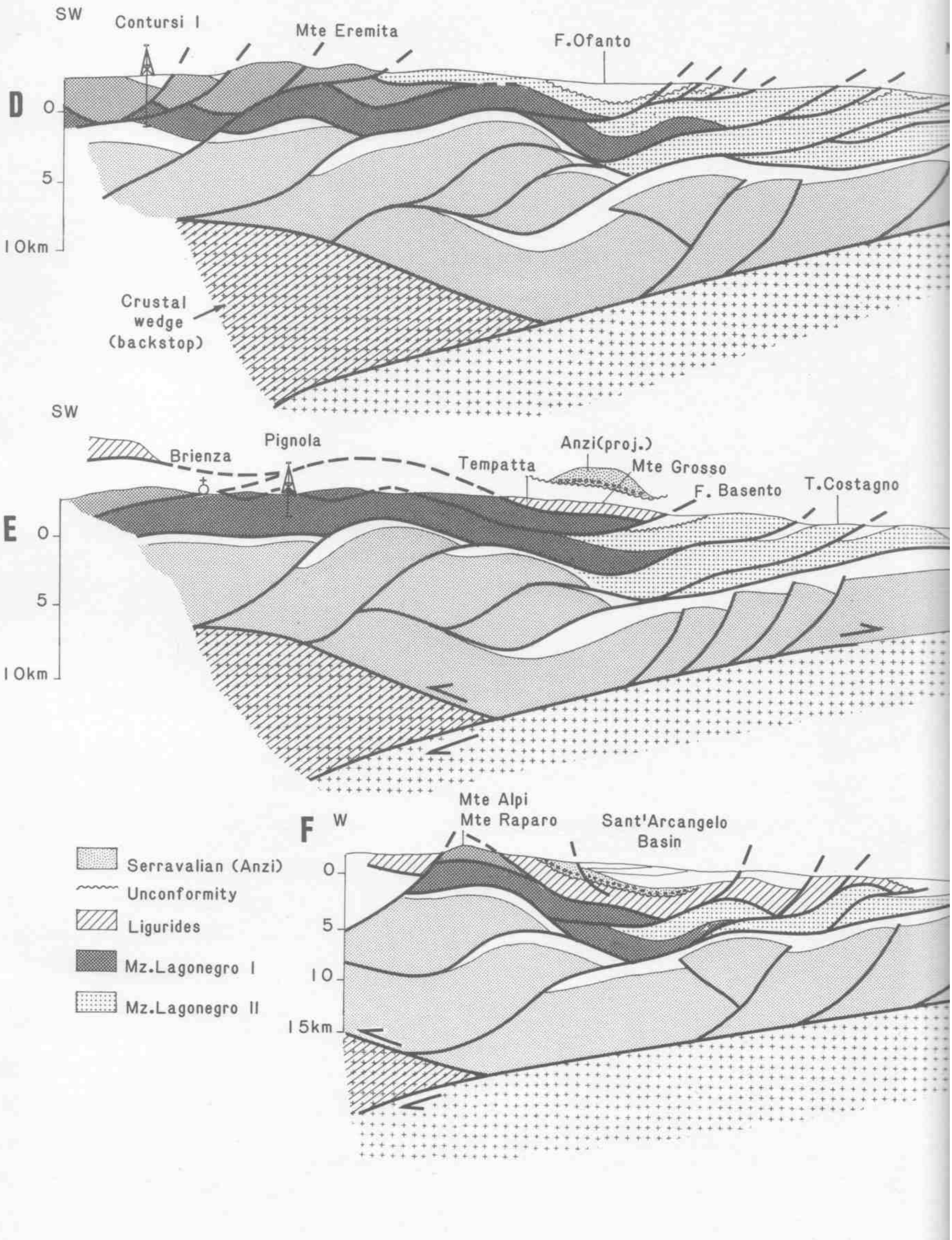
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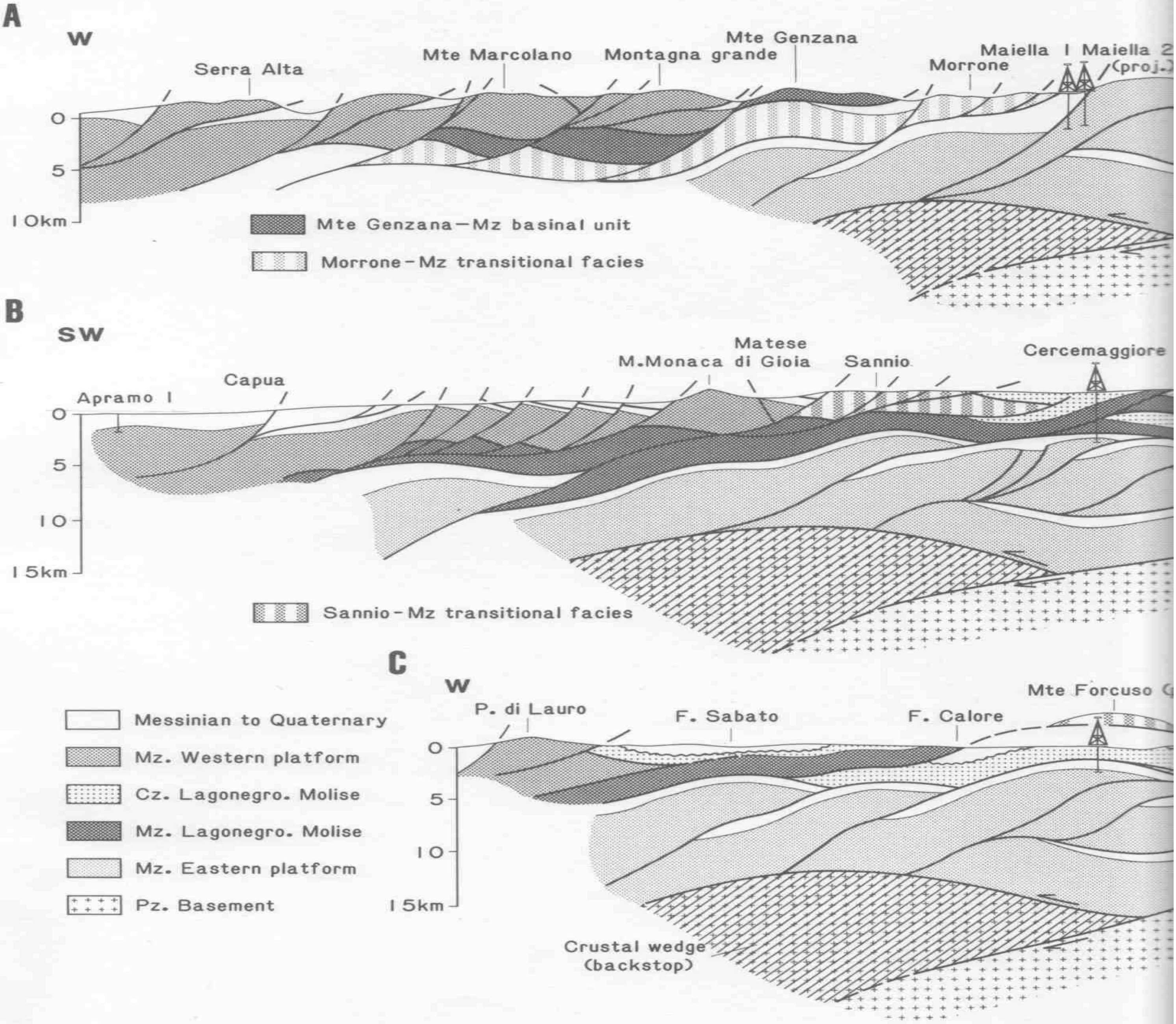

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