Field Trip Guide Book - P20

Volume n° 4 - from P14 to P36

32nd INTERNATIONAL GEOLOGICAL CONGRESS

A GEOLOGICAL TRANSECT ACROSS THE SOUTHERN APENNINES ALONG THE SEISMIC LINE CROP 04

Leaders: E. Patacca, P. Scandone

Post-Congress **P20**

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Front Cover:
Geologic Scheme of Italy 1:10.000.000. A historic document edited in 1950 by the Italian Geological Survey.
In the small pictures, historical monuments visited in the field trip.

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Introduction

This field trip is aimed at illustrating the major geological features of the Apennine thrust belt-foredeep-foreland system in Southern Italy from the Tyrrhenian margin of the mountain chain to the Murge hills in the foreland region. The trip route partly follows the trace of the line CROP-04, a non-commercial seismic profile that cuts across the entire thrust belt-foredeep-foreland system from Agropoli to Barletta showing well organised seismic signals down to 8-10 sec TWT corresponding to depths of 20-25 kilometres in the thrust belt and 25-30 kilometres in the foreland region (Mazzotti *et al*. 2000).

The field trip runs entirely on roads easily practicable by minibus or small coach. The only uncomfortable tract is represented by a narrow unpaved road of 15-20 kilometres between La Cerchiara and La Sellata during Day 3.

Accommodations during the field trip have been arranged in comfortable, though not luxurious hotels, with good local food.

At noon, a simple packet lunch will be distributed to the participants.

Topographic map: Touring Club Italiano, Atlante stradale d'Italia 1: 200.000, Foglio Sud.

Official geological maps: Servizio Geologico d'Italia, Carta Geologica d'Italia 1:100.000, Fogli 176 Barletta, 177 Bari, 185 Salerno, 186 Sant'Angelo dei Lombardi, 188 Gravina di Puglia, 198 Eboli, 199 Potenza and 200 Tricarico.

Synthetic structural map: CNR – Progetto Finalizzato Geodinamica, Structural Model of Italy 1:500.000, Sheet n. 4. S.E.L.C.A (Florence, Italy) 1992.

Regional geological setting

The overall structural architecture of the Apennine chain is described by a carbonate duplex system overlain by a thick pile of platform-and-basin-derived rootless nappes (Casero *et al.* 1988, 1991; Cello and Mazzoli 1999: Cello *et al.* 1987; Lentini *et al.* 1996, 2002; Monaco *et al.* 1998; Mattavelli *et al*. 1993; Menardi Noguera and Rea 2000; Mostardini and Merlini 1986; Patacca and Scandone 1989, 2001; 2004 a and b, Patacca *et al.* 1992; Roure and Sassi 1995; Roure *at al.* 1991). Figure 1 is a geological map of the region visited on the field trip.

Figure 2 is a rough scheme of the internal geometry of the Southern Apennines in the segment crossed by the line CROP 04. Figure 3 is a simplified geological section across the Southern Apennines that roughly follows the line CROP 04. Figure 4, finally, is an interpreted line drawing of the entire profile from Agropoli (Tyrrhenian coast) to Barletta (Adriatic coast of the Italian Peninsula). Several boreholes along the profile, together with commercial lines parallel to or cutting across the line CROP 04 have provided important constraints for the identification and characterization of the major tectonic features in the buried Apulia carbonates and in the Apenninic nappes.

The buried duplex system, basically made up of imbricates of Mesozoic-Tertiary shallow-water carbonates detached from the Apulia Platform, forms the backbone of the mountain chain in the whole Southern Apennines. Along the axis of the chain, the top of the Apulia carbonates lies at depths ranging from 1500 to more than 6000 metres below sea level. Only in the Monte Alpi tectonic window east of Lagonegro, Mesozoic-Tertiary carbonates surely belonging to the Apulia-carbonate duplex system have been uplifted to about 2000 metres above sea level.

The autochthonous portion of the Apulia Platform crops out in the Gargano, Murge and Salento regions. In the Murge region, the carbonate platform was entirely crossed by the Puglia 1 well (total depth: 7070 m). The borehole penetrated from 6112 m to the final depth middle Triassic to Permian terrigenous deposits stratigraphically underlying upper Triassic dolomites and evaporites. The contact between the shallow-water carbonates (plus anhydrites) and the underlying terrigenous deposits corresponds to a sudden decrease in the P-wave velocity. As a consequence of this velocity change, the contact is easily recognizable on several commercial lines, being everywhere evidenced both in the foreland region and in the thrust belt by a package of well-organized high amplitude/high frequency reflectors that strongly contrasts with the overlying reflection-free interval corresponding to the platform carbonates. In the visited region, the thickness of the reflection-free interval ranges from 2.0 to 2.4 seconds TWT. We do not know whether the Apulia-Platform carbonates and the underlying terrigenous deposits represent the sedimentary cover of a Hercynian crystalline basement or if they represent the upper portion of the sedimentary cover of an older, perhaps Caledonian, crystalline basement.

Between the Gargano-Murge region and the leading

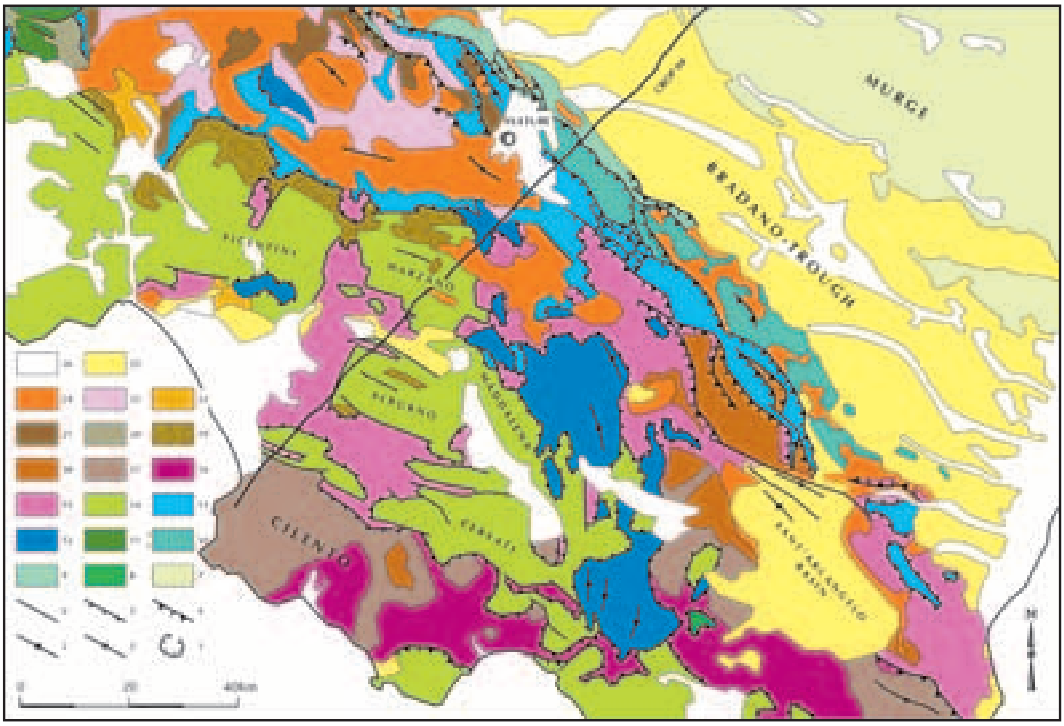
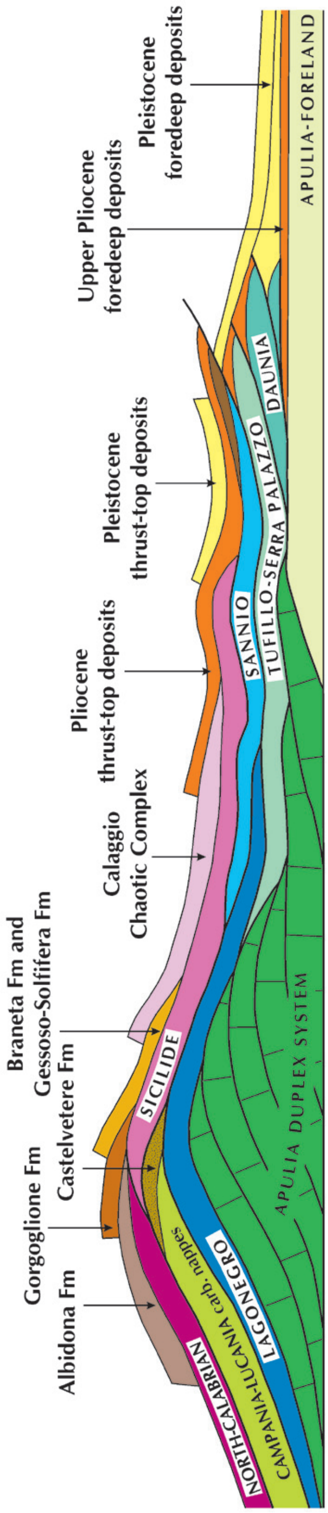


***Figure 1** - Simplified geological map of the area visited on the field trip. The solid line shows the trace of the line CROP 04. After Patacca et al. (2000) with slight modifications.*
***26** Continental and subordinate coastal deposits; volcanic rocks and volcaniclastic deposits (Holocene-middle Pleistocene p.p). **25** Terrigenous marine and paralic deposits filling the Bradano Trough and unconformable overlying the Apennine units (middle Pleistocene p.p.-lower Pleistocene) **24** Pliocene thrust-top deposits. **23** Calaggio Chaotic Complex (uppermost Messinian-lower Pliocene). **22** Messinian-upper Tortonian thrust-top deposits, including the Braneta and Gessoso-Solfifera formations. **21** Lower Messinian-upper Tortonian thrust-top deposits unconformably overlying the Sannio Unit (San Bartolomeo Formation). **20** Lower Messinian -upper Tortonian thrust-top deposits unconformably overlying the Matese Unit (San Massimo Sandstone). **19** Middle Miocene thrust-top deposits unconformably overlying the Alburno-Cervati and Monti della Maddalena units (Castelvetere Formation). **18** Middle Miocene thrust-.top deposits unconformably overlying the Sicilide Unit (Gorgoglione Formation). **17** Lower Miocene thrust-top deposits unconformably overlying the North-Calabrian Unit (Albidona Formation). **16** North-Calabrian Unit (Paleogene-Cretaceous). **15** Sicilide Unit (lower Miocene-Cretaceous). **14** Alburno-Cervati, Monti della Maddalena and minor units derived from the Campania-Lucania carbonate platform (lower Miocene-upper Triassic). **13** Sannio Unit (middle Miocene-lower Cretaceous. **12** Lagonegro Units (lower Cretaceous-middle Triassic). **11** Matese Unit (upper Miocene-upper Triassic). **10** Tufillo-Serra Palazzo Unit (upper Miocene-Paleogene). **9** Daunia Unit (upper Miocene-Paleogene). **8** Monte Alpi Unit (upper Miocene-Jurassic), including the overlying lower Pliocene thrust-top deposits (emergence of the Apulia-carbonate duplex system). **7** Cretaceous carbonates of the Murge foreland. **6** Faults, including normal faults and strike-slip faults. **5** Thrust flat.. **4** Thrust ramp. **3** Anticline axis. **2** Syncline axis. **1** Caldera rim (VultureVolcano).*

edge of the buried duplex system, the autochthonous Apulia carbonates and the underlying terrigenous deposits form a sort of homocline gently dipping towards the thrust belt. The structural depression at the front of the thrust belt caused by the flexural deflection of the foreland plate has been called in the geological literature the Bradano Trough. The Bradano Trough represents the youngest foredeep basin of the Southern Apennines, active in late Pliocene and Pleistocene times.

The allochthonous sheets lying on top of the Apulia-carbonate duplex system in the region crossed by the field trip are constituted of Mesozoic-Tertiary sedimentary sequences derived from platform-and-basin paleogeographic domains. Table 1 provides the principal characteristics of the stratigraphic sequences



representative of the tectonic units encountered in the field trip. The age of the unconformity at the base of the thrust-top deposits, becoming younger from the Tyrrhenian margin towards the Adriatic margin of the mountain chain, reflects the time-space migration of the compressional deformation in the Apennines from the internal (south-western) to the external (north-eastern) paleogeographic domains. Figure 5 is a palinspastic sketch of the Southern Apennine depositional realms in late Jurassic-Cretaceous times. In the picture, the trace of the line CROP 04 plotted on a restored section is also indicated.

Tectonic shortening and nappe stacking in the Southern Apennines took place principally in Miocene times. In the early Pliocene, the entire pile of nappes overthrust the Apulia-Platform carbonates before the latter began to be involved in the compressional deformation. In late Pliocene and early Pleistocene times, finally, the Apulia carbonates too were affected by compressional deformation. Tectonic shortening produced duplex structures in the Apulia carbonates and a forward (north-eastward) displacement of the allochthonous sheets by about 30 kilometres. In addition, duplex-breaching processes irregularly alternating with the forward nappes transport caused important re-imbrications of the allochthonous sheets and generation of huge antiformal stacks in the roof units of the Apennine system (Patacca and Scandone 2001).

In the Apennine mountain chain, the Mesozoic-Tertiary carbonates of the buried duplex system represent the main target of petroleum research. Due to extensive exploration in the region, considerable information on the thrust-belt subsurface structure is available. At the time in which line CROP 04 was planned, knowledge of the subsurface features, together with the stratigraphic and structural information derived from the surface regional geology, made the construction of realistic geological profiles across the thrust belt-foredeep-foreland system down to a depth of 8-10 kilometres possible. At greater depths, the interpretation of the tectonic structures was mostly based on the analysis of gravimetric and magnetic anomalies, as well as on a few constraints derived from scattered experiments of deep seismic soundings (see, among many others, Arisi Rosa and Fichera 1987; Cassano *et al.* 2001; Scarascia *et al.* 1994). Presently, line CROP 04 allows the interpretation

Figure 2 - Scheme of the internal geometry of the mountain chain in the visited segment. Colours as in Figure 1. After Patacca and Scandone (2004 a).

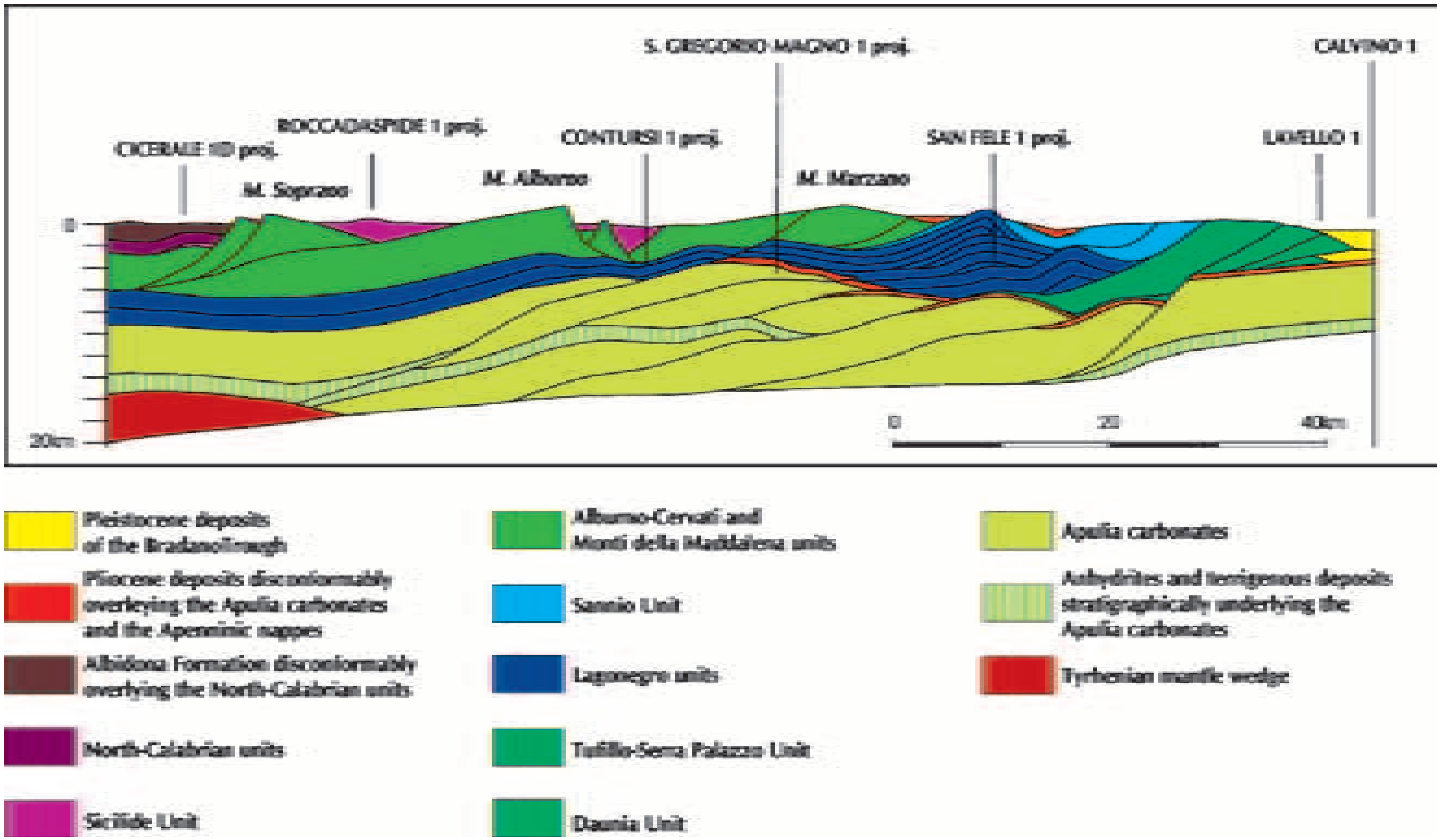


Figure 3 - Simplified geological section across the Southern Apennines along the line CROP 04. After Patacca et al. (2000) with some modifications.

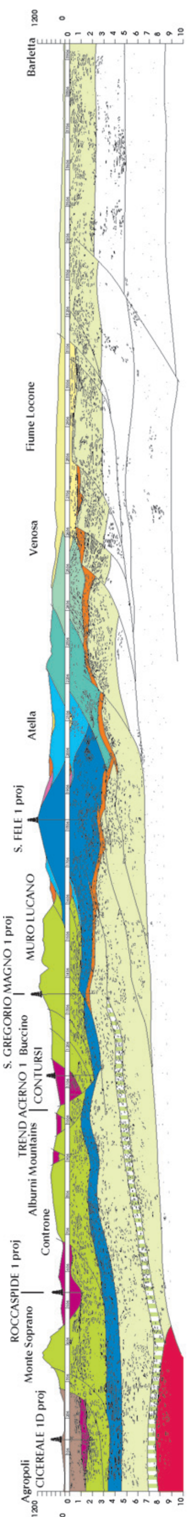


Figure 4 - Interpreted line drawing of the line CROP 04. Colours as in Figure 3 with the exception of the North-Calabrian Unit, the Sicilide Unit and the Albidona Formation that have been grouped. After Patacca and Scandone (2004 b) with slight modifications.

of the subsurface structural features down to 8-10 seconds TWT, which correspond in the thrust belt to a depth of 20-25 kilometres

Following the planned itinerary, the field trip moves from the Tyrrhenian coast, that is from quite internal regions of the Apennine thrust belt, towards the Adriatic coast, that is towards the stable Apulia foreland. However, a description of the principal features represented in figures 3 and 4 moving from the autochthonous carbonates of the foreland region towards more complex tectonic structures in the thrust-belt probably represents a more friendly approach for a visitor not familiar with Apennine geology.

Starting from the Apulia foreland and moving towards SW, the CROP 04 line cuts across the front of the Apenninic chain and the adjacent Plio-Pleistocene foredeep basin. Figure 6 is a line drawing of a commercial line located a few kilometres NW of the line CROP 04 that shows the Apennine frontal thrust and the Bradano foredeep basin in some detail. The autochthonous carbonates of the Apulia Platform form a sort of homocline gently dipping towards the SW beneath the Apenninic nappes. The front of the mountain chain is represented by a steep frontal ramp with a vertical displacement exceeding 1000 metres. The Plio-Pleistocene sediments filling the foredeep basin have been divided into pre-ramp, syn-ramp and post-ramp deposits on the base of their relations with the front of the Apenninic nappes. Well-exposed sections of Pleistocene clays, sands and conglomerates representing the prograding, uppermost portion of the post-ramp deposits will be visited in Day 5.

Between the Apennine front and the Ofanto Valley, the line CROP 04 cuts across a number of tight imbricates basically made up of Miocene basinal deposits referable to the Daunia and Tufillo-Serra Palazzo units. The Tufillo-Serra Palazzo Unit, in addition, is tectonically overlain by the Sannio Nappe. The tectonic superposition of the Sannio Unit on the Tufillo-Serra Palazzo one and the imbricate structures in the Tufillo-Serra Palazzo and Daunia deposits will be observed during Day 5 along a section located about 20 kilometres SE of the line CROP 04.

South of the Ofanto Valley, the line CROP 04 cuts across an important tectonic structure in the allochthonous sheets represented by a huge antiformal stack made up of at least seven imbricates of rock units referable to the Lagonegro Nappe. The antiformal stack has been explored by the San Fele 1 well, which reached a depth of 5315 metres before being abandoned in the middle Triassic deposits of the Monte Facito Formation (Lagonegro Unit II). The buried Apulia carbonates, not reached by the borehole, are supposed to form a ramp anticline beneath the antiformal stack at a depth exceeding 3 seconds TWT. Figure 7 is a simplified log of the San Fele 1 well. The San Fele antiformal stack will be visited on Day 4.

West of San Fele, the buried Apulia carbonates form as a whole an antiformal structure that reaches its culmination in correspondence to the Monte Marzano massif. The top of the carbonates rises from a depth likely exceeding 5000 metres below sea level in correspondence to San Fele to a depth slightly exceeding 3000 metres in correspondence to Monte Marzano. Figure 8 shows a simplified log of the San Gregorio Magno 1 well that crossed the Monte Marzano carbonates and the underlying Lagonegro deposits and reached the Mesozoic Apulia carbonates of the buried duplex system. We have related the growth of the antiformal structure to an important shortening in the Apulia carbonates.

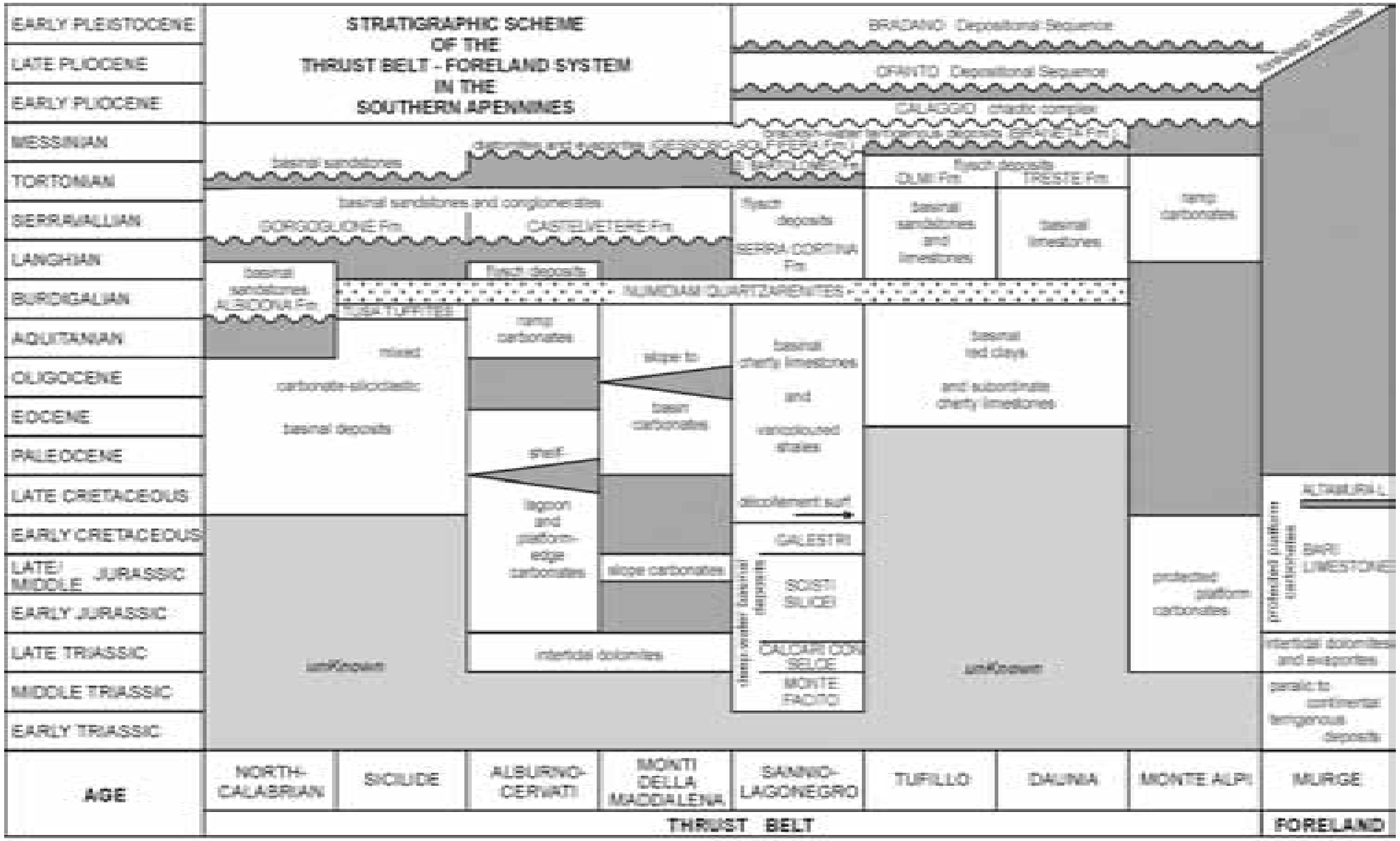


Table 1. Depositional characteristics and age of the stratigraphic sequences characterising the tectonic units and the thrust-top deposits observed in the field trip. The age of the unconformity at the base of the thrust-top deposits, becoming younger from the Tyrrhenian margin towards the Adriatic margin of the mountain chain, reflects the time-space migration of the compressional deformation in the Apennines from the internal (south-western) to the external (north-eastern) paleogeographic domains. After Patacca and Scandone (2004 a), with references therein.

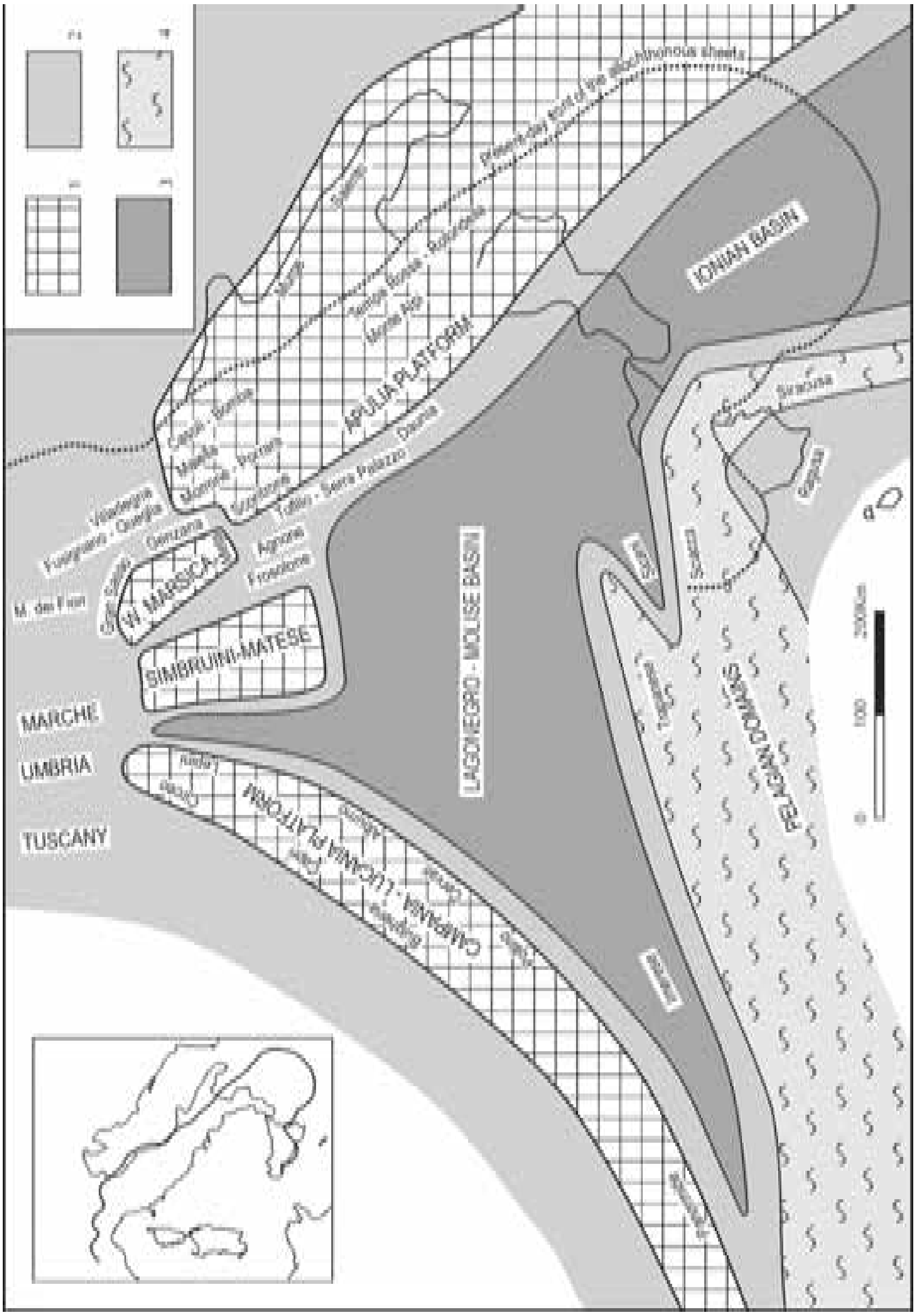


Figure 5 - Palinspastic sketch of the Southern Apennine paleogeographic realms in late Jurassic-Cretaceous times and trace of the line CROP 04 in a restored cross section. After Patacca and Scandone (2003) with slight modifications.

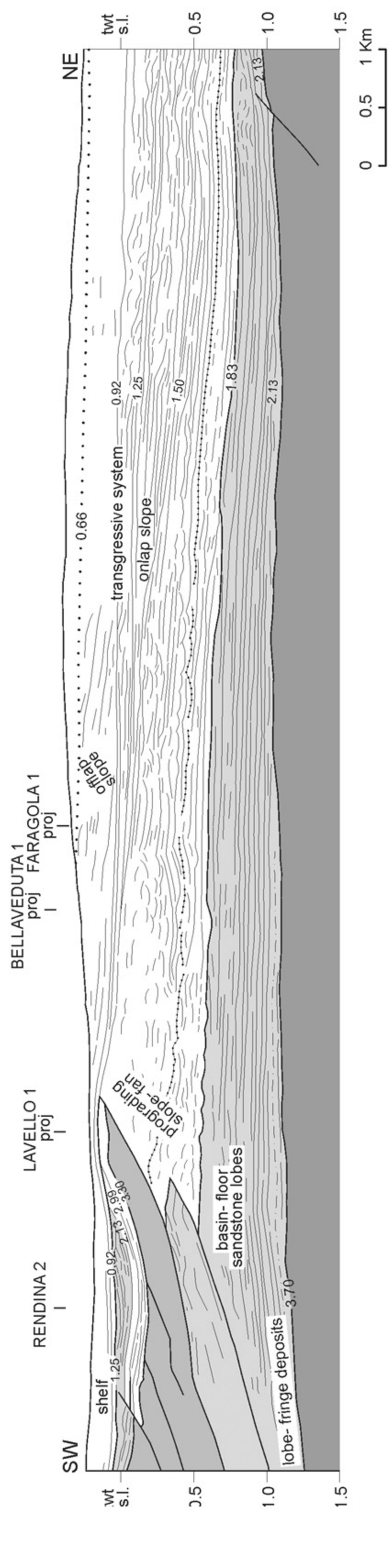


Figure 6 - Line drawing of a seismic profile cutting across the front of the Apenninic chain a few kilometres NW of the line CROP 04. Depths in seconds TWT. After Patacca and Scandone (2001) with slight modifications.

The well-structured package of high-frequency/low-amplitude reflectors that deepen from about 4.5 seconds TWT beneath the southern slope of Monte Marzano to about 7 seconds beneath the southern flank of Monte Alburno corresponds, in our opinion, to the Triassic-Permian terrigenous deposits that stratigraphically underlie the Apulia carbonates (see Puglia 1 well in the foreland belt) transported in the hangingwall block of the aforementioned thrust. Whatever the interpretation of these reflectors may be, they mark in any case a geological object that has been involved in the compressional deformation and has been incorporated in the thrust belt. Consequently, they constrain the Apennine base-thrust at a depth of about 8 seconds TWT that corresponds, in a depth-converted section, to a depth perhaps exceeding 20 kilometres.

Another important feature present in the western part of the CROP 04 profile is represented by a thick package of continuous, strong reflectors below the Alburno-Cervati carbonates. This package, roughly parallel to the top of the buried Apulia carbonates, is quite evident between the western termination of the seismic line and the northern margin of Monte Alburno at depths ranging from 3-4 seconds to 1-2 seconds TWT. Based on regional considerations, we have attributed these reflectors to the Lagonegro basinal deposits. This interpretation is strongly supported by the stratigraphy of the Acerno 1 well, which crossed more than 3500 metres of basinal deposits referable to the Lagonegro units before reaching the Apulia-carbonate duplex system. Acerno1 is located near the northern border of the Campagna tectonic window, about 20 Kilometres NW of the CROP-04 line and may be projected on our profile in correspondence to the northern margin of Monte Alburno.

Other schemes available in recent geological literature (e.g. Menardi Noguera and Rea 2000, Mazzoli *et al.* 2001) postulate quite a modest horizontal displacement of the buried Apulia carbonates. In our structural reconstruction, on the contrary, a telescopic shortening of several tens of kilometres is required in late Pliocene and early Pleistocene times in order to justify the forward transport of the Apenninic nappes on the upper Pliocene-lower Pleistocene deposits of

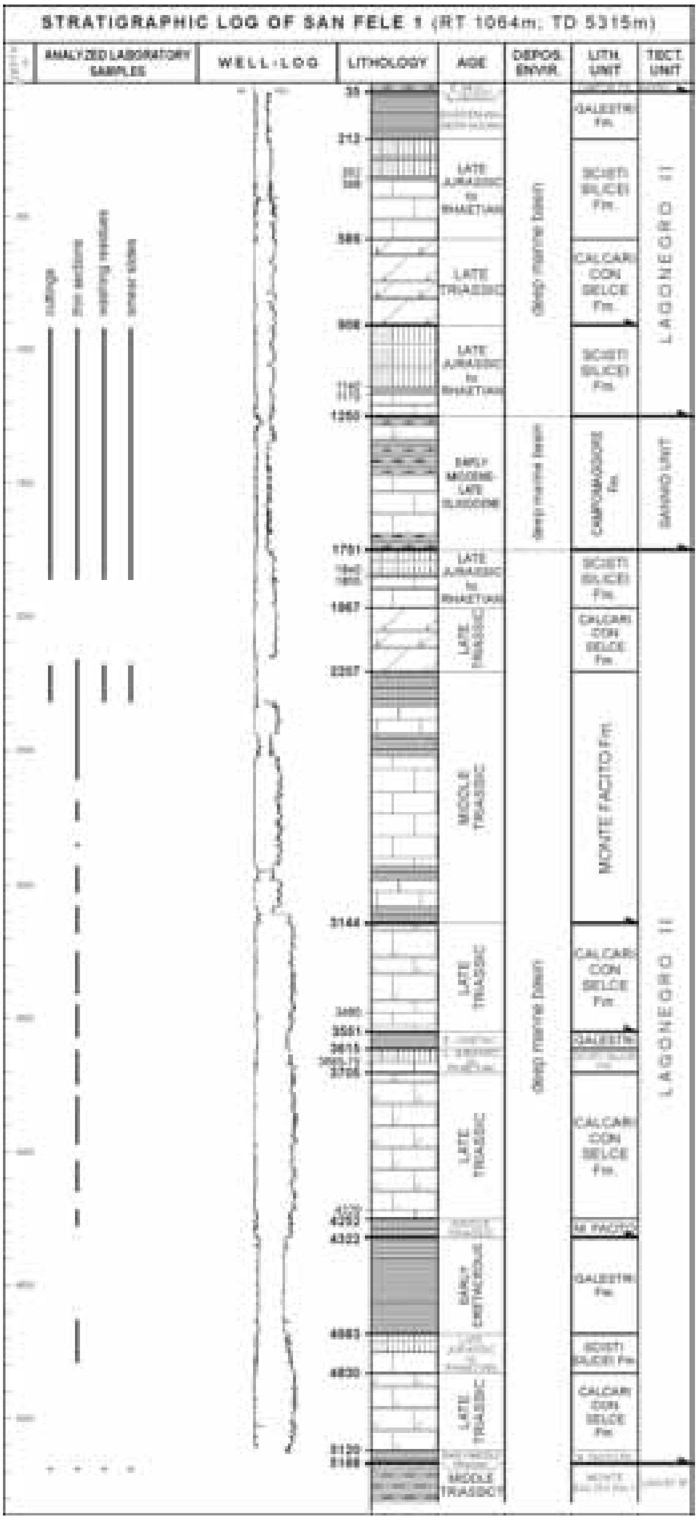


Figure 7 - Simplified log of the San Fele 1 well (T.D. 5315 m).

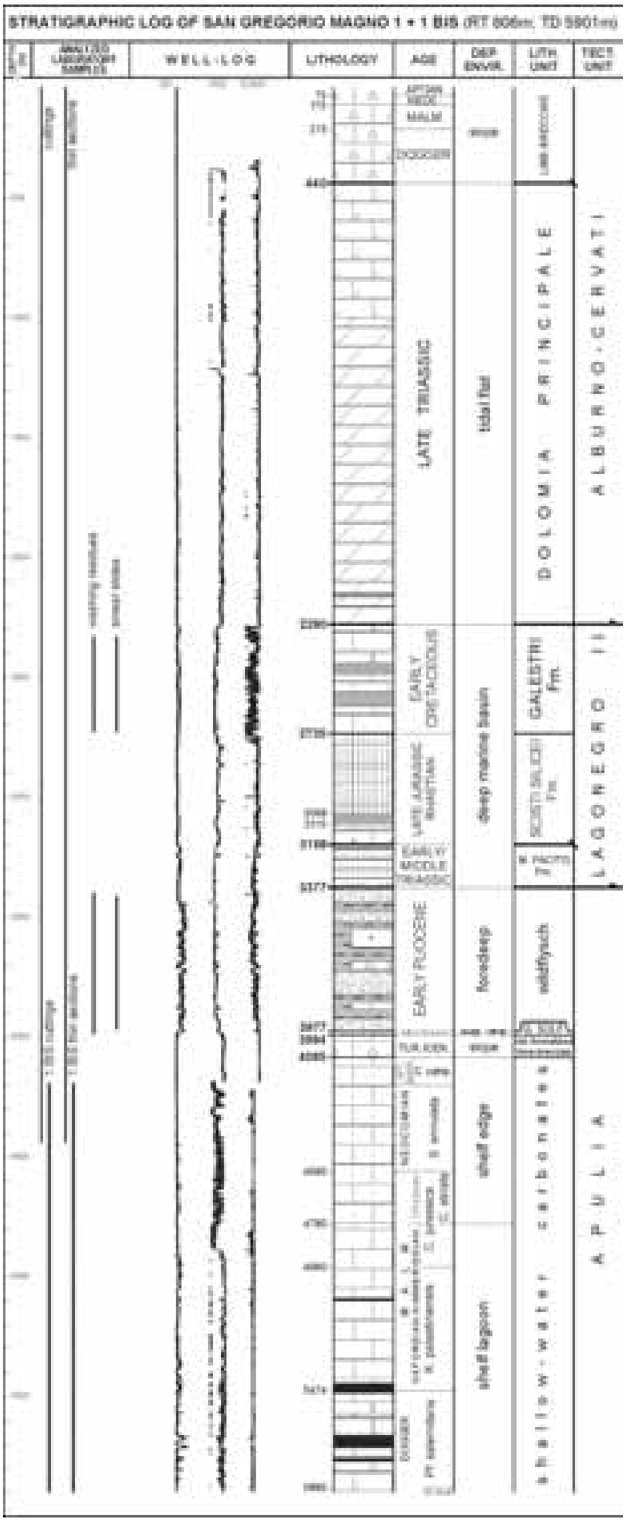


Figure 8 - Simplified log of the San Gregorio Magno 1 well (T.D. 5901 m).

the foredeep basin, the growth of huge antiformal stacks in the roof units of the duplex system and the generation of tight imbricates in the Sannio, Tufillo-Serra Palazzo and Daunia units along the outer (north-eastern) margin of the mountain chain.

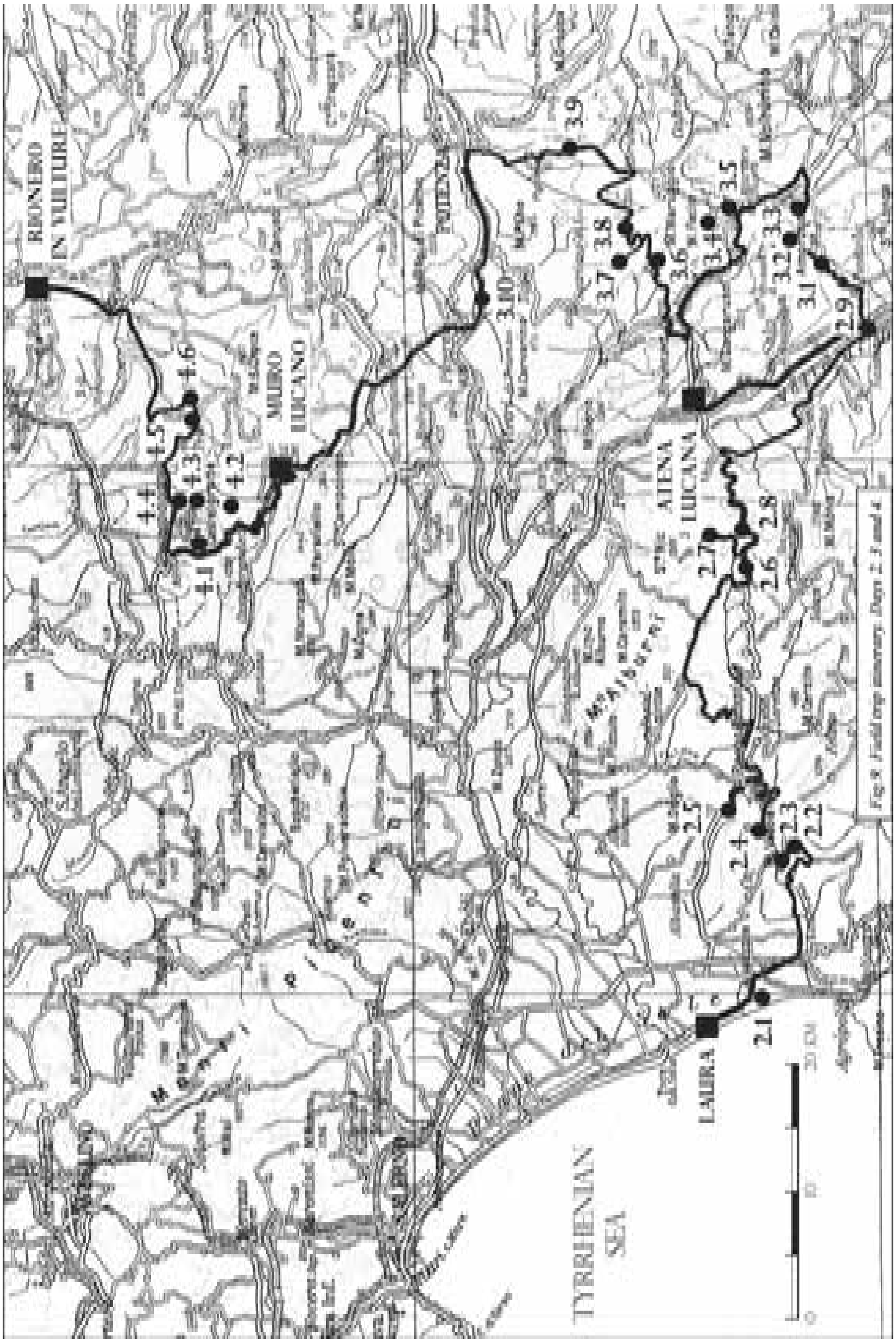
Field itinerary

DAY 1

Transfer from Florence to Paestum. Visit to the Paestum archeological sites. Paestum, the ancient Poseidonia dedicated to Poseidon (the Latin Neptune, the god of sea), was founded around 600 b.C. as a colony of Sybaris, important city of Magna Grecia on the Ionian Sea. Paestum is entirely surrounded by defensive walls made up of Quaternary travertine, a stone also used for the Doric temples and for all other preserved buildings. Among the major monuments, there is the so-called Basilica, or Temple of Hera I (Hera was the wife of Zeus, king of the gods), built around 550 b.C., the Temple of Athena, also called Temple of Ceres, built around 500 b.C. and the Temple of Hera II, also called Temple of Neptune, erected about 470/460 b.C.
Dinner and overnight stay in Paestum (Laura).

DAY 2

Paestum (Laura) – Giungano – Trentinara – Roccadaspide – Acquara - Sant'Angelo a Fasanella - Passo della Sentinella - San Rufo - Atena Lucana (about 150 kilometres, Figure 9).
Departure at 8 o' clock. Dinner and overnight stay in Atena Lucana.
Mesozoic-Tertiary carbonates of the Alburno-Cervati Unit. Relationships between the Alburno-Cervati Unit and thrust sheets of more internal (western) provenance (Sicilide Unit, North-Calabrian


RIONERO IN VULTURE
MURO LUCANO
ATENA LUCANA
LAURA
TYRRHENIAN SEA
4.1
4.2
4.3
4.4
4.5
4.6
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2.9

Unit and overlying Albidona Formation) cropping out in the Monte Sottano, Monte Soprano and Alburno areas. Relationships between the Alburno-Cervati plus Monti della Maddalena units and the Lagonegro units.

Stop 2.1:

Paestum, Porta Marina.

Panoramic view of the Monte Soprano-Monte Sottano mountains (Mesozoic-Tertiary carbonates of the Alburno-Cervati Unit) and of the Cicerale-Agropoli hills (lower Miocene terrigenous deposits of the Albidona Formation and underlying North-Calabrian Unit).

The Monte Soprano and Monte Sottano structures have been interpreted as different portions of a WNW-ESE-trending ramp anticline developed in the Alburno-Cervati carbonates. The forelimb and the axial part of the fold (Monte Soprano and Monte Sottano respectively) are separated by a WNW-ESE high-angle fault that dips towards SSW. A second SSE-dipping normal fault separates the Monte Sottano carbonates from terrigenous deposits referable to allochthonous sheets of more internal (western) provenance (North-Calabrian Unit and associated Albidona thrust-top deposits). Because of this fault, the Alburno-Cervati carbonates cropping out in the Monte Soprano-Monte Sottano anticline have been downthrown in the subsurface of the Cicerale-Agropoli hills with a vertical displacement exceeding 3000 metres. The Cicerale 1 well, located at about 5 kilometers from the fault trace, encountered the top of the carbonates at 3345 metres, corresponding to 2432 metres below sea level.

Between Stop 2.1 and Stop 2.2 the road runs along the margin of the Sele coastal plain until it reaches the upper Cretaceous limestones of the Monte Sottano structure after having crossed some poorly exposed outcrops of terrigenous deposits belonging to the lower Miocene Albidona Formation.

Stop 2.2:

Road Giungano-Trentinara, Madonna di Loreto.

Protected-platform limestones of the Monte Sottano structure (Coniacian-Santonian). Along the road, well-exposed section of rudistid floatstones organized in lens-shaped biostromes irregularly alternating with usually barren, laminated mudstones and wackestones.

Stop 2.3:

Trentinara village.

Shelf-lagoon Paleocene-Eocene deposits of the Trentinara Formation in the type locality. The section consists of lime wackestones with ostracods and charophytes, green nodular marls, solution breccias and subordinate packstones with *Alveolina* and *Spirolina*. The disconformable contact between the Paleocene limestones of the Trentinara Formation and the Coniacian-Santonian rudistid limestones is well exposed along the road. The uppermost portion of the rudistid limestones is characterized by the presence of red soils testifying to repeated emersions and stratigraphic hiatuses.

Between Stop 2.3 and Stop 2.4 the road cuts across the fault separating Monte Sottano from Monte Soprano and reaches the Cretaceous limestones exposed in the Monte Soprano structure.

Stop 2.4:

Parco delle Due Nevere, Monte Vesole Pass between Trentinara and Roccadaspide.

Panoramic view on the Alburni Mountains and on the Calore Valley. The Alburni Mountains form a SSW-dipping homocline slightly disturbed by WNW-ESE-trending normal faults. Along the southern margin of the homocline, the Alburno-Cervati carbonates (upper Cretaceous rudistid limestones, Paleocene-lower Eocene limestones of the Trentinara Formation and middle Eocene nummulitic limestones are tectonically overlain by allochthonous sheets referred to the Sicilide Unit. The allochthonous sheets reach their maximum thickness in the core of a synform developed with a WNW-ESE direction between the southern termination of the Alburni homocline and the northern foot of the Monte Soprano anticline. The Roccadaspide 1 well, located in the axis of the synform, penetrated 695 metres of Paleogene clays, marls, siliciclastic calcarenites and sandstones referable to the Corleto Perticara Formation before reaching lower Miocene limestones belonging to the Alburno-Cervati Unit at a depth of 278 metres below sea level.

Stop 2.5:

Quarry near Roccadaspide.

Well-exposed section in the lower Miocene Roccadaspide Formation showing cross-bedded glauconitic calcarenites with *Miogypsina*, deposited on a shallow carbonate ramp.

Between Stop 2.5 and Stop 2.6 the road cuts across the synform between Monte Soprano and Monte Alburno running in poorly exposed siliciclastic deposits of the Sicilide Unit (Corleto Perticara Formation, lower Miocene-Paleogene) until it reaches the Cretaceous-Tertiary platform limestones belonging to the southern margin of the Alburno structure.

Stop 2.6:

Road Corleto Monforte-San Rufo, Tempa della Serra.

Panoramic view on the carbonate massifs of Serra Nuda (southeastern margin of the Alburni Mountains), Monte Cocuzzo delle Puglie and Montagna della Mutola. The tectonic structure of this area is quite a bit more complex than that observed in the Monte Soprano-Monte Alburno region. In this area, in fact, the SSW-dipping termination on the Alburni homocline is laterally replaced by NNE-dipping structures (Serra Nuda-Cocuzzo delle Puglie and Montagna della Mutola) related to the development of backthrusts emanating from intracutaneous triangle zones. The southeastern continuation of the Monte Soprano-Monte Sottano structure is most likely represented by the Monte Cervati anticline.

Stop 2.7:

Costa dell'Icchio, Casone Acqua di Rugna.

In this locality, as in other areas of the Alburni Mountains, middle Miocene terrigenous deposits unconformably overlie the Mesozoic-Tertiary carbonates of the Alburno-Cervati Unit already affected by tectonic deformation and karstification. The terrigenous deposits, in turn, are tectonically overlain by the Sicilide Nappe. The terrigenous sequence of Acqua di Rugna represents a thrust-top deposit post-dating the incorporation of the Campania-Lucania Platform in the Apennine thrust belt and pre-dating the transport of the Sicilide Nappe over the Alburno-Cervati Unit.

Stop 2.8:

Road Passo della Sentinella-San Rufo.

Outcrop of polygenic conglomerates dubitatively attributed to the late Pliocene. The possible occurrence of upper Pliocene terrigenous deposits in the Alburni region is very important for establishing the beginning of the extensional faulting along the Tyrrhenian slope of the chain and the consequent change of the drainage.

Between Stop 2.8 and Stop 2.9, the road runs across the Cretaceous limestones of the Alburno-Cervati Unit. From the road, fine panoramic views of Monti della Maddalena, type locality of the Monti della Maddalena Unit, and of Vallo di Diano. The latter is a middle Pleistocene lacustrine basin eastward limited by an extensional WSW-dipping master fault.

Stop 2.9:

Road Sassano-Padula, bridge on the Tanagro River near Ascolese.

Panoramic view of the Padula tectonic window. In this window, upper Triassic-lower Cretaceous basinal deposits of the Lagonegro Unit II crop out below upper Triassic shallow-water dolomites and below Jurassic-lower Miocene slope-to-basin carbonate resediments belonging to the Monti della Maddalena Unit.

DAY 3

Atena Lucana – Padula – Paterno – Marsico Nuovo – Sasso di Castalda – Pignola – Baragiano Scalo – Muro Lucano (about 185 kilometres, Figure 9).

Departure at 8 o' clock. Dinner and overnight stay in Muro Lucano.

Lagonegro Unit II in the Padula tectonic window. Thrust of the Monti della Maddalena carbonates on the Lagonegro basinal deposits in the High Agri Valley and in the Melandro Valley. Tectonic structures and stratigraphic sections in the Lagonegro Unit II and LagonegroUnit I.

From Atena Lucana to Padula, panoramic views on the carbonate massifs of the Alburno-Cervati Unit west of Vallo di Diano. From Padula to Mandrano, basinal deposits of the Lagonegro Unit II (Scisti Silicei and Galestri formations) underlying upper Triassic shallow-water dolomites and upper Cretaceous lime breccias and calciturbidites belonging to the Monti della Maddalena Unit.

Stop 3.1:

Campo di Mandrano.

Panoramic view of the eastern margin of the Padula tectonic window where Rhaetian shallow-water dolomites tectonically overlie lower Cretaceous basinal deposits (Galestri Formation) of the Lagonegro Unit II.

Between Stop 3.1 and Stop 3.2 the road runs in Rhaetian shallow-water dolomites of the Monti della Maddalena Unit. Panoramic views of the High Agri Valley.

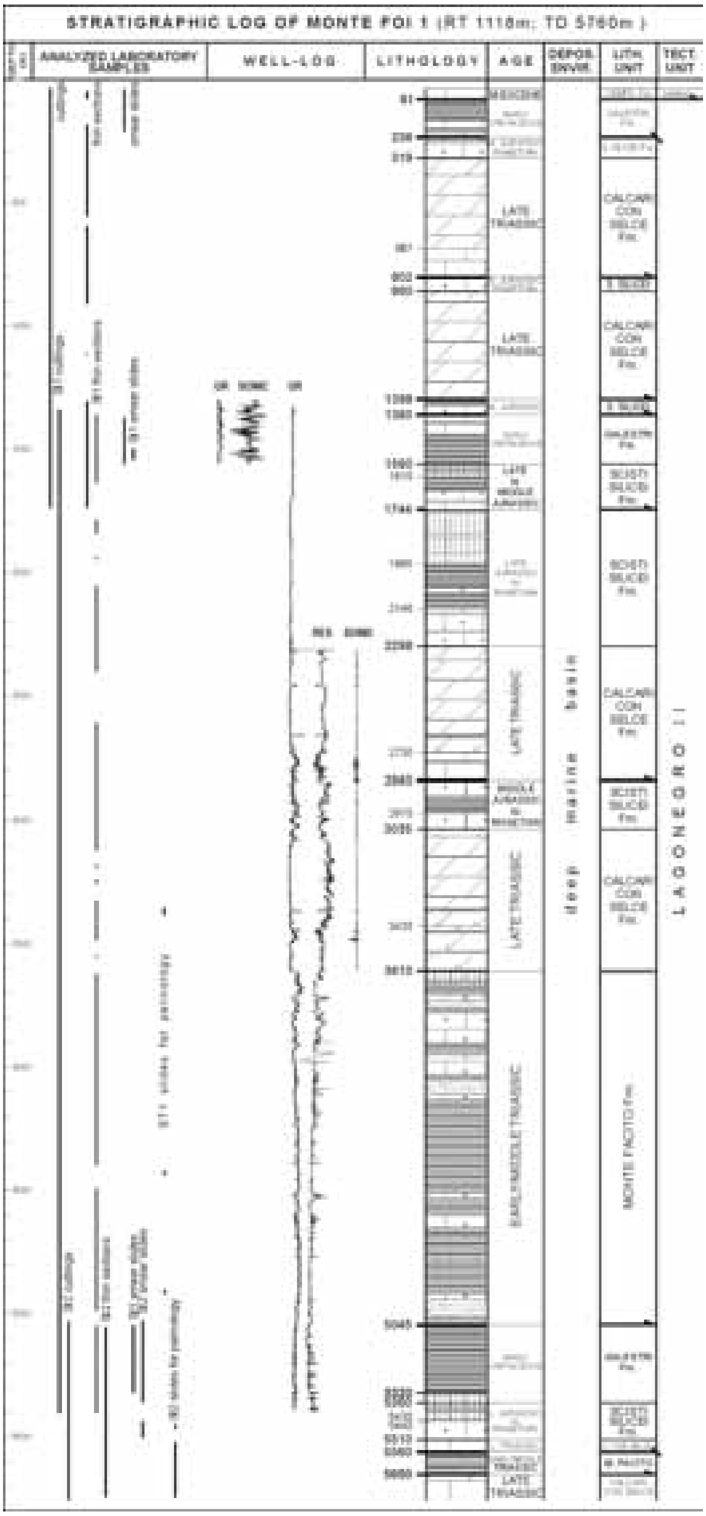

Figure 10 - Simplified log of the Monte Foi 1 well (T.D. 5760 m).

Stop 3.2:

Road Mandrano-Paterno.

Frontal thrust of the Monti della Maddalena Unit above the Lagonegro Unit II. The thrust surface dips westwards with an angle of about 20°. The hangingwall block is made up of shallow-water Rhaetian dolomites; the footwall is made up of lower Cretaceous shales of the Galestri Formation and of Jurassic radiolarites of the Scisti Silicei Formation. In addition, tectonic slices of Cretaceous-Miocene basinal deposits are sandwiched along the contact. These deposits (exposed in more complete sections in the region visited during Day 3) were originally part of the Lagonegro sequence. Subsequently, during the middle/late Miocene, they were detached from the original Lagonegro substratum. Presently, the detached upper portion of the Lagonegro sequence forms a nappe (Sannio Unit) structurally independent from the Lagonegro one.

Stop 3.3:

Road Mandrano-Paterno, near the Paterno cemetery.

Panoramic view of the High Agri Valley tectonic window. In this window, the entire stratigraphic sequence of the Lagonegro Unit I (Calcari con Selce, Scisti Silicei and Galestri formations) is widely exposed in N-S trending anticlines (Monte Vulturino, Monte San Nicola, Serra di Calvello-Monte Calvelluzzo and Monte Lama). All around the aforementioned anticlines, the Galestri Fm of the Lagonegro Unit I is tectonically overlain by the Monte Facito and

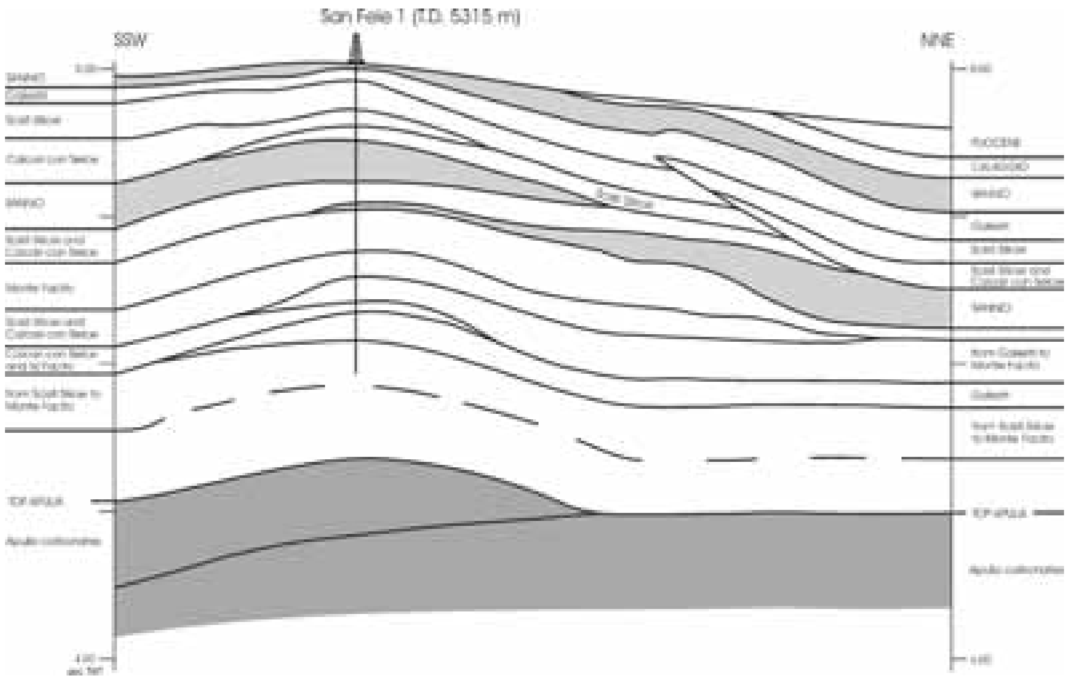

Figure 11 - Internal geometry of the San Fele antiformal stack based on the interpretation of a seismic line cutting across the structure and on the stratigraphy of the San Fele 1 well. Depths in seconds TWT.
After Patacca and Scandone (2004 b).

Calcari con Selce formations of the Lagonegro Unit II. The Lagonegro Unit II is widely exposed along the foot of the Maddalena Mountains from Grumento Nova to Marsico Nuovo, at Monte Facito- Monte Arioso and in the Monte Sant'Enoc-Monte Caldarosa anticlines. The deposits of the Lagonegro Unit II, in turn, are tectonically covered by the carbonates of the Monti della Maddalena and Alburno-Cervati units along the western margin of the window, and by siliciclastic deposits belonging to the Sicilide Unit (plus overlying Gorgoglione Formation) and to the North-Calabrian Unit (plus overlying Albidona Formation) along the eastern margin of the window. The Madonna di Viggiano carbonates, between Monte Vulturino and Monte Sant'Enoc, represent a Klippe of the Alburno-Cervati Unit. The Klippe is separated from Monte Volturino and Monte Corno by a low-angle normal fault dipping towards SE.

Stop 3.4:

Road Marsico Nuovo-Pietra Maura.

Middle Triassic Monte Facito Formation (lower portion of the Lagonegro Unit II) tectonically overlying the lower Cretaceous Galestri Formation of the Lagonegro Unit I. In the outcrop visited, the Monte Facito Formation is represented by chaotic deposits including algal-reef limestones, turbiditic sandstones, pebbly mudstones and radiolarites.

Stop 3.5:

Monte Cugnone, Torrente Occhio quarry.

Artificial section of *Halobia*-bearing cherty limestones (Calcari con Selce Formation) of the Lagonegro Unit I. In the quarry, the uppermost portion of the cherty limestone is also exposed, with the gradual transition between the upper Triassic Calcari con Selce Formation and the Jurassic Scisti Silicei Formation.

Between Stops 3.5 and 3.6 the road runs in the Lagonegro Unit II, except for a short tract between Marsico Nuovo and Pergola in which it crosses the front of the Monti della Maddalena carbonates. The latter are locally constituted of upper Cretaceous to lower Miocene coarse-grained lime resediments.

Stop 3.6:

Sasso di Castalda.

Panoramic view of the Sasso di Castalda anticline

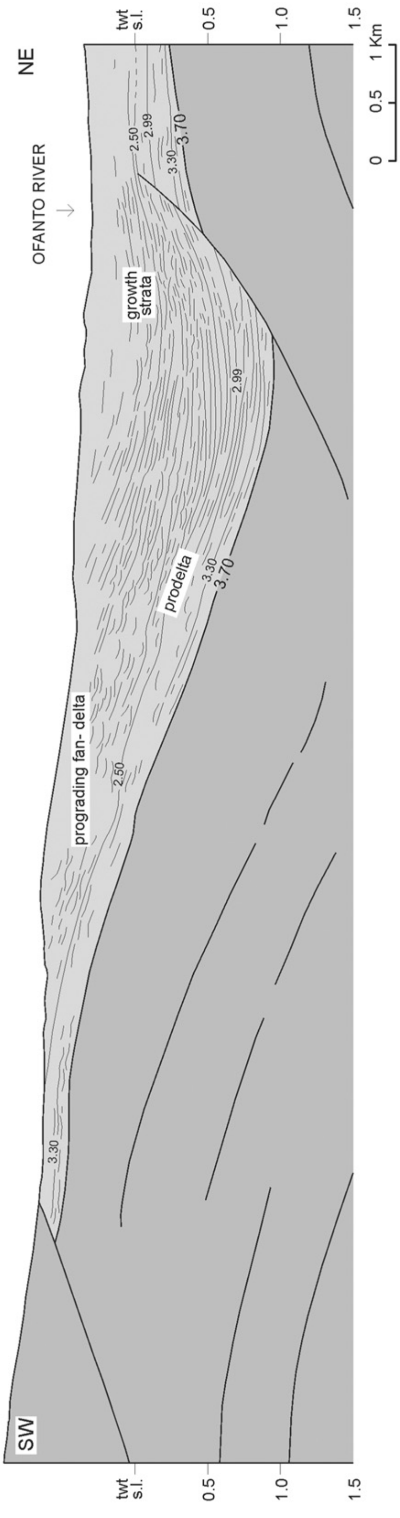

Figure 12 - Line drawing of a commercial line showing the overall wedge-shaped geometry of the upper Pliocene terrigenous deposits filling the Ofanto piggy-back basin in front of the San Fele antiformal stack. Depths in seconds TWT. After Patacca and Scandone (2001) with slight modifications.

with a good exposure of the Calcari con Selce, Scisti Silicei and Galestri formations of the Lagonegro Unit I. The Galestri shales of the Lagonegro Unit I are tectonically overlain by the Monte Facito Formation and by the Calcari con Selce Formation of the Lagonegro Unit II. Along the road, outcrop of radiolarites (upper part of the Scisti Silicei Formation of the Lagonegro Unit I) grading upwards into grey shales with intercalations of siliceous calcilutites (Galestri Formation).

Stop 3.7:
Fontana Cesine.

Panoramic view of the Monte Facito Formation exposed at La Cerchiara-Schiena Rasa from the northeastern border of the Sasso di Castalda tectonic window. Along the road, Galestri Formation of the Lagonegro Unit I.

Between Stops 3.7 and 3.8, the road cuts across the contact between the two Lagonegro units and runs in chaotic deposits of the Monte Facito Formation (Lagonegro Unit II) locally overlain by more or less dolomitized cherty limestones of the Calcari con Selce Formation.

Stop 3.8. :
La Cerchiara.

Well-exposed outcrops of the Monte Facito Formation. In the Cerchiara area, the chaotic complex includes huge blocks of algal limestones, calcarenites with ripple cross-lamination associated with red shales, turbiditic sandstones and siltstones, radiolarites, pebbly mudstones, calcareous microbreccias with reworked Permian microfossils and mafic pillow lavas. The algal-reef limestones are often crossed by sedimentary dykes of yellowish and pinkish marls and marly limestones with pelagic pelecypods and subordinate ammonites. In addition, Ammonitico-Rosso-type nodular limestones often encrust the top of the reefs. Along the road, the Monte Facito Formation is overlain by the Calcari con Selce Formation. In this outcrop, however, the original stratigraphic contact has been substituted by a décollement surface. In the lower part of the Calcari con Selce Formation, a key

horizon characterized by tuffitic green shales with *Halobia superba* is also present.
Between Stop 3.8 and Stop 3.9 the road cuts across different terms of the Lagonegro Unit II.

Stop 3.9:

Road La Sellata-Pignola

Well-exposed section in the Calcari con Selce Formation of the Lagonegro Unit II, from the tuffite horizon with *H. superba* to the conformable contact with the overlying Scisti Silicei Formation. Along the road, dolomitization features in the cherty calcilutites of the Calcari con Selce Formation.
Between Stop 3.9 and Potenza, well-exposed sections in the Scisti Silicei and Galestri formations. Near Potenza, upper Pliocene terrigenous deposits unconformably overlie the Lagonegro Unit II, the Sicilide Unit and the Sannio Unit.

Stop 3.10:

Road Potenza-Balvano (Basentana Highway).

Panoramic view of the Li Foi di Picerno anticline made up of radiolarites and shales of the Scisti Silicei and Galestri formations of Lagonegro Unit II. The Scisti Silicei and Galestri deposits cropping out at Li Foi constitute the uppermost part of a huge antiformal stack made up of at least seven imbricates, all referable to Lagonegro Unit II. The antiformal stack was explored by the Monte Foi 1 well, which was abandoned in the Lagonegro stack at 5760 m without having reached the buried
Apulia carbonates. Figure 10 is a simplified log of Monte Foi 1. The Li Foi di Picerno antiformal stack is the southern continuation of the San Fele structure, which has been explored by the San Fele 1 well and has been crossed by the seismic line CROP 04. It is interesting to observe that south of Monte Li Foi the telescopic shortening in the Lagonegro Unit II related to the duplexing of the allochthonous sheets has been almost entirely transferred to the Apulia carbonates with the creation of important horse imbrications. As a consequence of the different thrust array, the top of the Apulia carbonates, lying at depths exceeding 5000 metres b.s.l. in the San Fele-Picerno region, is uplifted to less than 2000 metres b.s.l. in the High Agri Valley.
Between Stop 3.10 and Muro Lucano, outcrops of upper Pliocene thrust-top deposits and panoramic views of Monte Marzano (Alburno-Cervati Unit) and of the Muro Lucano-Castelgrande mountains (Monti della Maddalena Unit).

DAY 4

Muro Lucano – Castelgrande – Monte Carruozzo – Toppo di Castelgrande – Pescopagano - Rapone – San Fele – Atella – Rionero in Vulture (about 100 kilometres, Figure 9).
Departure at 8 o' clock. Dinner and overnight stay in Rionero in Vulture.
Middle Miocene thrust-top deposits of the Castelvetere Formation unconformably overlying the Alburno-Cervati and Monti della Maddalena carbonates. Section in the Sannio Unit. Relationships between the Sannio Unit and the Lagonegro Unit II in the Pescopagano area. San Fele antiformal stack and stratigraphic section in the Calcari con Selce and Scisti Silicei formations of the Lagonegro Unit II. Upper Pliocene thrust-top deposits unconformably overlying the San Fele antiformal stack.
From Muro Lucano to Castelgrande and to Monte Carruozzo, the road runs in upper Jurassic-upper Cretaceous lime breccias of the Monti della Maddalena Unit and in middle Miocene terrigenous deposits referable to the Castelvetere Formation.

Stop 4.1:

Monte Carruozzo.

Well-exposed outcrop of coarse-grained sandstones of the Castelvetere Formation with blocks of Cretaceous protected-platform limestones, namely lower
Cretaceous Requienia-bearing limestones, derived from the Alburno-Cervati Unit.

Stop 4.2:

Road Monte Carruozzo-Toppo di Castelgrande.

Coarse-grained sandstones and polygenic conglomerates of the Castelvetere Formation. The pebbles of the conglomerate include protected-platform Mesozoic limestones, platform-edge *Orbitolina* limestones of early Cretaceous age, slope-to-basin lime breccias and calcarenites with *Orbitoides* and *Siderolites* of Campanian-Maastrichtian age, basinal siliceous limestones, green cherts, coarse-grained lithic sandstones, granites, acidic and mafic volcanites and low-grade metamorphites.

Stop 4.3:

Toppo di Castelgrande.

Panoramic view of the Monte Marzano Mesozoic carbonates, of the Castelvetere Formation and of the Sannio Unit. Well-exposed section in Cretaceous-Tertiary basinal deposits of the Sannio Unit in the Lago Saetta area.

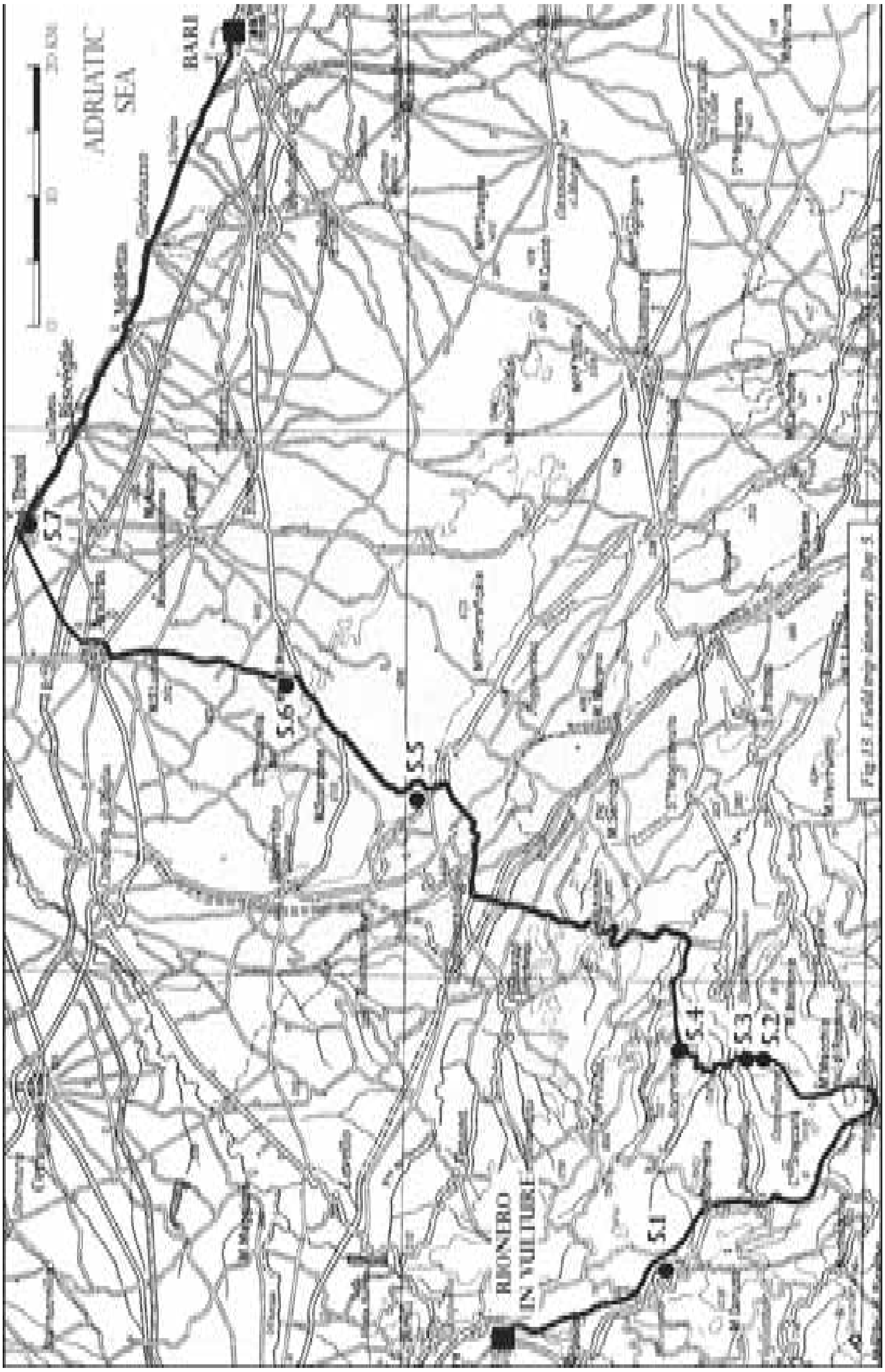

Fig.13 Field trip itinerary - Day 5

Stop 4.4:
Madonna di Montemauro, near Lago Saetta.

Panoramic view of the upper Pliocene terrigenous deposits of the Ofanto synform. Outcrop of radiolarites (Scisti Silicei Formation) of the Lagonegro Unit II emerging from the Sannio deposits in a narrow anticline that represents an axial culmination of the northward continuation of the San Fele antiformal stack.

After Stop 4.4 the road runs prevalently in the upper Cretaceous-lower Miocene deposits of the Sannio Unit. Between Pescopagano and San Fele, panoramic views of the Ofanto synform and of the San Fele anticline. As in the case of the Li Foi di Picerno structure, the San Fele anticline is the emergence of a huge antiformal stack in the Lagonegro deposits constituted of at least seven imbricates. The stack has been penetrated by the San Fele 1 well. Figure 11 is an interpretation of the tectonic structure based on a commercial seismic line cutting across the antiformal stack and on the stratigraphy of the San Fele 1 well.

Stop 4.5:
San Fele.

Panoramic view of San Fele and La Ralla sections. Good exposure of the upper part of the Calcari con Selce Formation and of the entire Scisti Silicei Formation of the Lagonegro Unit II. In these sections, the cherty calcilutites of the Calcari con Selce Formation have been completely dolomitized. The Scisti Silicei section is very rich in lime resediments derived from a shallow-water carbonate platform. Flute casts at the base of calciturbidites indicate a provenance of the shallow-water material from NW and NNW.

Stop 4.6:
Road San Fele- Ruvo del Monte.

Panoramic view of the northern flank of the San Fele anticline where upper Pliocene sandstones and subordinate clays unconformably cover the Scisti Silicei and Galestri formations of the Lagonegro Unit II, as well as the overlying deposits of the Sannio Unit. In the Ofanto synform, growth strata in the upper Pliocene deposits allowed us to establish the age of the antiformal- stack. Figure 12 is the line drawing of a commercial line showing the internal stratal architecture of the Pliocene fan-delta deposits overlying the Apenninic nappes in front of the San Fele antiformal stack and filling the Ofanto basin. The internal progressive unconformities give evidence of an early southward tilt of the basin, between 2.50 and 2.13 Ma, related to a breach emanating from the leading edge of the Apulia-carbonate duplex system, which cuts across the pile of nappes. The subsequent tilt towards the north was caused by the final growth of the San Fele antiformal stack. The normal fault displacing the 3.70-2.50 thrust-top deposits and gently deforming the portion of the Pliocene sequence younger than 2.50 Ma has been considered a minor feature providing accommodation in the backlimb of the ramp anticline developed in the hangingwall of an active ramp.

From San Fele to Rionero in Vulture, the road crosses red shales, calcarenites and lime breccias referable to the Sannio Unit, as well as Pliocene sandstones and conglomerates. Along the road, fine panoramas on the Vulture Volcano. Near Atella, Pleistocene lacustrine and fluvio-lacustrine deposits rich in volcaniclastic material.

DAY 5

Rionero in Vulture – Castel Lagopesole – Vaglio Basilicata – Cancellara – Acerenza – Genzano di Lucania – Spinazzola – Castel del Monte – Andria – Trani – Molfetta – Bari (about 270 kilometres, Figure 13).

Departure at 8 o' clock. Arrival at Bari around 7 o'clock p.m. Dinner and overnight in Bari.

Structural features of the outer (northeastern) margin of the Apennines: thrust of the Sannio Unit over the Tufillo-Serra Palazzo Unit and Pliocene-Pleistocene imbricates in the Tufillo-Serra Palazzo and Daunia units. Pleistocene deposits of the Bradano Trough. Cretaceous carbonates of the Murge foreland with the bauxite horizon.

Visit to the medieval castles of Castel Lagopesole and Castel del Monte. Visit to the Trani cathedral.

From Rionero in Vulture to Vaglio Basilicata the road runs parallel to the regional strike of the Apenninic structures and cuts across lacustrine deposits of the Atella Pleistocene basin and Tertiary deposits, namely Numidian sandstones, of the Sannio Unit.

Stop 5.1:
Castel Lagopesole.

Panoramic view of the Apennine mountain chain and visit to the medieval castle. The erection of the Lagopesole castle was ordered by Emperor Frederick II in 1242 and its construction was completed under the kingdom of Charles I the Angevin who came to the throne of Sicily after the military victories over

the Swabian army in 1266 and 1268. The castle, at that time entirely surrounded by woods, was the hunting residence of Frederick II. After the death of Frederick II, the castle was the summer residence of King Manfredi, son of Frederick. A legend tells about Helen, wife of Manfredi, whose ghost, on nights with a full moon, wanders through the rooms of the castle weeping bitter tears over the misfortune of her beloved husband killed by the Angevins in the 1266 battle of Benevento.
From Castel Lagopesole to Vaglio Basilicata the road runs prevalently in the Sannio Unit. Near Vaglio Basilicata, the Sannio Unit is tectonically overlain by the Sicilide Unit. The latter is widely developed south of Potenza, as far as the Gulf of Taranto, together with the overlying middle Miocene thrust-top deposits of the Gorgoglione Formation. Between Vaglio Basilicata and Cancellara, the road cuts across poorly exposed sections in the Numidian sandstones and in the pre-Numidian deposits of the Sannio Unit. Near Cancellara, tectonic superposition of the Sannio Unit on the Tufillo-Serra Palazzo Unit. The village of Cancellara is founded on upper Pliocene terrigenous deposits unconformably overlying the Tufillo-Serra Palazzo Unit.

Stop 5.2:
Cancellara, road Cancellara-Acerenza Railway Station.
Panoramic view of the tectonic contact between upper Cretaceous varicoloured shales plus lime resediments of the Sannio Unit and middle Miocene arkosic sandstones of the Tufillo-Serra Palazzo Unit. The contact post-dates the deposition of the Cancellara upper Pliocene deposits that lie in the footwall of the thrust. Along the road, outcrop of middle Miocene arkosic sandstones of the Tufillo-Serra Palazzo Unit.

Stop 5.3:
Road Cancellara-Acerenza Railway Station.
Panoramic view of a well-exposed section of Tufillo-Serra Palazzo deposits, from upper Burdigalian Numidian sandstones to middle Miocene arkosic sandstones. In the background, upper Pliocene thrust-top deposits unconformably overlying the Tufillo-Serra Palazzo sandstones.
Between Stop 5.3 and Acerenza, the road runs in poorly exposed outcrops of the Tufillo-Serra Palazzo Unit. Just before Acerenza, fine angular unconformity between horizontal upper Pliocene shore deposits and tilted Tufillo-Serra Palazzo sandstones.

Stop 5.4:
Acerenza.
Upper Pliocene thrust-top deposits represented by deltaic conglomerates grading upwards into cross-bedded shore calcarenites and sands conformably overlain by open-marine clays. From Belvedere, panoramic view of the Bradano Trough with the regressive upper portion of the Pleistocene foredeep sequence. In the background, Mesozoic carbonates of the Apulia foreland.
Between Acerenza and the Bradano River, the road cuts across the tectonic contact between the Tufillo-Serra Palazzo and the Daunia units. The deposits of the Daunia Unit, as those of the Tufillo-Serra Palazzo one, are unconformably overlain by upper Pliocene thrust-top deposits. The latter, in turn, are disconformably overlain by lower Pleistocene clays (Gravina Clay) of the Bradano sequence. Near Genzano di Lucania, the Gravina clays grade upwards into regressive sands (Monte Marano Sand). The Monte Marano sands, in turn, are stratigraphically overlain by fluvial conglomerates (Irsina Conglomerate). Between Genzano and Spinazzola, the contact between the Monte Marano Sand and the Irsina Conglomerate is an erosional contact. Near Spinazzola, the Irsina conglomerates directly overlie Cenomanian-Turonian limestones of the Murge foreland (Bari Limestone).

Stop 5.5:
Murgetta Rossa, near Spinazzola.
Well-exposed outcrop of Cenomanian-Turonian and Senonian limestones (Bari Limestone and Altamura Limestone respectively), separated by a bauxite horizon of Turonian age.
After Stop 5.5 the road runs in the Cenomanian-Turonian Bari Limestone and locally in Pleistocene shallow-water sands and calcarenites.

Stop 5.6:
Castel del Monte.
Visit to the medieval castle. Castel del Monte, with the octagonal external perimeter of the courtyard and with the eight octagonal-shaped towers, is a masterpiece of Swabian architecture in Southern Italy. The castle was ordered by Emperor Frederick II in 1240 and was possibly designed by the emperor himself. In 1266, after the fall of the Swabian imperial dynasty, the castle became property of King Charles I the Angevin. The original name of the edifice was the Castle of Santa Maria del Monte, from an ancient Benedictine abbey. The present name Castel del

Monte derives from a royal decree of King Ferdinand of Aragona in 1463.

Stop 5.7:

Trani.

Visit to the Trani cathedral. The cathedral, consecrated to St. Nicholas "the Pilgrim" who died in Trani in 1094, is one of the most beautiful churches of Apulia. The cathedral was founded in 1097 on the ancient church of Santa Maria (7th century) and its construction was completed around the half of the 13th century.

Acknowledgments

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Back Cover:
field trip itinerary

FIELD TRIP MAP

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