AN INTRODUCTION TO THE ITALIAN GEOLOGY

LAMISCO

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CENTRO DI GEODINAMICA

AN INTRODUCTION TO THE ITALIAN GEOLOGY

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Cover: Detail of the map "Les fonds de`la Méditerranée", by T. de Rémur, X. Le Pichon, and B. Biju-Duval, published by Hachette-Guides Bleus-Paris

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1 - GEOGRAPHY

Italy is a wonderful country whose variegate characteristics are strictly controlled by its peculiar geology. Italy covers an area of 301,217 km^2, and it is subdivided in 20 regions. Italy is for a large part mountainous, Alps in the north and Apennines along the peninsula; 68,000 km^2 (21%) are plains, e.g. the Po Plain (46,000 km^2) and the Tavoliere delle Puglie (3,500 km^2). From the northernmost point (Vetta d'Italia) to the southernmost (Lampedusa), Italy is 1330 km long. Italy has about 8600 km of coasts. Sicily (25,400 Km^2) and Sardinia (24,000 Km^2) are the two most important Italian islands. Other smaller islands include Elba, the Tremiti, Eolie, Egadi, Pantelleria, etc.. The climate is Mediterranean temperate in the south and continental in the north. Several small glaciers are present in the Alps. This mountain belt may be divided into western, central and eastern Alps (Fig. 1). From a geologic and geographic point of view it is useful to distinguish also the Southern Alps, which are the greatest part of northern Italy. From west to east the Southern Alps are represented by Piemonte, Lombardy, Trentino Alto Adige, Veneto and Friuli. The Val d'Aosta and W-Liguria regions are considered part of the western Alps. The main Alpine foreland is outside Italy (France, Switzerland, Austria and Germany). The internal foreland is represented by the Po Plain bording to the south the Southern Alps. The Apennines may be subdivided in northern (E-Liguria, Emilia Romagna, Tuscany, Marche), central (Latium, Umbria, Abruzzi, Molise) and southern Apennines (Campania, Basilicata, Calabria and Sicily); Puglia is to the east of the Apennines. The Sicilian mountains are considered the link between the Apennines and the Tunisian Maghrebides. The Apennines have their foreland in the Po plain, Adriatic sea, Puglia, Ionian seas and southern Sicily. The Tyrrhenian sea is a back-arc basin, located to the west of the Apenninic arc.

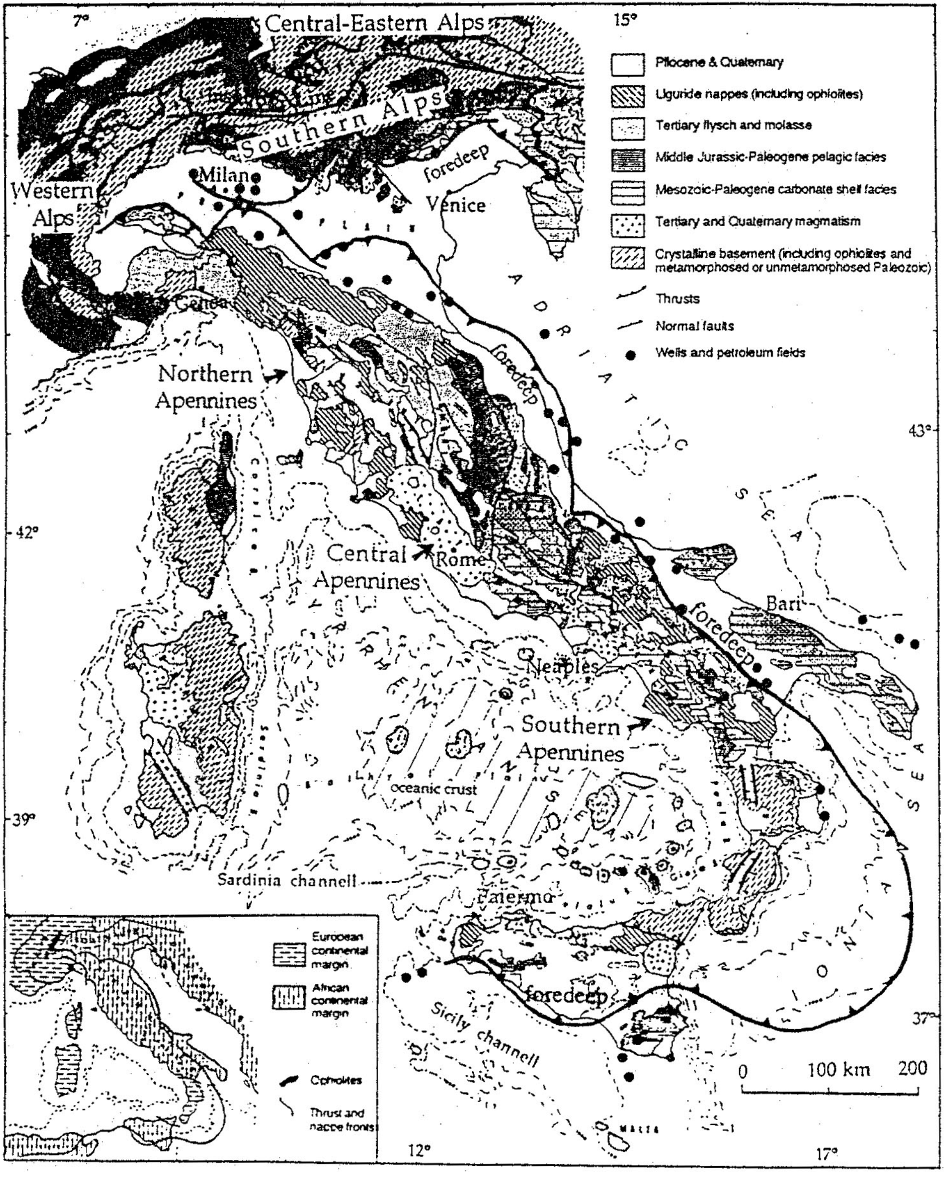


Fig. 1 - Geologic map of Italy, modified after Pieri and Mattavelli (1986).

2 - HISTORY OF EXPLORATION

Leonardo da Vinci (1452-1519) was probably the first to recognize the organic nature of fossils; he was also an excellent sedimentologist, describing sedimentary and erosional processes. He interpreted that present processes are able to explain past geological phenomena, much earlier than the James Hutton principle (1785). Ulisse Aldovrandi in 1603 appears to be the one who introduced the term *geology* as applied to earth sciences. Giovanni Arduino may be considered the forerunner of stratigraphy because he described in 1759 on lithologic basis the Primary (Paleozoic), Secondary (Mesozoic) and Tertiary in the Venetian Prealps. Geology in Italy began to develop since the second half of the last century. Geological mapping accumulated during the early part of this century. On the basis of these powerful background, the acquisition of geological information accelerated during the last 40 years both for the academic studies and for extensive oil exploration. The references quoted at the end of this text are very few with respect to the large amount of information that can be found in the Italian geological journals.

• 3 - REGIONAL GEOLOGY

GEOPHYSICS

The Italian crust (Fig. 2) is continental apart in the Tyrrhenian abyssal plain where 10 km thick Late Miocene - Pliocene oceanic crust is present, and the Ionian sea, where a Mesozoic oceanic crust is buried underneath a thick pile of sediments. The crust is thick underneath the Alpine belt (45-55 km) and is thin in west Tuscany and Latium (20-25 km). The Moho may be distinguished as a new forming Neogene Moho with low velocities in the Tyrrhenian basin and western Apennines, and as an old Mesozoic Moho in the foreland areas and the Alpine belt, where the Adriatic plate Moho was thrust onto the European Moho. Stable areas have Moho depths at about 30 km (Sardinia, Adriatic sea and Puglia). The lithosphere is very thick in the western Alps (200 km), while it is in the order of about 140 km along the central and eastern Alps. In foreland areas the lithosphere thins in the northern Adriatic sea at about 70 km, while is about 110 km to the southeast in Puglia (Fig. 3). In the Tyrrhenian sea the lithosphere thins to 20-30 km. The Adriatic continental lithosphere and the Ionian oceanic lithosphere are subducting westward almost vertically underneath the Apennines. A positive gravimetric Bouger anomaly and a magnetic anomaly occur in Piemonte along the Ivrea-Verbano zone (Fig. 4). High Bouguer anomalies characterize the Tyrrhenian sea (180 mGal).

Negative gravimetric anomalies are along the Apenninic foredeep (Po Plain - 160 mGal, Adriatic coast), while positive magnetic anomalies occur in correspondence of magmatic spots. Heat flow values (Fig. 5) are very high in the Tyrrhenian sea (200 mW/m^2) and western Apennines, particularly Tuscany, while they decrease to 30-40 mW/m^2 in the foreland areas (Po Plain, Adriatic coast and Ionian sea).

Italy is seismically very active due to the active subduction zones surrounding the Adriatic plate (Figs. 6, 7 and 8). The most dangerous regions are Friuli, Umbria,

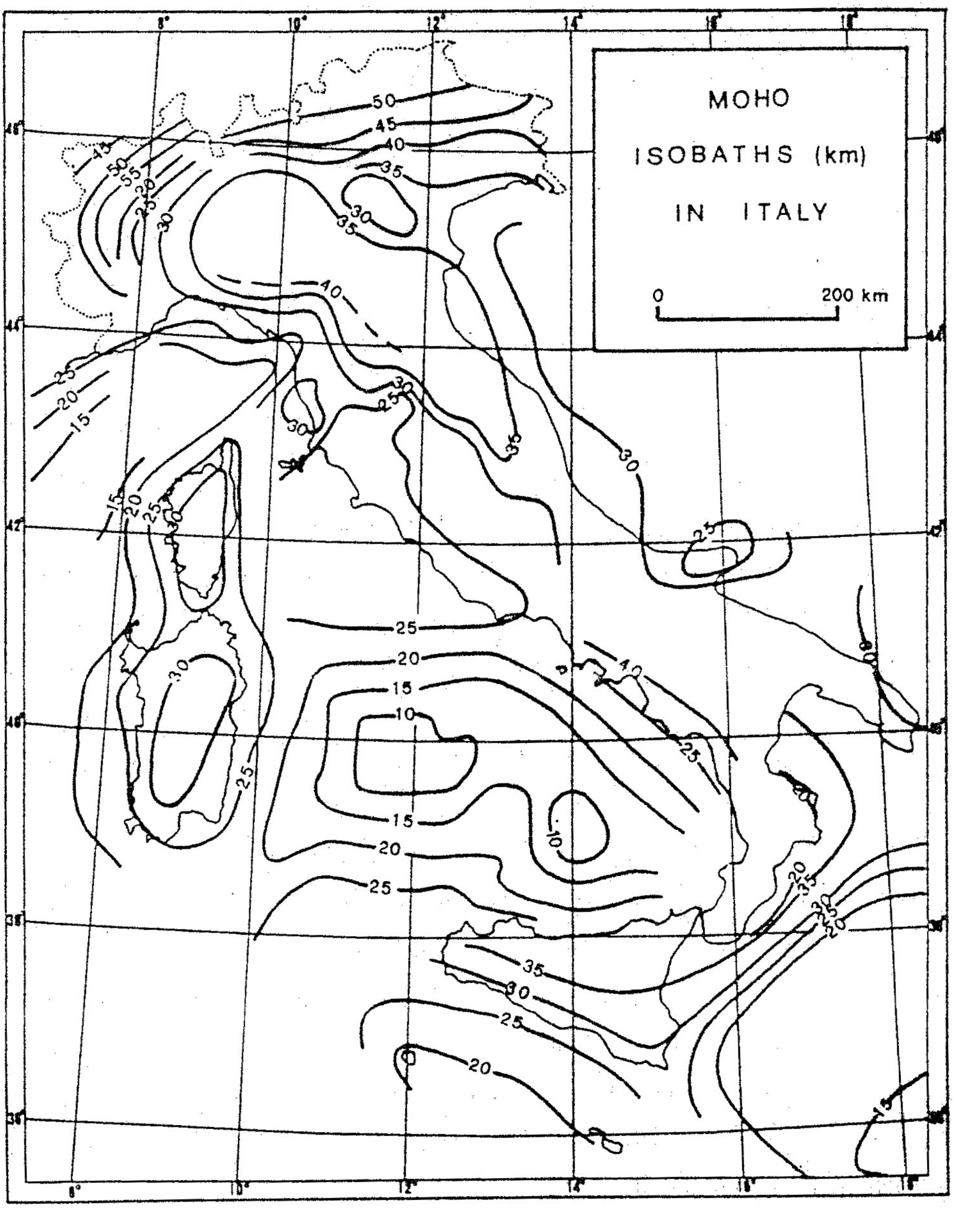


Fig. 2 - Isobaths in Km of the Moho discontinuity in the Italian area, after Nicolich (1989).

Abruzzi, Campania, Basilicata, Calabria and Sicily. The main focal mechanisms of the Apenninic belt earthquakes are related to normal faults at 10-15 km depth. Compressive mechanisms (thrust ramps or decollements) are reported in the frontal Apennines, in the foredeep, and in the Alps. Strike slip mechanisms are also common in the Giudicarie, in Friuli and in the Apennines. The seismicity is a great social problem in Italy because the recent Friuli (1976) and Campania-Basilicata (Irpinia, 1980) earthquakes killed a few thousand people. Other dramatic earthquakes to remember are those of Calabria (1783) with 30.000 people killed, Messina (1908) with about 100.000 people dead, Avezzano (1915) with 30.000 thousand people dead, and Irpinia (1930). Historical strong (X-XII Mercalli) earthquakes are also those famous of 1117 and 1348 in the Alps. Lower seismicity occurs all around Italy, showing the active geodynamic setting in which the country is at present. Low magnitude deep seismicity in the Tyrrhenian Sea is the evidence for a W-dipping slab subducting at least 550 km (Figs. 6, 7 and 8). Sardinia is quite a stable area, apart the Neogene-Quaternary Campidano graben in the south. This extension represents the NW-prolongation of the Sicily channell - Sirte Basin - Red Sea rift zones alignment.

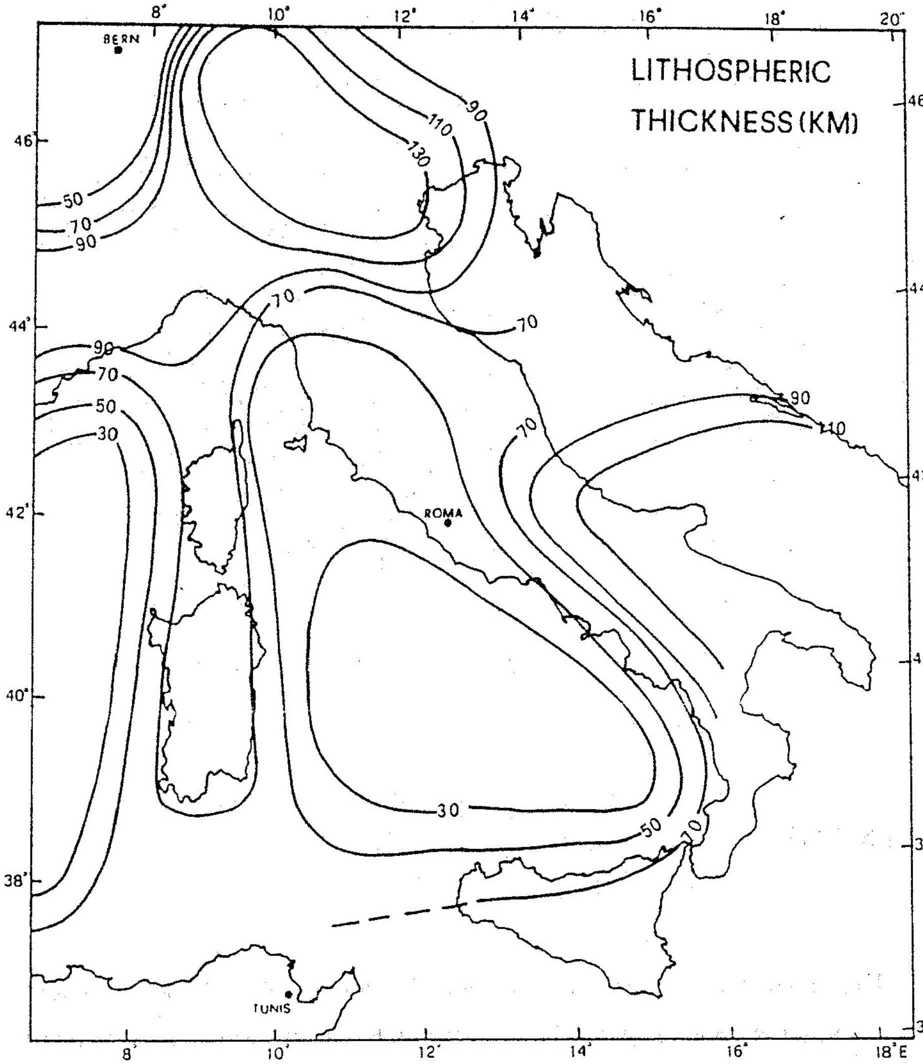


Fig. 3 - Lithospheric thickness in the Italian area, after Calcagnile and Panza (1981).

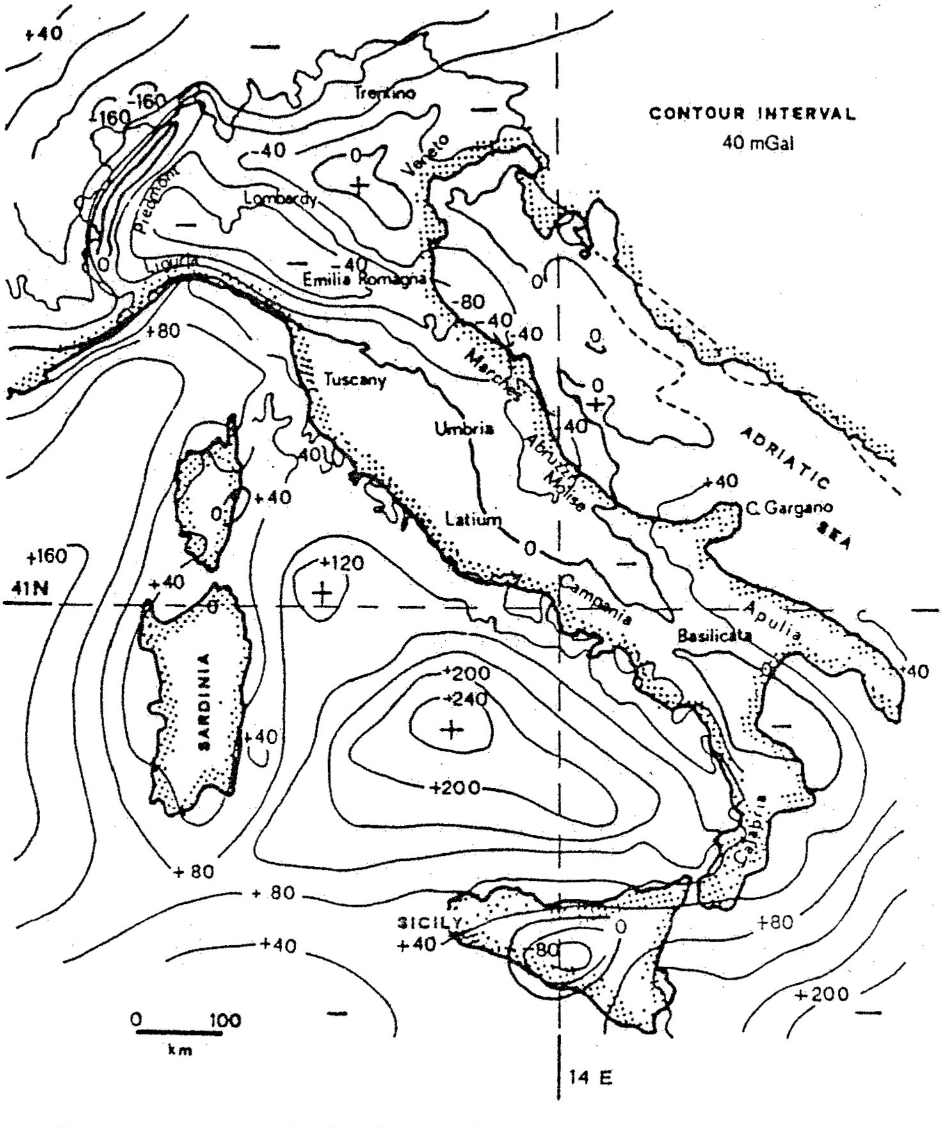


Fig. 4 - Bouger gravity map of Italy, after Morelli, in Ogniben et al. (1975)

BASEMENT

The Italian basement recorded a possible Caledonian subduction of oceanic crust, with Ordovician granites (e.g. the 440 Ma granite found offshore Venice by the Agip Assunta well), later deformed in orthogneiss during the Hercynian collision processes.

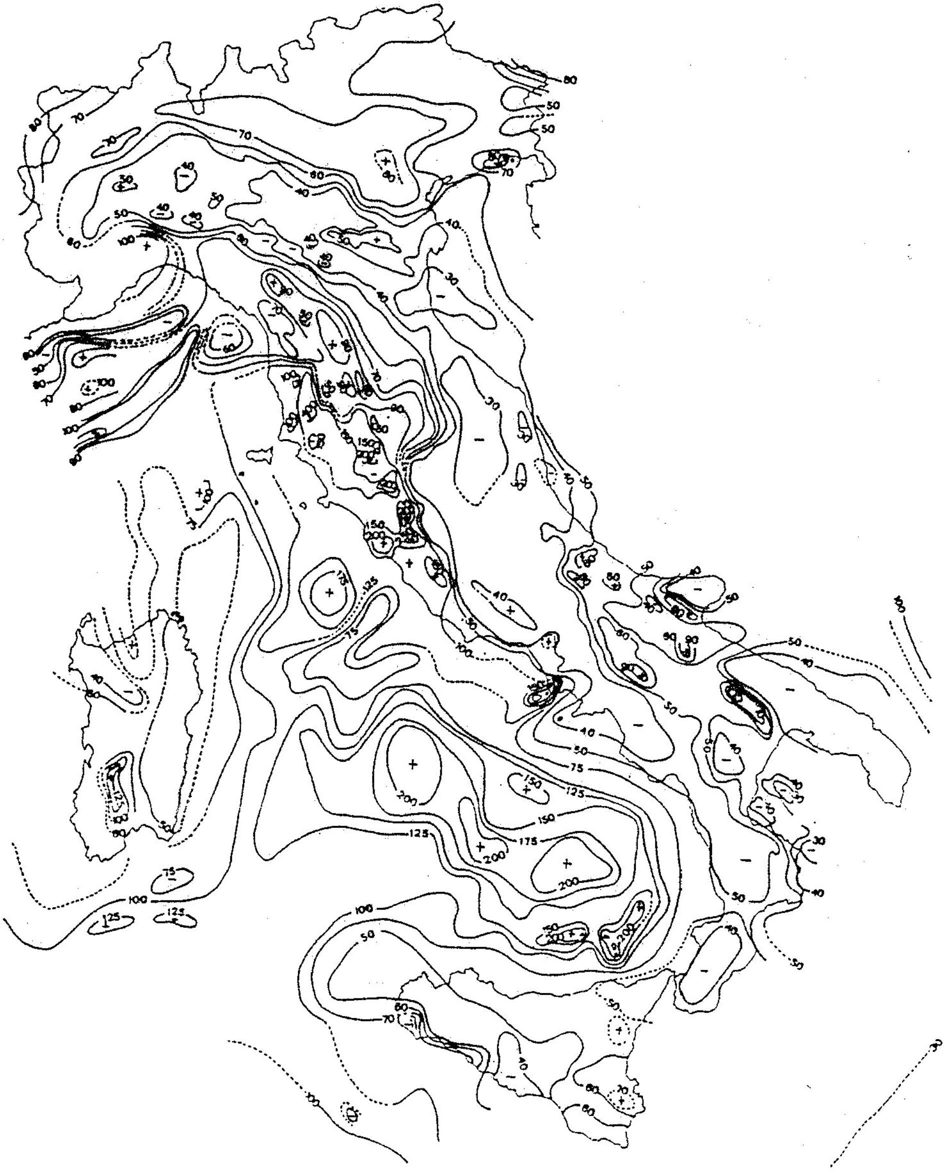


Fig. 5 - Surface heat flow density map of Italy, in mW/m^2, after Mongelli et al. (1991).

This last orogeny is very well preserved in Italy, in all the areas where the basement crops out, i.e. in the Alps, in Sardinia, in Calabria, in NE-Sicily (Peloritani Mts.) and a few scattered outcrops in W-Tuscany (e.g. the Apuane Alps). The Hercynian or Variscan orogen developed between Devonian and Early Permian times. Crustal thickening, polyphasic metamorphism characterized this thrust belt. Typical lithologies are phyllites, gneiss, amphibolites, etc.. The metamorphism evolved from relative high pressure (Kyanite), to low pressure conditions (Andalusite).

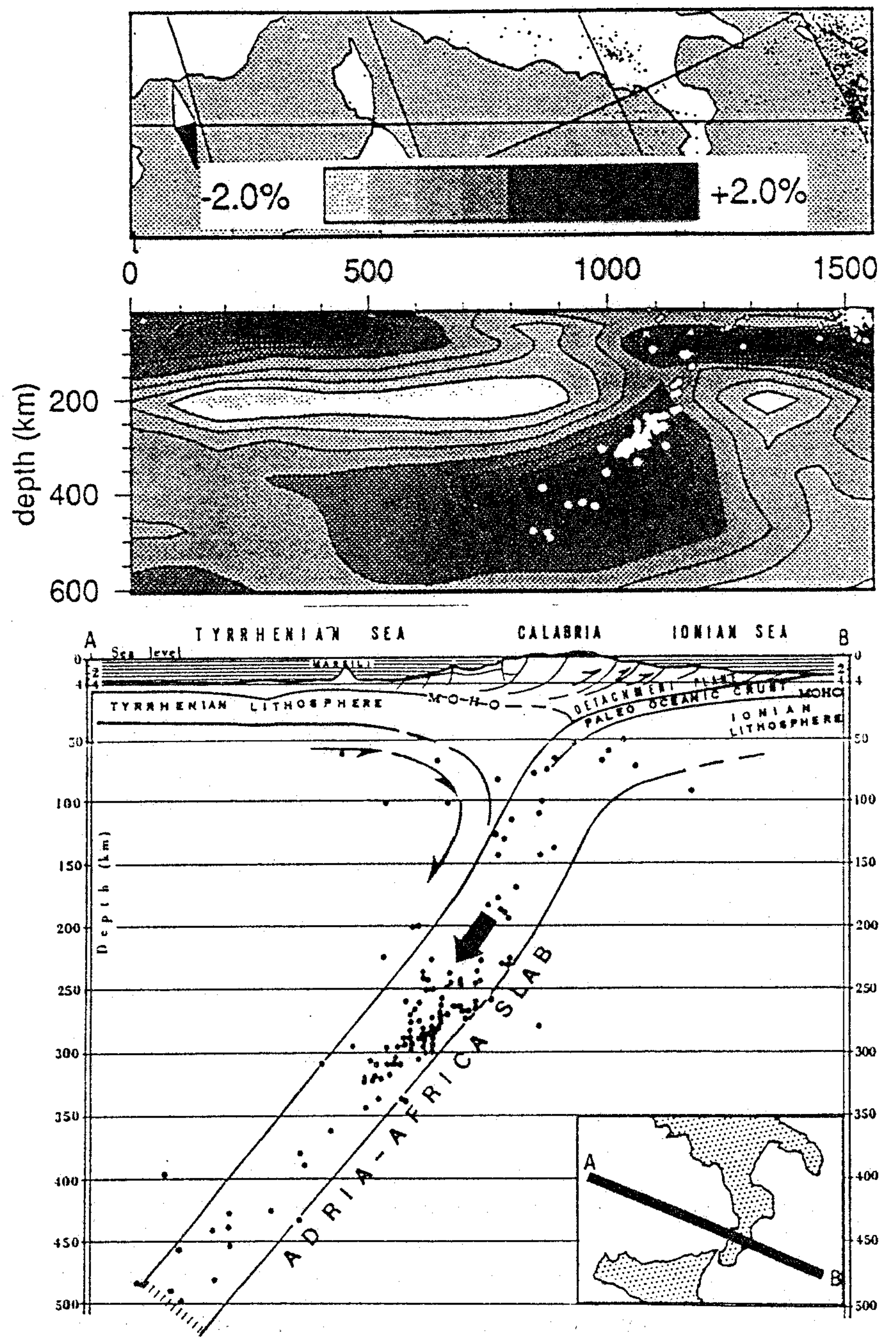


Fig. 6 - Upper figure: Tomographic section from northern Sardinia to the Ionian sea crossing the Tyrrhenian sea and Calabria, after Wortel and Spakman (1992). White spots are heartquake locations depicting the Apenninic subduction. Note also the asthenospheric wedging in the Tyrrenian sea (lighter areas). Lower part: Cross-section of the deep seismicity of the Tyrrenian sea (h > 50Km), after Finetti and Del Ben (1986).

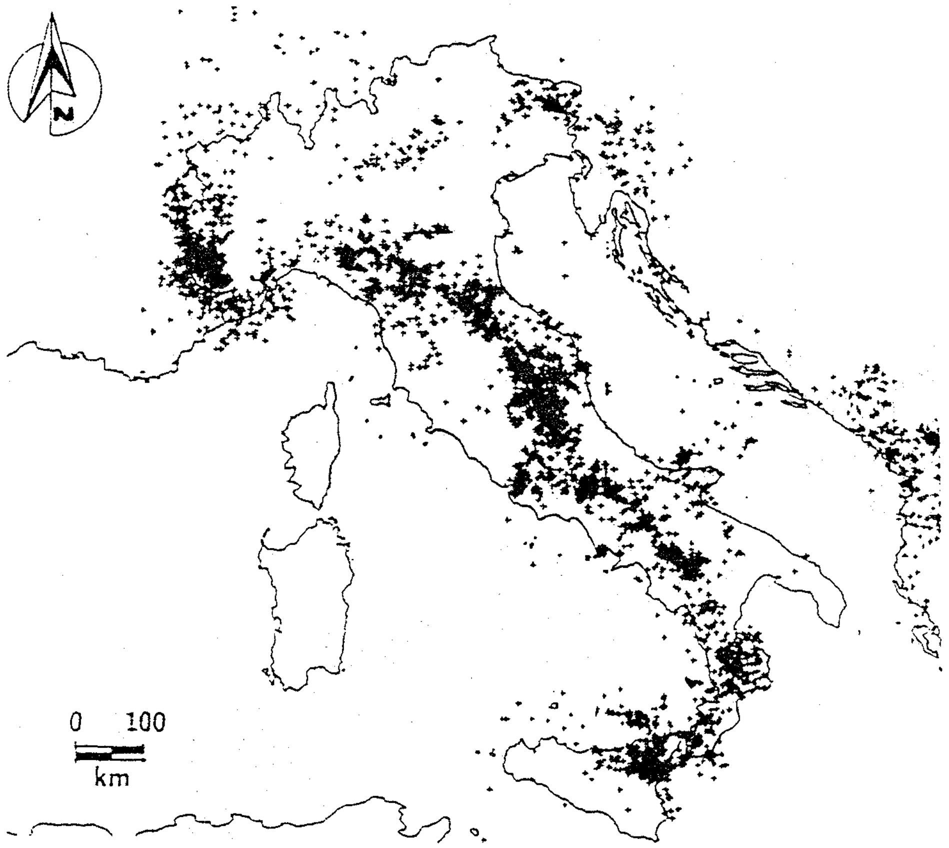


Fig. 7 - Epicentral map of the Italian seismicity of 4700 selected crustal earthquakes occurred between 1983 and 1991, after Amato et al. (1993).

A late orogenic calcalkaline magmatic phase during Late Carboniferous - Early Permian generated abundant granitic batholiths or plutons (e.g. Mont Blanc, Monte Rosa in the Western Alps, Baveno in the western Southern Alps, Doss del Sabion, Brixen and Cima d'Asta in the Dolomites, central-eastern Southern Alps, Barbagia and Gallura granites in Sardinia, Sila and Serre in Calabria, etc.) and ignimbritic effusions as those of the Piastrone Porfirico Atesino in Trentino-Alto Adige (central Southern Alps). The only sector of the outcropping Hercynian orogen not superimposed by the Alpine or Apenninic thrust belts is situated in Sardinia. There the metamorphic climax is at about 340 Ma. The Hercynian orogen was double vergent, toward 'SW' in Sardinia, with the metamorphic degree growing toward northeastward (but Sardinia rotated about 35° during Oligocene-Miocene, and the restored Hercynian vergence is mainly westward), and vergent toward the east in the Southern Alps, northern Italy, being the Hercynian foredeep located in the Carnian Alps, and in the Adriatic Sea.

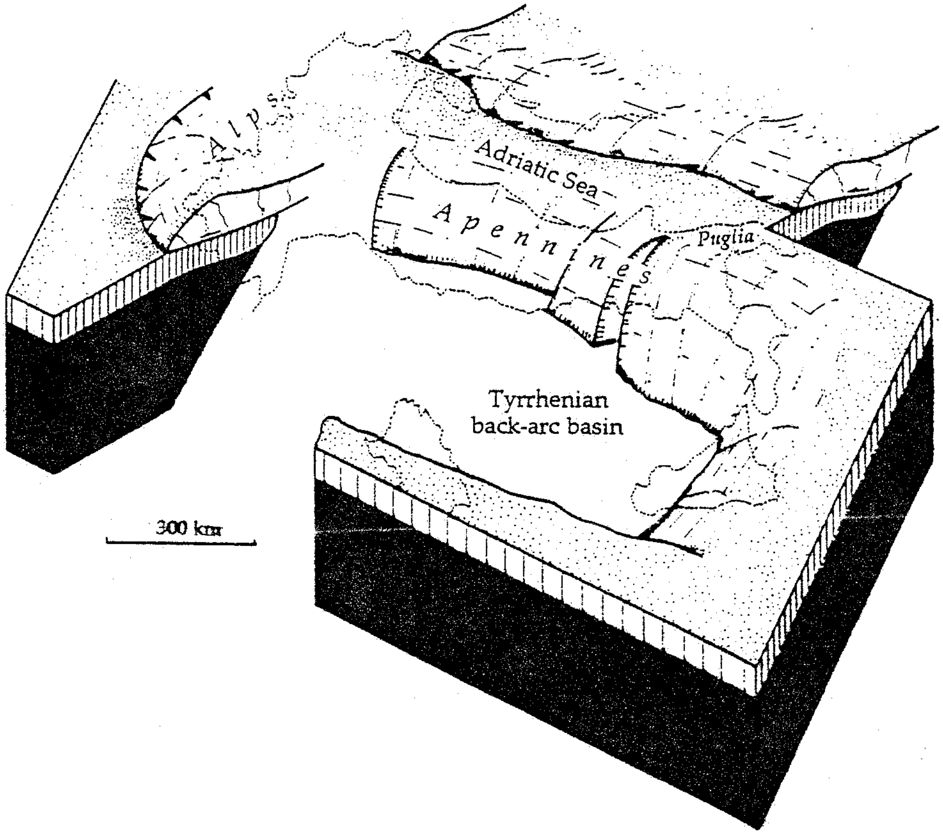


Fig. 8 - Schematic diagram showing that the Adriatic plate is subducting W-ward underneath the Apennines, while it is thrusting the European plate generating the Alps. The Adriaric plate is also subducting toward ENE, generating the Dinaric orogen.

In the Paleo-Carnian chain (a relict of the Hercynian orogen in the eastern Southern Alps), where unmetamorphosed, or low-grade metamorphosed pre-Permian sedimentary rocks are present. The metamorphic degree grows toward the west in the basement of the Southern Alps, with green schist facies phyllites and gneisses in the basement of the Dolomites, amphibolite facies in the Orobic Alps and granulitic facies in the western Southern Alps (Ivrea-Verbano zone). Biotite-sillimanite gneisses (Diorite-Kinzigite unit) outcrop in Calabria (Fig. 9). The Hercynian orogen was immediately after dissected by extensional tectonics, the prelude to the Tethyan opening: the basal unconformity with red beds of Late Permian - Triassic age gradually covered the subsiding orogen, suturing both Hercynian thrusts and later normal faults witnesses of its collapse.

Detrital zircons from the Alps show pre-Cambrian age. The Cambrian outcrops in the Iglesiente (SW-Sardinia) with sandstones and marls. It is deformed by the 'Sardic' phase (about 500 Ma), considered as an early Caledonian phase.

In Italy two areas exhibit sections of lower continental crust uplifted during the Alpine orogeny: the Ivrea-Verbano in the western Alps, and the Serre in the Alpine Calabrian rocks. The peridotites of Finero are considered a section of upper mantle in the Ivrea-Verbano zone, uplifted also by the Mesozoic rifting.

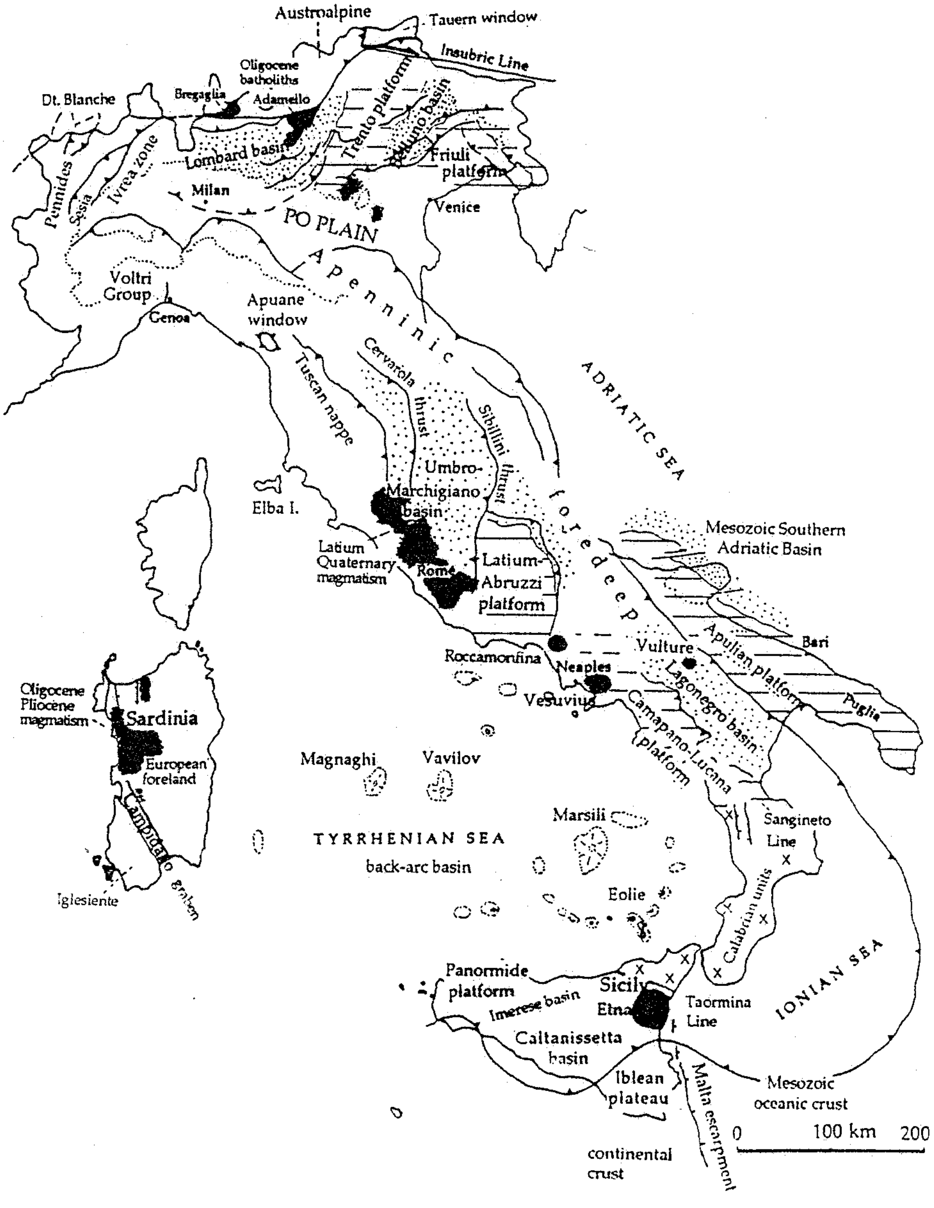


Fig. 9 - Location map of the main paleogeographic or structural units mentioned in the text.

PASSIVE MARGIN STRATIGRAPHY

The stratigraphy of Italy reflects the geodynamic evolution of the central Mediterranean. The Late Permian to Cretaceous sequences recorded the rifting and the drifting history of the Tethys margins. In particular Italy was part of the passive margin of the western and northern Adriatic plate during the opening of the western Tethys or Ligure-Piemontese oceanic basin (Figs. 9, 10, 11, 12, 13, 14 and 15). This margin underwent both tensional or transtensional tectonics. The typical basal succession with red beds, evaporites and carbonates gradually evolved through time all along these margins. In the Southern Alps, a general marine transgression toward the west resulted in fluvial continental facies (Verrucano Lombardo, Valgardena Sandstone) covered by sabkhas, lagoons (Bellerophon Formation), shallow marine areas (Fig. 16), and terrigenous infill (Werfen and Servino Formations) and volcanic episodes. In the Dolomites and Carnian Alps (Eastern Southern Alps) spectacular examples of atoll-like Ladinian and Carnian carbonate platforms (Sciliar and Cassian Dolomites) prograding over adjacent coeval basins (Livinallongo and S. Cassiano Formations) were known since the last century (Figs. 15 and 16). After the deposition of terrigenous clastics and peritidal sediments during Late Carnian times with the Raibl Formation, the Late Triassic was characterized by the deposition of peritidal shallow water carbonate platform, the widespread 0.3-2 km thick Dolomia Principale. Shaly interposed thick basins occurred in the Lombard basin, Fig. 17, (Zorzino Limestone, Rhaetian Choncodon Dolomite, Zu Limestone, Riva di Solto Shale). Tensional or transtensional tectonics during Late Permian-Triassic times controlled subsidence rates on horsts and grabens, and facies development. In the Apennines the Late Triassic is also represented by the Verrucano red beds and the Burano Anhydrite, an evaporitic layer seat of many Apenninic decollements. Cherts, limestones and marls deposited in Basilicata-Campania in deep-water conditions during the upper Triassic (Lagonegro basin).

During Jurassic times, oolitic Bahamas-type carbonate platforms formed along the passive continental margin (Liassic Calcari Grigi in the Southern Alps, Calcare Massiccio in the Apennines). Extensional tectonics affected broader areas and new basins formed. Early Jurassic basinal embayments in the Southern Alps were filled by the marls of the Soverzene and Igne Formations (Belluno Basin) and by the marls and limestones of the Moltrasio and Medolo Formations in the Lombard Basin. Nodular red limestone, Ammonitico Rosso facies, cherts (Fonzaso Formation, Selcifero Lombardo) and oolitic turbidites (Vajont Limestone) deposited in the basinal areas during Middle-Late Jurassic. At the end of Jurassic three main paleogeographic environments

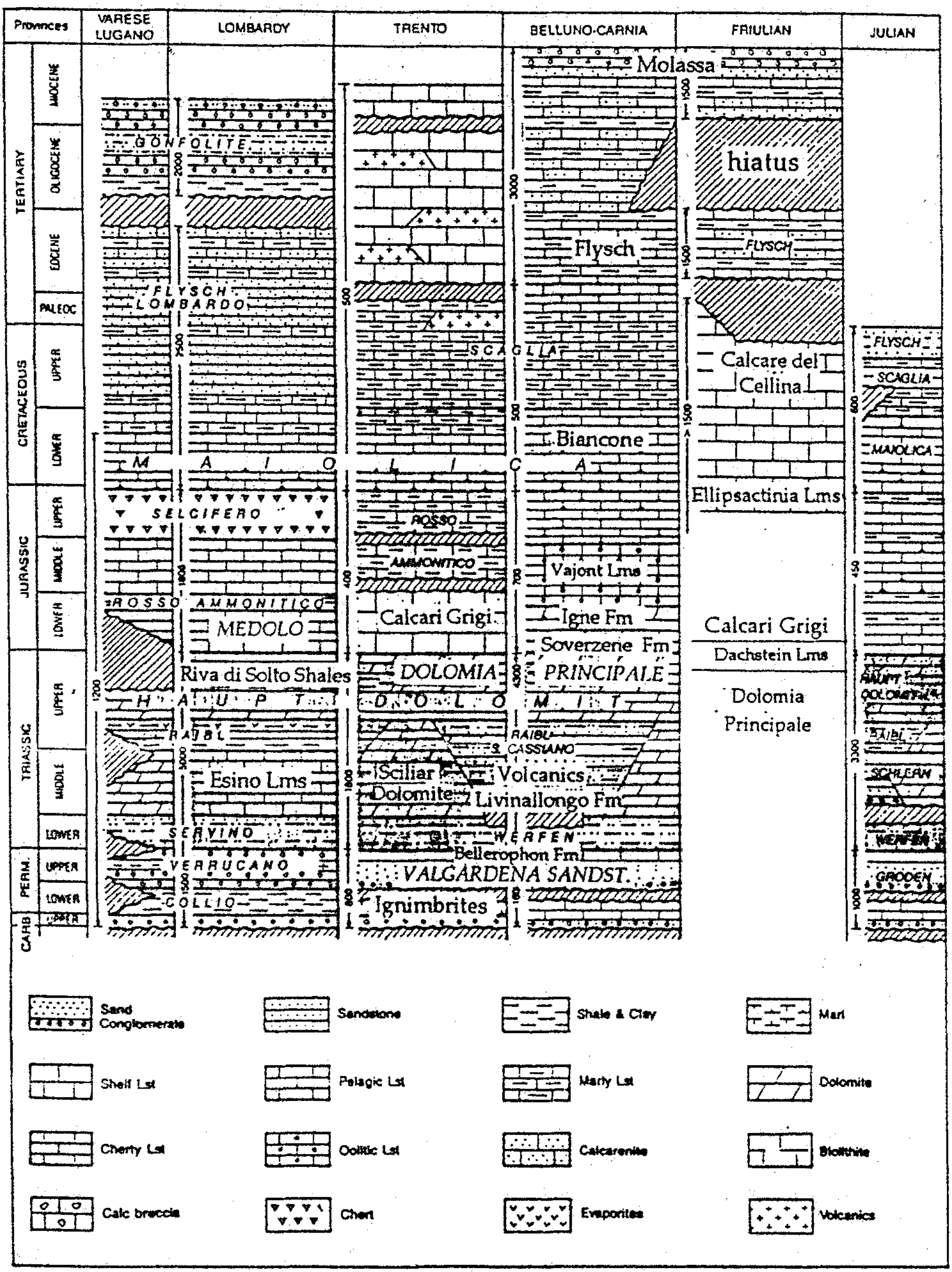


Fig. 10 - Main stratigraphic columns of the Southern Alps, modified after Pieri (1969).

were present: 1) An oceanic domain, where radiolarites and basinal limestones were deposited above ophiolites, the Piemontese basin, the Ligure basin (Liguria, W-Tuscany) and possibly part of the Lagonegro basin in Southern Apennines which should have been the northward prolongation of the Ionian sea. 2) A basinal domain following foundering of the continental margin, where carbonate pelagic and hemipelagic sedimentation dominated with deeper areas alternating with seamounts (e.g. the Trento swell in the Southern Alps, or the Trapanese, Saccense and Iblean zones in Sicily), where the sedimentary section is condensed. 3) Wide shelves, where deposition of shallow marine carbonates continued (Fig. 18). Some of the residual carbonate shelf areas persisted throughout the Cretaceous like the Apulia (Puglia) platform (Bari and Altamura Limestones), the Friuli platform (Calcare del Cellina), the Latium-Abruzzi and Campano-Lucana platforms. Widespread Lithiotis facies developed during the Liassic and Rudistic facies during the Late Cretaceous on these carbonate platforms.

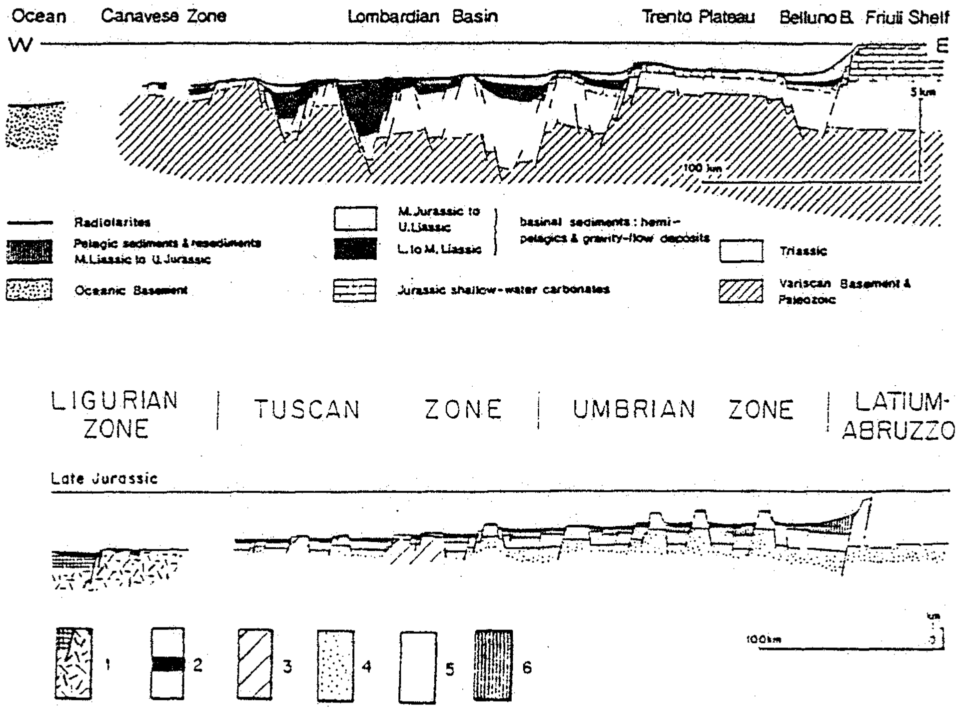


Fig. 11 - Schematic cross-sections of the Southern Alps (upper) and the central-northern Apennines (lower) during Jurassic times, which represented the northwestern and western passive continental margins of the Adriatic plate, after Bernoulli et al. (1979).
Legend of the lower section: 1, Pillow lavas, gabbros and serpentinites; 2, Pelagic and hemipelagic sediments; 3, Continental basement, including Paleozoic and Triassic sediments; 4, Upper Triassic evaporites; 5, Platform carbonates; 6, Basinal limestones with redeposited shallow-water sediments.

Typical pelagic and hemipelagic sedimentation was the Maiolica or Biancone (white marly limestone) during the Early Cretaceous and the Scaglia Rossa (reddish marls and marly limestone) during the Late Cretaceous. Platform-to-basin transitions (Figs. 15, 16, 18, 19, 20, 21, 22, 23 and 24) were characterized by debris flows and somewhere megabreccias. Well preserved outcropping carbonate platform-to-basin transitions are visible at the western margin of the Friuli Platform (Fig. 18), in Abruzzi (the Maiella Massif, Fig. 20), and in Puglia (in the eastern Gargano and offshore, Fig. 21).

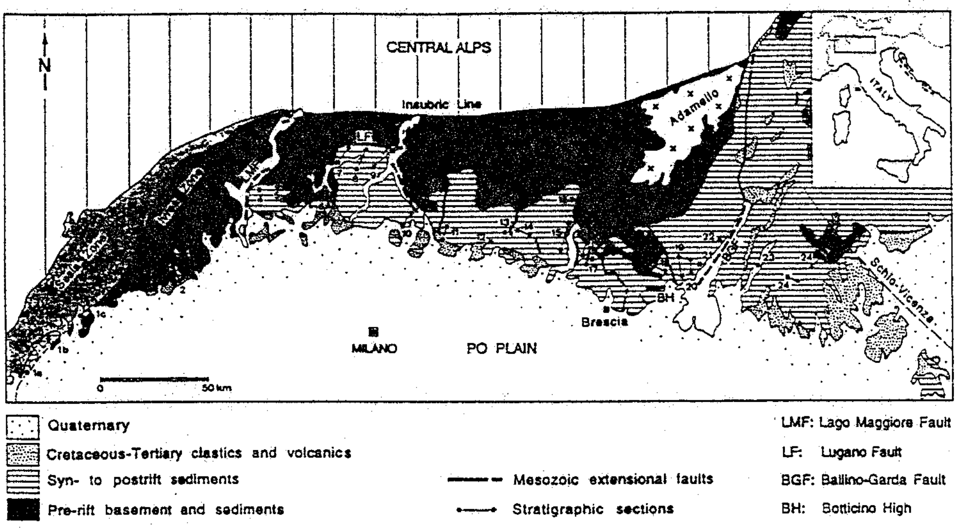


Fig. 12 - Schematic tectonic map of the western Southern Alps with evidenced Mesozoic extensional faults. Thrusts are neglected for clarity (after Bertotti et al., 1993).

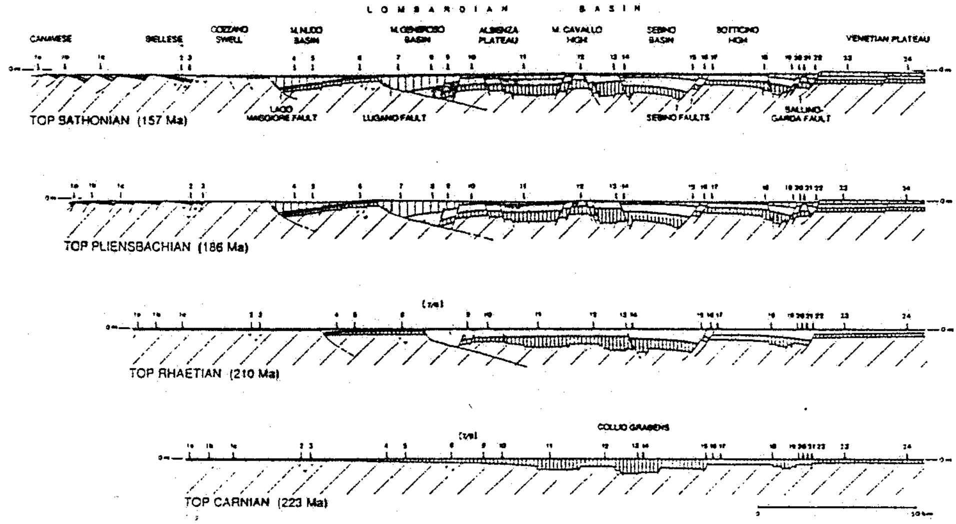


Fig. 13 - Palinspastic profiles across the western Southern Alps from Late Triassic to Middle Jurassic, after Bertotti, et al., (1993).

The thickness of the Permian-Mesozoic sedimentary cover in Italy is in the average between 1 and 6 km. In Sardinia a few isolated patches of Triassic (Germanic facies) to Upper Cretaceous sediments consist mostly of shallow marine carbonates and they are about 1 km thick. They overlie a Lower Cambrian to Lower Carboniferous basement which was deformed and metamorphosed by the Caledonian and Hercynian orogenies (Fig. 25).

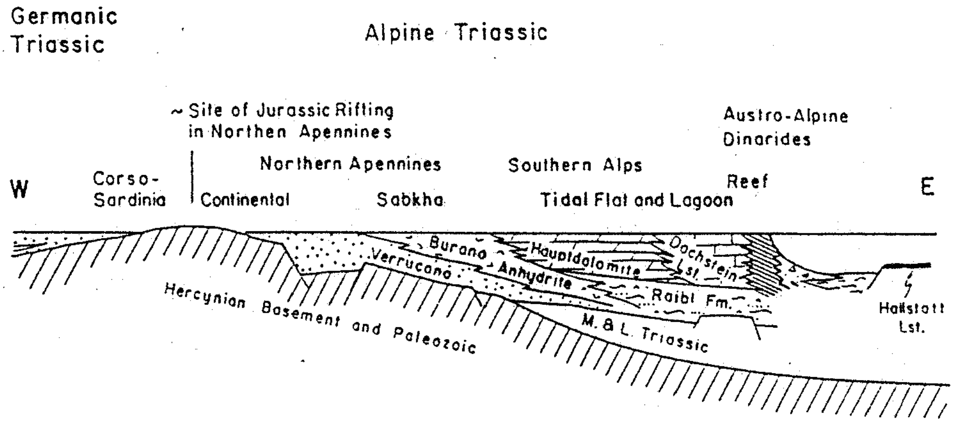


Fig. 14 - Paleogeographic profile for the Upper Triassic deposits, after Laubscher and Bernoulli (1977).

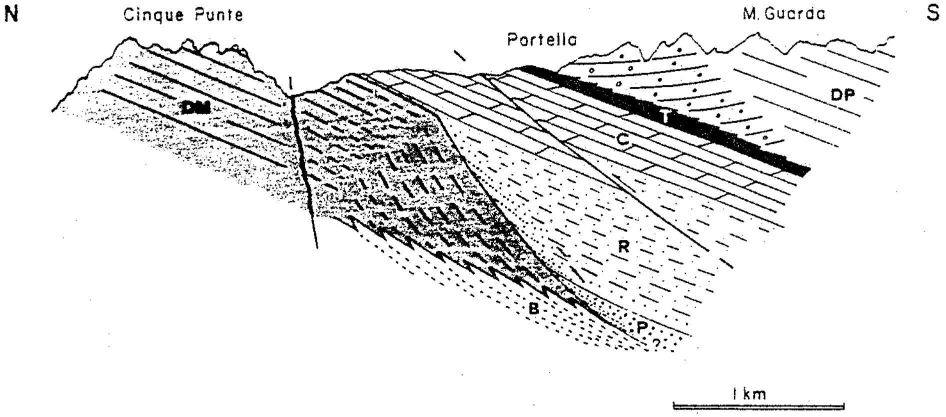


Fig. 15 - Section of Raibl, at the northeasternmost corner of Italy, taken as an example of the platform to basin geometries of the Middle-Late Triassic of the Southern Alps. Legend: DM, Dolomia Metallifera, carbonate platform of Ladinian age; B, Livinallongo Formation, basinal Ladinian; P, Calcare del Predil, Lower Carnian; R, Rio del Lago Formation, Lower Carnian; C, Conzen Dolomite, Middle Carnian; T, Tor Formation, Upper Carnian; DP, Dolomia Principale, Upper Carnian - Norian.

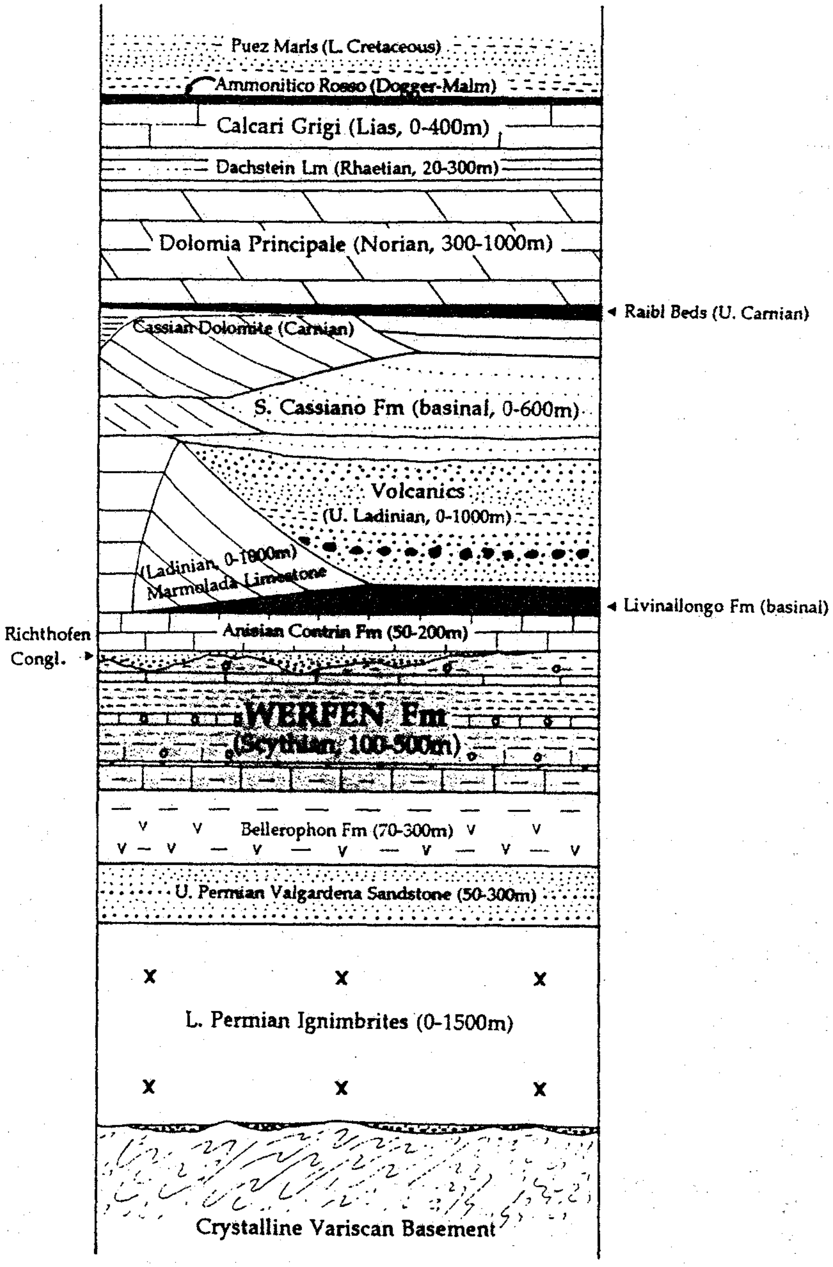


Fig. 16 - Schematic stratigraphic column of the Dolomites (Southern Alps).

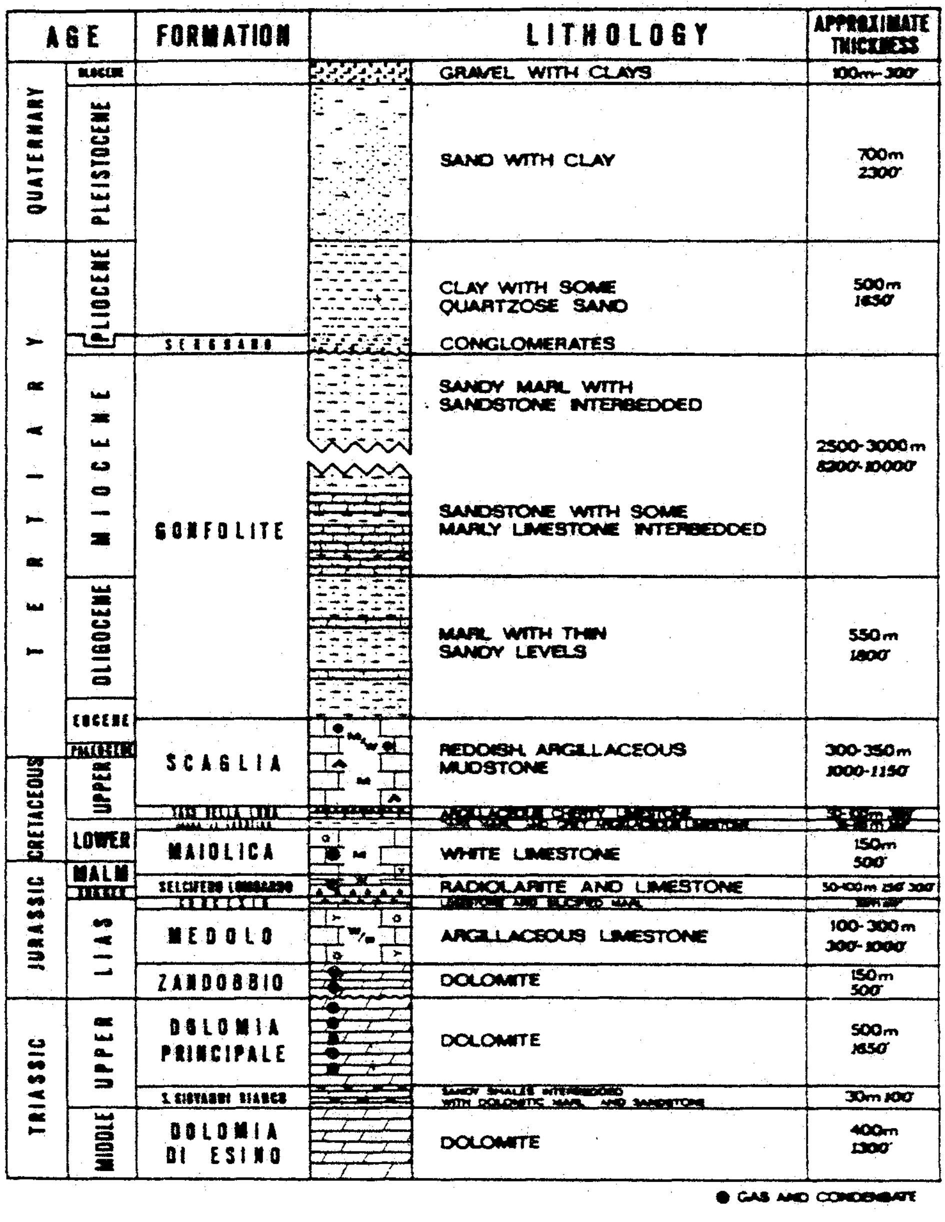


Fig. 17 - Stratigraphic column of the western Southern Alps buried in the Po Basin, after Errico et al. (1980).

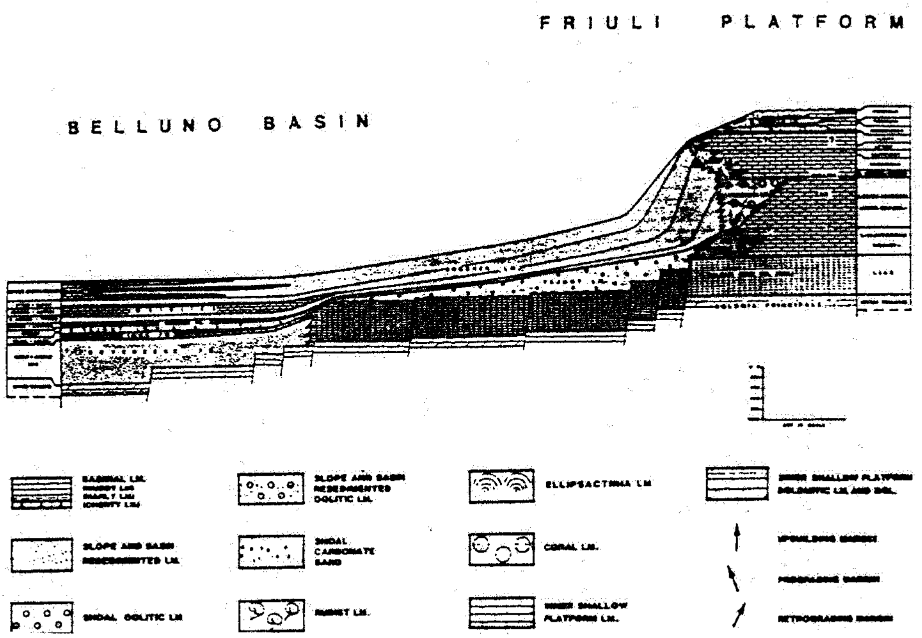


Fig. 18 - Mesozoic stratigraphic relationships between the Friuli platform and the Belluno basin in the Venetian plain, after Cati et al. (1987).

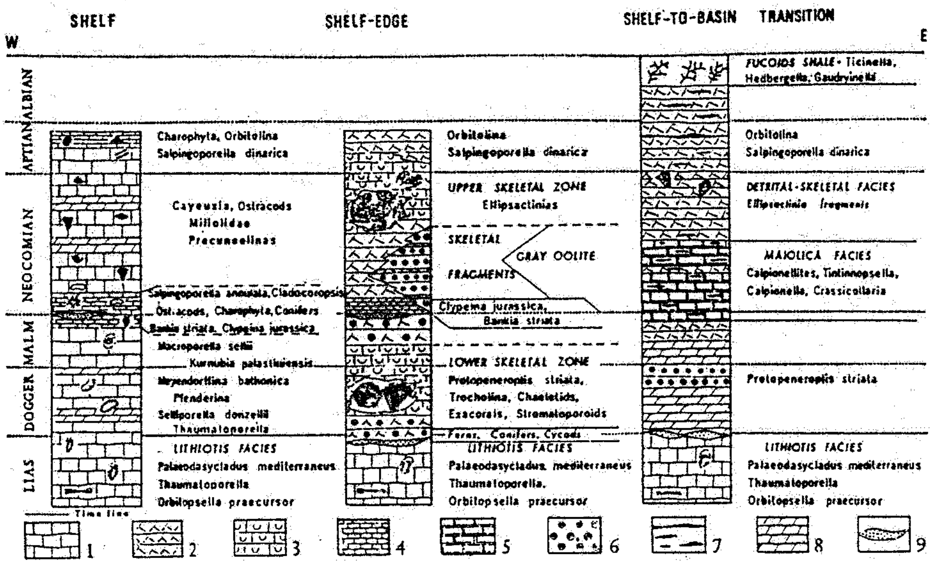


Fig. 19 - Stratigraphic correlations between the Latium-Abruzzi platform and the Molise basin to the east during Jurassic-Cretaceous in the central Apennines, after Parotto and Praturlon, in Ogniben et al. (1975). 1, Lump-micritic, algal, molluscan, ostracods platform limestone; 2, Skeletal-fragmental and detrital-skeletal limestone; 3, Reef and bank facies with corals and spongiomorphs; 4, Micritic-skeletal limestone in lagoon facies; 5, pelagic mudstone with tintinnids; 6, Oolitic limestone; 7, Cherty levels; 8, Dolomite and dolomitic limestone; 9, Hardgrounds, reddened beds.

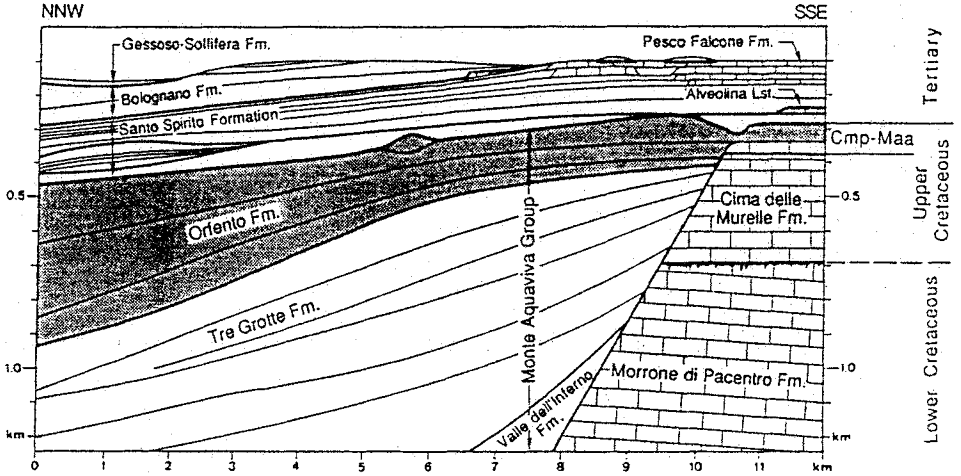


Fig. 20 - Schematic platform-basin cross-section of the northern margin of the Maiella platform (central Apennines), after Eberli et al. (1993). Lower Cretaceous platform strata are bound to the north by a steep escarpment and unconformably overlain by Upper Cretaceous shallow water carbonates. Onlapping basinal sedimentary rocks bury the nondepositional escarpment, thus decreasing the slope angle. Upper Campanian and higher depositional units are continuous from the platform interior onto the low angle slope. A major unconformity separates the Cretaceous from the Tertiary section. During the Paleocene-middle Eocene, the former Cretaceous platform was repeatedly flooded, but only small relics of Paleocene-lower Eocene shallow water areas is documented by lithic breccias and turbidites on the lower slope. Progradation of reefs over the former basin occurred in the late Eocene and Oligocene.

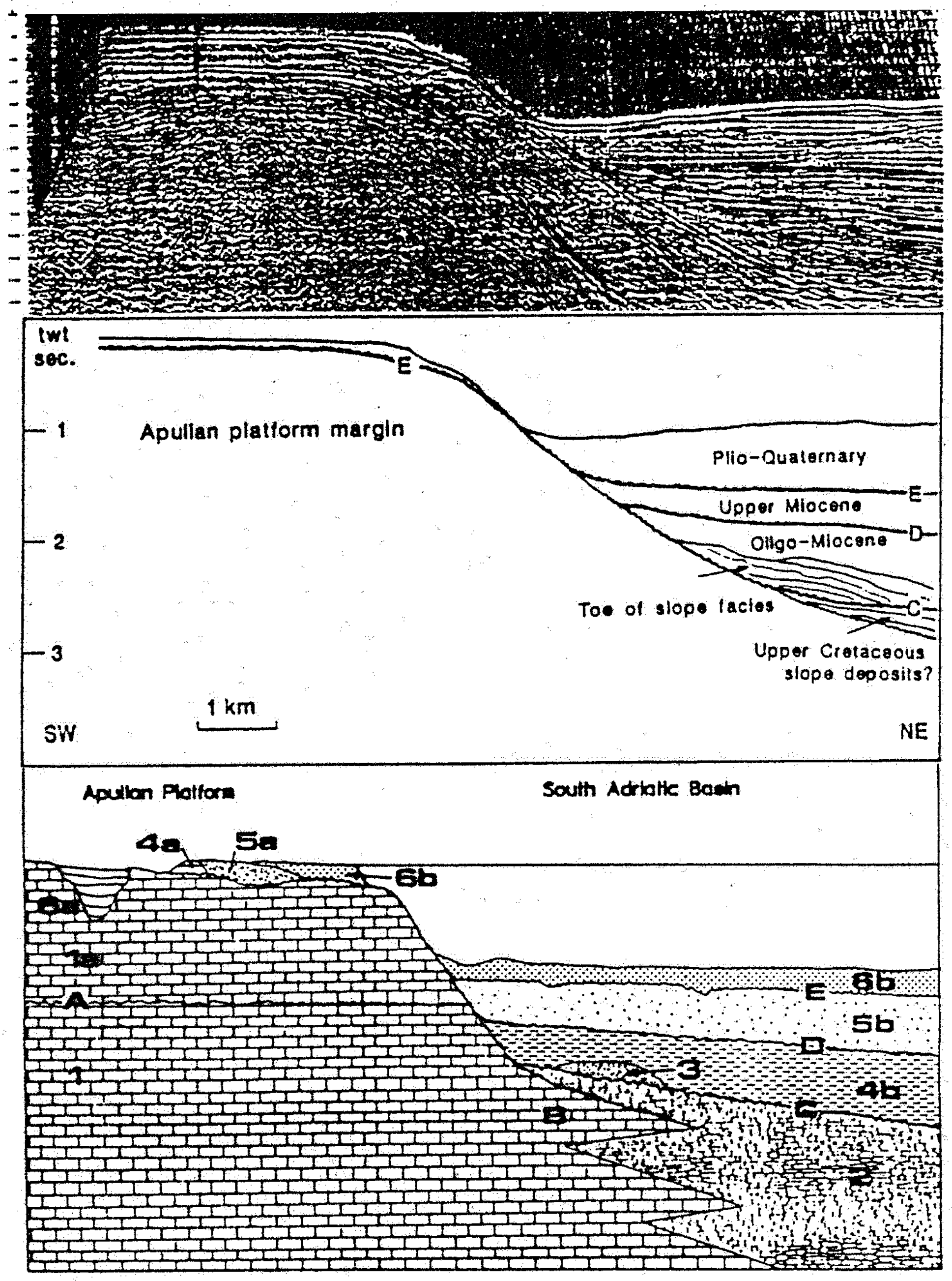


Fig. 21 - Eastern margin of the Mesozoic Apulian platform toward the South Adriatic basin in the E-Puglia offshore, after De Alteriis and Aiello (1993). The slope is eroded and partially buried by Tertiary clastics. 1 and 1a, Shallow water carbonates, Lower and Upper Cretaceous; 2, Pelagic limestone and marls (Maiolica and Scaglia formations); 3, Organogenic and bioclastic limestone, Eocene; 4a, Reef and bioclastic limestone, Oligocene; 4b, Calcareous and marly turbidites, Upper Oligocene/Lower Miocene; 5a, Detrital limestone and calcarenites, Miocene; 5b, Siliciclastic turbidites (Miocene); 6a and 6b, Plio-Quaternary continental and marine clastics.

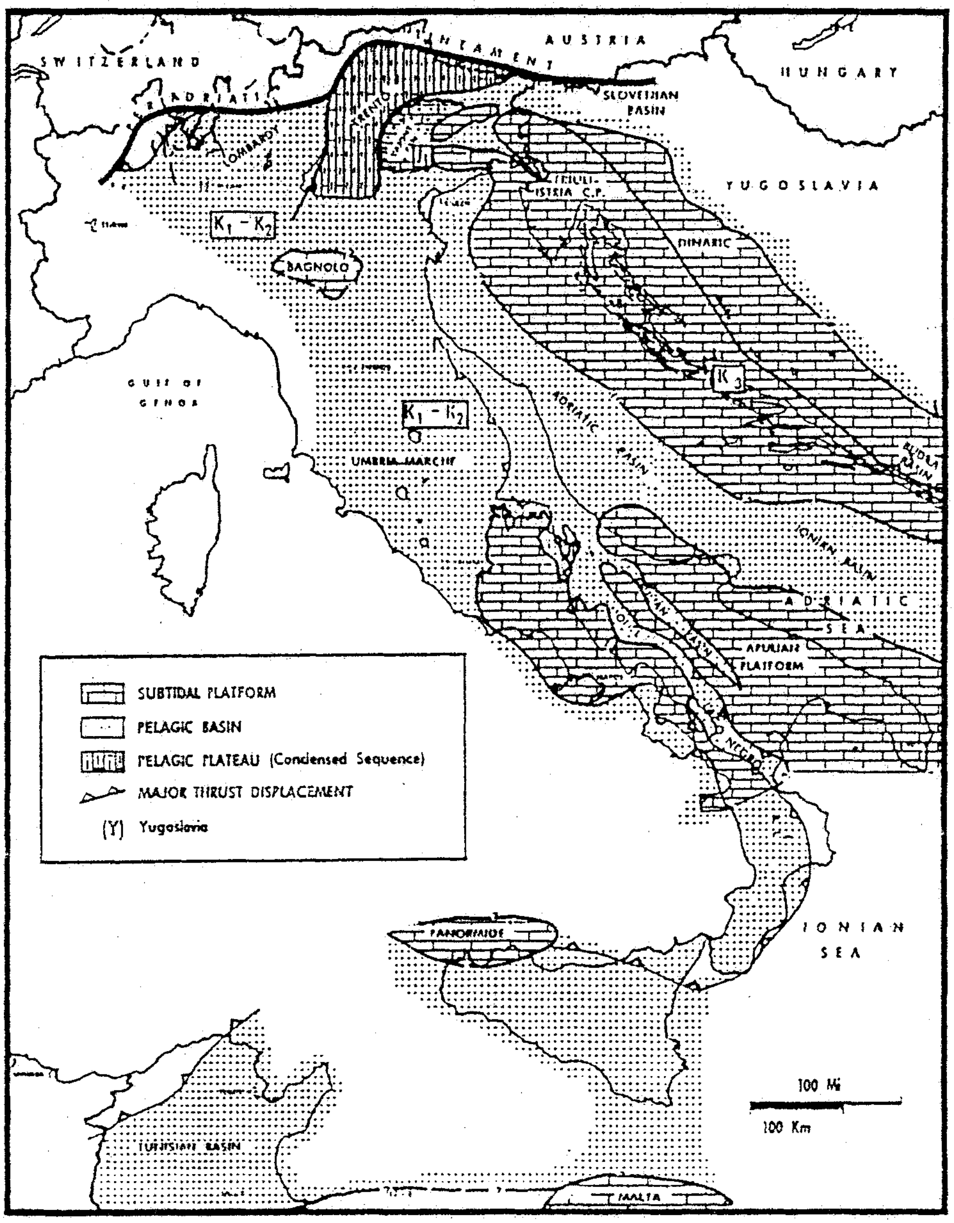
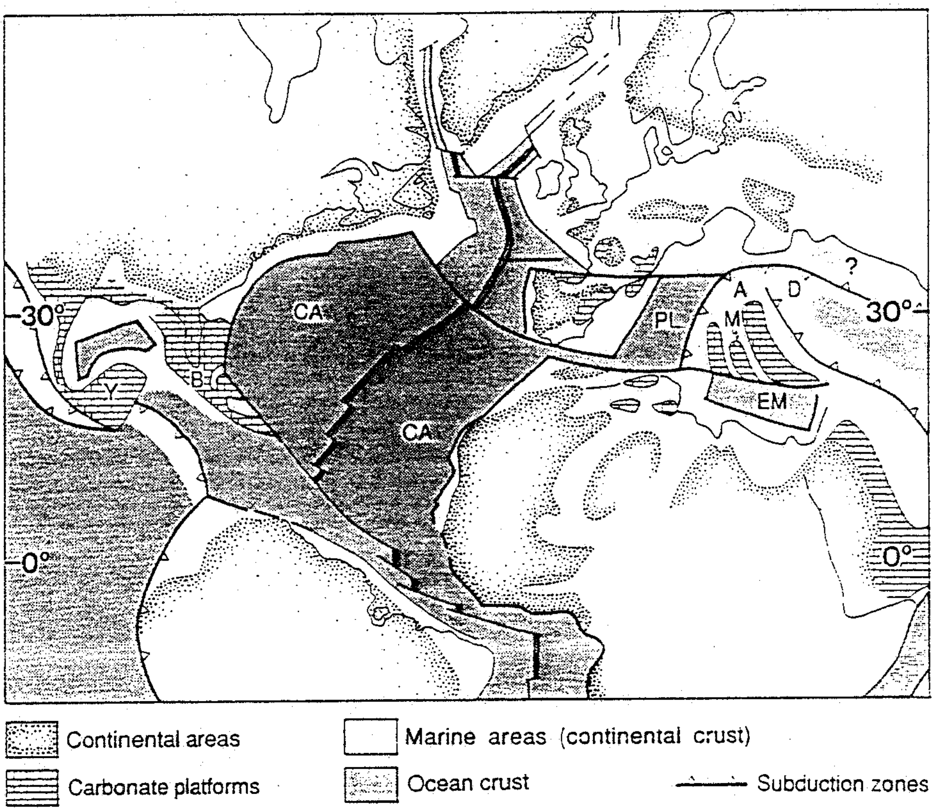


Fig. 22 - Facies map of Italy between Late Jurassic and Early Cretaceous, after Zappaterra, in AA.VV. (1990).

Opposite page:

above: Fig. 23 - Late Cretaceous (84 Ma) paleogeography and location of the peri-Adriatic platforms within the frame of the Cretaceous Tethys ocean. After Eberli et al. (1993). Italy is located in the area of A, Adria, and M, Maiella. B, Bahamas; CA, central Atlantic; D, Dinarides; EM, eastern Mediterranean; PL, Piemonte-Liguria ocean; Y, Yucatan.

below: Fig. 24 - Main stratigraphic columns of the Apennines, modified after Pieri (1969).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30°
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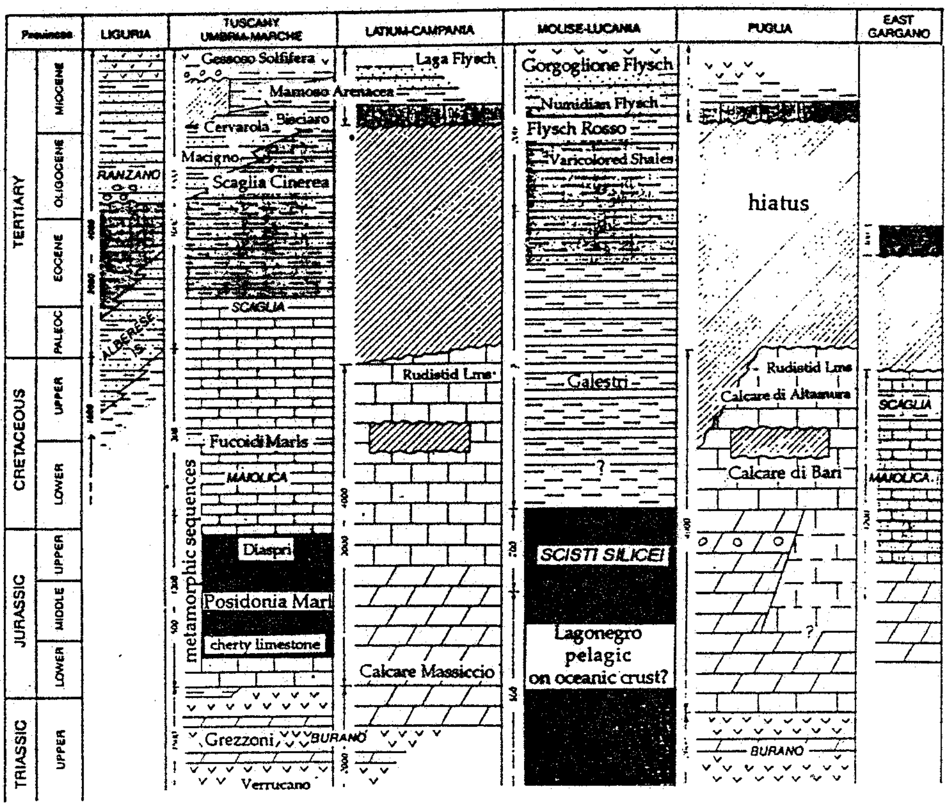
Continental areas
Carbonate platforms
Marine areas (continental crust)
Ocean crust
Subduction zones


Provinces
LIGURIA
TUSCANY UMBRIA-MARCHE
LATIUM-CAMPANIA
MOLISE-LUCANIA
PUGLIA
EAST GARGANO
TERTIARY
MIOCENE
OLIGOCENE
EOCENE
PALEOC
CRETACEOUS
UPPER
LOWER
JURASSIC
UPPER
MIDDLE
LOWER
TRIASSIC
UPPER
RANZANO
ALBERESE
Gessoso Solfifera
Marnoso Arenacea
Cervarola
Bisciaro
Macigno
Scaglia Cinerea
SCAGLIA
Fucoidi Marls
MAJOLICA
metamorphic sequences
Diaspri
Posidonia Marl
cherty limestone
Grezzoni
BURANO
Verrucano
Laga Flysch
Rudistid Lms
Calcare Massiccio
Gorgoglione Flysch
Numidian Flysch
Flysch Rosso
Varicolored Shales
Galestri
?
SCISTI SILICEI
Lagonegro pelagic on oceanic crust?
hiatus
Rudistid Lms
Calcare di Altamura
Calcare di Bari
?
BURANO
SCAGLIA
MAJOLICA

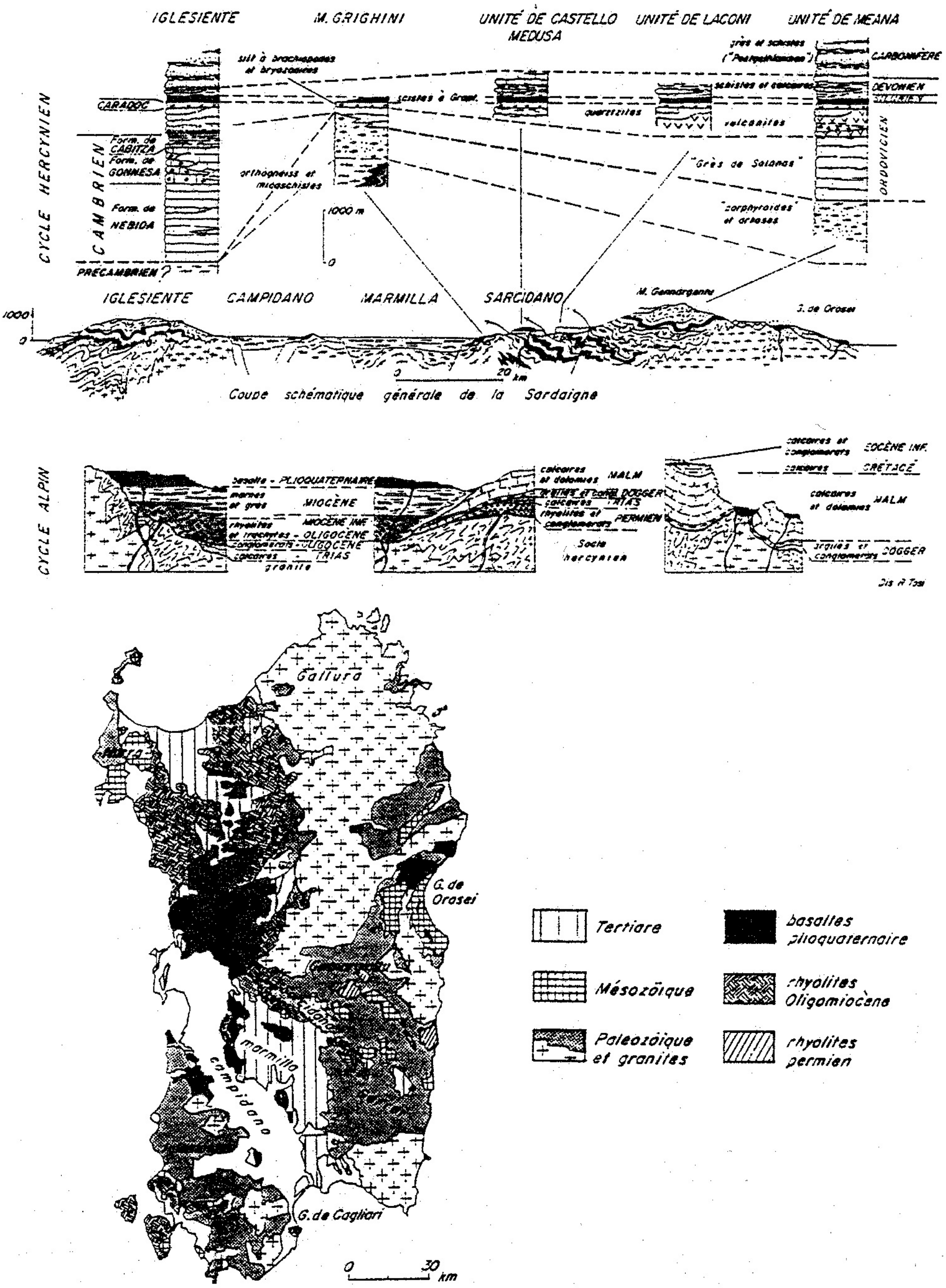


Fig. 25 - Schematic stratigraphy and structure of Sardinia, after Carmignani et al., in AA.VV. (1980).

ACTIVE MARGIN STRATIGRAPHY

The inversion of relative motion between Europe and Adriatic plates began during Cretaceous and generated compression at the western margin or dextral transpression at the northern margin of the Adriatic plate.

The spatial and temporal evolution of the Alps and later of the Apennines during the Tertiary is recorded by the clastic sediments, flysches and molasses, which overlaid diachronously the earlier passive margin sequences (Figs. 26, 27, 28 and 29). Alpine and Apenninic foredeeps were fed by the relative orogens and migrated through time with the coeval lateral migration of the thrust belts. In the Southern Alps, Upper Cretaceous flysch related to the early compressional phase deposited in the Lombard basin (Bergamo Flysch). Eocene flysch related to the Dinaric orogen and its interference with the eastern Alps deposited in NE Italy (Friuli and east Veneto foothills and plains). In areas not yet affected by the thrust belt, shallow water carbonate platforms and related shaly basins developed during Paleogene times (e.g. the Venetian foothills, Lessini).

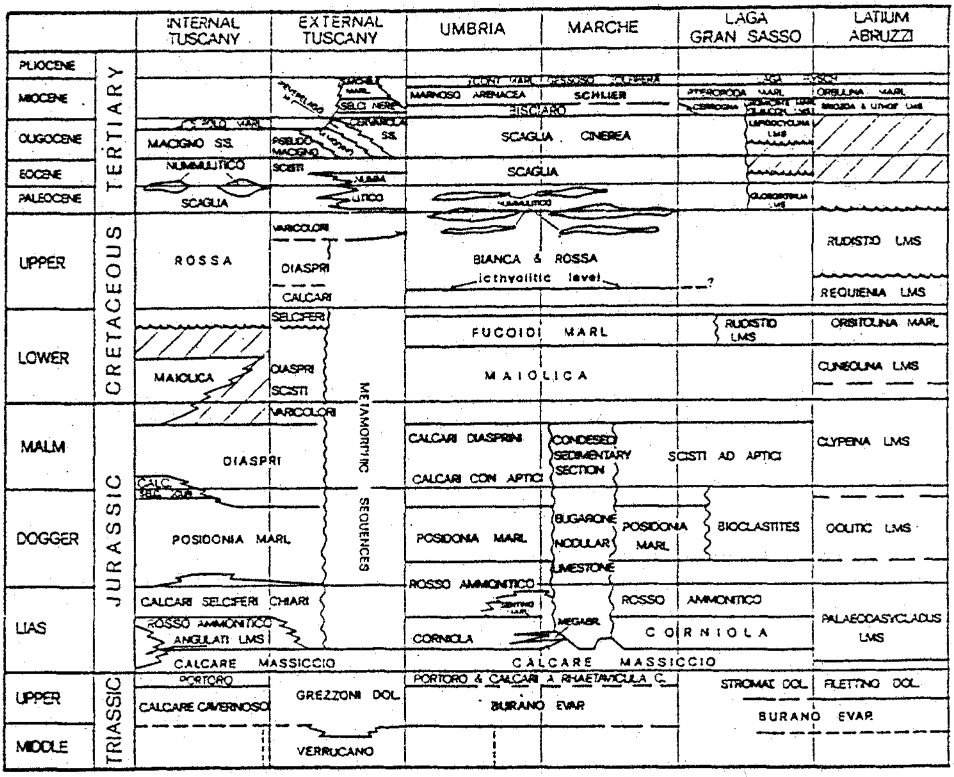


Fig. 26 - Stratigraphic correlations of the central Apennines, after Bally et al. (1986).

Famous is Bolca, a quarry near Verona providing a rich fish fauna. Molassic deposits accumulated in the Southern Alps southward migrating foredeep since Oligocene, like the Gonfolite Lombarda and the Miocene Molassa Bellunese. Messinian conglomerates also formed during the Mediterranean sea-level drop in the Southern Alps foredeep, while evaporitic facies deposited all around the Apennines (the Gessoso-Solfifera Formation). Cretaceous-Eocene flysch deposits accumulated along the Apenninic foredeeps during the Alpine phase and the Early Apenninic evolution. The Apenninic foredeeps migrated eastward, particularly during the Neogene (Fig. 27) as indicated for instance by the forward propagation both of thrusts and of piggy-back basins (Ricci Lucchi 1986, Boccaletti et al. 1990): e.g. the Chattian to Pleistocene migration of the central Apenninic foredeep, from west to east, and from older to younger, the Macigno basin, Cervarola basin, Marnoso-Arenacea basin, Camerino basin, Laga basin, Cellino basin, and present foredeep. The Frido Flysch (shales, turbidites and ophiolitic slices), the Cilento Flysch (shales, sandstones and conglomerates), the Varicolored Clays and the Flysch Rosso are deposits recording the early deformational compressive history of the southern Apennines (Cretaceous-Early Miocene). The Numidian Flysch is a widespread quartzarenitic Early Miocene deposits marking the onset of the clastic deposition in the Southern Apennines. The Flysch del Gorgoglione is an overlying Miocene coarse-grained deposit. Eastward migration of the foredeep is documented also for the Bradanic trough. The Quaternary sections of Calabria (Le Castella) and the Bradanic trough in Basilicata are among the most thick and exposed sections of the world. Due to high tectonism Pleistocene deposits are somewhere now uplifted to more than 1000 m (Calabria).

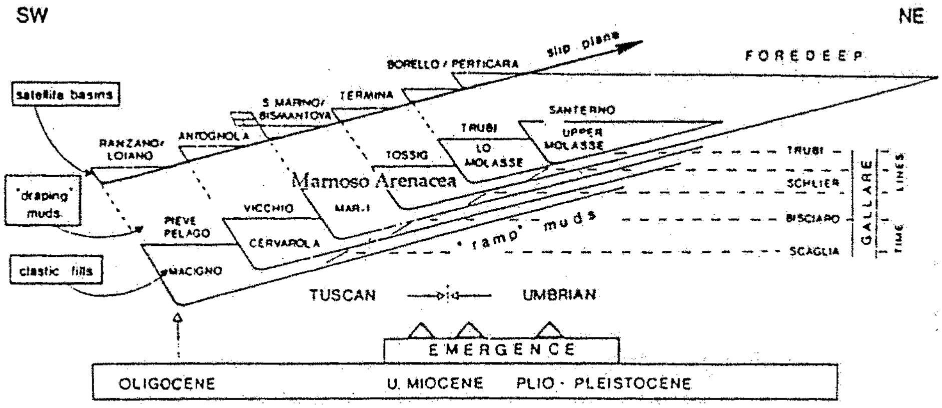


Fig. 27 - The 'eastward' migration of the Apennines is also documented by the eastward shift of the clastic wedges filling the foredeep, after Ricci Lucchi (1986).

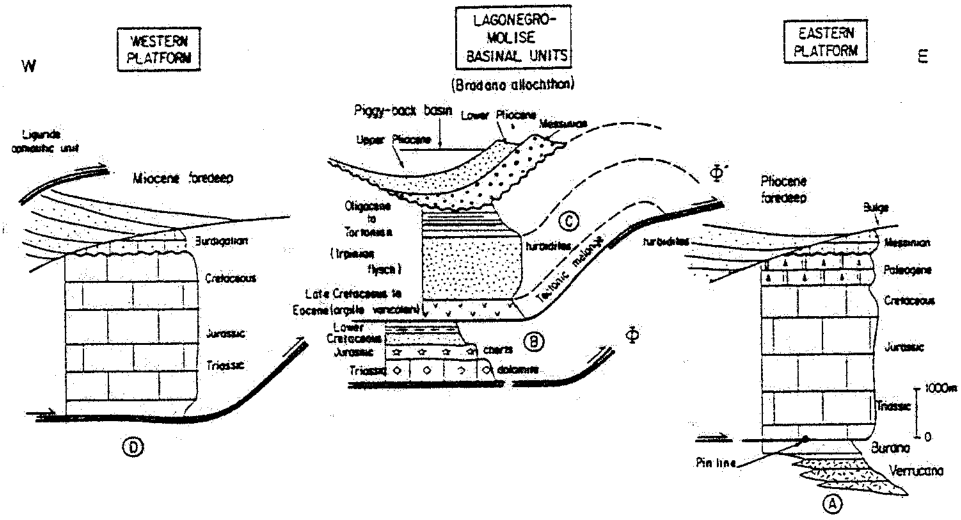


Fig. 28 - Synthetic stratigraphic columns of the Southern Apennines and location of the main thrust planes, after Casero et al., in AA.VV. (1988). Read Western Platform as Campano-Lucana platform, and Eastern Platform as Apulian platform.

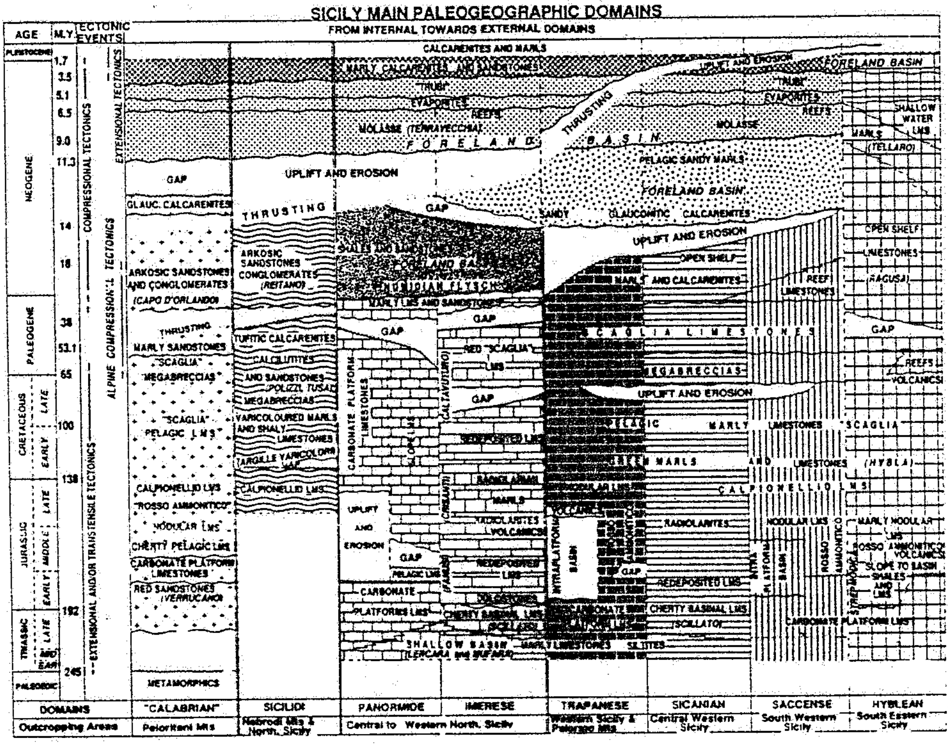


Fig. 29 - Stratigraphic correlations in Sicily, after Catalano and D'Argenio (1990).

MAGMATISM

Apart from the former mentioned Ordovician and Late Carboniferous - Early Permian magmatism, several other Triassic - to present magmatic episodes with different geodynamic significance occurred in Italy. A magmatic episode of Late Anisian - Ladinian age emplaced in the Rio Freddo area, in NE Friuli. Late Anisian - Early Ladinian sandstones called 'Pietra Verde' recorded an acid calcalkaline magmatic event in the Southern Alps whose magmatic sources are uncertain. These green sandstones are interbedded to the Livinallongo (or Buchenstein, german name) Formation.

During Middle Triassic a shoshonitic magmatic event formed in the Dolomites. Granitic and monzonitic bodies intruded the upper crust of the Dolomites during Late Ladinian - Early Carnian times in Predazzo and Monzoni. Coeval lavas, pillow-lavas and volcaniclastic deposits spread out all around that region. Triassic magmatism is also reported in the western Venetian foothills (Recoaro area), in the Po Plain subsurface, in western Trentino region, in Lombardia (the volcaniclastic Carnian Val Sabbia Sandstone, the subvolcanic body of Barghe), in the northern Apennines, in the Lagonegro Basin (southern Apennines) and in Sicily. Mantle peridotites, serpentinites, gabbros, prasinites, and pillow lavas of ophiolitic suites recording the oceanic crust of the Jurassic-Early Cretaceous Tethys are entirely or partially preserved in northern Calabria, in the northern Apennines (Tuscany and Liguria), in the western Alps (Piemonte, Val d'Aosta), in Liguria (Gruppo di Voltri), and outside Italy in the Engadine, Tauern and Rechnitz windows in Switzerland and Austria. Alpine ophiolites are metamorphosed by subduction processes, whereas in the Apennines the ophiolites related to the Apenninic subduction are not or poorly metamorphosed. Alpine ophiolites are large slices of oceanic crust accreted during the convergent-collision process. Northern Apennines ophiolites are rather olistoliths or small size blocks included in the 'Liguridi' or 'Argille Scagliose' flyschoid units, or remnants of Alpine crustal slices inherited by the Apenninic evolution. High temperature shear zones and metamorphism of the Jurassic-Cretaceous gabbros of the northern Apennines ophiolitic suite have been related to the initial stages of break-up and oceanization (Piccardo et al., 1992; Molli, 1994). Pelagic sediments of Callovian to Santonian age cover the northern Apenninic ophiolites. In Sicily magmatic episodes on the Iblean Plateau are reported for the Middle Jurassic of the Ragusa basin, and for the Middle-Late Cretaceous and Pliocene of the Siracusa area. Volcanism developed also in the Trapanese basin during Late Jurassic.

Alkaline basaltic dikes of about 60 Ma have been reported in the Dolomites. The Traversella, Biella, Val Masino-Bregaglia, Alta Valtellina (Sondrio), Adamello and Vedrette di Ries are plutons or batholiths of granodiorites, tonalites, sienites-monzonites of Late Eocene - Oligocene age (42-29 Ma), recording the late Alpine magmatic event. Several minor dikes of basaltic andesites occur close to the intrusions. The Adamello is the largest outcropping Tertiary intrusion of Italy (Fig. 9). The Adamello batholith cross-cut pre-existing folds and thrusts of the Orobic-Brescian Alps, indicating a pre-Late Eocene compressional phase in the western Southern Alps (Brack, 1981). This phase has been interpreted as active since Late Cretaceous for coeval flysch deposits and other structural indicators. The shape of the Bregaglia batholith shows instead to have been sheared during its emplacement by dextral Oligocene

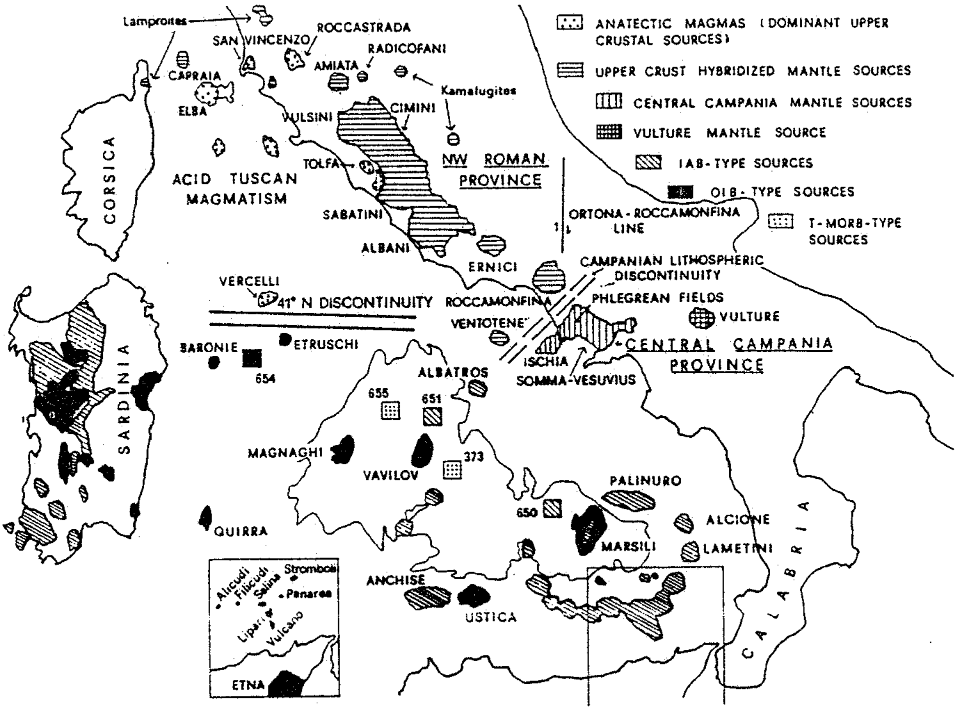


Fig. 30 - Interpretation of the Neogene-Quaternary magmatism of the Tyrrhenian region in terms of magma sources relevant for geodynamic processes. The 41°N and Campanian lithospheric discontinuities were identified on geochemical and petrological grounds. Numbers show locations of DSDP holes. After Serri (1990).

slip along the Insubric Lineament (Centovalli-Tonale segments). All these complexes of magmatic bodies are confined in a belt a few tens of km wide along the Insubric Lineament, generated by the anatexis induced by the rising of the isotherms with the decrease of the convergence rates between Europe and the Adriatic plates after the collision process.

In the Lessini Mountains and Colli Euganei in west Veneto, an alkaline magmatic event took place during Paleogene. Basalts and volcaniclastic debris were confined in synsedimentary N-S trending grabens (Lessini), and trachitic laccholites and sills intruded the Mesozoic sequences (Colli Euganei). Tertiary alkaline sienites crop out at the Punta delle Pietre Nere (N-Puglia). Magmatic occurrences are also in the Iblean (o Ragusan) Plateau in SE-Sicily. In west Sardinia (Fig. 1) during Late Oligocene-Middle Miocene (32-13 Ma) calcalkaline lavas emplaced, whereas alkaline to subalkaline lavas formed from Late Miocene to Late Pleistocene (7-0.1 Ma) in the Orosei Gulf, Logudoro and the Mt. Ferru, which is the biggest volcanic body of Sardinia. Volcanism in Sardinia was associated to extensional tectonics (e.g. the Campidano Graben).

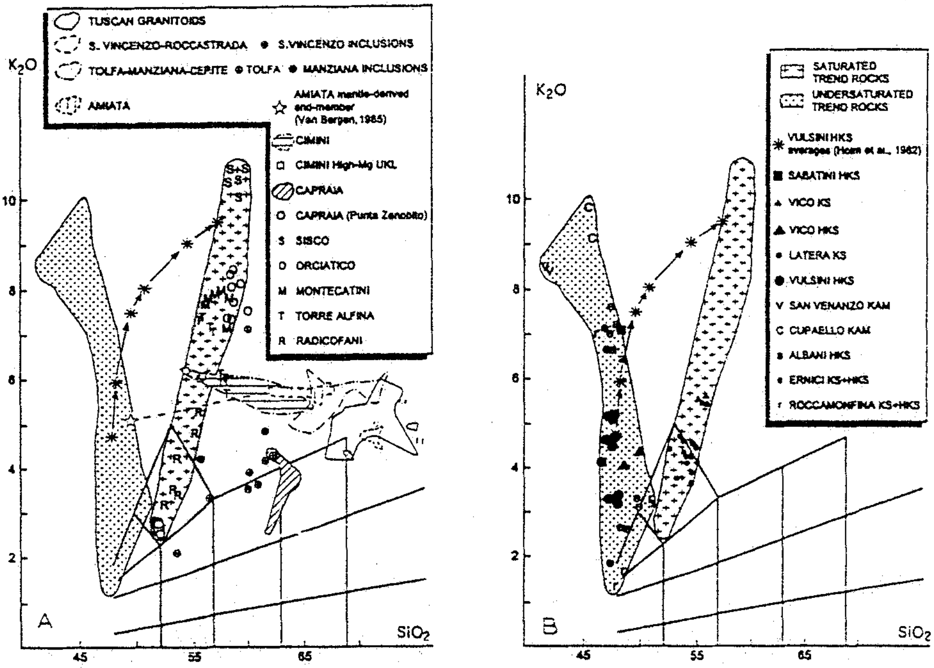


Fig. 31 - K_20 versus SiO_2 (wt%) diagram (anhydrous basis) for the Provincia Magmatica Toscana (A) and northwestern Provincia Magmatica Romana (B) rocks. After Serri et al. (1993).

During Miocene (Burdigalian - Serravallian) calcalkaline riodacitic volcaniclastic tuffites deposited along the external Apennines (both northern and southern, Emilia Romagna, Irpinia and Sicily). During Pliocene and Pleistocene times several volcanoes were operating in Italy (Figs. 30 and 31): the Roccamonfina (1.5 Ma), north of the Vesuvio, the Island of Ponza (1.0 Ma), Ventotene (0.8 Ma), seamount volcanoes in the Tyrrhenian sea (Magnaghi, Marsili, Vavilov, Palinuro, with ages ranging between 3.5 to 0.1 Ma) and Ionian sea (Marconi). A series of volcanoes were active in Tuscany, Latium and northern Campania (Roman Province). These volcanoes emplaced along grabens with an Apenninic trend (NNW-SSE). The Vulture was an active cone in eastern Basilicata between 0.8-0.5 Ma. Geochemistry of all this magmatic activity covers a wide spectrum: from alkaline - tholeiitic magmas of the Tyrrhenian basin, where oceanic crust of the back-arc is interpreted around the Vavilov and Marsili seamounts; to calcalkaline shoshonitic rocks of the Eolian Islands, interpreted as subduction related magmas; the Roman Province (Volsini, Cimini and Albani mountains) shows higher K contents, but still with subduction related signature, more contaminated by continental crust (Fig. 31). Crateric lakes are still visible on these abandoned volcanoes: the Bolsena, Mt. Volsini and Bracciano lakes. Other crateric lakes are the Vico Lake in the Cimini Mountains, the Nemi and Albano lakes in the Colli Laziali, the Averno

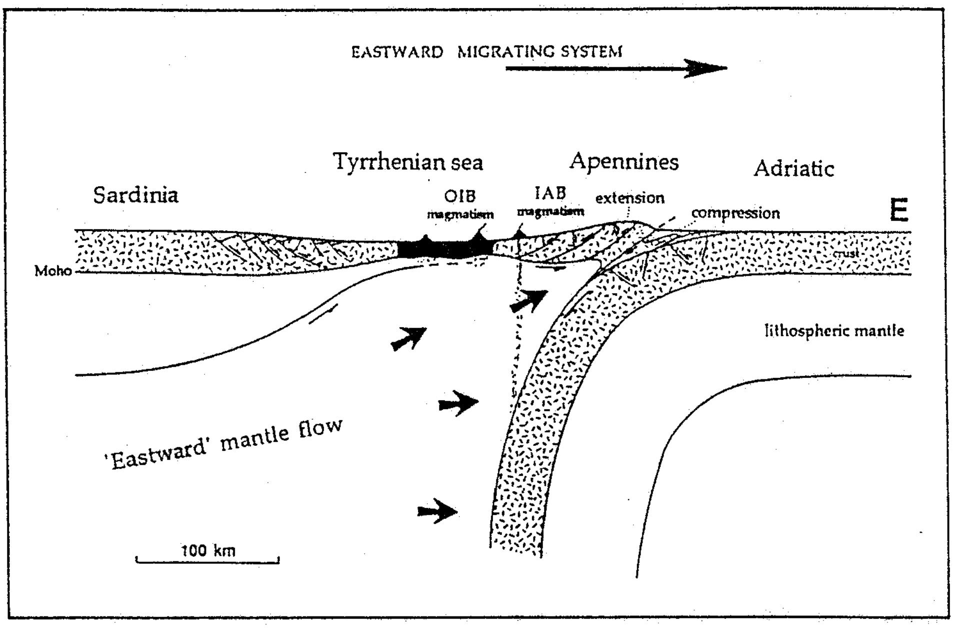


Fig. 32 - Schematic cross-section of the Tyrrhenian-Apennines system. OIB, ocean island basalts; IAB, island arc basalts. Note that the active Apenninic accretionary wedge is located to the east of the chain, mainly below sea-level, whereas the chain is in extension.

lake in the Phlegrean Fields and Monticchio lake on the Mt. Vulture. The Etna and the Vulture are magmatic bodies which are geologically outside the subduction of the Adriatic-Ionian lithosphere, and they also are not related to the back-arc extension of the Tyrrhenian basin. They are located along extensional features (the Malta Escarpment for the Etna and the Ofanto Graben for the Vulture), and they also show alkaline characters (Fig. 30).

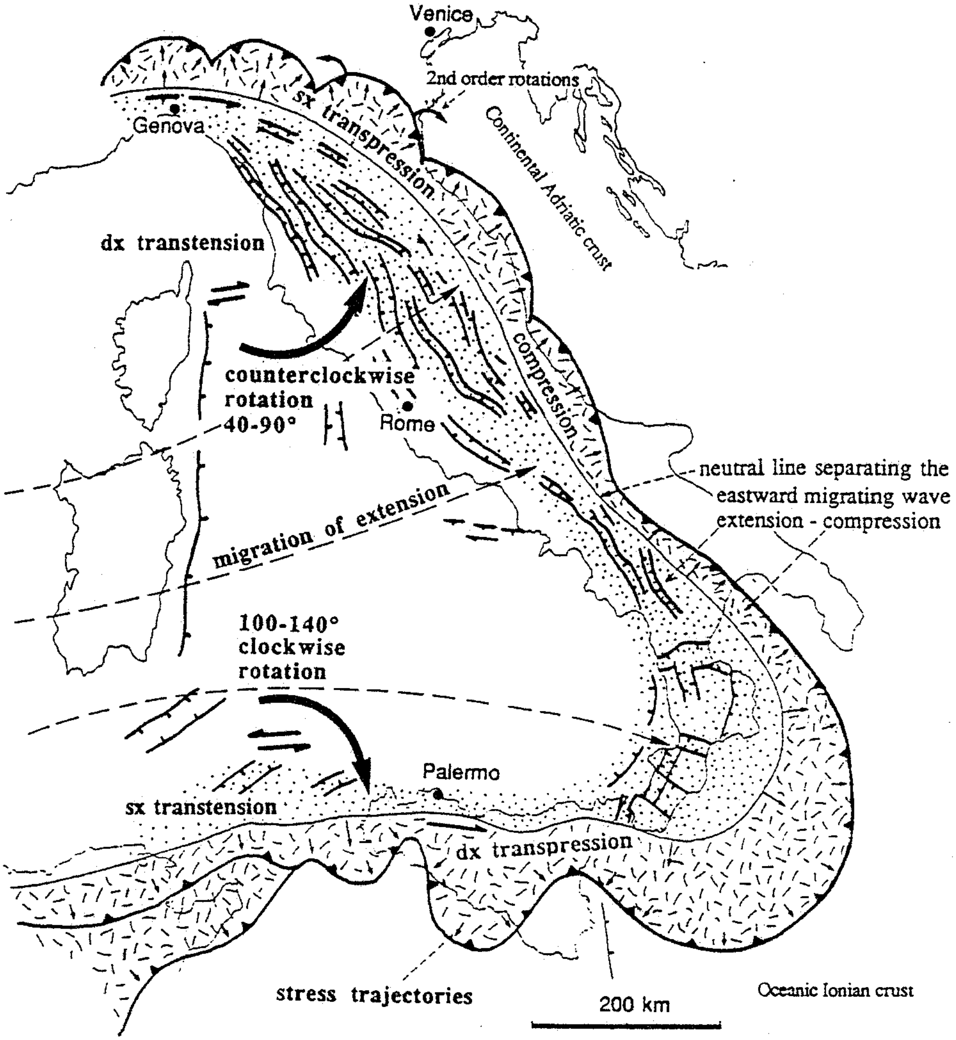


Fig. 33 - The present Tyrrhenian-Apennines system is related to a W-dipping subduction which began to migrate eastward from the eastern margin of Sardinia about 10-15 Ma ago. Note that the external Apennines are in compression, while the main ridge is in tensional regime. The main asymmetric shape of the arc is controlled by the composition and thickness of the subducting lithosphere: the Ionian part is thinner and oceanic, more subductable with respect to the thicker and continental in origin Adriatic crust. Second order arcs formed in correspondence of inherited downgoing horsts and grabens or facies changes in the upper layers of the crust, after Doglioni (1991).

Both in Tuscany and in the Tyrrhenian sea the rifting migrated eastward since Tortonian (e.g. the rejuvenating Magnaghi, Vavilov and Marsili volcanoes in the southern Tyrrhenian over oceanic crust), and it was accompanied by magmatism in the northern Tyrrhenian - Tuscany by a wave of magmas (both plutons and effusive products) ranging in age from 9 to 0.18 Ma (the islands of Capraia, Elba, Montecristo, Giglio, Gavorrano, Mt. Amiata, Radicofani, Mt. Cimino, etc.). Southern Italy has a few active volcanoes: the most important cones are the Vesuvio, Etna, Stromboli, Vulcano and a few scattered centers in the Sicily channell. One of these last ones generated in 1891 an island called Ferdinandea, but the island was soon destroyed by sea currents and it is now known as Graham Bank. The continuum basaltic effusions of the Etna make this volcano much less dangerous with respect to the Vesuvio or Vulcano, two explosive apparatus which erupt episodically and with large destruction, e.g. the famous plinian eruption of Vesuvio the 79 a.C., which destroyed Pompei, Ercolano and other minor villages. The Campanian Ignimbrite is a widespread thick 35,000 yr old pyroclastic flow deposited in Campania and erupted by the Phlegrean Fields near Neaples.

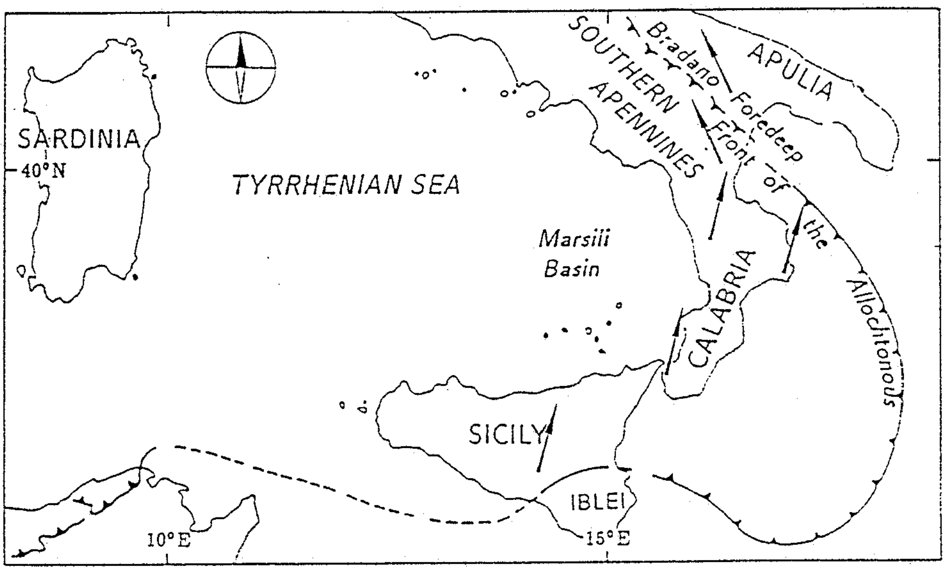


Fig. 34 - Paleomagnetic declinations (arrows) reported in the literature for Pleistocene sediments in southern Italy, after Sagnotti and Meloni (1993). Note the clockwise rotation from Calabria southward and the counterclockwise rotation to the north indicating the main hinge zone of the Apenninic arc.

Geodynamically in the Tyrrhenian-Apennines system we may distinguish a few different magmatic associations: the calcalkaline-shoshonitic series which are related to the subduction of the Adriatic continental lithosphere (Tuscan and Roman Province), and of the Ionian oceanic lithosphere (Eolian Islands), with a transitional area in between given by the Pontine Islands-Roccamonfina-Vesuvio; alkaline-tholeiitic associations are instead related to the back-arc extension of the Tyrrhenian basin (Magnaghi-Vavilov and Marsili seamounts). The associations migrated eastward since Late Miocene. These geochemical variations are then related to the different composition of the Adriatic subducting lithosphere (Figs. 32, 33 and 34). Mount Etna and part of the Eolian magmatism (Vulcano) may be instead related to the E-W stretching going on between Calabria and Sicily, generating a N-S extensional alignment, probably related to the rupture of the subducting slab. The magmatism in the Sicily channell (Pantelleria) is instead related to the extension since Pliocene which is separating the Pelagian shelf (Africa) from Sicily.

4 - TECTONICS

Geology of Italy is marked by the two orogens, the Alps to the north, and the Apennines along the peninsula and Sicily. The Alps are due to the thrusting toward the west and northwest of the Adriatic plate over the European plate, while the Apennines have been generated by the subduction of the Adriatic plate toward the west (Fig. 8). The Apennines show to the west a back-arc basin, the Tyrrhenian sea (Figs. 1, 32 and 33). Very limited areas in Italy have not been involved by the two orogenic waves, i.e. the Puglia region, part of the Iblean Plateau (SE-Sicily), a few areas in the Po and Venetian plains, and the Sardinia island. But these foreland areas, even if not or weakly compressed by the orogenic waves, underwent subsidence or uplift movements connected to the migration of the Alpine or Apenninic fronts.

Alps and Apennines show typical thrust belt geometries, with fault-propagation folds, fault-bend folds, triangle zones, imbricate fans, etc.. Particularly in the Apennines the thrust belt is dissected by several younger (Plio-Quaternary) normal faults. The main Alpine and Apenninic structures observed in Italy formed in brittle conditions.

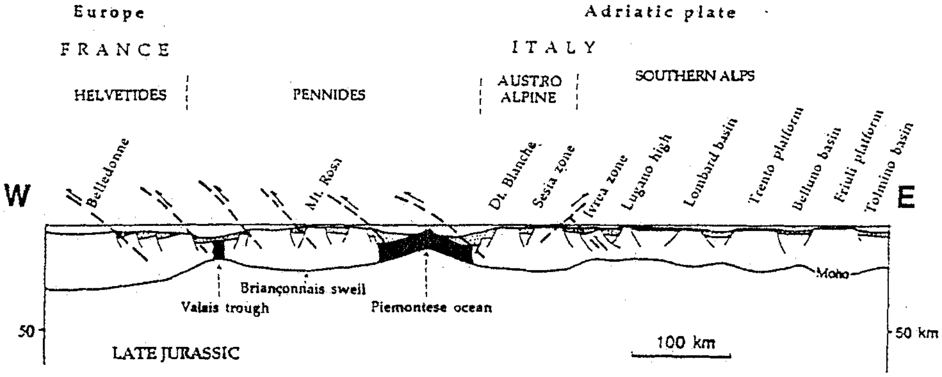


Fig. 35 - Schematic cross section illustrating the rifting between the European and the Adriatic plates at the end of Jurassic. The section runs across the Western Alps and the Southern Alps, from France to northern Italy. Names correspond to present Alpine structural units, and dashed lines indicate the later location of the major Alpine thrusts, modified after Pfiffner, in Blundell et al. (1992).

Ductile deformation affected the Austroalpine and Penninic units in Piemonte and Val d'Aosta, the Hercynian and Alpine metamorphic rocks of Calabria and the Apuane window, and the largest part of the Hercynian basement.

Alps and Apennines deformed the northern and western Mesozoic passive continental margin of the Adriatic plate (Fig. 35). Synonymous of the Adriatic plate are Apulian plate, or African promontory. The connection with Africa has been generally proposed on the basis of the paleomagnetic data showing a similar apparent polar wander path of the Adriatic Mesozoic values with those interpreted for Africa. However the opening of the Ionian sea during the Early Jurassic-Cretaceous had to generate an independent Adriatic plate with respect to Africa at least during the growth of the Ionian oceanic basin.

The Ionian sea is floored by 8-11 km of oceanic crust and 6-8 km of sedimentary cover of Mesozoic and Tertiary age. Low heat flow values (<40 mW/m^2) and a thick lithospheric mantle (70-90 km) suggest an old age for this oceanic embayment. According to Finetti (1982) the oceanic crust began to spread during the Liassic. The Malta escarpment offshore east Sicily and the Salento offshore southwest Puglia appear to be two conjugate passive continental margins of Triassic-Jurassic age. A consequence of this is that the Ionian sea in a section between Sicily and Puglia should be a complete oceanic section containing an aborted oceanic ridge of Mesozoic age whose relief is lost by thermal cooling and hidden by thick pelagic deposits ranging in age from Jurassic to Tertiary, and by the overlapping Apenninic thrust sheets. In this view the continental extension that evolved to form the oceanic crust in the Ionian sea should have began at least during the Triassic. However pelagic faunas have been reported from the Permian of Sicily, and this could be an indication of a very early history of the Ionian rift.

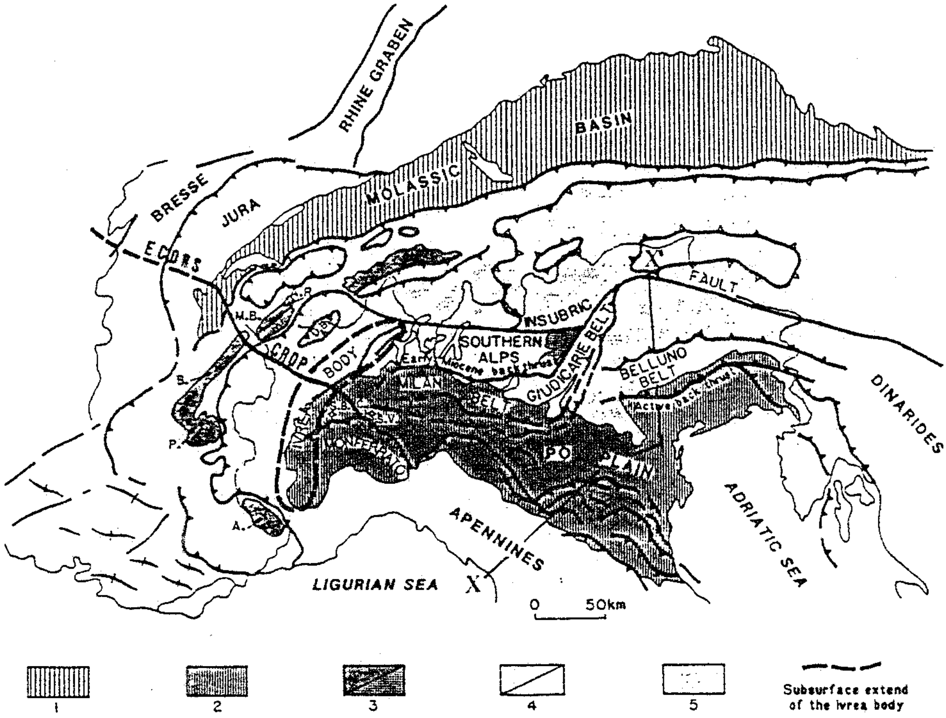


Fig. 36 - Schematic structural map of the Alps, after Roure et al. (1990). Legend: 1, Miocene molasse; 2, Plio-Quaternary infill of the Po Plain; 3, Cristalline massifs; 4, Pennides; 5, Southern Alps. A, Argentera massif; P. Pelvoux; B, Belledonne; MB, Mont-Blanc; A.R., Aiguille Rouge; D.B., Dent Blanche. Note location of the ECORS/CROP traverse; X-X' is the location of Fig. 43.

WHY DO WE DISTINGUISH ALPS AND APENNINES?

The Alps and the Apennines provide a unique geodynamic setting in which to compare structural differences between thrust belts associated to opposite subductions, namely E-dipping and W-dipping. The Alps have high structural and morphologic relief, deep crustal rocks cropping out (widespread outcrops of crystalline basement), and a shallow foredeep (Figs. 36, 37, 38, 39, 40, 41 and 42). The Apennines have low structural and morphologic relief, shallow rocks involved (mainly sedimentary Mesozoic-Tertiary rocks), back-arc basin, and a deep foredeep (Figs, 43, 44, 45, 46 and 47).

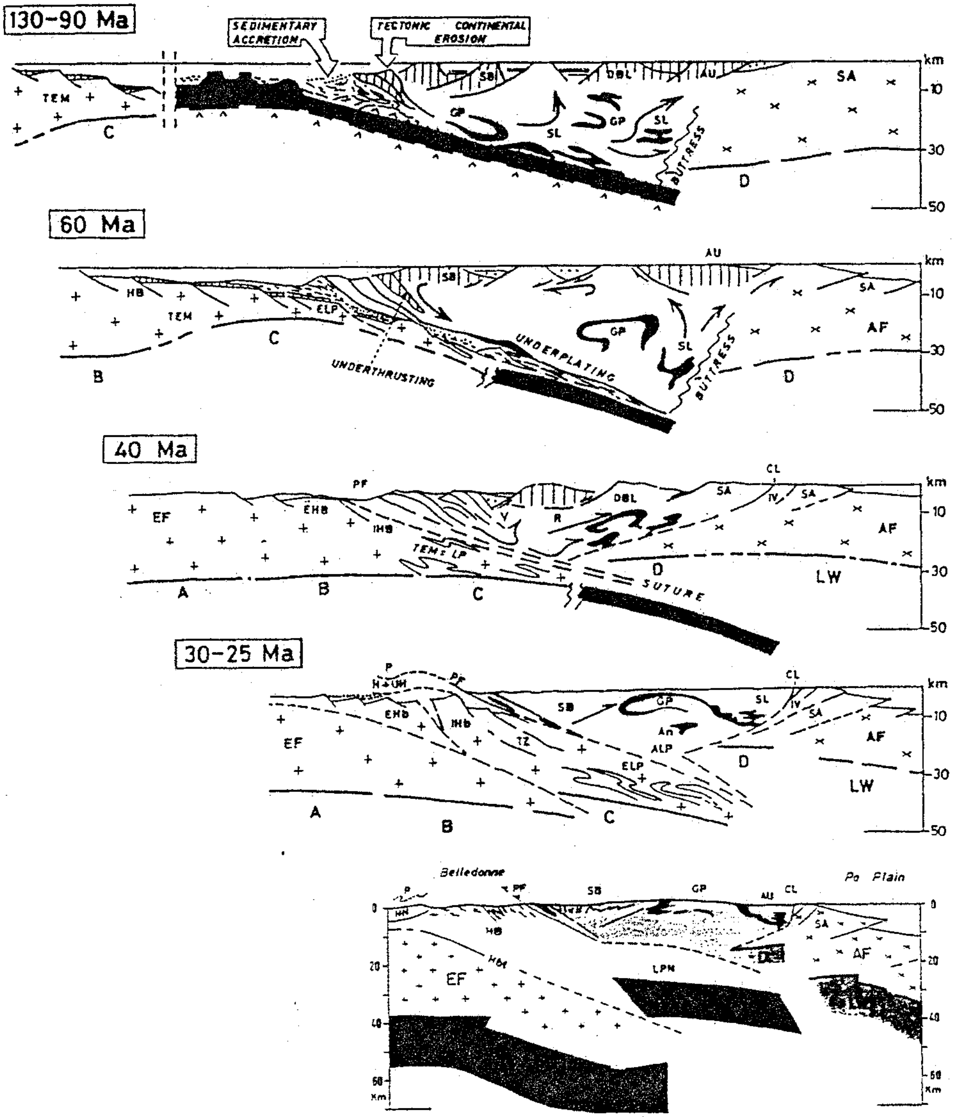


Fig. 37 - Alpine kinematic evolution of the Western Alps, and in the bottom present crustal image of the CROP/ECORS traverse, after Polino et al., in Roure et al. (1990). Legend: A, B, C, D, LW, upper mantle; SA, Southern Alps; AU, Austroalpine; SB, Grand St. Bernard; DBL, Dent Blanche; GP, Gran Paradiso; SL, Sesia Lanzo; AF, Adriatic foreland; EF, European foreland; PF, Pennides thrust front; LPN, lower Penninic Front; H, UH, Helvetides. CL, Canavese, Insubric Line; black, ophiolitic units.

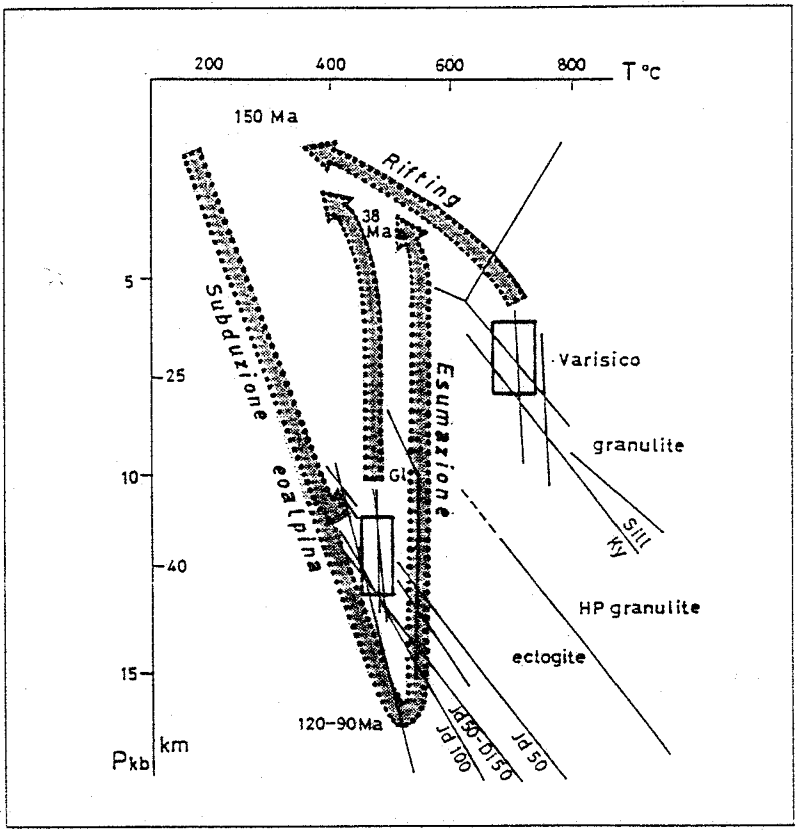


Fig. 38 - P-T-t trajectories of the Austroalpine units in the Western Alps (M. Emilius and Sesia-Lanzo), after Dal Piaz (1992).

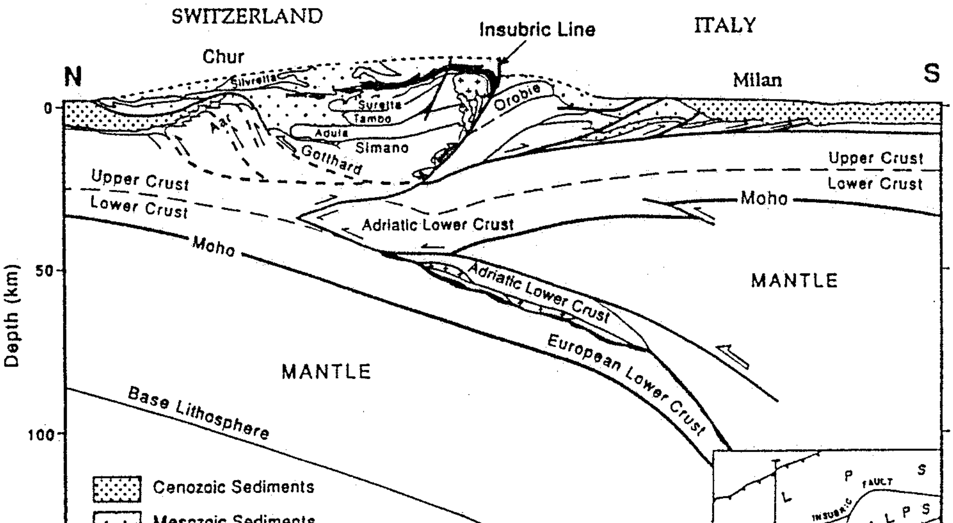


Fig. 39 - Interpretative cross section of the Alps between Switzerland and Italy, after Pfiffner, in Blundell et al. (1992).

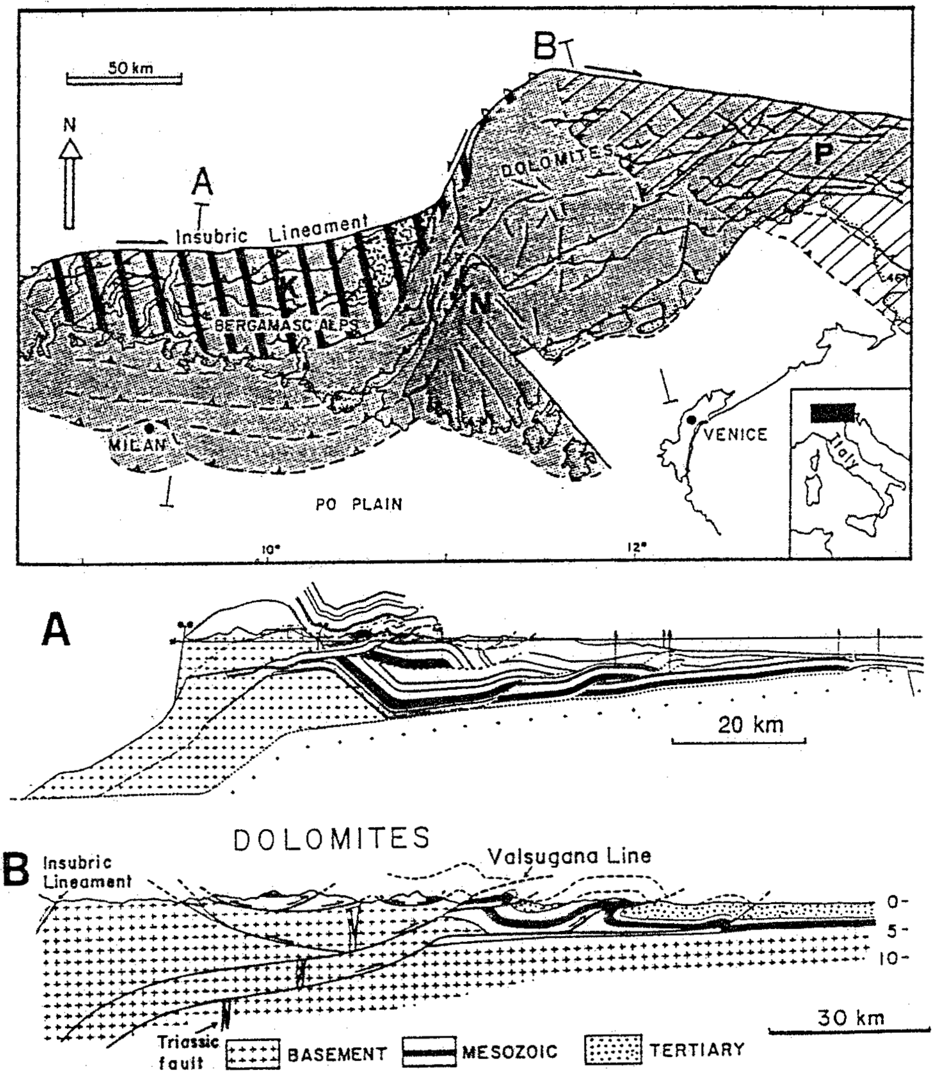
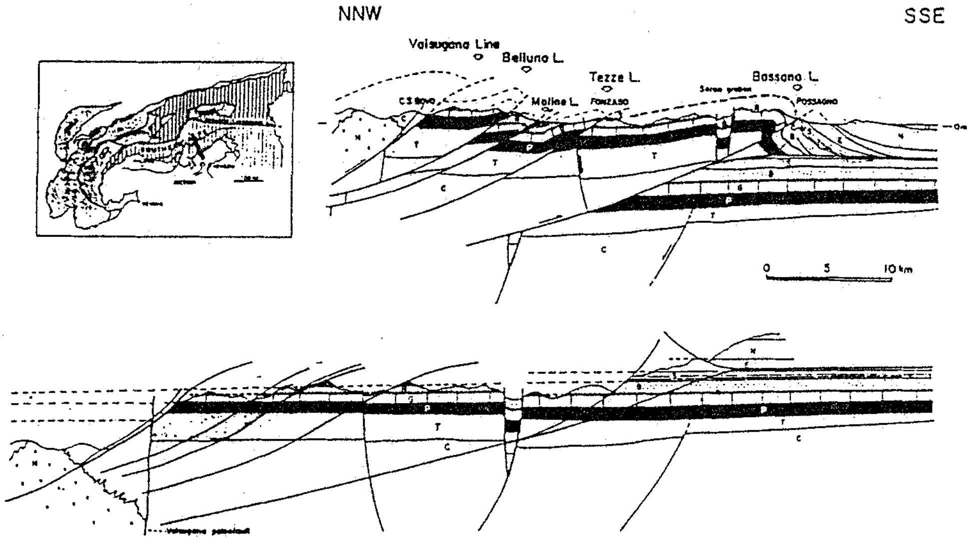
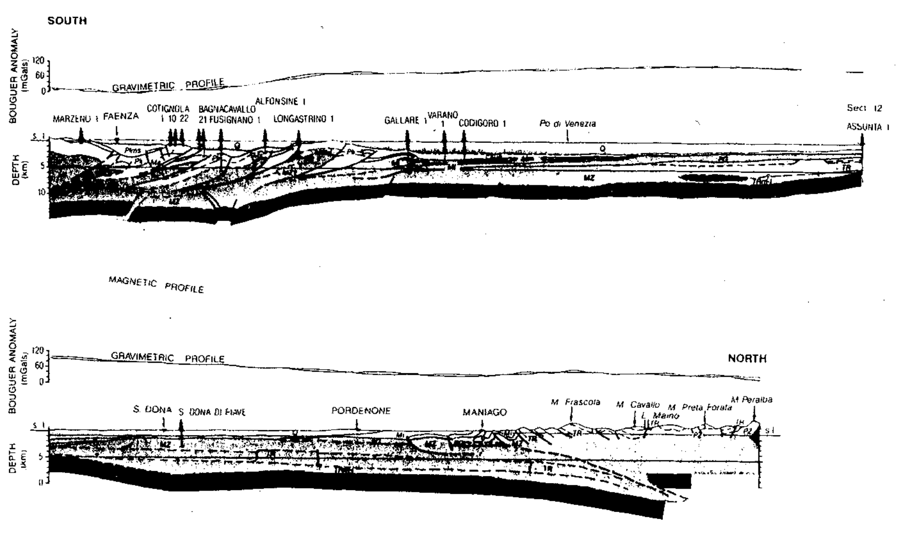


Fig. 40 - The Southern Alps thrust belt began to be deformed during the Eoalpine Late Cretaceous tectonics in their western part (K), while Oligocene to Neogene tectonics affected the entire area (N). In the eastern part the Southern Alps interfered with the Dinarides (P) during Eocene and Miocene times. A, section after Schönborn (1992), across the Orobies and the Po Plain; B, cross-section from the Dolomites to the Venetian Plain.

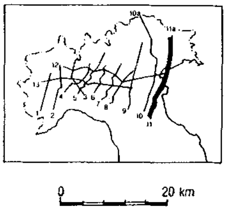
Opposite page:
above: Fig. 41 - Balanced cross section across the Venetian Alps, after Doglioni, in Boccaletti et al. (1990b). Legend: C, crystalline basement; H, Late Hercynian granite; T, Late Permian-Lower and Middle Triassic formations; P, Late Triassic (Dolomia Principale); G, Liassic platform facies (Calcari Grigi) gradually southward passing to Liassic-Dogger basinal facies in the Venetian Plain (Soverzene Formation, Igne Formation, Vajont Limestone); R, Dogger-Malm basinal facies (Lower and Upper Rosso Ammonitico, Fonzaso Formation; B, Early Cretaceous (Biancone); S, Late Cretaceous (Scaglia Rossa); E, Paleogene (Possagno Marls, etc.); N, Late Oligocene-Neogene Molasse; Q, Quaternary.
below: Fig. 42 - Cross-section from the northeast Apennines to Friuli, after Cassano et al. (1986).





ITALY
NORTHERN AREA
GEOPHYSICAL AND GEOLOGICAL INTEGRATED INTERPRETATION

SECTION N. 11



LEGEND

		DENSITY gr/cm³
Q	Quaternary	2.24-2.25
Plms	Upper middle pliocene	2.33-2.34
Pli	Lower pliocene	2.43-2.44
Ms	Upper miocene	2.48-2.49
Mm	Middle miocene	2.49-2.54
Mi	Lower miocene	2.59-2.60
PG	Paleogene	2.68-2.69
MZ	Mesozoic {K, J, TR	2.69-2.81

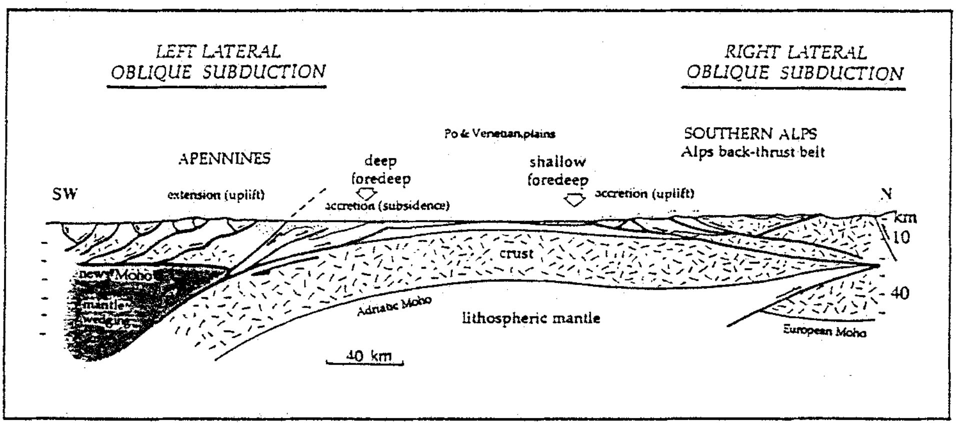
		DENSITY gr/cm³	SUSCEPTIBILITY C.G.S. u ×10⁶
■	Magnetic basement	2.80-2.81	50-400
▨	Ophiolite		
▨	Tertiary volcanite		
■	Triassic volcanite	2.77-2.80	500-600
▨	Permian volcanite		

—— Horizon by gephysical and geological data

– – – Phantom by geophysical and geological data

–/– Fault or discontinuity

FLIGHT ALTITUDE 1200 and 2700 m.



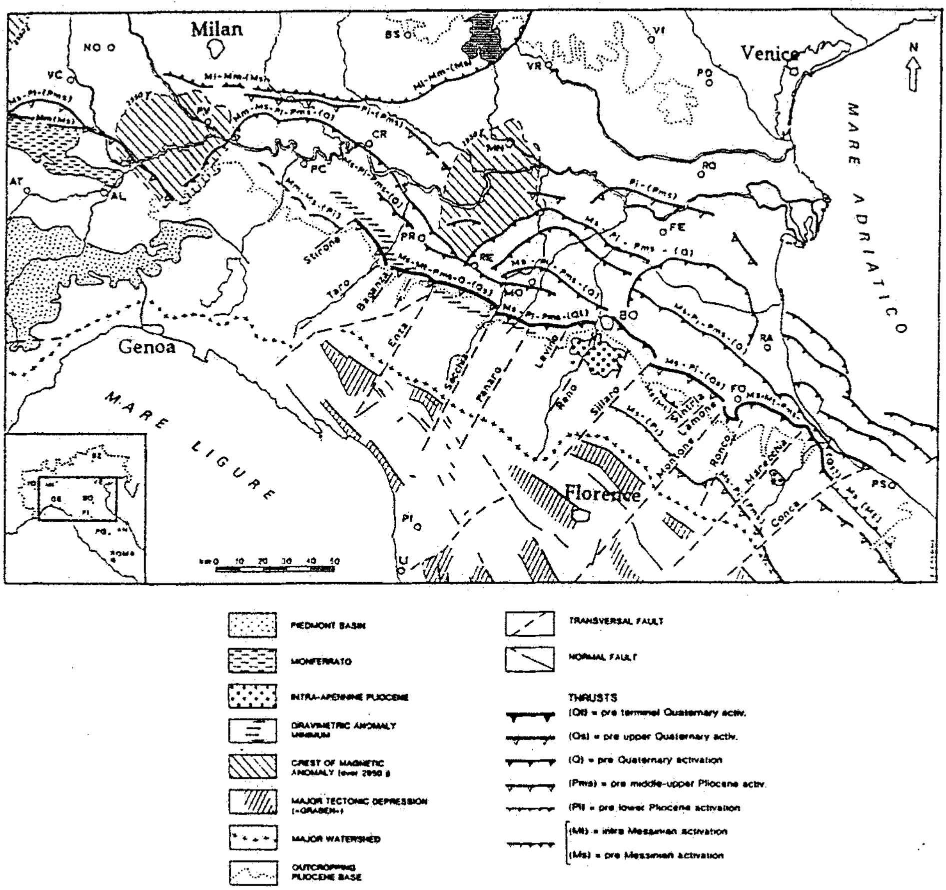


Fig. 44 - Schematic tectonic map of the Northern Apennines, after Castellarin et al. (1985). Pliocene-Quaternary thrusts are buried in the Po Plain, while the outcropping Appennines are characterized by grabens cross-cutting the earlier accretionary wedge.

Opposite above: Fig. 43 - Schematic crustal-scale section between the Ligurian Sea, northern Apennines, Po - Venetian plains and Dolomites, showing the major differences between Apennines and Southern Alps Neogene thrust belts. The Southern Alps formed with uplift, while in the Apennines the accretion developed in a subsiding area. Basement rocks are more deeply involved in the Southern Alps, while in the Apennines they are mainly relicts of earlier Alpine phases. The extension and back-arc development of the Apennines-Tyrrhenian system is absent in the Alps. The Moho is relatively deeper underneath the Southern Alps with respect to the foreland; in the Apennines the Moho is shallower and 'new' underneath the belt. See former map of the Alps (Fig. 36) for location (X-X').

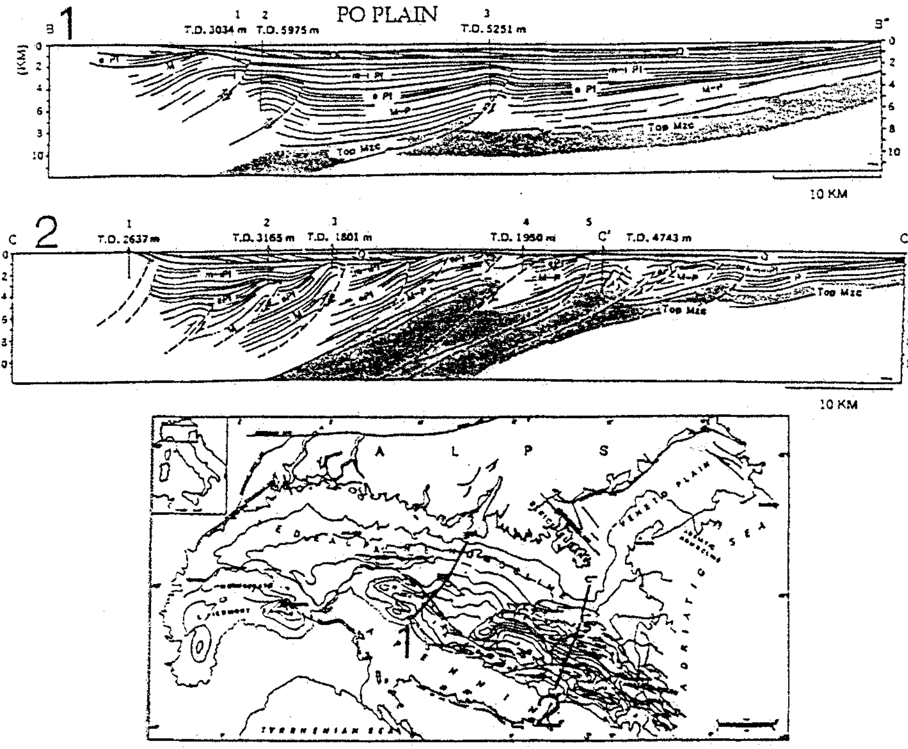


Fig. 45 - Cross-sections of the frontal Apenninic accretionary wedge buried in the Po Plain, after Bally et al. (1985).

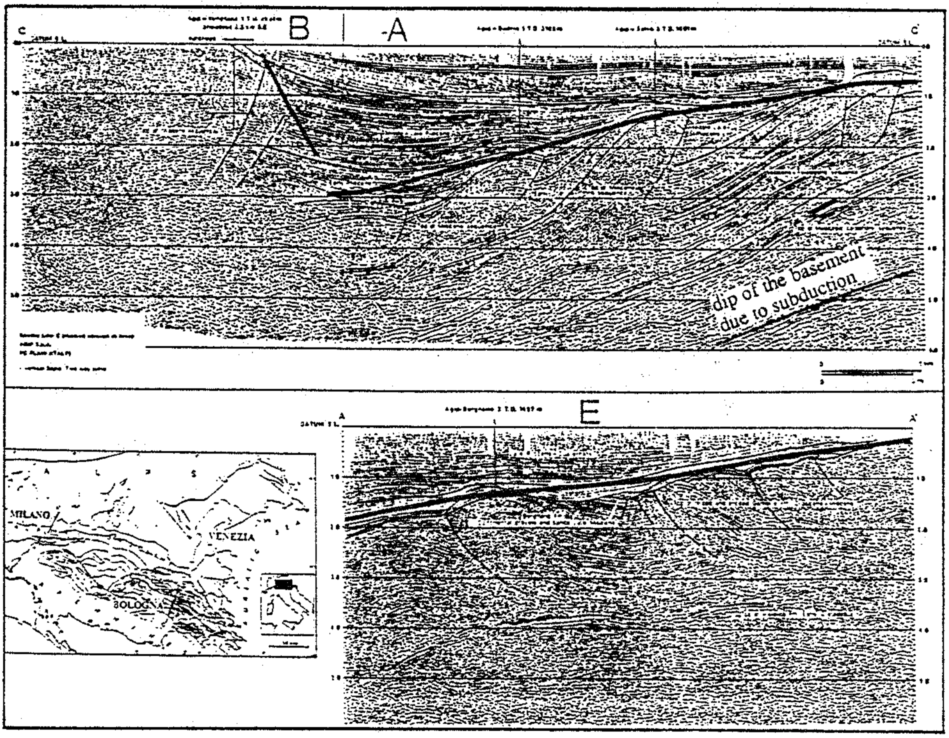
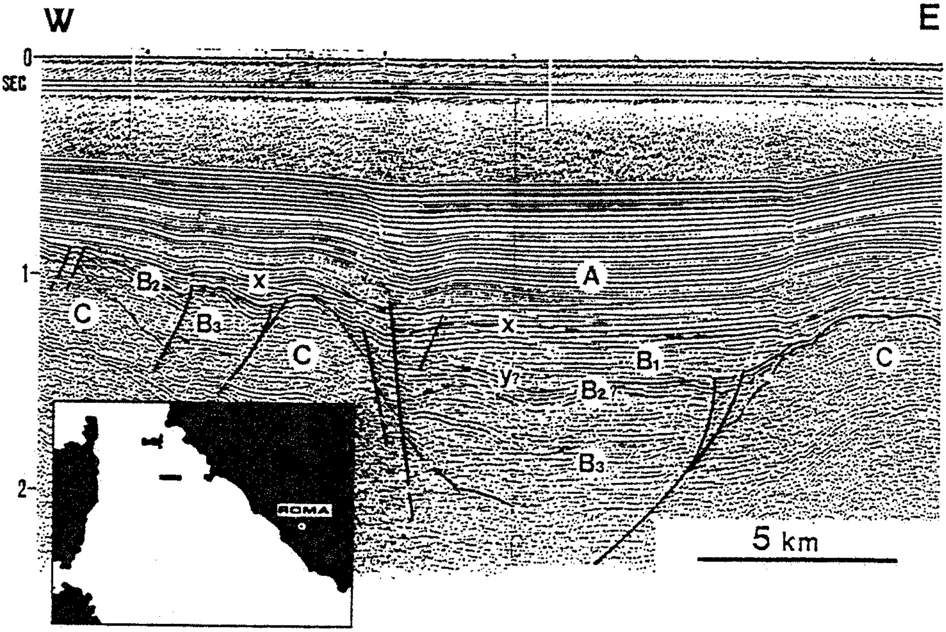


Fig. 46 - Seismic examples from the Po Plain (northern Italy) of accretionary wedges related to the Apennines (upper) and the Southern Alps (lower). Note in the field A of the Apenninic section (C-C′) that the envelope tangential to the fold crests is dipping toward the hinterland of the belt and the depocenter of the foredeep is located behind the thrusts. Folds are transported down in subduction and poorly eroded. Syntectonic sediments drape the folds. Deformation is in sequence (the younger thrust is to the right) but Quaternary out-of-sequence thrusting coeval with the most external one occurs at the transition with field B. In the Alpine section (A-A′) the envelope to the fold crests is instead rising toward the hinterland of the thrust belt and the anticlines are strongly eroded. The Pliocene-Quaternary sedimentary wedge on top records the influence of the Apenninic subduction on the Southalpine thrust belt. Seismics from Pieri (1983), reprinted by permission of the American Association of Petroleum Geologists.



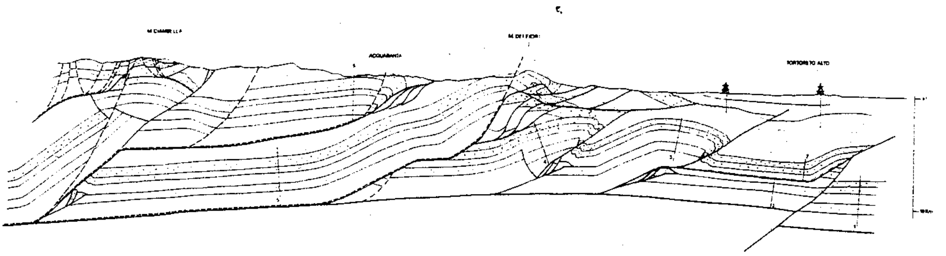


Fig. 48 - Section of the central eastern Apennines across the Montagna dei Fiori, after Calamita et al. (1994).

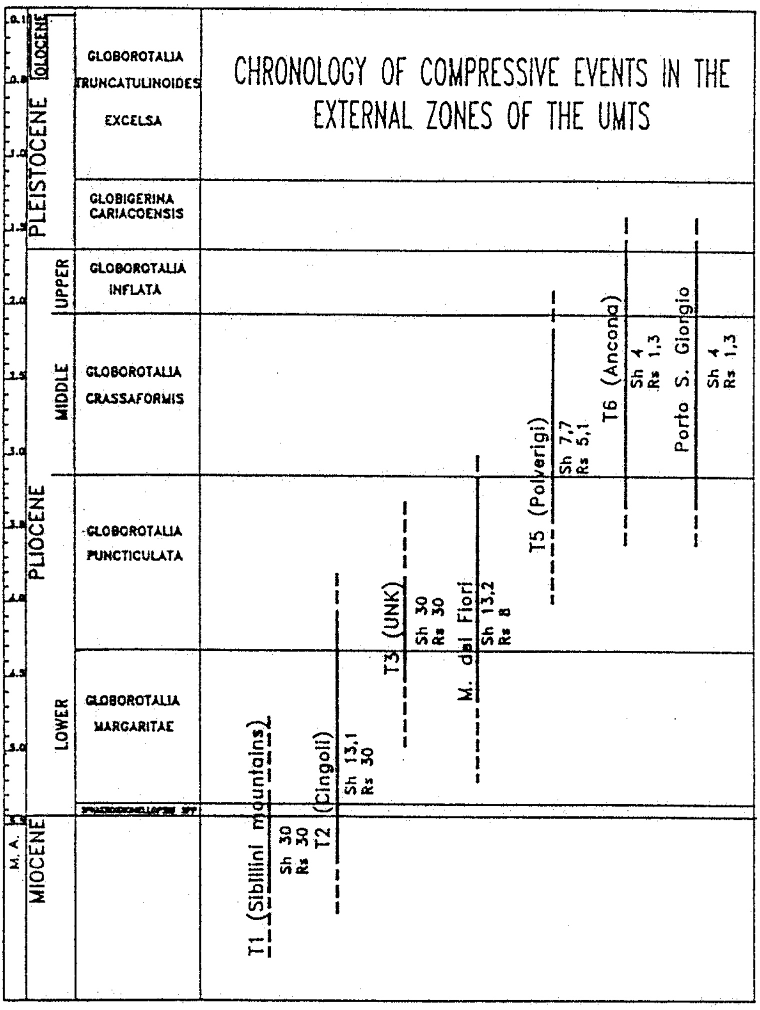


Fig. 49 - Timing of deformation in different sectors of the external zones of the Umbria-Marche Apennines. Sh, is the amount of shortening in km; Rs is the rate of slip in mm/yr, after Calamita et al. (1994).

Left below: Fig. 47 - Sparker section along the northern Tyrrhenian coast of the Apennines, showing an example of the Neogene-Quaternary extensional tectonics following to the west the Apenninic compressive wave migrating toward the Adriatic sea, after Bartole et al. (1991).

The first macroscopic difference between Alps and Apennines is the morphology. The average altitude is obviously higher for the Alps: the highest mountain in the Alps is the Mont Blanc (4810 m), while in the the Apennines is the Gran Sasso d'Italia (2914 m). The average altitude of the Alps is 1200-1300 m, while for the Apennines is about 400-600 m.

The Alps have also a much higher structural relief. The erosion eliminated a large part of the uplifted thrust sheets which would have reached some tens of kilometers of altitude if they could have maintained their original position. Such structural elevation is also marked by the extensive outcrops of metamorphic rocks which are not present in the Apennines (Figs. 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59 and 60).

Blue schists and eclogite facies rocks bearing coesite, a mineral indicating very high pressure (30 kbar, Chopin, 1984) show that now at the surface in the Alps are rocks previously formed at several tens of kilometers in depth (even 100 km). In the other hand the Apennines exhibit predominant outcrops of sedimentary cover, and only a few scattered occurrences of metamorphic rocks, mainly relicts of the Hercynian basement uplifted during the earlier Alpine phase.

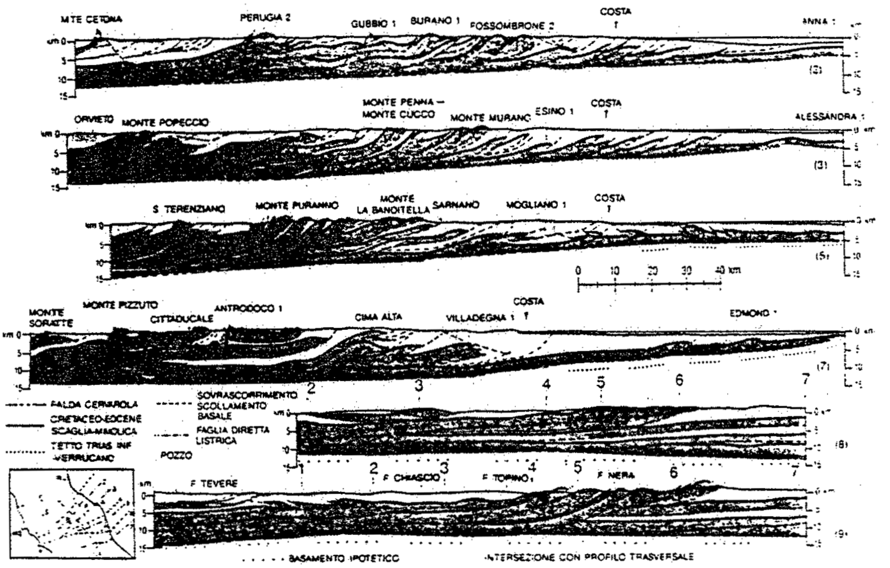


Fig. 50 - Cross-sections of the central Apennines, after Bally et al. (1986).

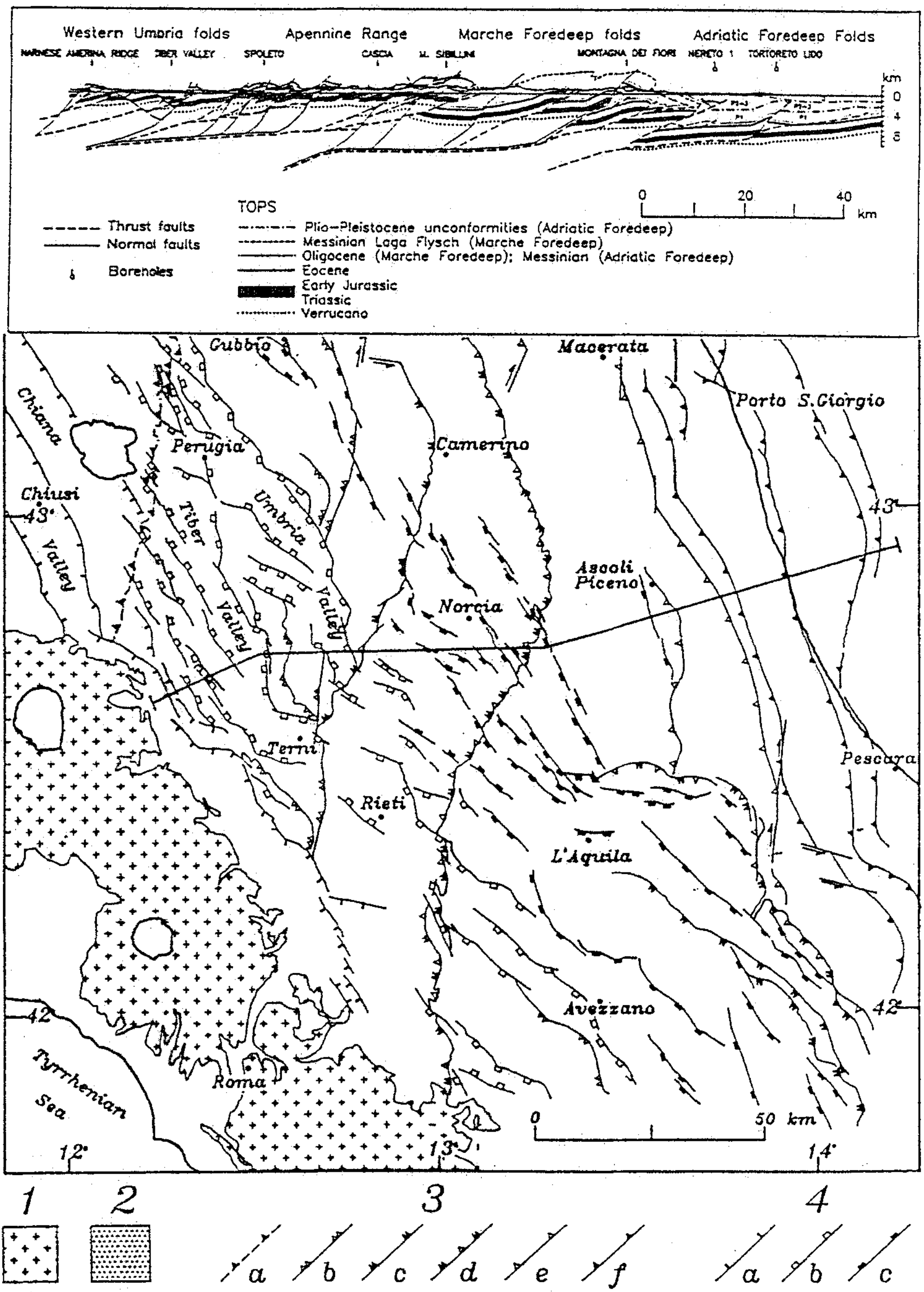


Fig. 51 - Cross-section and structural map of the central Apennines, after Lavecchia et al. (1994). Legend: 1, Roman-Campanian magmatic province of late Pleistocene age. 2, Val Marecchia deposits. 3, major reverse and oblique fault zones with progressive younger ages of deformation eastward (a, Serravallian; b, Tortonian; c, Messinian; d, Messinian-early Pliocene; e, early Pliocene; f, late Pliocene-Pleistocene). 4, normal and normal-oblique fault whose onset can be dated as early as: a, lower part of early Pliocene; b, upper part of early Pliocene; c, late Pliocene. The extensional tectonics has continued, respectively, up to late Pliocene (a), Pleistocene (b), and Holocene (c). The timing of the deformations is highly schematic and generalized.

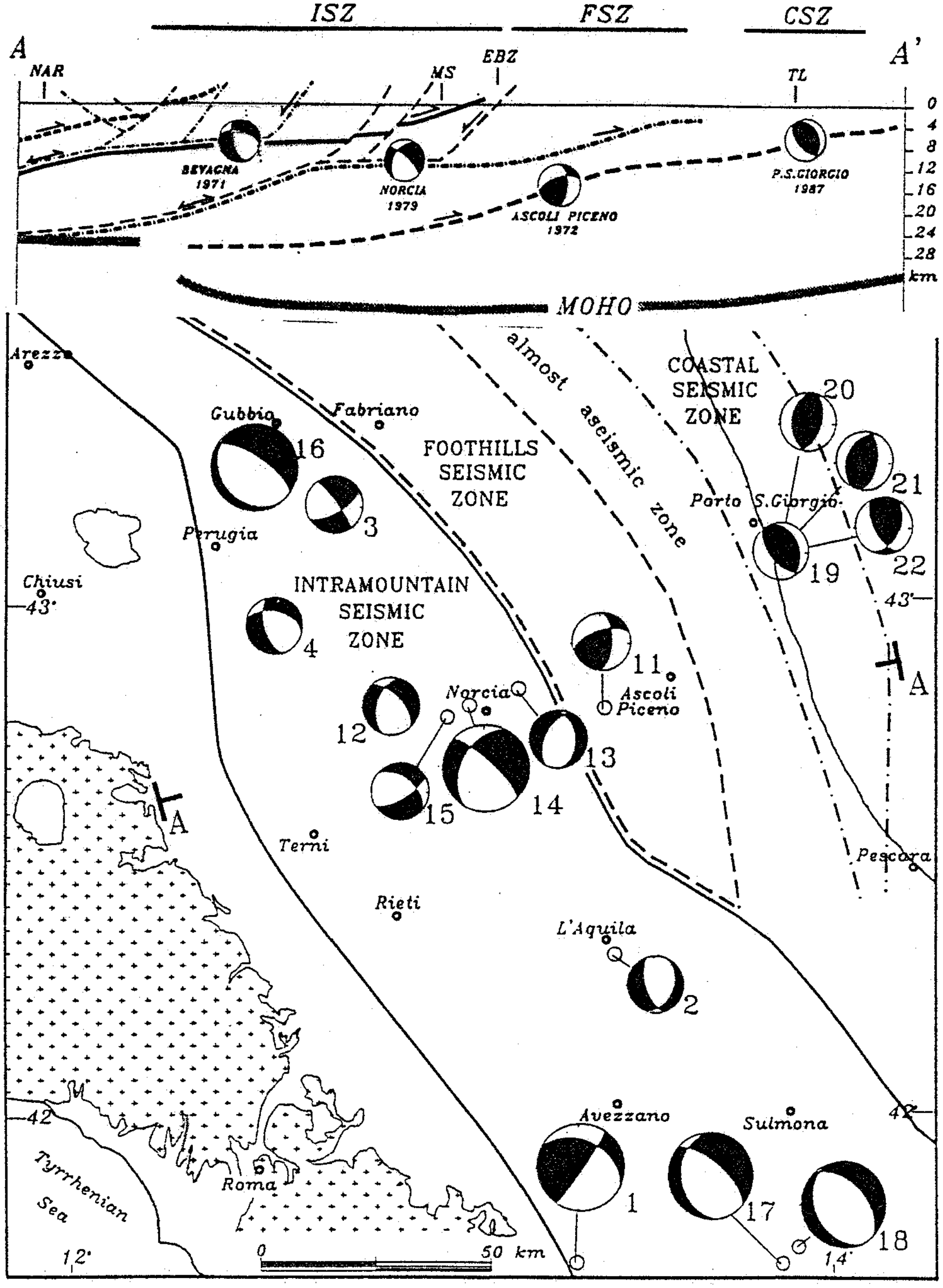


Fig. 52 - Seismotectonic zoning and focal mechanisms of the central Apennines relative to the period 1915-1987, after Lavecchia et al. (1994). Projections are lower-hemisphere, and compressional quadrants are in black. The larger stereographic plots refer to events with M > 5; the smaller stereographic plots, to events with 4<M<5. A-A' is the trace of the section at the top. Legend of the section: ISZ, Intramountain Seismic Zone; FSZ, Foothills Seismic Zone; CSZ, Coastal Seismic Zone; EBZ, extensional breakaway zone.

Note the coexistence of extensional regime in the belt to the west and compressional regime confined only to the east in the external zone. Note also the shallow Moho below the belt to the west.

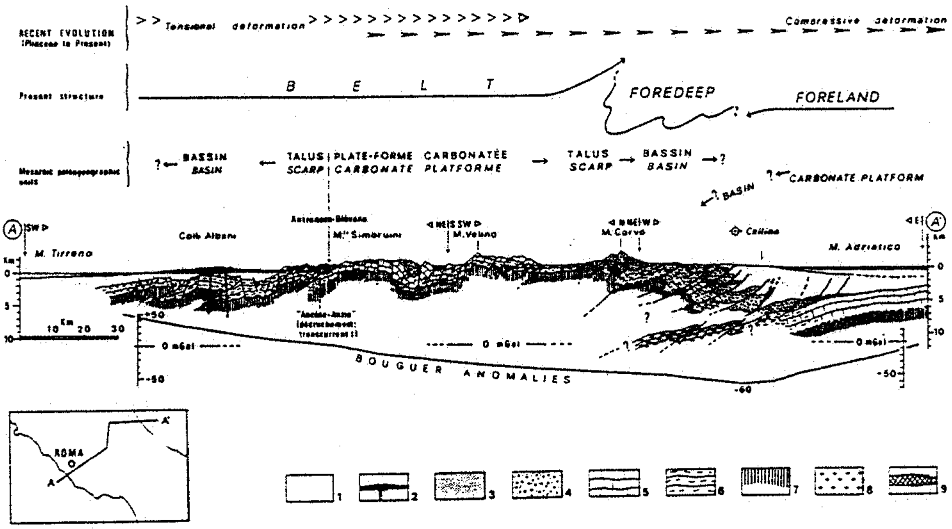


Fig. 53 - Cross-section of the central Apennines (after Parotto, in AA.VV., 1980). Legend: 1, Continental Pliocene-Quaternary; 2, Pleistocene Alkali-potassic volcanism; 3, Marine Pliocene-Quaternary; 4, Tortonian-Messinian terrigenous turbidites; 5, Liassic-Lower Miocene carbonatic platform sequences; 6, Liassic-Lower Miocene basinal sequences; 7, Triassic limestones and evaporites,

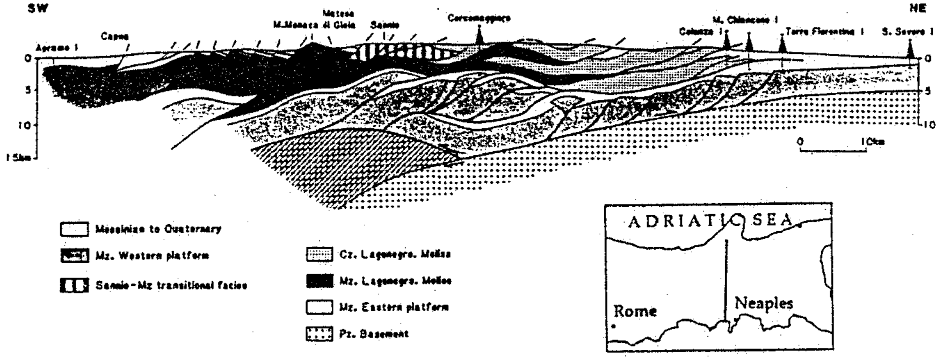


Fig. 54 - Cross-section of the Southern Apennines, after Casero et al. (1988). Read Apennine platform as Campano-Lucana platform, and Eastern platform as Apulian platform.

In contrast with the Alps, the Apennines don't need a thick pile of nappes above them to have been eroded. In other words they have a very low structural elevation, which is at least a few tens of kilometers lower with respect to the Alps.
However the most impressive difference between the two orogens is the presence of a back-arc basin only to the west of the Apennines, i.e. the Tyrrhenian Sea (Figs. 32, 61 and 62). Moreover the Apenninic relief is marked by extension, or more exactly the uplift of the belt is controlled by tensional regime, while in the Alps the uplift of the orogen is due to thickening of the crusts-lithospheres systems generated by compression, even if there are evident tensional manifestations of normal faulting in its core.
Tensional faulting in the Alps is probably determined by orogenic overthickening and by interference with other geodynamic factors (e.g. the Oligocene extension

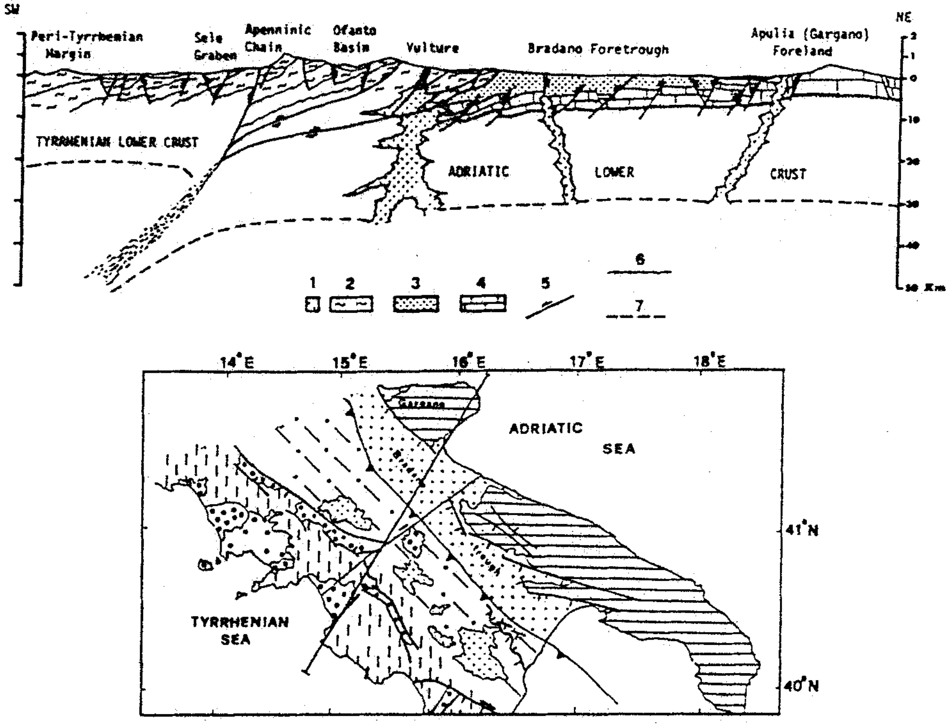
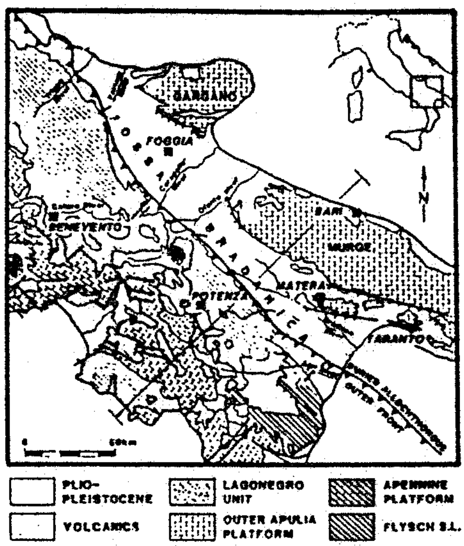
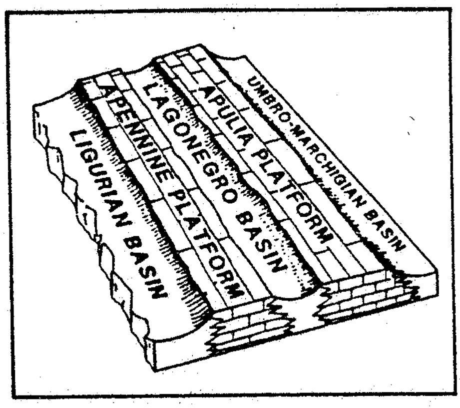
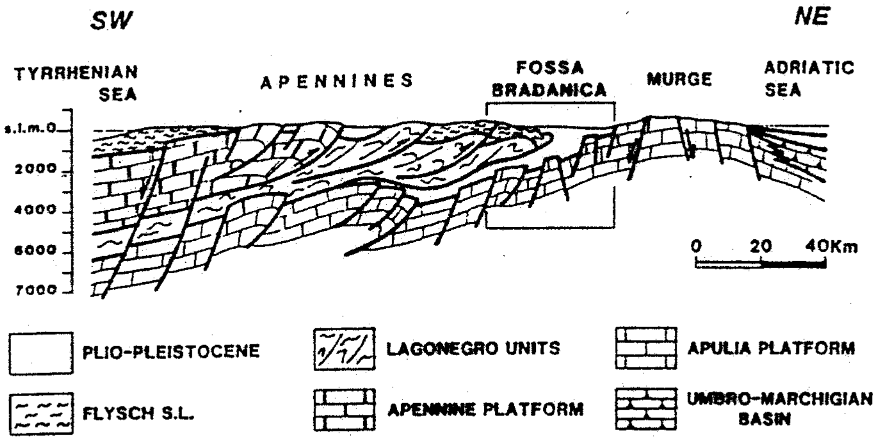


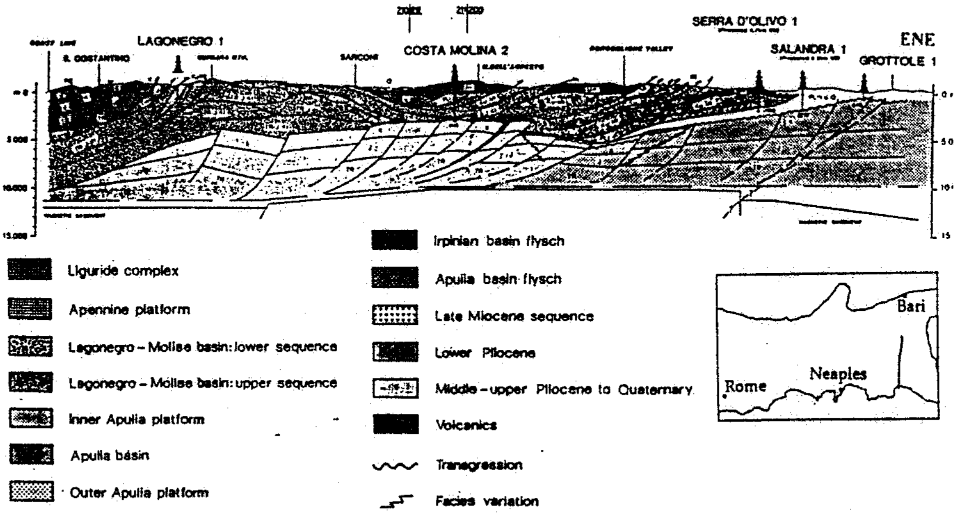
Fig. 55 - Structural sketch of the Southern Apennines, after Cristofolini et al. (1985). 1, volcanic rocks; 2, Apenninic units; 3, Foredeep sediments; 4, Apulian platform; 5, faults; 6, thrusts; 7, Moho.

Opposite page:
above, Fig. 56 - Schematic paleogeography and cross-section of the Southern Apennines, after Sella et al., in AA.VV. (1988). Read Apennine platform as Campano-Lucana platform.
below, Fig. 57 - Cross-section of the Southern Apennines, after Mostardini and Merlini (1986). The Apennine (or Campano-Lucana) platform was thrust onto the basinal Lagonegro units, which in turn overlie the Apulian platform to the east.


GARGANO
FOGGIA
FOSSA BRADANICA
BENEVENTO
BARI
MURGE
MATERA
POTENZA
TARANTO
OUTER FRONT
N
0
50km
PLIO-PLEISTOCENE
VOLCANICS
LAGONEGRO UNIT
OUTER APULIA PLATFORM
APENNINE PLATFORM
FLYSCH S.L.


UMBRO-MARCHIGIAN BASIN
APULIA PLATFORM
LAGONEGRO BASIN
APENNINE PLATFORM
LIGURIAN BASIN


SW
NE
TYRRHENIAN SEA
APENNINES
FOSSA BRADANICA
MURGE
ADRIATIC SEA
s.l.m. 0
2000
4000
6000
7000
0
20
40Km
PLIO-PLEISTOCENE
FLYSCH S.L.
LAGONEGRO UNITS
APENNINE PLATFORM
APULIA PLATFORM
UMBRO-MARCHIGIAN BASIN


LAGONEGRO 1
S. COSTANTINO
SARCONI
COSTA MOLINA 2
SERRA D'OLIVO 1
SALANDRA 1
GROTTOLE 1
ENE
0
5.000
10.000
15.000
0
5.0
10
15
Liguride complex
Apennine platform
Lagonegro – Molise basin: lower sequence
Lagonegro – Molise basin: upper sequence
Inner Apulia platform
Apulia basin
Outer Apulia platform
Irpinian basin flysch
Apulia basin flysch
Late Miocene sequence
Lower Pliocene
Middle – upper Pliocene to Quaternary
Volcanics
Transgression
Facies variation
Bari
Rome
Neaples

evident in the Rhine and Rhone grabens, the interference with the opening of the Pannonian Basin in the Eastern Alps). The N-S-trending Sestri-Voltaggio Line in Liguria is a conventional feature presently separating Alpine and Apenninic structures, to the west the Voltri Group with ophiolites, sheared peridotites, and to the east the Argille Scagliose, a flyschoid complex. In reality the Alps continue southward.

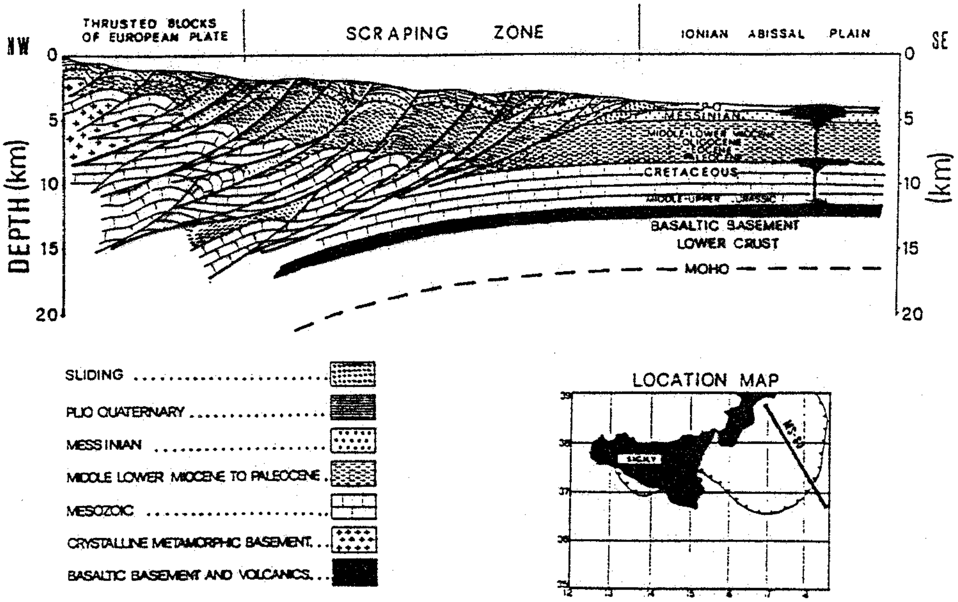


Fig. 58 - Cross-section of the Calabrian arc and Ionian sea, based on seismic reflection profile, after Finetti (1982).

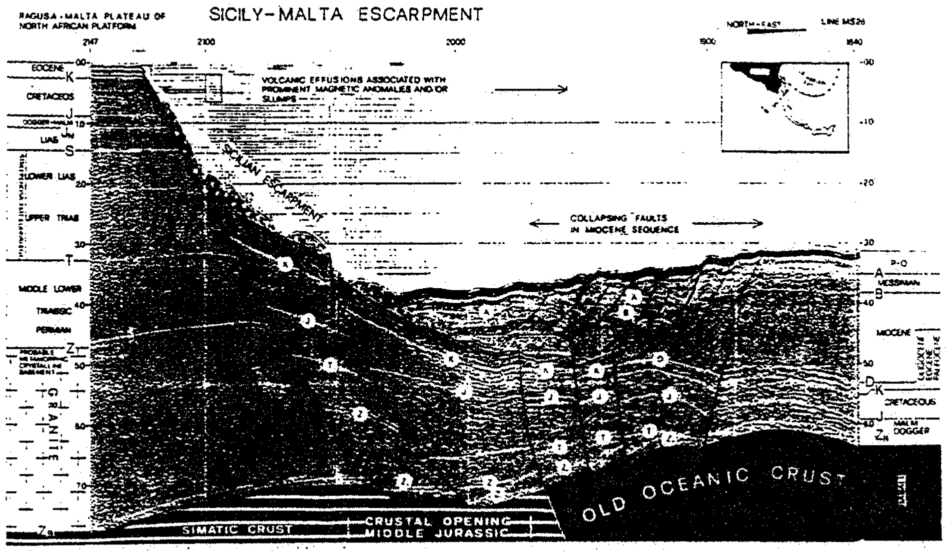


Fig. 59 - Seismic profile across the Malta escarpment, from the Iblean-Ragusa platform to the Ionian basin, after Finetti (1982). Note the oceanic nature of the Ionian crust to the east.

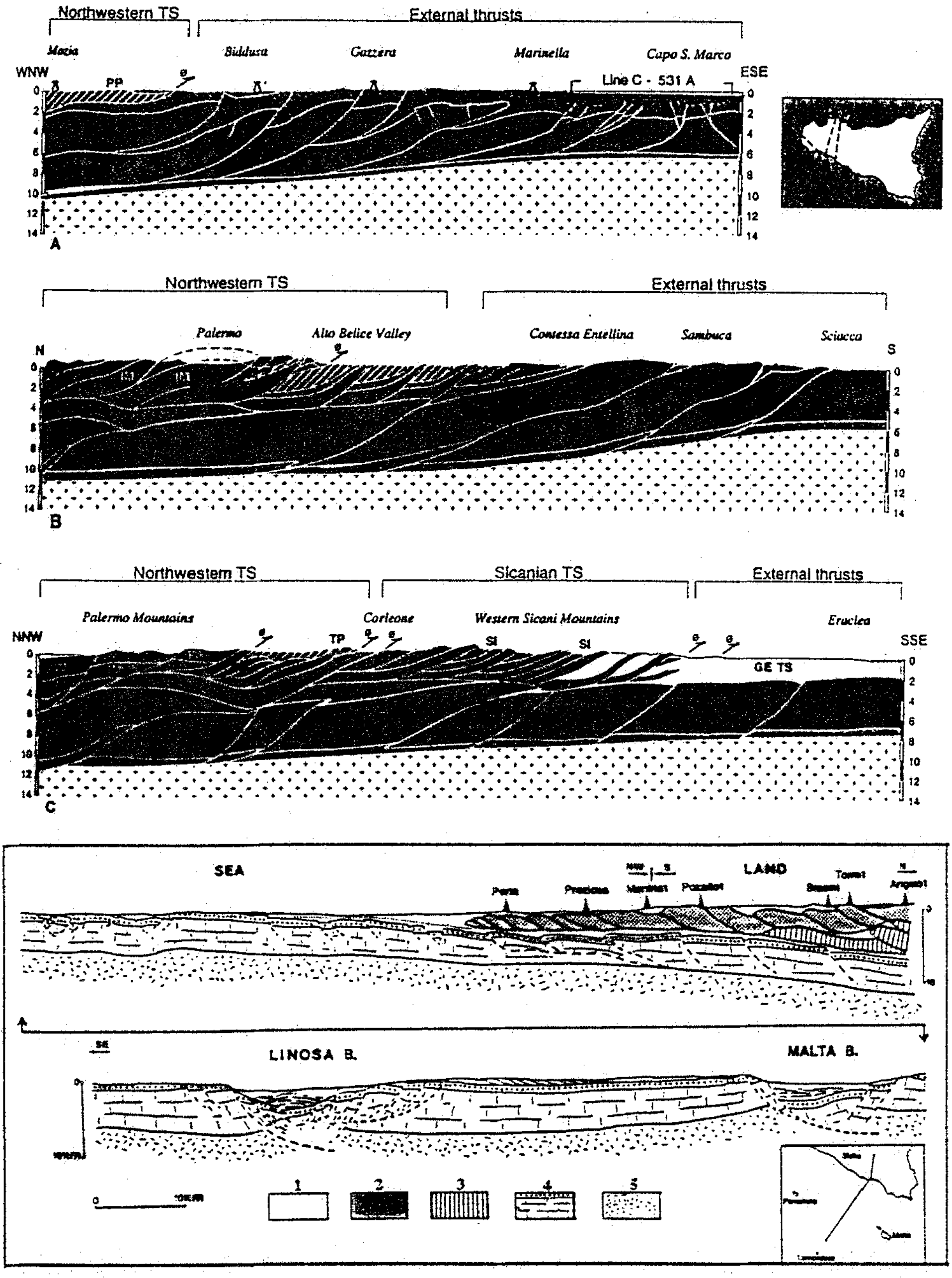


Fig. 60 - Schematic cross-sections of western Sicily and between the Pelagian shelf (offshore Tunisia) and Sicily, showing the Linosa and Malta grabens to the south, and the Gela nappe at the front of the Apenninic accretionary wedge, after Catalano et al., in Max and Colantoni (1993). Legend: 1, Plio-Pleistocene deposits; 2, Gela Nappe; 3, Sicanian units; 4, Carbonate substrate of the Hyblean and Pelagian foreland; 5, basement.

Fragments of the Alps outcrop in the Apenninic belt (e.g. Calabria, Pontine islands, Tuscany, Elba island). They also have been found scattered and disrupted on the floor of the Tyrrhenian basin and they may be interpreted buried below the western Apennines. Those indicate that the extension and shape of the Alps during their Cretaceous-Eocene subduction-collision history was continuous toward the south. A frontal thrust belt and the relative conjugate back-thrust belt of the Alps have been overprinted since Oligocene on by the Apenninic wave, and the Alps are therefore part of the core of the western Apennines.

Alps and Apennines are diachronous and have very different rates of evolution and vitality. The Alpine subduction began during Early Cretaceous and continued until the Pliocene, with slower later reactivations. The Apenninic-Tyrrhenian system is instead a very recent feature because it mainly formed during the last 10-15 Ma. However within the Apennines there are structures related to earlier subduction phases, i.e. the W-dipping subduction connected to the back-arc opening of the Provencal Basin during Late Eocene-Early Miocene times, but in particular, this system inverted the earlier Alpine orogen.

The Neogene extension in the Apennines has a different character from the extension in the Alps. The geodynamic context is different, timing, and uplift rates strongly differ. The extension in the Apenninic ridge cannot be considered as the collapse of the orogen, but rather the uplift of the accretionary wedge that formed in

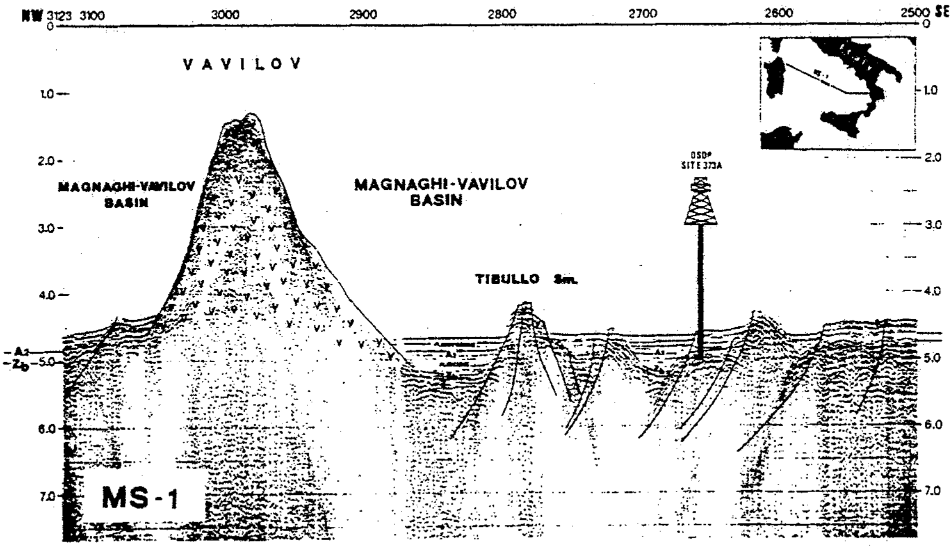


Fig. 61 - Seismic profile of the central Tyrrhenian abyssal plain, after Finetti and Del Ben (1986). The Vavilov volcano began to form during Pliocene times.

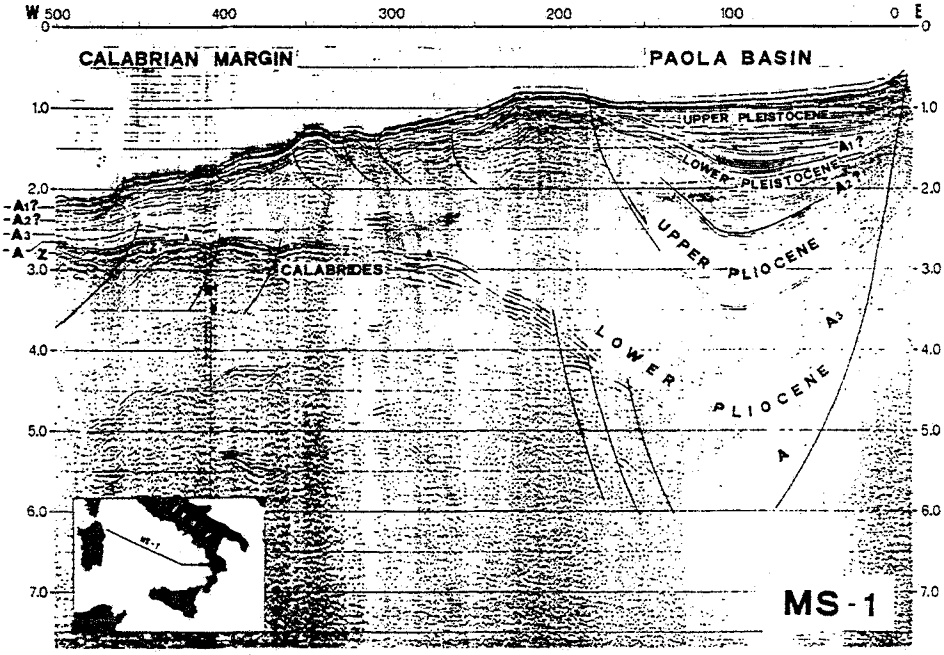


Fig. 62 - Seismic profile of the southeastern Tyrrhenian basin, crossing the Paola basin, after Finetti and Del Ben (1986).

the external parts of the arc at lower morphological and structural conditions. The Alps have a different structural evolution, first they thickened and uplifted, and then they may have collapsed.

The Southern Alps are the back-thrust belt of the Alpine orogen. They propagated south-southeastward between the Late Cretaceous (western part) and the Pliocene. The Southalpine foredeep had subsidence rates which rarely exceeded the 300m/Myr, dividing the entire thickness of the flysch and molasse deposits by their duration of deposition (2-6 km of sediments deposited in 15-40 or more Ma). In the eastern part of the Southalpine foredeep, the Dinaric foredeep also interferes with its effects of subsidence since at least the Paleocene up to the Early Miocene.

The Apennines are characterized by a frontal active accretionary wedge, below sea-level, whereas the main elevated ridge is instead in uplift and extension. More to the west toward the Tyrrhenian sea, seismicity decreases and the subsidence is mainly related to thermal cooling. These different tectonic fields moved and are still moving eastward expanding the Apenninic arc at velocities of 1 to 7 cm/yr, rates comparable with other arcs related to W-dipping subduction. The eastward roll-back of the Adriatic lithosphere (Malinverno and Ryan, 1986) accompanies this migration.

In the elevated Apenninic ridge, what was previously accreted in the frontal part (mainly Mesozoic cover and deep facies foredeep deposits) has been uplifted and cross-cut by normal faulting. In contrast with the Alps, the Apennines have a very pronounced foredeep (Fig. 63), with the Pliocene base even at 8.5 km (Bigi et al., 1989) and indicating subsidence rates ranging between 1000-1600m/Ma. Much part of the Apenninic foredeep is located on top of the accretionary wedge, and not only to its front. This means that the so-called piggy-back basin is often the real foredeep for the Apennines. Clastic supply in the Apenninic foredeep is provided not only by the Apenninic accretionary wedge, but also by the Alps and Dinarides surrounding the Adriatic plate. The differences between Alps and Apennines are similar to those we may observe in oceanic environments between the eastern and western Pacific accretionary wedges, and this may be related to the relative westward drift of the lithosphere detected in the hot spot reference frame.

The Apennines from Piemonte (NW-Italy) to Sicily form an asymmetric arc (Fig. 33). Counterclockwise rotations (20-60°, up to 90°) have been pointed out in the thrust sheets of the central-northern Apennines, the northern arm of the arc, and stronger clockwise rotations (Fig. 34) ranging between 90° and 140° have been described in the shorter Sicilian thrust belt which represents the southern Apenninic arm, characterized by dextral transpression inland and by sinistral transtension in the south-western Tyrrhenian sea (Fig. 33). Extensional tectonics is forward prograding just behind the narrow compressive belt. Smaller arcs due to inherited Mesozoic horsts and grabens or facies changes produce several fans with dispersion of the maximum stress trajectories. The major undulations occur in the northern and southern parts of the arc, at the intersection with inherited N-S trending features, i.e. the big undulation of the Ionian Sea at the Iblean Plateau - Malta escarpment intersection (Figs. 33 and 59), or the Adventure Bank, etc.. Similar undulations occur in the buried northern Apenninic chain along the Po Plain. Comb graben, perpendicular to the belt seem to occur in Calabria.

Throughout the Apennines the eastward migrating extension is coeval with compression in adjacent thrust-fold belts to the east. There is a clear eastward migration of rifting in the Tyrrhenian itself, from Tortonian in the western part to Plio-Pleistocene in the east. Similarly, continental rifting and related magmatism in Tuscany show an eastward migration. Following the kinematics of W-dipping

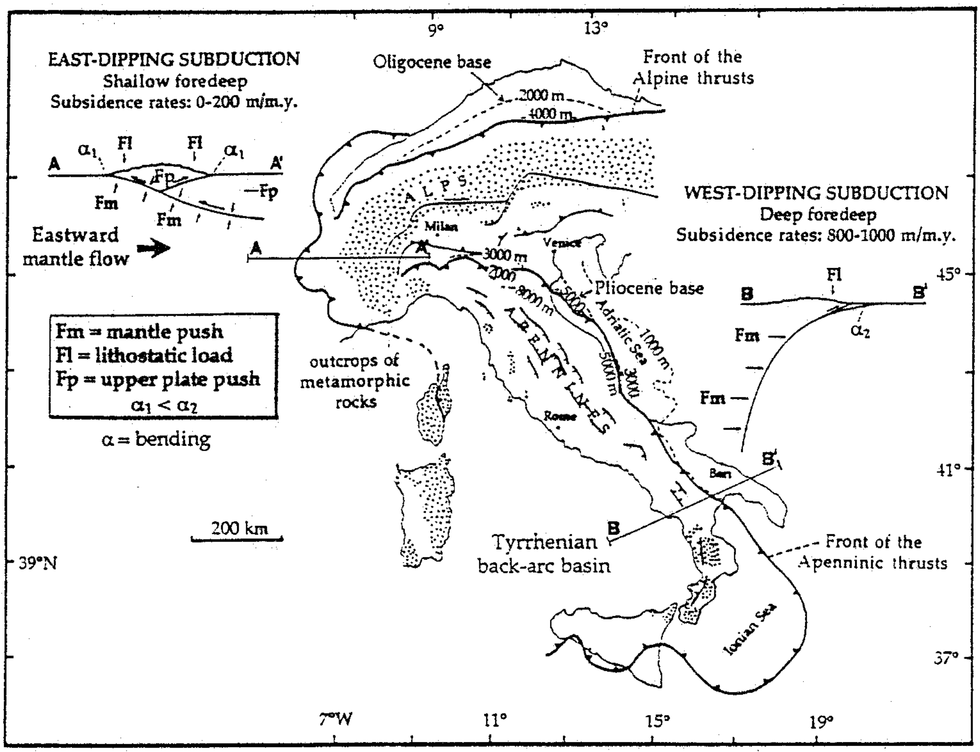


Fig. 63 - Alps and Apennines are thrust belts with very different characters: The Alps have a shallow foredeep, broad outcrops of metamorphic rocks, and high structural and morphologic elevation. The Apennines have a deep foredeep, few outcrops of basement rocks partly inherited by the earlier 'Alpine' phase, low structural and morphologic elevation, and the Tyrrhenian back-arc basin. These differences mimics the asymmetries of the Pacific E-dipping Chilean and W-dipping Marianas subductions.

subductions and applying the westward drift of the lithosphere, the western Apennines should float above a new asthenospheric mantle which replaced the subducted lithosphere (Fig. 32). This seems to be in agreement with the new data of the Moho in the Apennines. Moreover heat flow data show a strong positive thermal anomaly beneath western Apennines and Tyrrhenian Sea which may be interpreted as a dramatic and diffused mantle wedging at the subduction hinge.

The Italian peninsula and Sicily are mainly formed by an asymmetric disrupted thrust belt (the Apennines) surrounding a corresponding asymmetric back-arc basin. The Italian asymmetry may be interpreted as the result of an irregular subduction beneath northern and southern Apennines: in fact the Adriatic lithosphere is continental in origin with respect to the Ionian oceanic lithosphere, possibly a relict of the Mesozoic Tethys. Due to this asymmetry the Apenninic arc and its Puglia foreland assumed the shape of a "boot", typical term descriptive the Italian peninsula.

The northward decreasing extension of the Tyrrhenian basin may be interpreted as a function of the northward decreasing capability to subduct of the thicker northern Adriatic continental lithosphere.
The main transition is between parallels 40° and 41°, along the Taranto - Neaples alignment, separating two major magmatic provinces. The differences in composition and thickness of the Apenninic subducting slab are in fact also recorded by the peri - Tyrrhenian magmatism and by the present seismicity. The Apennines result in a greater shortening in the Calabrian arc and a corresponding maximum back-arc extension in the southern Tyrrhenian sea. In the central-northern Apennines shortening is linearly northward decreasing from 170 to 35 km according to Bally et al., in AA.VV., (1986), and the extension in the Tyrrhenian sea is linearly northward decreasing as well, confirming that extension and compression are genetically linked. In summary the present shape of Italy reflects an asymmetric Late Miocene - Quaternary subduction controlled by the inherited Mesozoic lateral thickness and composition variations of the Adriatic-Ionian lithosphere.

Puglia is a region of southeastern Italy and is part of the Apulia swell, a NW trending, narrow ridge of continental crust, running from central Italy to offshore Greece. Puglia constitutes the southwestern margin of the Adriatic plate in the central Mediterranean, and it is considered a poorly tectonized area in the Apenninic foreland. The region is marked by an anomalous late Pleistocene uplift (Hearty and Dai Pra, 1992), in contrast with adjacent foreland areas such as the central and northern Adriatic where subsidence occurred at the same time (Doglioni et al., 1994). Therefore the Apenninic foreland shows two distinct structural signatures comparing the central Adriatic Sea and the Puglia region (Figs. 64 and 65). During the Pliocene-Pleistocene the central Adriatic underwent high subsidence rates due to the eastward rollback of the hinge of the west dipping Apenninic subduction. The Puglia region and the Bradanic foredeep are located southward along strike in the same foreland, but, in contrast with the central Adriatic, after Pliocene-early Pleistocene subsidence they underwent uplift since the middle Pleistocene. The geometry and the kinematics of the frontal accretionary wedge and related foreland changed from that moment on between the two areas. At the front of the central northern Apennines, off scraping and subsidence continued, whereas the foredeep and foreland of the southern Apennines were buckled. Those differences are interpreted as being due to the larger subduction hinge rollback rate since middle Pleistocene of the central Adriatic lithosphere (70 km thick) with respect to the thicker Puglia (110 km, Fig. 3). The different thicknesses of the continental crust and lithosphere were inherited from the Mesozoic rifting that disrupted the Adriatic plate. The different thicknesses appear to have controlled the variable degree of flexure of the lithosphere and its asthenospheric penetration rate.

The Tremiti E-W alignment is the right-lateral lithospheric transfer zone of those different tectonic regimes. The larger eastward rollback of the Apenninic subduction hinge in the central Adriatic lithosphere with respect to the Puglia lithosphere needs a right-lateral transfer zone which can be identified with the Tremiti alignment. This feature is, in fact, seismically active in the foreland of the Apenninic front, and it has an eastward propagating tip line in the eastern side of the lower Adriatic basin. In other words, this system of faults exists in order to accommodate the different behavior of the subduction of the Adriatic plate underneath the Apennines, separating two segments with different rollback rates. In fact, the subduction of the lithosphere to the west of Puglia below the southern Apennines is slower with respect to the segments to the north (central Adriatic) and to the south (Ionian Sea). In this last sector the rollback of the Ionian lithosphere presents the highest value (5-7 cm/yr). The transfer zone is located in the Taranto Gulf. Also, in the Ionian Sea, high subsidence rates are observed.

In conclusion, the entire Apennines are the consequence of the subduction of three types of lithosphere with different characteristics, but pertaining to the same Adriatic plate. (1) In the north central Apennines, thin continental lithosphere at the surface in the foreland, and probably thinner at depth, occurs. (2) In the southern Apennines, thick continental lithosphere occurs in the foreland, whereas probably old oceanic lithosphere constitutes the slab at depth to the west (northern prolongation of the Ionian Mesozoic basin). (3) In the southern sector, offshore Calabria, old oceanic Ionian lithosphere occurs both in the foreland and at depth.

If we accept the existence of an eastward moving asthenosphere relative to the lithosphere, as evidenced by the hot spot reference frame, then there should be an eastward oriented push acting on the Adriatic slab in depth. This means that in addition to the forces generally considered in the study of the flexural behavior of the lithosphere, this other force has to be taken into account. The pressure of the asthenospheric flow generated an increase of the slab slope and favored the increase

of the bulge in the foreland (Fig. 64). This buckling is responsible for the uplift of the foreland (Puglia) and of the Moho that is missing in the adjacent Adriatic and Ionian segments. The arrival of the Puglia thicker lithosphere (Fig. 3) at the subduction hinge is coeval with the deviation toward the southeast of the Tyrrhenian rifting, suggesting a common denominator for the two phenomena (Fig. 66).
The more rigid obstacle represented by Puglia could be responsible for the larger expansion toward the more subductable Ionian oceanic lithosphere, forming the large Apenninic arc in the Ionian Sea. This deviation generated an apparently independent subduction which is the most seismically active in southern Italy. Threfore the Apenninic arc has been slit into two minor active arcs (Central-Northern Apennines and Calabria) due to the lower subduction rates of the Southern Apennines foreland lithosphere in between.

The buckling of the Adriatic lithosphere has several dramatic consequences for the structural evolution of the southern Apennines. The relative lower subduction with respect to the other Apenninic sectors has to control a lower detachment between the sedimentary cover and the crystalline basement in comparison with the other

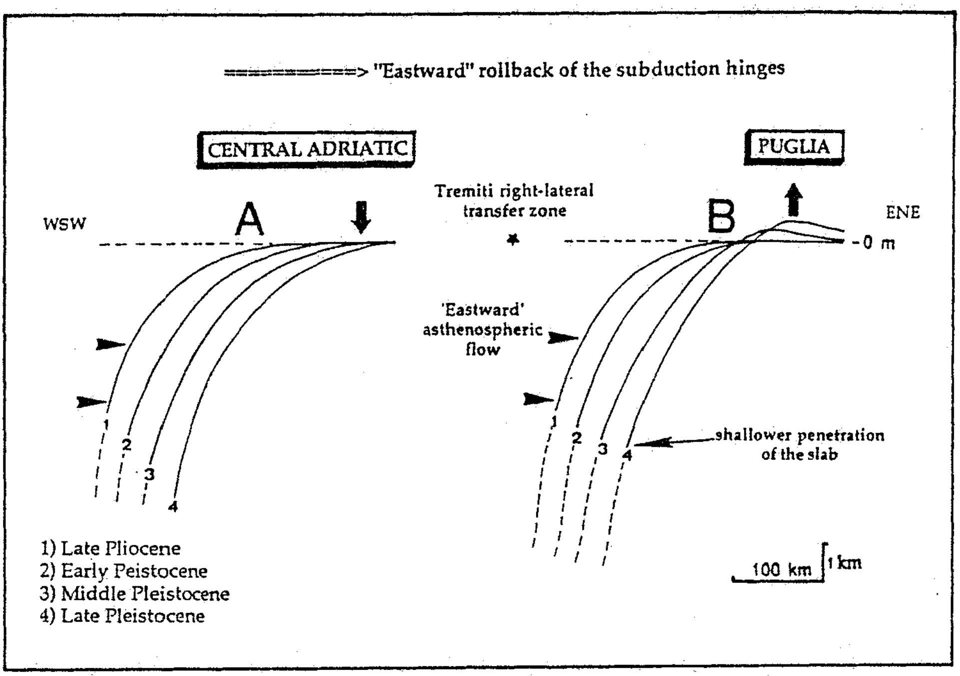


Fig. 64 - Comparison of the different evolutions of the subduction hinge rollback of the central Adriatic and Puglia. The existence of Puglia, as present land, may be interpreted as being caused by the uplift of the lithosphere as a consequence of the lower penetration of the slab, which is due to the thicker continental lithosphere reached the subduction zone; this is compensated by buckling of the lithosphere, after Doglioni et al. (1994).

parts of the Apenninic accretionary wedge. In other words, the regular off scraping of the sedimentary cover is more inhibited at the front of the southern Apennines relative to the adjacent areas, due to the slower descent of the lithosphere. Therefore rather than off scraping and active decollements, the front of the southern Apennines (i.e., the Bradano trough and the Puglia foreland) is characterized by buckling, and the shape and kinematics of the accretionary wedge change with respect to the north central Apennines and the Ionian arc.

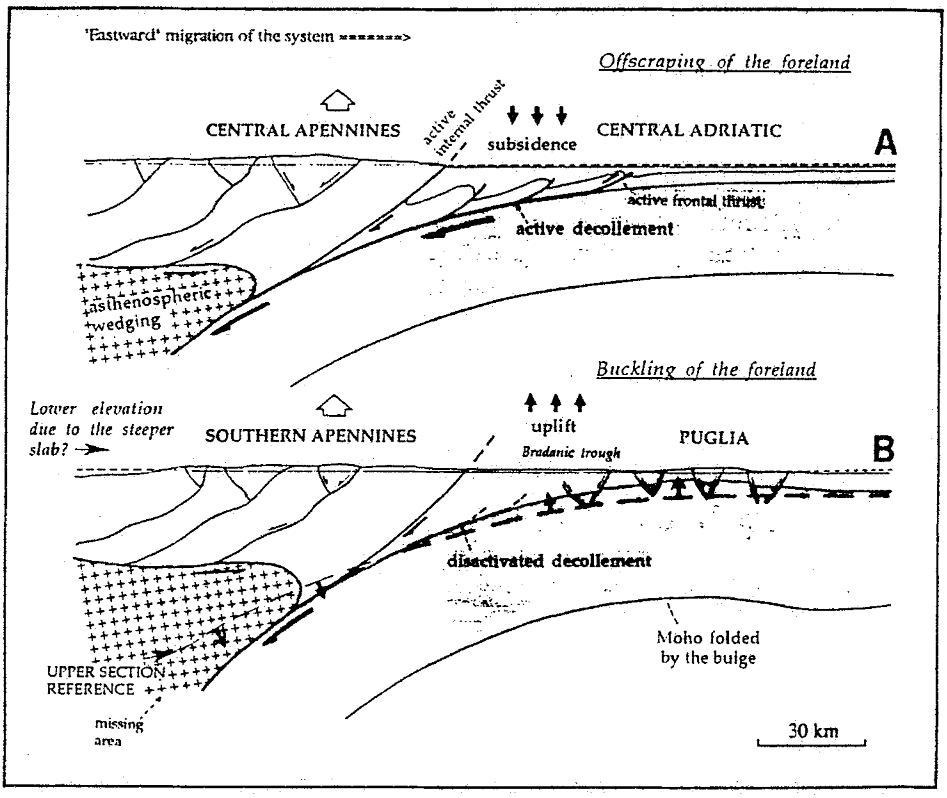


Fig. 65 - Two schematic cross sections interpreting the differences between central and southern Apennines. During the late Pleistocene evolution the geometry and kinematics of the "eastward" migrating accretionary wedge and foredeep differ between the two sectors. (A) In the northern section the accretion continues through off scraping of the upper layers of the "westward" downgoing subducting Adriatic plate. (B) In the southern section the lower rollback of the subduction hinge is compensated by buckling and formation of the Puglia bulge. The Bradanic trough was inverted from subsidence to uplift from middle Pleistocene on. Comparing the top of the crystalline basement (shaded areas) of the upper section with that of the lower section, the "upper section reference" plotted in Figure B is lower in the foreland and in the foredeep where, in fact, there is ongoing uplift, whereas it is deeper and steeper underneath the southern Apennines. Therefore the southern section in Figure B needs a steeper monocline of the top of the subducting plate in depth. This may have controlled the lower elevation of the southern Apennines due to the wider available room occurring in the hanging wall, after Doglioni et al. (1994).

The first difference is that the foreland is uplifting, whereas in the adjacent areas this is subsiding. The second difference is that the shape and propagation of the thrust planes are inhibited and lower at the front of the southern Apennines, even if the system is clearly alive. Probably, the compressive belt is presently concentrated in the "out-of-sequence" thrust located at the western margin of the Bradanic trough.

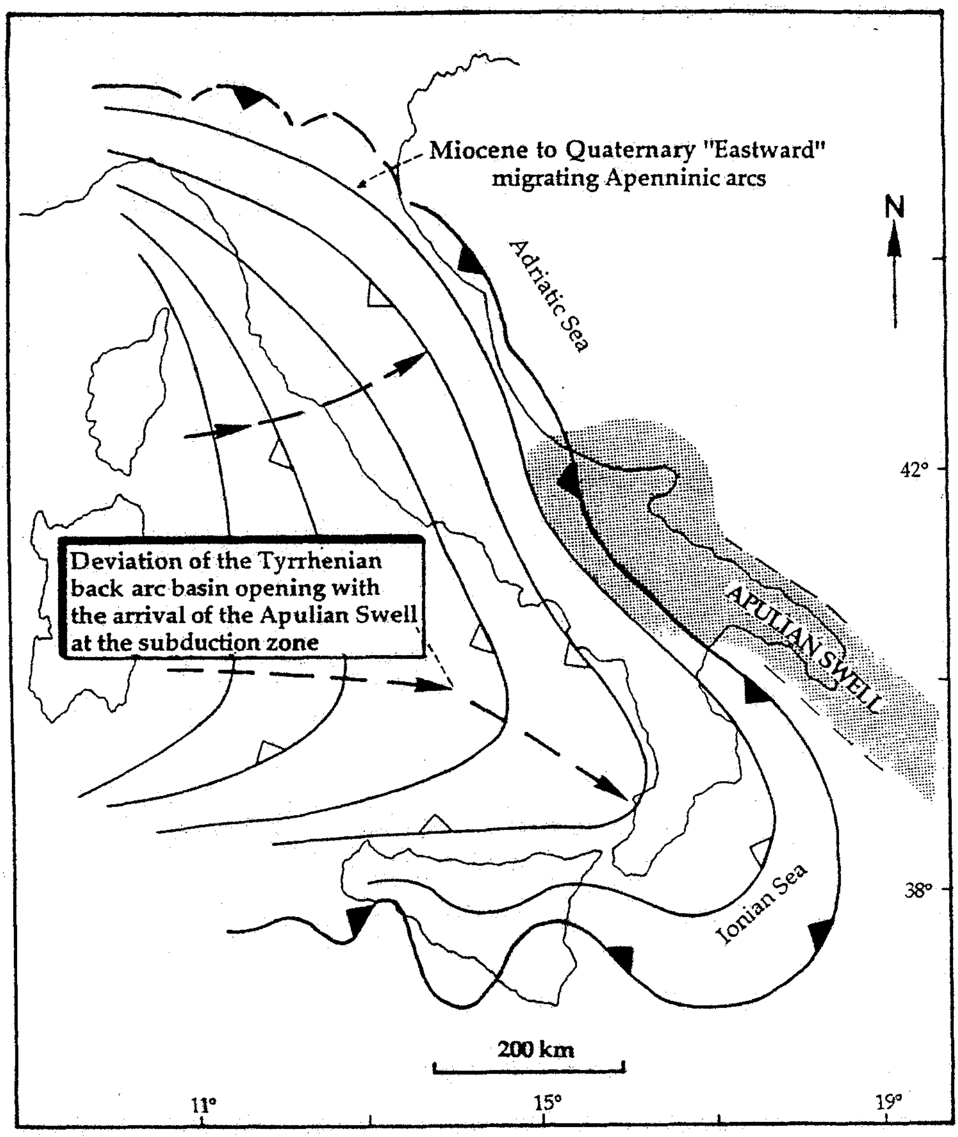


Fig. 66 - The Apenninic arc migrated "eastward" during Neogene and Pleistocene times, associated with the rollback of the subduction hinge. The arrival of the thick continental lithosphere of the Apulian swell to the subduction hinge probably controlled the larger southeastward deviation of the Ionian arc and of the Tyrrhenian back arc spreading, and the contemporaneous eastward migration of the central-northern Apennines.

The buckling of the foreland should be compensated by a steeper slab underneath the southern Apennines. The top of the crystalline basement has a smoother shape in the section between central Apennines and central Adriatic, in comparison with the southern Apennines and Puglia cross section (compare the "upper section reference" in Fig. 65).

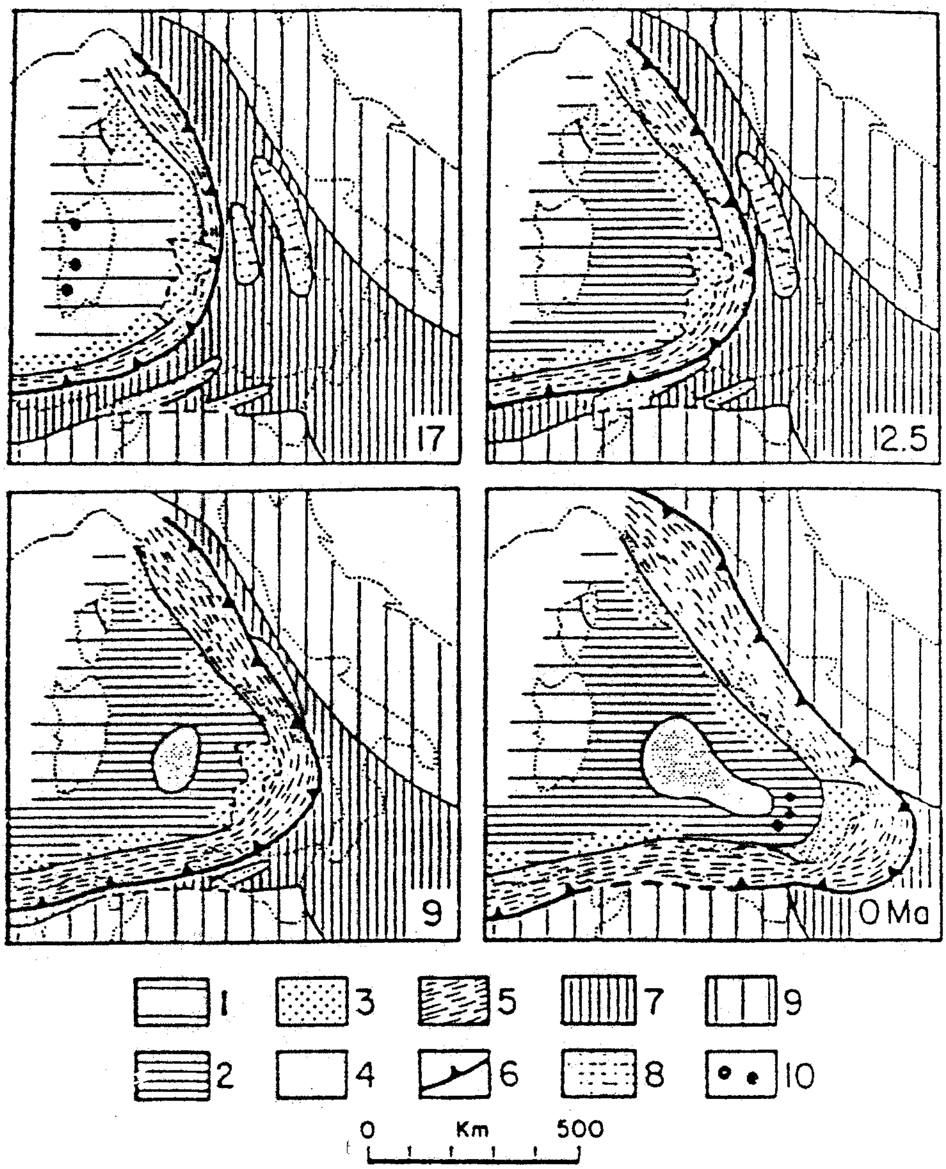


Fig. 67 - Hypothetical evolution of the Tyrrhenian area from the Burdigalian (17 Ma; top left) to the present time, after Malinverno and Ryan (1986). 1, Sardinia-Tyrrhenian-Calabria block; 2, stretched portion of the Tyrrhenian domain; 3, former Alpine belt; 4, New-formed oceanic crust; 5, Apenninic accretionary wedge; 6, Accretionary wedge front; 7, Deep basins; 8, Carbonate platforms in the African-Adriatic domain; 9, African and Adriatic foreland; 10, Active calalkaline volcanoes.

The latter section shows a large-scale crustal folding (80-100 km), with a relative uplift of the top of the basement, with respect to the central Apennines section. However, this uplift is compensated by a deepening of the top of the basement (corresponding to the top of the downgoing Adriatic lithosphere) more to the west underneath the southern Apennines; this has the consequence of expanding the available area above the subduction zone in this section, with respect to its northern counterpart.

The consequence of this larger available room may be the lowering of the entire crust and asthenosphere in the southern Apennines section, responsible for the lower elevation of the southern Apennines, with respect to the central Apennines, where the highest mountains (Gran Sasso, Maiella, etc.) are located in spite of a shallower subduction.

In fact from the maximum depth underneath Calabria (about 600 km), the subduction decreases northwestward to 0 in western Piemonte, northern Italy.

ALPS

The main paleogeographic units of the Alps are from northwest to southeast: Helvetides, Pennides, Austroalpine and Southern Alps (Fig. 35). The Helvetides represent the European continental margin, to the north and west of the ocean Tethys (Fig. 36). The Pennides are constituted by ophiolites of the Tethys (Piemontese and Valais oceanic basins), the interposed Briançonnais continental crust, and flysches of the Tethys. The Austroalpine and the Southern Alps are the Adriatic continental margin, to the south and east of the Tethys.

The convergence began with the subduction toward the east or southeast of the interposed oceanic embayment underneath the Austroalpine and Southern Alps (Adriatic) continental lithosphere during Early Cretaceous (Fig. 37). The first nappes formed during this early deformation called eo-Alpine phase. Blue schists and eclogites facies recorded this eo-Alpine HP/LT event in the Penninic and Austroalpine units of the western Alps at 130-90 Ma. This is considered the prograde part of the alpine metamorphic P-T-t path (Fig. 38).

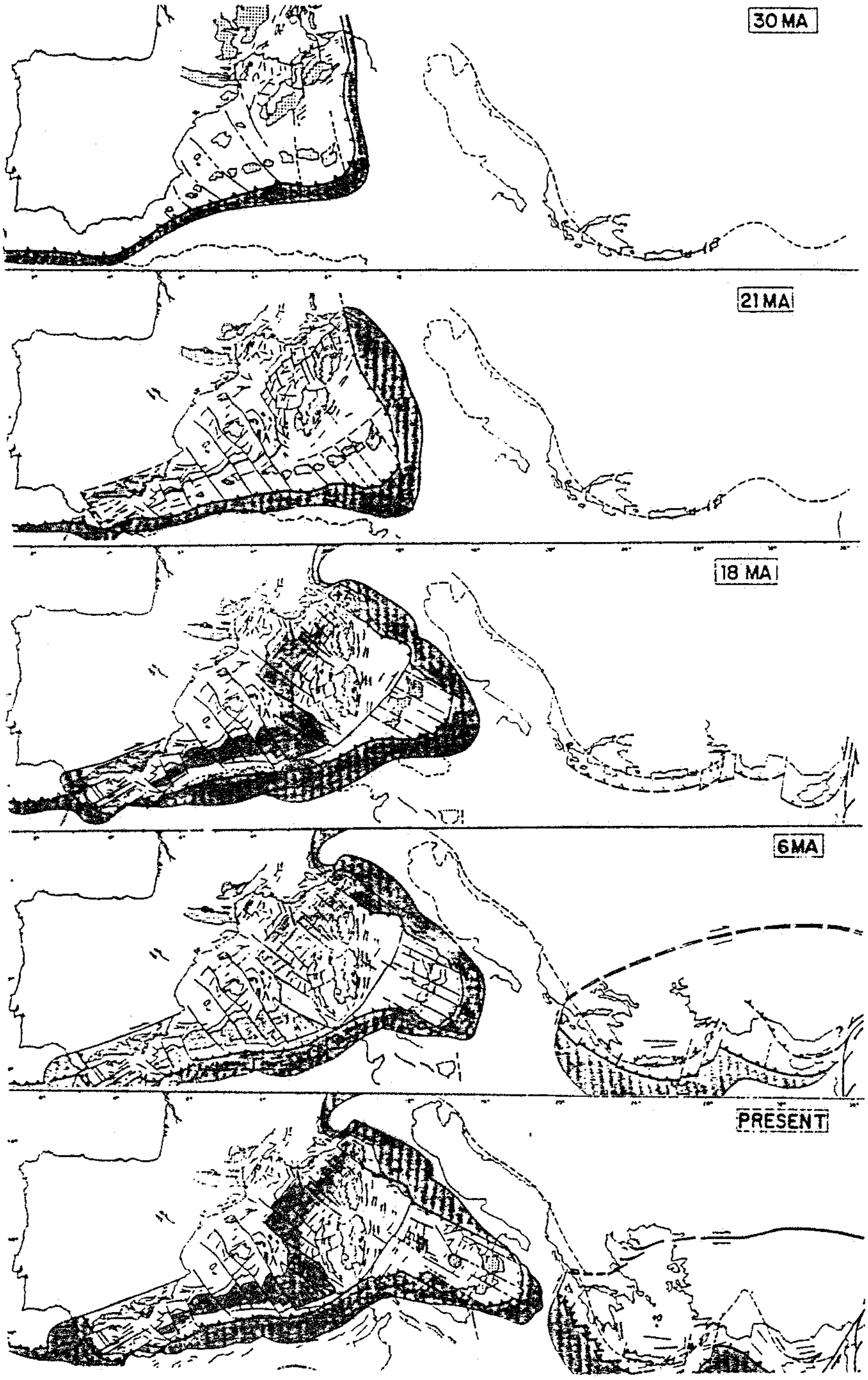


Fig. 68 - Schematic evolution of the western Mediterranean of the last 30 Ma (Late Oligocene), after Rehault et al. (1984).

The collision with the overthrusting of the Adriatic plate over the European plate is dated at the Eocene, and it is referred as the meso-Alpine phase. The convergence continued with high intensity during the Neogene (neo-Alpine phase), and it is still active as indicated by the deformation of Pliocene sequences and the present seismicity. The E-W striking central-eastern Alps and Southern Alps are considered the right lateral transpressive arm of the Alpine orogen (Figs. 39, 40 and 41).

Austroalpine to the north and Southern Alps are separated by the Insubric Line, a composite feature active at least since the Oligocene (Fig. 9). The roughly E-W segments of this line (Tonale and Pusteria Lines) are characterized by dextral transpression during Oligocene and Neogene, whereas the oblique NNE-SSW segments are thrusts or conjugate antithetic sinistral Riedel shears (Canavese and Giudicarie Lines).

The Southern Alps show a general south-southeast vergence (Fig. 40). The other Alpine units are vergent toward the European plate, westward and northwestward. The Southern Alps have an inherited Mesozoic architecture from west to east, the Canavese zone (transition with the ocean Tethys or Ligure-Piemontese to the west), the Lugano horst, the Lombard basin, the Trento horst, the Belluno basin, the Friuli platform and the Tolmino basin. These schematic subdivisions are sometimes a misleading mixture of paleogeographic and paleostructural features. In fact the term platform indicates shallow water carbonate platform environment, which may or may not have drowned during the Middle Jurassic (e.g. the Trento Platform, where the Liassic carbonate platform is covered by the pelagic Ammonitico Rosso). Thickness variations of the sedimentary cover which more precisely identify horsts and grabens also occur within the former main paleogeographic units. Toward the east the Vardar ocean was also bordering the Adriatic plate. These Mesozoic features were mainly N-S trending, and have been cut obliquely by the Southern Alps thrusts. Main thrusts in the Southern Alps to remember from west to east are the Orobic and Gallinera thrusts, the Val Trompia thrust, the Valsugana thrust, Fella-Sava line, the Belluno and Periadriatic thrusts, being the last one responsible for the Friuli 1976 earthquake. The Giudicarie belt in the central Southern Alps is a major structural undulation characterized by sinistral transpression occurred at the hinge zone between the Mesozoic Trento platform to the east and the Lombard basin to the west.

Since the onset of the inversion, from passive to active continental margin, the paleogeographic zones changed their configuration, and the foredeep of the Southern

Alps formed in a E-W trend. To the east of the Southern Alps, during Late Cretaceous and Paleogene, the Alps interfered with the Dinarides, an orogen due to the underthrusting of the Adriatic plate under the eastern European plate, after the consumption of the interposed Vardar ocean (an eastern arm of the Tethys ocean). Eocene thrusts and foredeep of the NNW-SSE trending Dinarides are preserved in NE-Italy.

Austroalpine units outcrop in Italy in Alto Adige, to the north of the Insubric (Pusteria) Line. The Silvretta Nappe is a very large and thick basement slice of this area. The Austroalpine basement crops out in the Ortles-Cevedale zone with its Permo-Mesozoic sedimentary cover. The Venosta Valley, Pejo Valley are also classic areas for the Austroalpine, in Lombardy, always to the north of the Insubric (Tonale segment) line, and to the west of the Ivrea-Verbano zone, where it is called Sesia-Lanzo Zone. In the western Alps is also found in klippen with blue schists and green schists facies (Verres, Dent Blanche, Pillonet, M. Mary), and eclogitic facies (Santanel, Glacier-Rafay, Mt. Emilius, Tour Ponton). The Austroalpine is constituted by polymetamorphic (both Hercynian and Alpine) paraschists and intrusive acid and basic bodies of Late Paleozoic age, more or less metamorphosed by the Alpine overprinting. The Penninic units are considered the ophiolitic remnants of the Piemontese, Antrona and Vallesana zones, the Gran Paradiso, Monte Rosa, Arcesa-Brusson, Dora Maira and Gran San Bernardo massifs, the lower part of the Ossola window, Adula, Margna and other smaller units. The Dora Maira, Gran Paradiso and Mt. Rosa areas are considered the 'internal' massifs of the Alpine edifice, whereas the 'external' Alpine massifs are the Argentera, Pelvoux-Belledonne (in France), Mt. Blanc and Aar-Gottardo (Switzerland). The internal massifs are basement nappes of the Adriatic continental margin (Austroalpine), whereas the external massifs are basement nappes of the European continental margin (Helvetides). Penninic units of the Tauern window (e.g. calceschists) outcrop in north Alto-Adige. Austroalpine and Penninic units are thrust-sheets arranged in antiformal stack duplexes, with a strong ductile component. Stretching lineations show mainly E-W component of the slip vectors during Cretaceous and Eocene times. Thrust planes and ductile milonitic zones are generally folded. The Southern Alps show instead a more brittle deformation, with thrust planes arranged with classic imbricate fan geometries. The western front of the Southern Alps is buried underneath the Po Plain, due to the southward tilting operated on the orogen by the advancing wave of the Apenninic foredeep.

APENNINES

The Apenninic history follows the 'Alpine' evolution until the Late Eocene. They underwent a similar Mesozoic paleogeography and later inversion. But during the Oligocene a W-dipping subduction started to the east of the Alpine belt, east of the Sardinia-Corsica, before and during its counterclockwise rotation. During the Neogene the Apennines (Fig. 33) accreted the sediments of the Adriatic plate Mesozoic passive continental margin, and of the Ionian oceanic basin during the eastward roll-back of the subduction hinge (Fig. 22). The Apennines migrated northeastward in the northern Apennines, eastward in the central-southern Apennines, and southeastward in Calabria and Sicily.

The main Mesozoic paleogeographic and structural subdivisions in the Apennines are: in the northern part, from west to east, the Ligurian basin (largely oceanic, e.g. Bracco Nappe), the Tuscan zone with platform facies until the Liassic, then pelagic sedimentation like in the adjacent Umbro-Marchigiano basin.

To the south-east is the Latium-Abruzzi platform. In the southern Apennines, from west to east the main paleogeographic zones are the Campano-Lucana platform, the Lagonegro-Molise basins (Ionian oceanic basin?) and the Apulian platform (Fig. 9). To the east of the Apulian platform another basin developed during the Mesozoic (e.g. the East Gargano basinal sediments), and this was coeval to the opening of the southern Adriatic basin. The forward propagation of thrusts piled up the paleogeographic domains, having in the hangingwall of the thrusts units originally located westward relative to the footwall, e.g. the Liguride units thrusting the Tuscan nappe, which in turn was thrust onto the Cervarola unit, mainly composed of foredeep sediments, which has in the following footwall the Umbro-Marchigiano basin. To the south, the Campano-Lucana platform was thrust onto the Lagonegrese pelagic units, which in turn was thrust onto the Apulian platform. This occurred because thrust planes were running in some cases parallel to the pre-existing paleogeographic zones. In Sicily similar Mesozoic subdivisions are indicated by the Panormide platform, Imerese basin, Trapanese platform, Sicanian basin, Saccense and Iblean platforms. The Trapanese, Saccense and Iblean carbonate platforms drowned to pelagic facies during the Middle Jurassic (Catalano et al., in Max and Colantoni, 1993).

Like in the Alps, the inversion due to the subduction regimes generated new paleogeographic zones superimposing with different angles the earlier subdivisions: e.g. the Plio-Pleistocene Apenninic foredeep, running from Monferrato in Piemonte, through the Po Plain (Fig. 1), the Adriatic sea, the Bradanic trough, the Ionian sea, and the Caltanissetta basin in S-Sicily. The most important structural features to remember in the Apennines are the Tuscany Nappe and Cervarola thrust fronts, M. Sibillini thrust, the Olevano-Antrodoco line (former Ancona-Anzio Line), the Gran Sasso and Morrone thrusts, the Gela nappe in Sicily, etc.. Several Pleistocene grabens cross-cut the Apennines i.e. the Mugello, Tiberina, Valdarno, Chiana, Radicofani, Dell'Elsa, Siena, Radicondoli, Bassa Val Cecina, Volterra grabens, (Tuscany and Umbria), Paglia-Tevere, Fucino, Volturno grabens (Latium), S. Arcangelo, Sibari, Crati, Catanzaro, Mesima e Messina grabens, (Calabria). The Alpine units in Calabria and NE Sicily are bounded by the Sangineto Line to the north in Calabria, and by the Taormina Line in NE Sicily (Peloritani). Apart those Calabrian and Sicilian outcrops, the basement in the Apennines is visible in the Apuane window, east of Pisa, in the Montagnole Senesi, Elba Island, Argentario (Tuscany), and in other smaller outcrops on the west coast.

The main steps of the Apennines evolution may be considered the Eo-Alpine phase (Cretaceous?) and Liguride phase (Paleocene-Eocene) with Alpine W-vergence and structural style, and the Sub-Ligure phase (Oligocene). The Tuscan phase (Tortonian) is considered the one during which the main nappes emplaced (Liguridi, Tuscan nappe, Cervarola nappe); during the Tuscan phase the Apuane area underwent metamorphism. However the Apennines continued to move throughout the Pliocene and Pleistocene, with a frontal active accretionary wedge and an internal elevated ridge in extensional regime (Figs. 65, 66, 67 and 68).

Several problems concerning Apenninic paleogeography are still open, e.g. the extension and oceanic nature of the Ionian-Lagonegro basin, the shape and distribution of the Mesozoic carbonate platforms (Fig. 9), and their significance in the Apenninic kinematics where paleogeographic zones have partly become structural units. It is also under debate the amount of involvement of the basement in the Apenninic accretionary wedge, and whether the Adriatic plate basement is entirely subducted or not (Fig. 32). Is there continental crust under the Apennines or is it lost by the Apenninic subduction? Are the Apenninic basement outcrops only remnants of the earlier Alpine tectonics?

The Tyrrhenian Neogene back-arc basin includes several smaller basins developed on the continental shelf, slope (Fig. 61), and bathyal plain which arrives to 3,000-3,600 m depth (Fig. 62). Horsts and grabens are mainly N-S trending, with several transfer zones, disturbing the cylindricity of the stretching. Several kilometers thick peri-Tyrrhenian Neogene basins are located off-shore Sardinia (Sardinia basin), Calabria and Sicily (e.g. the Paola, 4 Km thick, Gioia and Cefalù basins).

On the Tyrrhenian sea floor there are outcrops of the Hercynian basement, abyssal oceanic tholeiites dated 6 Ma, and sedimentary basins filled with Miocene clastics, Messinian evaporites and Pliocene-Quaternary clastics. Where oceanic, the crust of the Tyrrhenian basin is even less than 8 km thick. Diapiric structures occur in the central part of the deeper Tyrrhenian basins, where thick Messinian halite is present.

The Sicily channell is due to extension between Sicily and Tunisia (Africa) active since Neogene times. This is responsible for the Pantelleria, Malta and Linosa basins, NW-SE trending grabens, parallel to similar features outcropping in Tunisia and the offshore Pelagian shelf (Fig. 60).

• 5 - RESOURCES

PETROLEUM AND NATURAL GAS

Petroleum exploration and production began in Italy in the second half of the XIX century. Modern exploration and development began in 1944 with the discovery of the Caviaga gas field near Milano. Agip, the Italian oil company, made important discoveries in the last 40 years and contributed fundamentally to the geologic knowledges of Italy throughout acquisition of a large net of seismic reflection profiles and wells. Gas and oil production in Italy is very active (Figs. 69, 70 and 71).

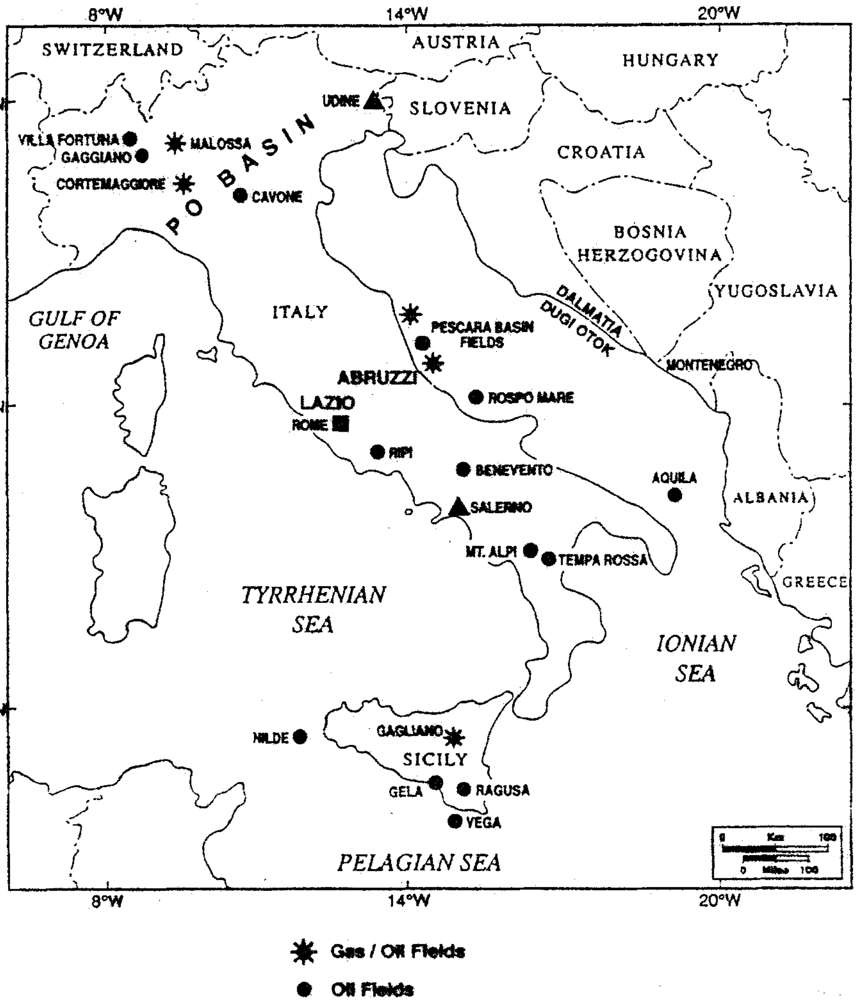


Fig. 69 - Major gas and oil fields in Italy, after Zappaterra (1994).

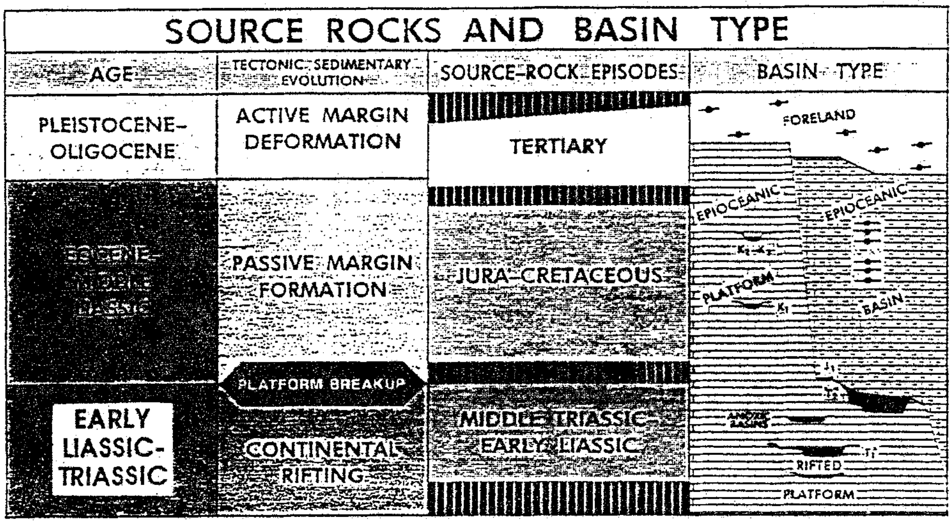


Fig. 70 - Source rocks and basin type, after Zappaterra, in AA.VV. (1990).

Gas reserves are primarily in Pliocene sand reservoirs of the foredeep in structural traps originated by the external Apennines folding (Po Plain, Adriatic sea, Bradanic trough, Fig. 1). Along the pedi-Alpine side between Milano and Brescia the traps are mainly stratigraphical at the base of the Pliocene transgression. The gas is biogenic, and the source is immature organic matter in coeval shales. The major part of the oil and part of the gas are thermogenic, mainly derived from black shales deposited in Middle and Upper Triassic, and lower Liassic basins.

AGE		NORTH ITALY Lombardy, Po Basin		CENTRAL - SO. ITALY Onshore / Offshore		SICILY	
		Source Rock	Main Oil Fields	Source Rock	Main Oil Fields	Source Rock	Main Oil Fields
TERTIARY		Marnoso - Arenacea Gallare Marls	Cortemaggiore	Various Shale Units	So. Apennines: Benevento Candela Castelpagano	Shale	Gagliano
LOWER JURASSIC	Sinemurian					Streppenosa Shale	SE. Sicily: Ragusa Gela Vega Perla Mila
	Hettangian			Emma Lst.	C. Adriatic: Piropo Emma	Noto Marls	
TRIASSIC	Rhaetian	Riva Di Solto Shale	Malossa Seregna	Burano Dol.	So. Adriatic: Aquila		
	Norian			Gilfoni Marls Equivalent	So. Apennines: Tempa Rossa Monte Alpi		
	Carnian						
	Ladinian	Meride Lst. & Marls	Gaggiano Villafortuna-Trecate Cavone (?)				

Fig. 71 - Main formations considered source rocks in Italy, after Zappaterra (1994).

According to Pieri and Mattavelli (1986), petroleum generation began during the Mesozoic in the deepest parts of these basins, and heavy oil migrated into the adjacent Mesozoic carbonate platforms reservoirs. Condensate and wet gas originated in the areas of major Tertiary subsidence and migrated into Neogene clastic reservoir where tectonism was more intense. A minor part of the oil in Tertiary sand reservoirs may have been sourced by organic matter of Miocene flysch. Miocene, mostly flyschoid gas-condensate reservoirs produce in northeast Sicily (Gagliano) and eastern Calabria (offshore Crotone), as well as in the offshore of Trapani in western Sicily. More important oil reservoirs and oilfields produce from Mesozoic (Liassic-Triassic) carbonates. Aside from the eastern Sicily (Ragusa and Gela oilfields), ultra-deep production, beyond 5,000 m, is obtained from the Malossa field, east of Milano, and from the Trecate-Villa Fortuna field near Novara. The same upper Triassic carbonates, mainly dolomites, are the reservoirs of southern Adriatic offshore and of the onshore of Irpinia.

Although petroleum exploration has been heavy since 1950, plays with good potential still exist. Original reserves discovered by the end of 1984 were 560 billion m^3 of gas and 132 million metric tons of oil, distributed in more than 200 fields. In 1984, gas and oil production was of 13.8 billion m^3 of gas and 2.2 million metric tons of oil. In 1991 the production was of 17.4 billion m^3 of gas and 4.3 million metric tons of oil. Recent new discoveries were announced (1992-1993) in Southern Italy, with reserves yet to be ascertained. Original reserves have increased continuously from the 1950s, and every year, on the average, reserves estimated from discoveries have exceeded production. Among the most important discoveries of the last years there are the fields of Malossa and Villa Fortuna (near Milan) in the Po Plain, and Aquila (offshore Brindisi) in the Otranto Channell. The total Italian hydrocarbon production covers roughly 10-12 % of demand.

COALS

Lignitic coal is the most abundant solid fossil fuel known in Italy. Its largest deposits (Sardinia) are of Eocene age and contain >8% sulfur. Although the total reserves are relatively large (a few hundred millions tons) only part of them can be viably exploited due to severe tectonic complications and to the reduced thickness of the seams. Total production (1990) was 1,492,761 tons. Very small deposits of graphitic anthracite, exist in the Val d'Aosta Carboniferous section, as well as in the Sardinian Permian section, none of which are presently active. There are also some minor peat deposits of Tertiary age in central Italy and Calabria.

MINERAL RESOURCES

In spite of the mineral richness of Italy, its present industrial mining resources are limited. This is due not only to the small dimensions of the deposits but also to the fact that they have been exploited for several centuries, since pre-Roman times. However several ore deposits have to be mentioned: Fe, Mn, Co, Cr, Ti, Hg, Sb, As, pi, Cu, S, Pb, Zn, Ag, F, Ba, Sr, Al, Au, Be, Mo, Sn, W, U. Other minerals or industrial rocks are: Na, K, feldspar, quartz, magnesite, amiante, talc, kaolinite, bentonite, graphite, leucite, perlite, bituminous rocks. In the past Italy was a good producer of mercury (M. Amiata, Tuscany), lead, zinc and silver (Sardinia), Monte Neve (north of Bolzano) and Raibl (Eastern Alps); antimony and fluorite (Sardinia), pyrite (Tuscany). Rather important iron deposits were exploited in the past in Sardinia (Nurra province), at Cogne in Val d' Aosta Valley, and at the Elba Island in Tuscany. Other ore deposits are: Cu in Val d'Aosta; Ni in Piemonte, Al, bauxites in Puglia and Campania; talc and amiant (asbestos) in the western Alps (Piemonte); Mn in Liguria and Sardinia, F in Latium and Trentino-Alto Adige. U deposits occur in the Marittime Alps. Talc, Mn, Ba, Ag, F, Ag, Cu are also present in Sardinia; the Iglesiente in SW Sardinia is an old minerary district. Sicily is very active for marine and potassium salts and S production. At present the reserves of mercury, antimony and bauxite are almost totally exhausted, and the residual ores of lead, zinc and silver have a lower yield. The reserves of sulfur are also greatly reduced, and the pyrite reserves of sulfur (mostly Tuscany) although still considerable, are of difficult exploitation. An interesting potential for extraction of aluminum is represented by the large volumes of leucitic lavas of central Italy. However the cost of processing makes its extraction, at present, not viable. The most active mining activity remains the quarrying of several kinds of high-quality marbles and building stones of igneous, metamorphic and sedimentary origin, e.g. granites, slate, various kinds of limestones and massive sandstones. Famous are the marbles of the Apuane in NW-Tuscany (Marmo di Carrara).

GEOTHERMAL ENERGY

Italy is the oldest and one of the principal producers of geothermal energy, although its total production of electricity by geothermics covers only about the 3% of demand. The main geothermal area is in Tuscany (Larderello near Pisa) where the thermal energy of the natural geysers (110-150°C natural steam) is exploited. The steam derives from Triassic carbonates overlying the intrusive stock of Monte Amiata. Other geothermal areas are the Colle Euganei (west of Padua), Casaglia (Ferrara), Viterbo, the Phlegrean Fields and Ischia (Neaples), the Alcamo and Sciacca in west Sicily. Active exploration of other potential areas are underway, in Tuscany, Latium, Campania and Eolian Islands (Sicily).

6 - SPECIAL GEOLOGIC FEATURES

Mud volcanoes are reported from the Emilian Apenninic foothills (Sassuolo, Lesignano, Nirano and Querciola), in the Marche (S. Paolo di Iesi, Rotella, Cellino, Mutignano) and in the Irpinia (Castelfranco in Miscano and S. Angelo dei Lombardi). In Sicily mud volcanoes are in Paternò, Terra Pilata, Aragona and Valle dei Platani. It is very famous the bradisism phenomena of the Phlegrean Fields near Neaples, uplifts or subsidence movements related to the evolution of a few km deep magma chamber.

Famous geysers or 'soffioni boraciferi' are in Larderello. Hot springs are reported in the Alps from Acqui, Vinadio, Valdieri, Sirmione, Abano and Montegrotto (Colli Euganei), in the Apennines Bagni di Lucca, Larderello, Phlegrean Fields, Vulcano Island, in Sicily Sciacca, and in Sardinia Terme di Sàrdara. Fumarolic occurrences are in Ischia, Phlegrean Fields, Vulcano, Mt. Amiata and Larderello.

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Chapters 1-2-3-4: CARLO DOGLIONI
Chapters 5-6: GIOVANNI FLORES

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INDEX

CAP. 3 - REGIONAL GEOLOGY

CAP. 5 - RESOURCES

Finito di stampare presso
L'Aquilone / La Bottega della Stampa - Potenza
nel mese di settembre 1997

The geology of Italy is a lively system that can be traced from the early Paleozoic Hercynian orogen, throughout the Mesozoic opening of Tethys oceans to the later closure of these oceanic embayments during the Alpine and Apenninic subductions.

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