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STRATIGRAPHY AND EVOLUTION OF THE NORTHERN APENNINE ACCRETIONARY WEDGE WITH PARTICULAR REGARD TO THE OPHIOLITIC SEQUENCES: A REVIEW

Abstract. The Northern Apennines are an east-migrating accretionary wedge in an ensialic stage, made up of several east-verging nappes. The most internal units (Ligurids) belong to the Ligurid domain, the basement of which was the oceanic crust of the Western Tethys. The most external units (Tuscan and Umbria-Marches units) belong to the Adriatic continental domain. Only the Calcshists with Ophiolites and Vara Supergroup units present a Tethyan oceanic basement at the base of the Jurassic-Cretaceous cover. The other Ligurid units, cut below at the level of their Cretaceous 'basal complexes', do not show any record of their Jurassic oceanic basement. The Ligurid units more external than the Vara Sopergroup include ophiolites as olistolites and olistostromes in their Upper Cretaceous turbidites. Stratigraphic, sedimentologic, structural and palaeogeographic considerations led to the hypothesis that also these Ligurids have an oceanic basement. The opening of the Western Tethys occurred during the Middle-Upper Jurassic after a Triassic-Jurassic rifting stage. The oceanic crust of the Western Tethys is made up of a serpentinitic-gabbroic basement, which was extensively exposed on the oceanic bottom and directly covered by ophiolitic breccias and pelagic sediments. The basalts follow the latter and were discontinous and scarce in thickness. During the Upper Cretaceous the Western Tethys began to close and an embryonic (Ligurid) accretionary wedge of the Northern Apennine orogen formed. The progressive eastward migration, starting from Upper Cretaceous, of the turbiditic basins, and the western provenance of the siliciclastic material of the more internal (and older) turbidites, indicate the European margin (Corsica and Sardinia) as the active (overlying) one. Two main phases characterized the evolution of this tectonic wedge : a) an Upper Cretaceous-Eocene Ligurid phase, during which the Tethyan oceanic crust was subducted and the Ligurid units (both of Corsica and the Northern Apennine) were accreted (and metamorphosed) by underplating processes; b) a post-Upper Eocene ensialic phase, which started after the Europa-Adria collision, occurred between Upper Eocene and Oligocene, during which the Tuscan and Umbria-Marches units were structured. After the Middle Eocene, probably during the collision, the metamorphic 'Alpine' Corsica units was exhumed and emplaced westward as backthrusts of the east-verging Northern Apennine accretionary wedge. The amount of shortening decreases from W to E, as does the age of the turbidites at the top of each unit. From the Middle Miocene, extensional tectonics, with related magmatism, active to the west of the compressive front, began to migrate eastwards. The magmatic activity seems to have ceased in Quaternary times. At present, the compressive front is active on the Po Valley- Adriatic Sea side; the distensive front remains 80-100 km behind, near the Apenninic watershed divide. A new structural and rheologic model for the Northern Apennine lithosphere, based on old and new seismic reflectors in the Liguria-Parma Apennines, assume a pure shear behaviour for the upper crust, and a simple-shear model for the lower crust, and a lozenge geometric pattern for the crust-mantle boundary. A main listric fault dipping westwards separates (Mt. Orsaro) the extensional (Tyrrhenian) domain from the compressive domain. An east-dipping crustal shear zone (LANF) lies above relics of old deep west-dipping Moho compressional structures. A new west-dipping Moho plane, which may be a new compressional structure, is present eastwards below the compressional domain of the Northern Apennines.

GENERAL OUTLINE OF THE NORTHERN APENNINES

The Northern Apennines are a Cenozoic arcuate orogenic chain conventionally separated westwards from the Alps by the Sestri-Voltaggio Line (Genua), and south-eastwards from the Central-Southern Apennines by the Ancona-Anzio Line.

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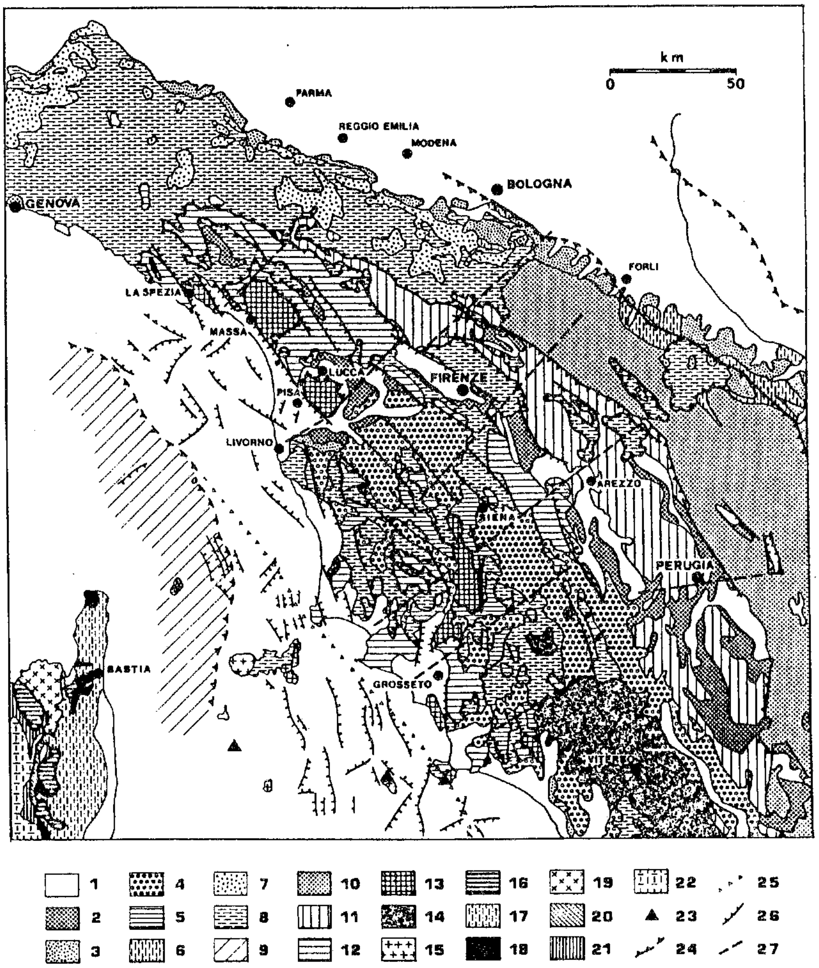


Fig. 1 - Tectonic scheme of Northern Apennines (redrawned by Società Geologica Italiana, 1992. Legend: 1 - Continental and marine deposits (Late Pleistocene-Olocene); 2 - Lacustrine and fluvial deposits of the Middle Pliocene-Middle Pleistocene (Villafranchian); 3 - Mainly marine clastic deposits of the Peripadanian margin, Early Pliocene-Early Pleistocene; 4 - Tyrrhenian marine clastic deposits, Pleistocene; 5 - Lacustrine and marine deposits with evaporites of the Tyrrhenian margin, Messinian-Early Pliocene; 6 - Evaporitic and hypoyaline deposits (Gessoso-Solfifera F.) of the Po Valley-Adriatic Sea margin, Messinian; 7 - Epiliguride Unit, Middle-Late Eocene-Miocene; 8 - Apenninic Ligurid Units s.l., Jurassic-Oligocene; 9 - Calcschist with ophiolites Unit (from Bartole et al., 1991), Jurassic-Cretaceous?; 10 - The Umbria-Marches Unit, Late Triassic-Late Miocene; 11 - Mt. Cervarola-Mt. Falterona Unit, Late Cretaceous-Middle Miocene; 12 - Tuscan Nappe, Late Triassic-early Miocene; 13 - Tuscan Metamorphic Unit (Triassic-Late Oligocene) and the pre-Triassic basement; 14 - Effusive magmatic rocks, Miocene-Olocene; 15 - Intrusive magmatic rocks, Miocene-Pliocene; 16 - Corsica Ligurid Units s.l., Jurassic-Eocene; 17 - Schistes Lustrès with ophiolites Unit, Jurassic-Late Cretaceous?; 18 - Parautochthonous crystalline basement involved with Schistes Lustrès, pre-Triassic basement; 19 - Tenda Unit, pre-Triassic basement; 20 - Parautochthon Slices of Corte,Permian-Triassic/Liassic; 21 - Neoautochthon transgressive, Middle Eocene; 22 - Basement, pre-Triassic; 23 - Outcrops and dredge hauling of Calcschistes with Ophiolites in the Tyrrhenian area; 24 - Main thrust fronts; 25 - Possible southward extension of the Calcschists with Ophiolites Unit; 26 - Main extensional faults; 27 - Main transversal tectonic lineations.

The Northern Apennine orogen is an east-migrating accretionary wedge in an ensialic stage made up of several east-vergent nappes (Principi and Treves, 1984; Treves, 1984).

The Northern Apennine accretionary wedge units

The tectonic units of the Northern Apennine accretionary wedge consist of more or less continous stratigraphic sequences, topped by turbidites progressively younger eastwards (shifting

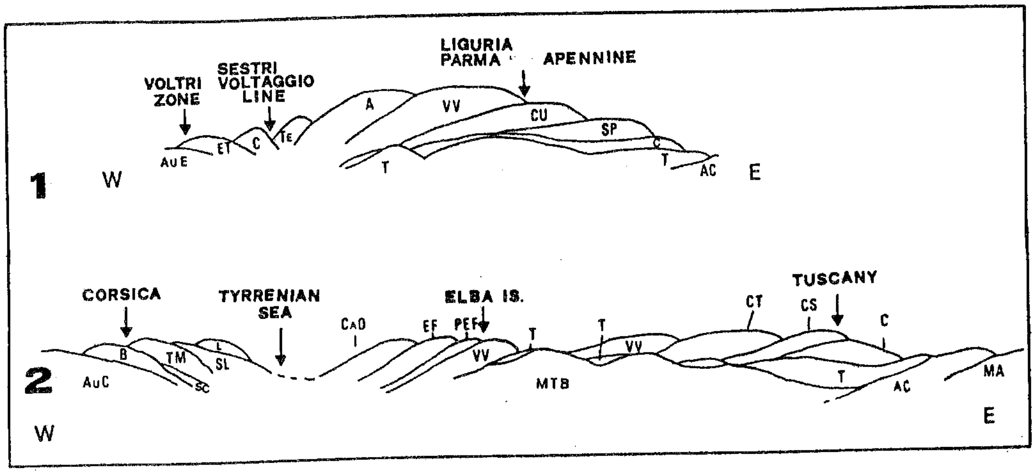


Fig. 2 - Schematic structural cross-sections of the Northern Apennines.
1 - From Voltri Group to Liguria-Parma Apennines: AuE-European autochthon Massif; ET - Erro Tobbio Unit; C - Cravasco Unit; Teiolo Unit; A - Mt. Antola Unit; VV - Vara Supergroup; CU - Mt. Caio Unit; SP - Mt. Sporno (and Mt. Dosso) Unit; C - Canetolo Unit; T - Tuscan Nappe; AC - Mt. Cervarola Unit.
2 - From Corsica to Umbria-Marches Apennines: AuC - Corsica autochthon Massif; B - Ligurid complex of Balagne; SC - Slices of Corte; TM - Tenda Massif Unit; SL - Schistes Lustrés with Ophiolites Unit; L - Ligurid Units; CaO - Calcschists with Ophiolites Unit; EF - Elba Flysch Unit; PF - Paleocene-Eocene Flysch of Elba I.; VV - Vara Supergroup; CT - Helmin thoid Unit (Caio Unit) of Tuscany; CS - Calvana Supergroup (and S. Fiora Unit); C - Canetolo Unit; T - Tuscan Nappe; MTB-Tuscan metamorphic sequences and basement; AC - Mt. Cervarola Unit; MA - Umbria-Marches Unit.

of the sedimentary/turbiditic basins), moving from the uppermost to the lowermost units.

There are three main groups of nappes belonging to three paleogeographic domains. From west to east they are:

a) the Ligurides: the higher units in the wedge pile, deposited in an oceanic environment;

b) the Subliguride Sequence (Canetolo Unit);

c) the Tuscan and Umbria-Marches nappes, at the base of the wedge, deposited on a continental basement.

Ligurid Sequences

We subdivide the Ligurid nappes into two main groups, the so-called 'internal' (westwards from VV, included, in Fig. 2) and 'external' (from VV to T, both excluded, in Fig. 2) Ligurids. The former thrust over the latter. The original distinction into these two palaeogeographic positions of the Ligurid basins with respect to the 'Ruga del Bracco' (VV Unit in Fig. 2a), as hypothized by Elter and Raggi (1965), is now unsupported by petrological and geochemical data for ophiolites of the Ligurid Units (Beccaluva et al., 1980; 1984; 1989). The 'immature' ophiolites occurring as clasts in olistostromes in the eastern Ligurids of the Liguria-Emilia Apennines have no affinity with the 'mature' ophiolites of the ophiolitic nappe (VV = Vara Supergroup), considered as source of the former. On the other hand (for the outcrops of the Liguria-Parma Apennines only), the geochemical data justify a distinction of the Ligurid units in two main groups , respectively internal and external (Beccaluva et al., 1980; 1984; 1989). But this distinction does not exists southwards, in the Tuscan Apennines (The Units of the Fig. 2b). However, we maintain this conventional distinction as a geometric reference for the Ligurids. So, on the basis of the structural position, the Vara Sequence represents the lower unit in the Northern Apennine accretionary wedge among the 'Internal' Ligurids.

The other Ligurids (a more complete scheme of these is seen in Fig. 4Na-b and S, in particular; in Fig. 4Na the Units from 2 to 7; in Fig. 4Nb the Units from 5 to 9; in Fig. 4S the Units from 11 to 14), with some exceptions (e.g., Mt. Antola Unit, A in Fig. 2a and the Ligurids of Elba Island ; see also Fig. 3b) occupy a more 'external' position (see the schemes in Fig. 2).

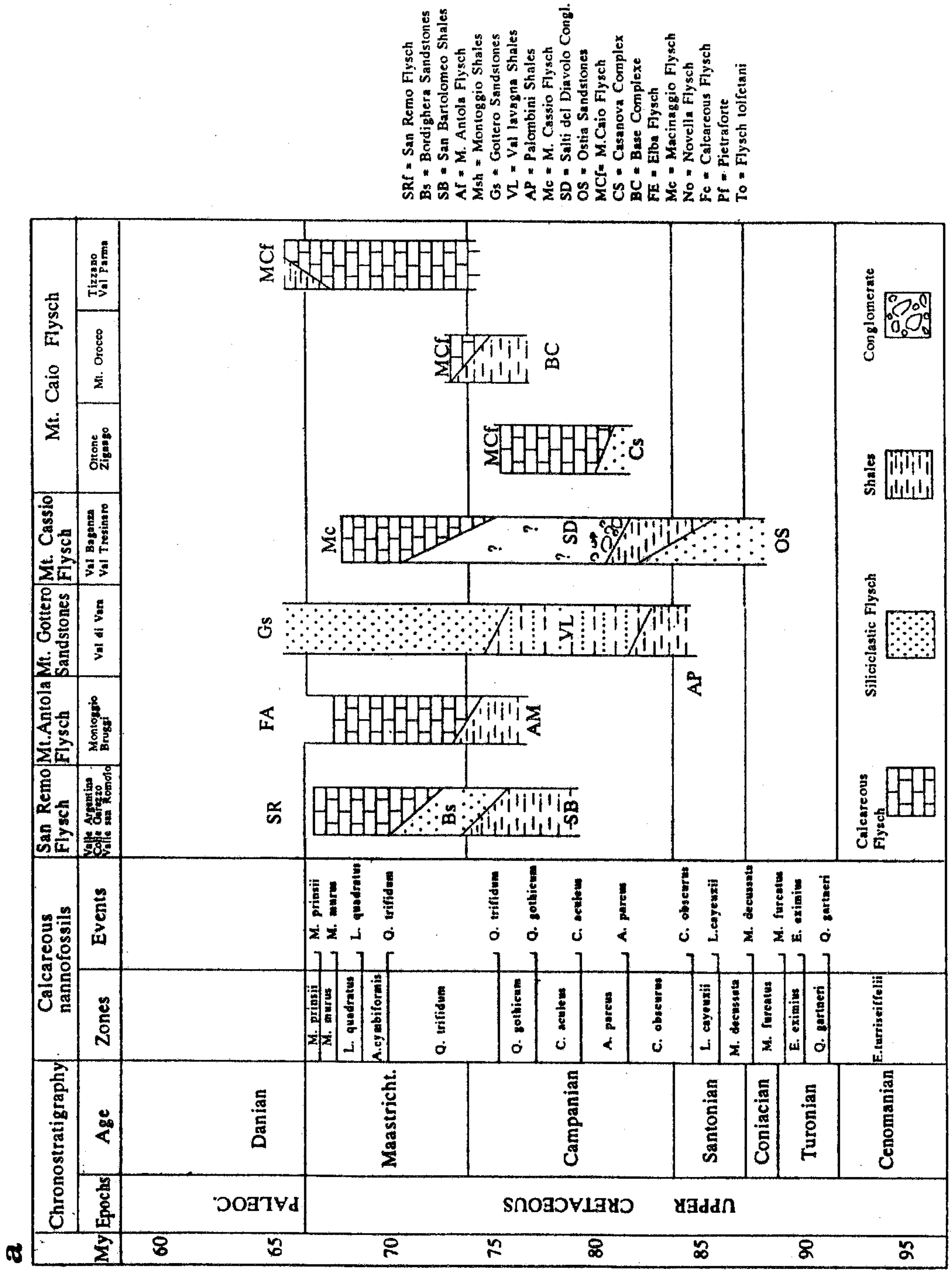


Fig. 3a - Ages of the Ligurid turbidites (from Gardin et al., 1993): - Ligurian Alps and Liguria-Parma Apennines.

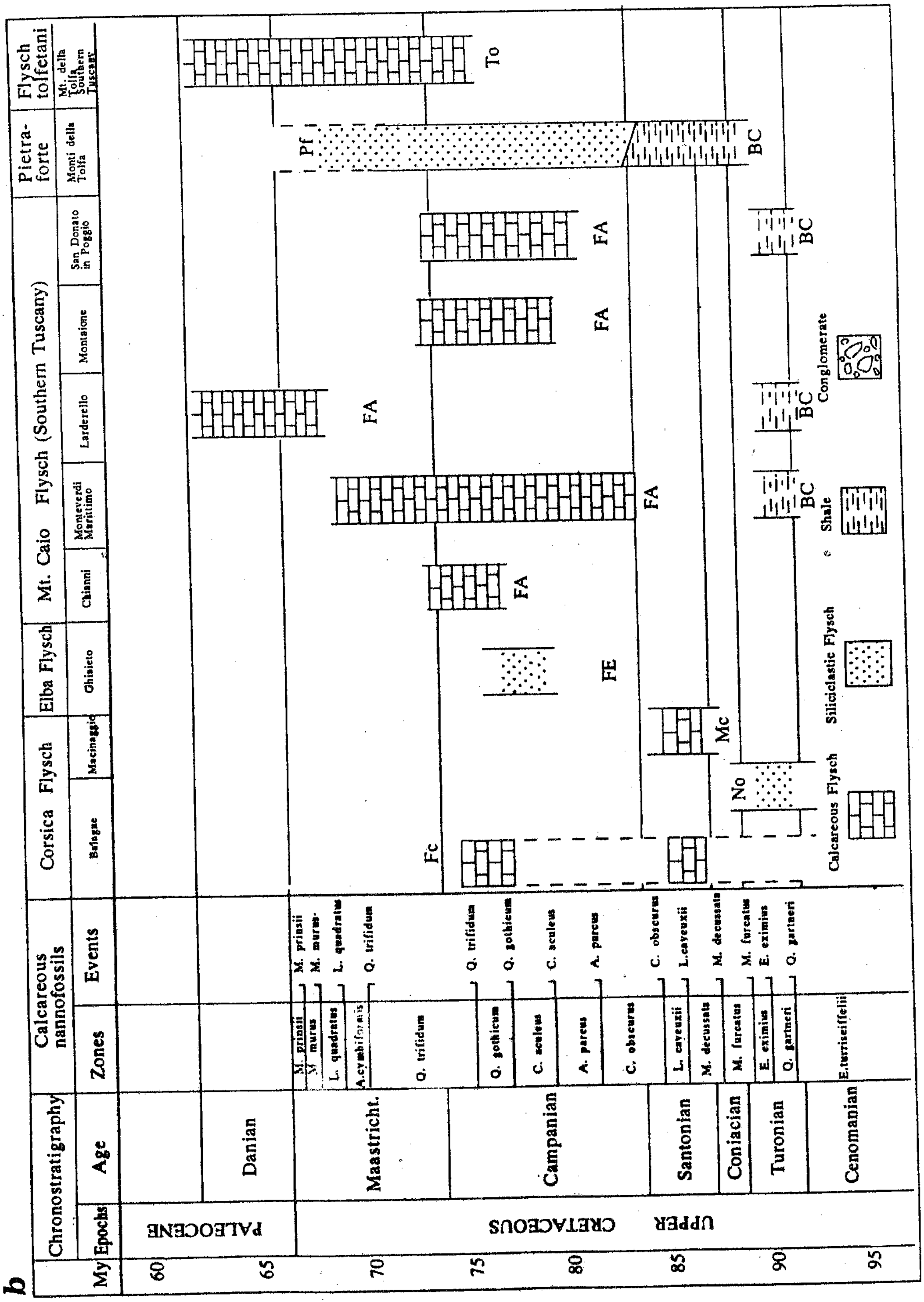


Fig. 3b - Ages of the Ligurid turbidites (from Gardin et al., 1993): - Corsica and Tuscany.

Except for the Calcshists with Ophiolites and the Vara Supergroup, both containing an oceanic (ophiolitic) basement (see later), all other Ligurid Units are cut below at the level of the 'basal complexes' (white in the columns of Fig. 4a and b) of the Upper Cretaceous-Eocene turbiditic sequences. Their basement is unknown except, perhaps, for the Calvana Supergroup (Principi and De Luca Cardillo, 1975), and for the 'Ligure-Maremmano' Group (Brunacci and Manganelli, 1983), both in Tuscany. But the latter can be considered a fragment of the Vara Supergroup with an uncertain tectonic position. Nevertheless, it is generally accepted that all Ligurid sequences had an oceanic basement as documented only for the Vara Supergroup. Stratigraphic and structural considerations contribute to support this idea. They are:

a) the correlation between the Vara Sequence and many other Ligurid Units represented by the ubiquitous Palombini Shale Formation (Ap in Figs. 3 and 4, see also later in the stratigraphy of the Vara Sequence);

b) the presence of Upper Cretaceous turbidites in the Vara and many others Ligurid Units;

c) some Ligurid Units (Antola Unit, Elba Island Ligurid Units) have a geometric (and palaeogeographic) position between the Vara Supergroup and the ophiolitic sequences of the Sestri-Voltaggio Zone (Antola Unit) or of Corsica (Elba Island Ligurides).

Since the Ligurid turbidites are often the only component of many Ligurid Units, a detailed knoweledge of the age, composition and other sedimentological characteristics of these rocks is indispensable for any attempt at a restoration of the Ligurid basin palaegeographic framework.

The age of the base of the Ligurid turbidites ranges from Coniacian-Santonian to Campanian-Maastrichtian (Marroni et al., 1992) (see Fig. 3a and b). In the Internal and western External Units (e.g., Mt. Caio Unit) sedimentation ended in the Lower Paleocene. In the easternmost External Ligurid Units (e. g., Mt. Sporno to the north and Calvana Supergroup to the south) the turbiditic sedimentation continued up to Middle-Upper Eocene.

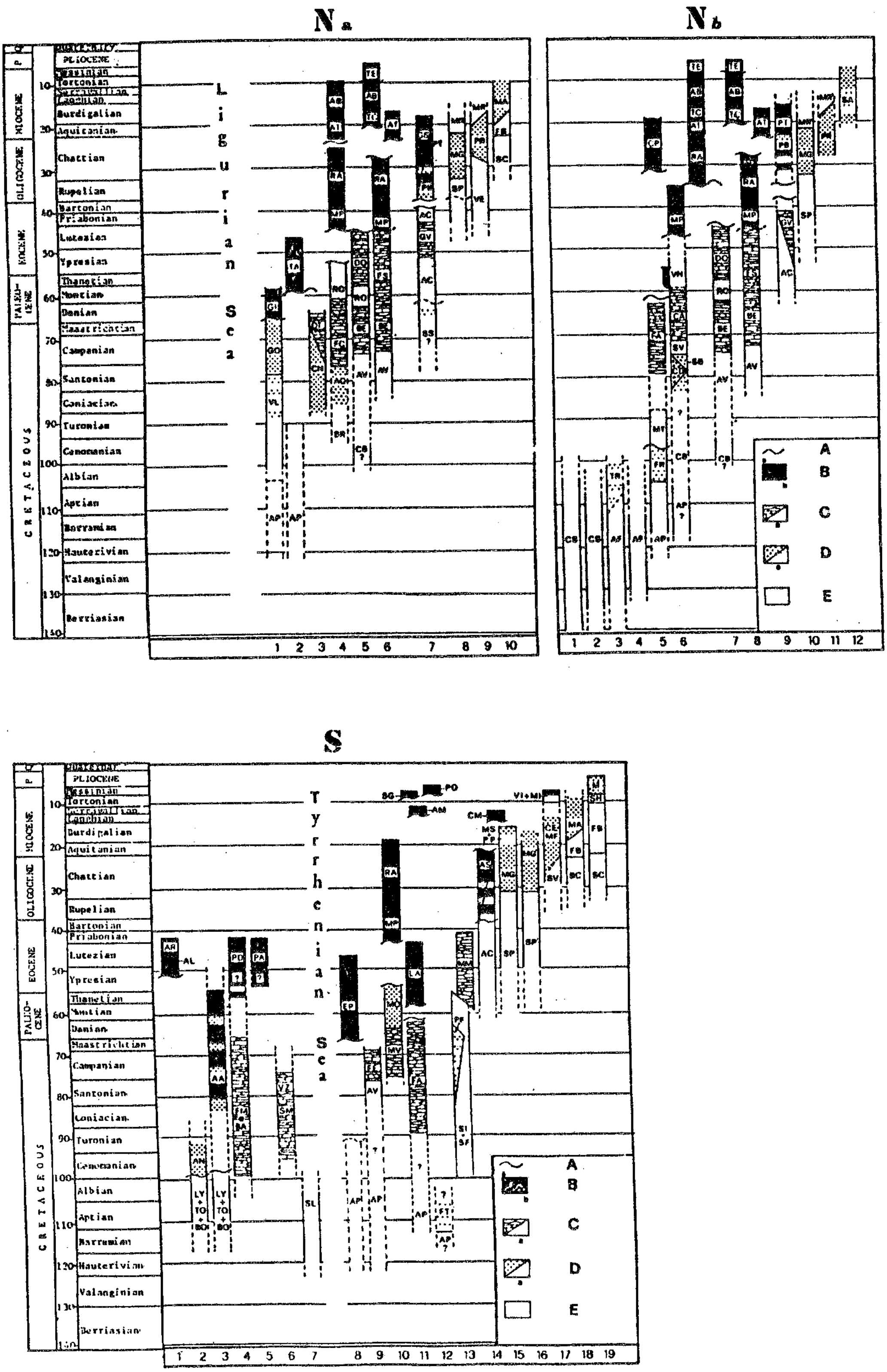
The turbidites of the Ligurid sequences are both siliciclastic and marly-carbonatic (Helminthoid flysch). The clasts of the former came from the Corsica-Sardinian Massif (Abbate and Sagri 1982, see also Fig. 13); those of the 'Pietraforte' Fm. (Calvana Supergroup, Cretaceous in age), came, on the contrary, from the Alpine Insubric border (perhaps as a continuation of the coalescent trough of the Lombard Flysches, Bortolotti and Malesani, 1967; Gardin et al. 1993 and references within).

The Helminthoid turbidites of the eastern Ligurian Apennines came from the NW (NE in Cretaceous times, see Fig. 13) longitudinally along the Tethyan basin. Those of Tuscany, on the contrary, came from the SW (W-NW in the Cretaceous palaeogeography), transversally to the basin (Sagri 1969; Gardin et al., 1993).

The Ligurid Units are covered unconformably by diachronous post-deformation deposits (Abbate et al., 1970; Principi and Treves, 1984a; see Fig. 4), mainly argillites and shales.

In the Liguria-Parma Apennines, from west to east, the post- deformational deposits range in age from Paleocene (Giariette Shales on the Gottero Sandstones) to Eocene (Montepiano Marls on the External Ligurids).

Fig. 4 - Space-Time distribution of the clastic sediments of the Northern Apennines (from Principi and Treves, 1984). Na - from Liguria Sea to Liguria-Parma Apennines; Nb - from Sestri Voltaggio Zone to Piacenza Apennine: 1) Vara Supergroup U.; 2) Tavarone/Lizza-Serò U.; 3) Casanova-Ottone U.; 4) Mt. Caio U.; 5) Mt. Dosso U.; 6) Mt. Sporno U.; 7) Canetolo U.; 8) Tuscan Nappe; 9) Pracchiola-Mt. Cervarola U.; 10) Umbria-Marches U..
S - From Corsica to Umbria-Marches Apennines:
1) Neoautochthonous on the Corsica basement; 2) Navaccia-Novella U.; 3) Navaccia-Alturaia U.; 4) Macinaggio/Calcareous Flysch of Balagne U.; 5) Palasca U.; 6) Vezzani/ St. Maria U. (Ligurids); 7) Schistes Lustrès U.; 8) Elba I. Paleogenic Flysch U.; 9) Elba Flysch U.; 10) Mt. Venere-Monghidoro (Sambro) U.; 11) Mt. Caio/ Antola U. of Tuscany; 12) Arenaceous flysch of Southern Tuscany; 13) Calvana Supergroup-St. Fiora-Pietraforte U.; 14) Canetolo U.; 15) Tuscan Nappe; 16) Tuscan metamorphic U. ; 17) Mt. Cervarola-Mt.Falterona U.; 18) and 19) Umbria-Marches U.. Window: A - Hiatus; B -Postdeformation sediments; C - Calcareous turbidites (a- hemipelagites); D - Siliciclastic turbidites (a - hemipelagites); E - 'Basal Complexes' (mainly pelagites and fine grained turbidites). For the legend of the formations see the article by Principi and Treves (1984).


Na
Nb
S
Ligurian Sea
Tyrrhenian Sea
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEO-CENE
CRETACEOUS
Messinian
Tortonian
Serravallian
Langhian
Burdigalian
Aquitanian
Chattian
Rupelian
Bartonian
Priabonian
Lutezian
Ypresian
Thanetian
Montian
Danian
Maastrichtian
Campanian
Santonian
Coniacian
Turonian
Cenomanian
Albian
Aptian
Barremian
Hauterivian
Valanginian
Berriasian
A
B
C
D
E

In Tuscany (Fig. 4) the deformed Helminthoid flysch (Mt. Caio Unit of Tuscany) and the overlying fragment of Vara Unit are unconformably covered by Middle-Paleocene post-deformation deposits (Lanciaia Fm.).

The Ophiolitic sequences

The Northern Apennines Ophiolites represent remnants of the Western Tethys Jurassic oceanic lithosphere, which was also the source of the Alps, Calabria, Corsica and Betica ophiolites.

In the Northern Apennines accretionary wedge, the ophiolites have the following two main types of occurrence (Abbate et al., 1980a).

1) As the basement of a coherent pile of oceanic sediments in (at least) two Units of internal position. In the Northern Apennine this occurrence is typical of the Vara Supergroup Unit (Abbate et al. 1970), one of the more internal and higher units of the prism. In the North Tyrrhenian zone, the presence of an east-vergent 'Calcschists with Ophiolites' Unit, with a more internal position than the former Unit, has been recently documented (Bacini Sedimentari, 1981; Bartole et al., 1991).

2) As olistolites and olistostromes included in Upper Cretaceous-Oligocene turbidites of several external units. This second type of occurrence is typical of the sequences more external than the Vara Supergroup, both oceanic (Ligurid Units with Cretaceous - to - Eocene flysches) and of continental margin (with Oligocene - to - Miocene flysches).

From the stratigraphic point of view, the ophiolitic sequences present as olistolites and olistostromes in the external units are very similar to those of the (more complete) oceanic sequences of the internal Units.

1 - Calcschists with Ophiolites

This unit crops out only on Gorgona and Giglio Islands (Capponi et al. 1990, 1993) and in the Argentario Peninsula. Samples of this unit were dredged up at Mt. Cialdi, a submarine ridge south-east from the Pianosa Island Ridge (Bacini Sedimentari, 1981). According to seismic data (Bartole et al., 1991) this unit represents the uppermost thrust nappe of the east-vergent Apennine wedge and occupies a wide area from Elba to Corsica and 150 km north of Pianosa in the North Tyrrhenian Sea.

The Giglio Island ophiolites are described by Capponi et al. (1993) as a strongly deformed and metamorphosed sequence of a basal intrusive complex (gabbros, Fe-diorites, Fe-gabbros), followed by a thin level of ophiolitic breccias and by phillites and marbles. The mineral assemblage linked to S1 foliation records blueschist facies conditions.

On Gorgona Island the occurrence of serpentinites and serpentinoschists with metagabbros and metabasalts is reported by Capponi et al. (1990). This complex overlies a sequence of metasandstones and calcschists with prasinites. These authors correlate the underlying sequence with the Alpine 'Complex of Calcschists with Ophiolites' (present both in the Western and Liguria Alps) and the uppermost serpentinitic unit to those of the Montenotte Unit of the Voltri Group (an HP metamorhpic ophiolitic sequence of Liguria Alps, Genua).

2 - Vara Supergroup

This is the main ophiolitic sequence of the Northern Apennines, occurring from Eastern Liguria to Southern Tuscany. It consists of a Jurassic ophiolite with a Jurassic-Early (till Late) Cretaceous sedimentary cover followed, locally, by Late Cretaceous siliciclastic turbidites (Fig. 5).

The Vara sequence may be divided into two sections:

1) a mafic-ultramafic 'basement';

2) a sedimentary and volcanic 'cover'.

Between these two portions there is a first order unconformity (see Fig. 5).

The mafic-ultramafic basement

The ophiolitic basement consists mainly of serpentinized peridotites and minor gabbroic

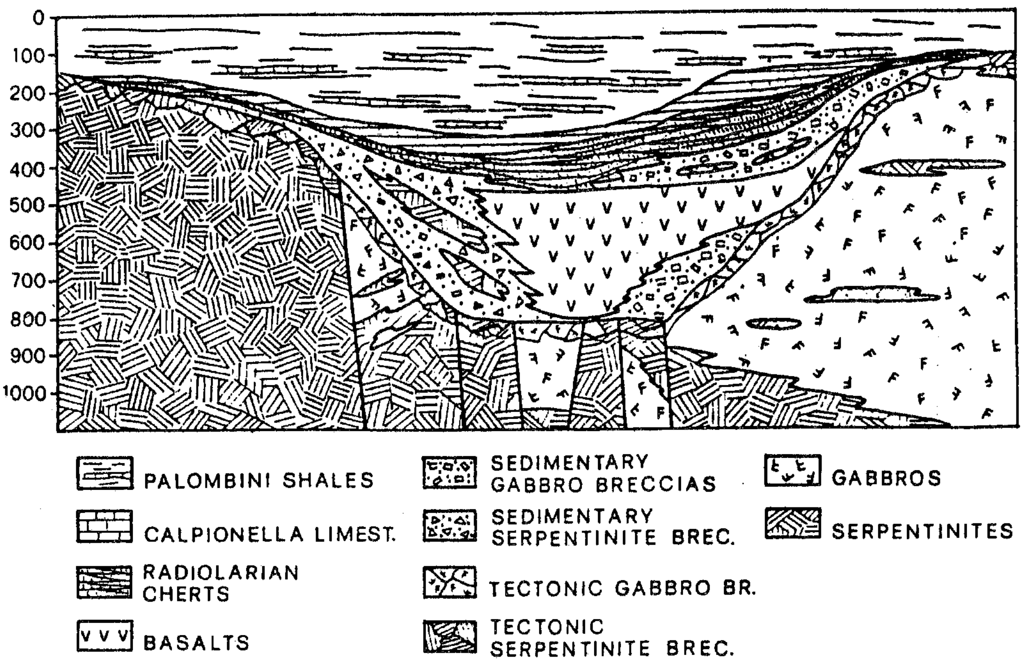


Fig. 5 - Stratigraphic scheme of the ophiolitic sequence of the Vara Supergroup (from Abbate et al., 1986).

rocks, both cumulitic and isotropic. The peridotites range in composition from a more or less depleted lherzolite to harzburgite. Cumulates range from dunite to plagioclasite.

The sheeted dyke complex is lacking, except for some small outcrops in Southern Tuscany.

A few swarms of basaltic dykes cut both serpentinites and gabbros. Serpentinites are cut also by gabbroic dykes often rodingitized. Locally gabbros are intruded by fe-gabbro, diorite and plagiogranite.

Magmatic relationships show that cumulates were emplaced in the lherzolites. The unconformable stratigraphic position of the sedimentary-volcanic cover on a basement both gabbroic and serpentinitic shows that some tectonic relationships between them occurred in the Jurassic (e.g., in the Levanto-Bonassola area, Eastern Liguria).

The volcano-sedimentary cover

The serpentinitic and gabbroic basement is covered by ophiolitic breccias, sometimes interbedded with pelagic sediments and by basalt flows followed by a silico-radiolaritic, carbonatic and shaly- carbonatic pelagic sequence.

The top of the basement is extensively fractured. The serpentinites expecially show several swarms of fractures filled by calcite and by sediments composed of serpentinitic clasts and micrites. Sediment penetration and spatic calcite growth alternate many times. The hydrothermalism that produced calcite and other minerals represents the last phase of the first oceanic metamorphic cycle (Cortesogno et al, 1987; see Fig. 7). This level is known as the 'Ophicalcites' p.p. (Levanto Breccia).

Sedimentary ophiolitic breccias blanket the just-fractured, serpentinized and hydrothermalized basement (Lower Ophiolitic Breccias: Framura, Case Boeno, Mt. Capra Breccias). The composition of the clasts and of the matrix generally reflects the nature of the underlying basement. Levels of argillitic, siliceous and cherty sediments are present within this basal breccia.

Discontinous levels of basalt overlie the breccias. They are missing in the reduced sequences, in which the sedimentary breccias are also absent or very thin, as are the overlying cherts (Fig. 5). The basalts are mainly pillow lavas , rarely massive (Levanto). The thickness of the basalts

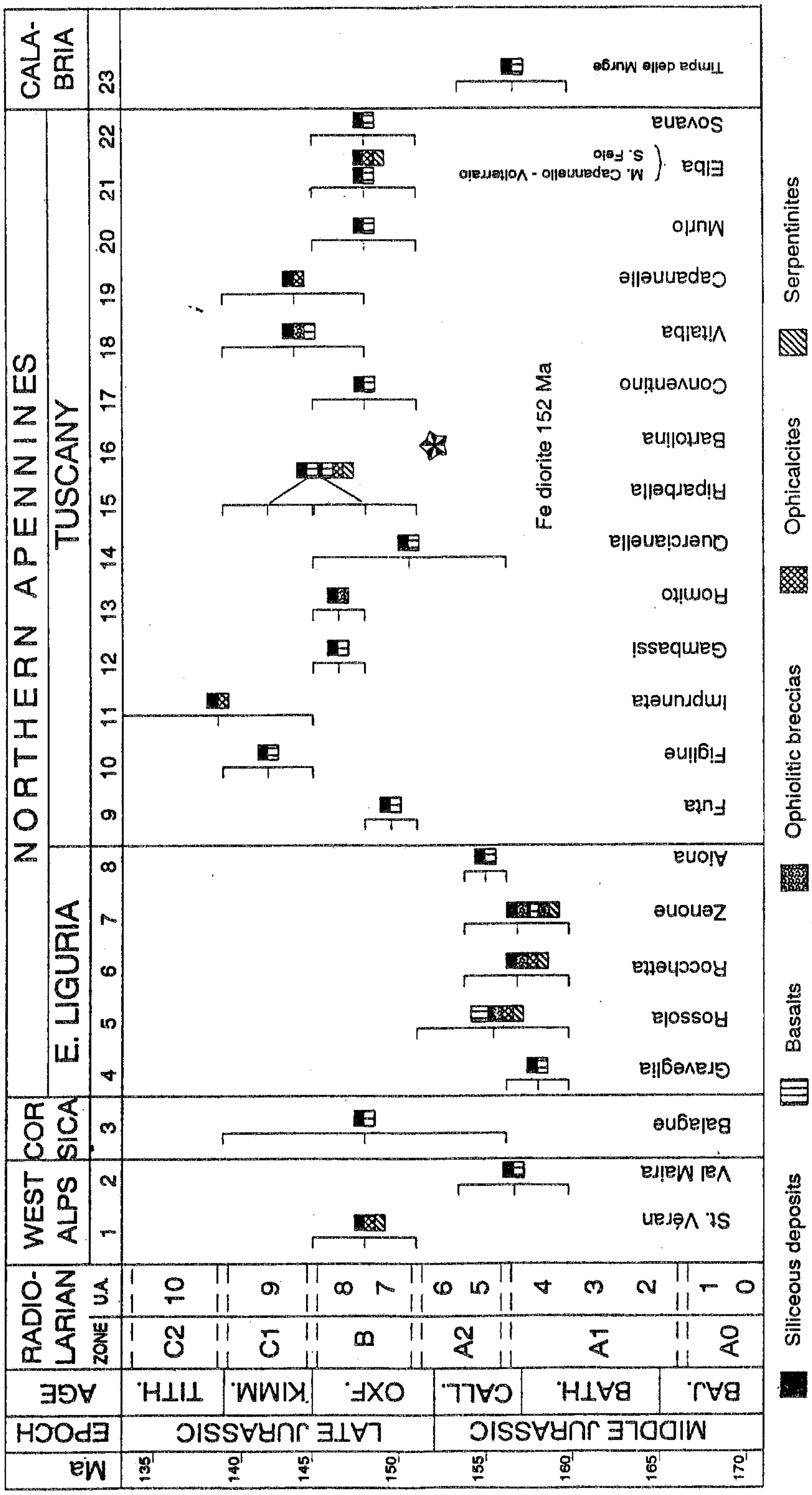


Fig. 6 - Ages of inception of the radiolarian chert deposition in different domains of the Tethyan Ocean (from Abbate et al., 1986).

ranges from nil to 200 meters. They display a MORB to transitional MORB tholeiite composition (Beccaluva et al., 1980; 1989).

Other ophiolitic sedimentary breccias (Upper Ophiolitic Breccias), interfingered with cherts, can follow the basalt flows (Fig. 5). The clasts and the matrix of these breccias derive from gabbros only (Mt. Zenone Breccia), or also from basalts (Mt. Rossola, Movea Breccias).

The main chert deposition (Mt. Alpe Cherts Fm.) follows the basalt flows and associated breccias. The thickness of this formation ranges from a few meters in the reduced sequences to 200 meters. Turbiditic structures show that part of the cherts represent intrabasinal redeposition.

Chronological data based on radiolarian biostratigraphy permit a division of the Northern Apennine ophiolites into two main groups (Fig. 6):

- the first group is formed by the Liguria-Parma outcrops, in which the age of the base of the Mt. Alpe Cherts is Middle Callovian / Lower Oxfordian (Conti and Marcucci, 1986; Baumgartner, 1987);
- the second group is represented by the younger Tuscan outcrops, Middle Oxfordian / Kimmeridjan in age (Conti and Marcucci, 1986).

The gap is rough, since no intermediate ages are documented. The age of the top of the Mt. Alpe Cherts goes up to Tithonian or, sometimes, to lower Berriasian.

The two ophiolitic suites belong to two adjoining oceanic sections with separate magmatic, sedimentary and structural evolutions (Abbate et al., 1989).

The sedimentary sequence at the top of the Mt. Alpe Cherts had locally a different evolution:

- in the Liguria-Parma zone the Mt. Alpe Cherts are directly overlain by Calpionella Limestone or by Palombini Shales. The base of Calpionella Limestone is Tithonic-Berriasian (Cobianchi and Villa, 1992);
- in Tuscany a transitional formation , the Nisportino Formation (Bortolotti et al., 1991), lies between Mt. Alpe Cherts and Calpionella Limestone.

The Nisportino Formation is made up of marls, argillites and siltstones interbedded with limestones, and is from several tens of meters up to 100 m thick. This formation is Lower Berriasian at the base, Berriasian-Valanginian at the top.

The Calpionella Limestone is a light grey micrite with thickness ranging from a few meters up to 200 meter. It is locally replaced by Palombini Shales. Biostratigraphic data (Cobianchi et al., 1993) evidence a chronological gap between the cherts and Palombini Shales, where Calpionella Limestone is missing. Cobianchi and Villa (1992) dated the base of the Calpionella Limestone of Liguria to Upper Tithonic-Berriasian; in Tuscany it is Upper Berriasian-Valanginian in age (Bortolotti and et al., 1991). This diachrony of the pelagic limestones has the same paleogeographic distribution as that of the cherts, described above.

The Palombini Shales are the most extensive sedimentary facies of the Western Tethys before the Late Cretaceous turbidites. They consist of argillites alternating with dark grey micritic limestones, and with silts and quartzarenites towards the top. Their age ranges from Valanginian-Hauterivian to early Campanian (Marroni and Perilli, 1990).

In several ligurid sequences (see before) the Palombini Shales are capped by turbidites. In the Vara Supergroup sequence, Palombini Shales are followed by west-coming siliciclastic turbidites (Val Lavagna Formation and Gottero Sandstones). The age of these turbidites ranges from early Campanian to early Paleocene (Passerini and Pirini, 1964; Marroni and Perilli, 1990).

The evolution of the Ligurid oceanic basin

For the opening of the Western Tethys ocean, important data can be obtained from structural and petrographic analyses on ophiolitic rocks. The basement was deformed and metamorphosed before, during and after the oceanic magmatism. The earlier metamorphic phase (from spinel lherzolites to plagioclase lherzolites) and the older deformations (tectonitic textures) affected the lherzolites and the harzburgites (e.g. Beccaluva et al.,1984). These processes probably occurred during their ascent throught the mantle beneath an oceanic ridge (Beccaluva et al.,1984),

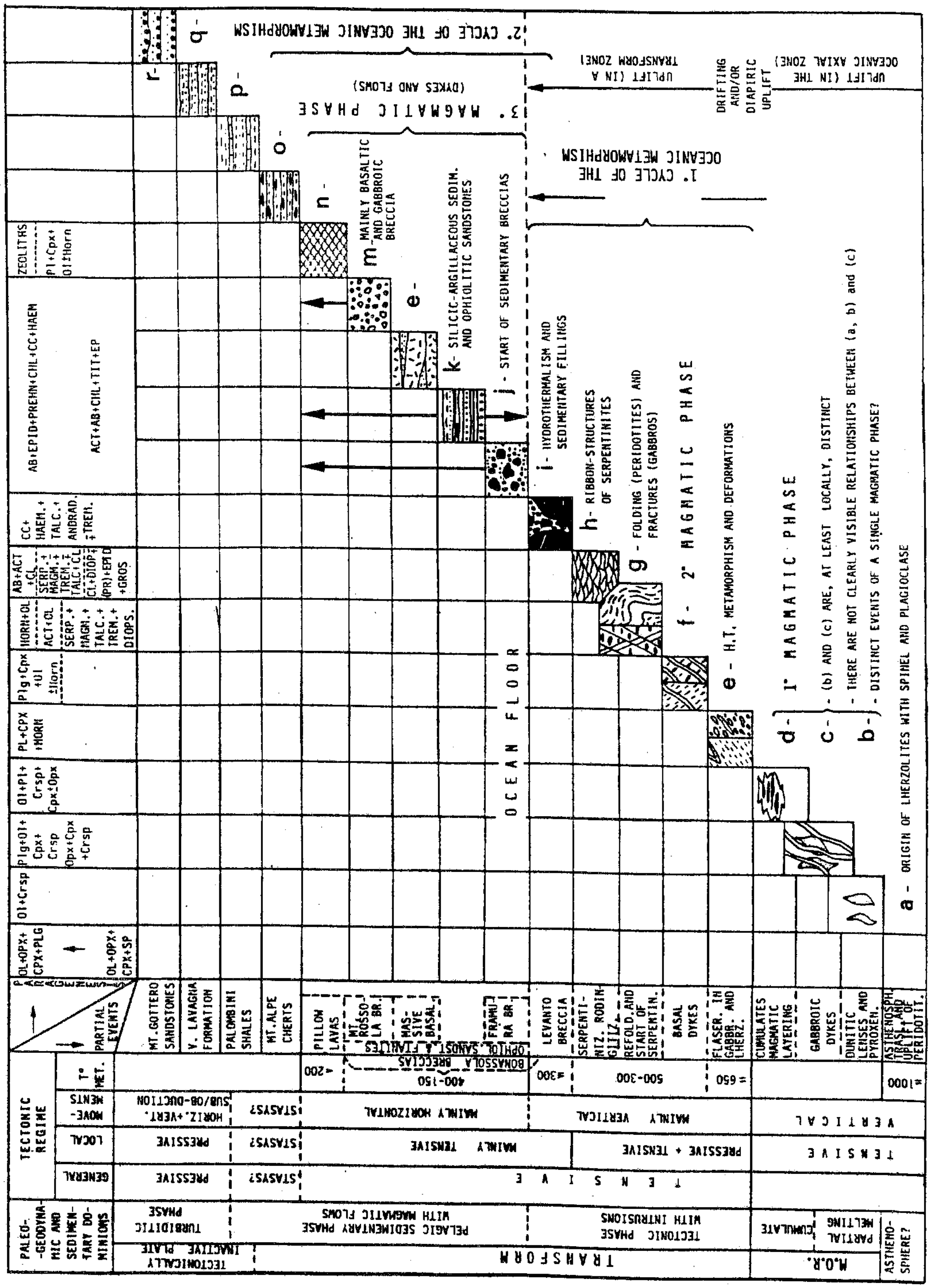


Fig. 7 - Main magmatic, metamorphic and tectonic events affecting the Vara Supergroup ophiolitic sequence (from Cortesogno et al., 1987).

where (steps a,b and c of Fig.7) the ultramafics were intruded by gabbro dykes and plutons (first magmatic event). Later, harzburgites, lherzolites and gabbros underwent a polyphase oceanic metamorphism (e.g. Gianelli and Principi, 1974; Cortesogno et al., 1987; Fig. 7, steps d-h).

The first step in this metamorphism reached the amphibolite facies condition, as recorded mainly by brown hornblende (ca. 700° C and 3-4 Kb, Cortesogno et al., 1987 with references therein). Several retrograde metamorphic steps followed to give hydrothermal facies conditions (under 300°C, near the ocean bottom; step h in Fig. 7). Ductile deformations (folds and flaser textures) are associated with the high-T assemblages. The low-T metamorphic alterations are associated mainly with brittle deformations.

The intermediate step of the first metamorphic event characterized by amphibols (brown-green hornblende or actinolite) and oligoclase occurred almost contemporaneously with basalt dyke emplacement (second magmatic event), often injected in the same fractures. This was followed by the serpentinization of peridotites and the rodingitic alteration of gabbroic dykes (step g in Fig.7).

Lastly (Fig.7, step h) the hydrothermal activity (mainly haematitic-carbonatic) occurred in connection with swarms of extensional fractures filled with carbonates, talc and serpentinitic clasts (ophicalcites).

At this time the gabbroic and serpentinitic basement reached the ocean bottom and was broken up and covered by sedimentary ophiolitic breccias, and then by pelagic sediments and basalt flows (third magmatic event).

The second oceanic metamorphic cycle was probably induced by basalt flows, because it affects only the breccias (clasts and matrix) and sediments underlying the basalts (e.g., Cortesogno et al., 1987). Until this phase the environment was tectonically very active, as demonstrated by metamorphic, magmatic and sedimentary evidence, and possibly near to a mid-ocean ridge or a transform zone.

The most widely accepted hypothesis considers the ophiolitic sequences of the Northern Apennines as having been formed in a zone of transform faulting (Galbiati et al., 1976; Gianelli and Principi, 1977; Abbate et al., 1980b; Cortesogno et al., 1987). A sketch of this model is shown in Fig. 8.

New studies on the axial zones of the present oceans (e.g., Mevel et al., 1991) seem to prove the validity of models based on "cold" and/or "amagmatic" uprising of mantle material also along ridge zones far from transform faults. A discussion on these models is presented in Abbate et al., 1993.

Subligurid Sequence

This palaeogeographic domain is represented by the composite sequences of the Canetolo Complex (Barbieri and Zanzucchi, 1963; Elter et al., 1964; Abbate and Sagri, 1970; Plesi, 1975).

The Canetolo sequences are sometimes very thin and consist of two parts:

- a basal portion formed by the typical 'Argille e Calcari' Formation (Paleocene-Eocene) and by an Eocene Helminthoid flysch (Groppo del Vescovo Limestones) interbedded;

- an upper portion consisting in siliciclastic turbidites of Oligocene to Lower Miocene age, often very rich in andesitic clasts (Petrignacola and Ponte Bratica Sandstones; Fig. 4).

According to Montanari and Rossi (1982), before the deposition of the Oligo-Miocene turbidites, the Paleocene-Eocene formations were deformed.

Tuscan and Umbria-Marches Sequences

There are at least three Tuscan Units:

a) the Tuscan Nappe;

b) the Apuane Metamorphic Complex;

c) the M. Cervarola Nappe.

The Tuscan Nappe overlies the others. However, the relative palaeogeographic position

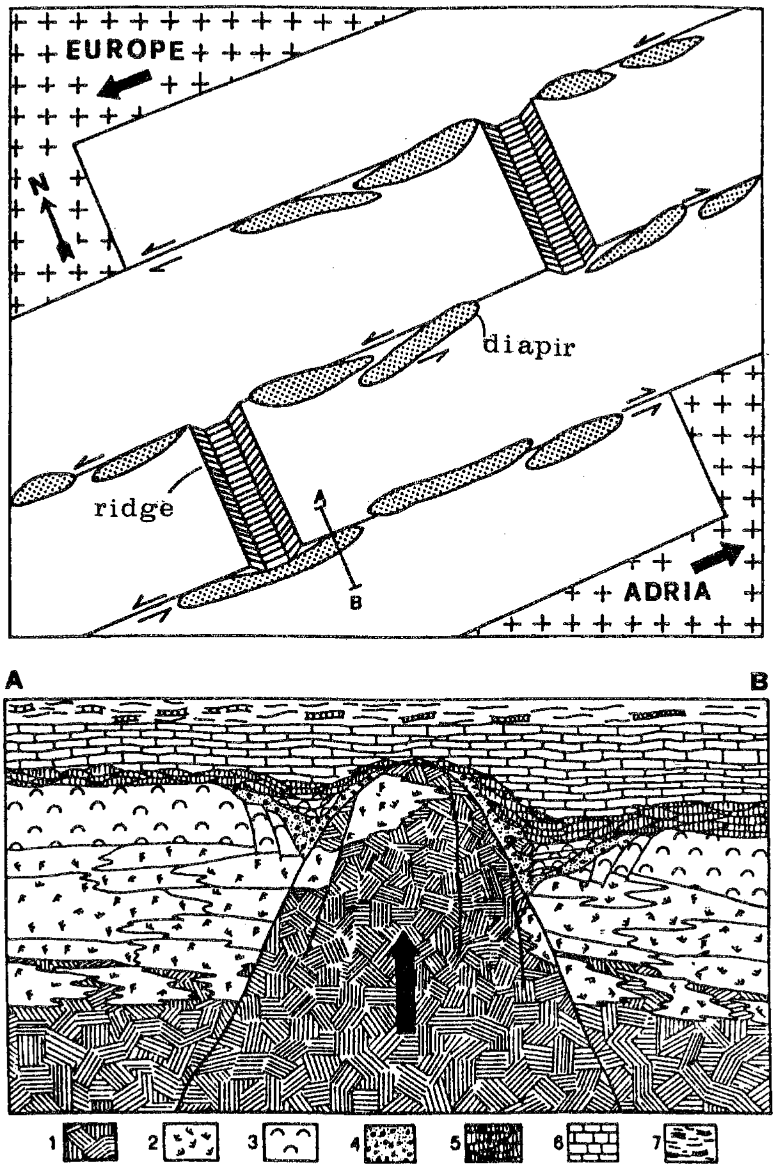


Fig. 8 - According to this model, the spreading of the Tethyan Ocean took place along short ridge segments joined by long transform faults along in which serpentinites were emplaced as diapirs. A-B: cross-section of a serpentinite diapir (from Abbate et al., 1984).
Legend: 1 - Serpentinites; 2 - Cumulates; 3 - Basalts; 4 - Ophiolitic Breccias; 5 - Radiolarites; 6 - Calpionella Limestone; 7 - Palombini Shales.

of these three nappes is still o matter of debate, especially that of the Tuscan Nappe relative to the Apuane Metamorphic Complex sequence (Abbate et al.,1970; Boccaletti et al.,1980; Carmignani and Giglia,1984; Abbate and Bruni,1987 with references therein) . The more external Umbria-Marches sequences can be considered as a single nappe subdivided by main thrust lines.

All these sequences developed on the Adria continental basement and, at least for the Mesozoic, the stratigraphic evolution was very similar. They lie on a strongly deformed and metamorphosed Hercynian basement in which, at least for the Tuscan Sequences, the main Hercynian phases (Breton, Sudetic and Asturian phases), and even some Caledonian events (Sardinian phase) are documented (Conti et al., 1991).

The sedimentary cover starts with continental-transitional sediments (Verrucano), Upper Ladinian-Carnic-Noric in age. They are followed by an evaporitic level (Noric), locally (Tuscan Metamorphic sequence) replaced by a Noric-Rhaetic dolomitized platform limestone (Grezzoni) (Coli and Fazzuoli,1992, and references therein).

In the Tuscan Nappe the post-evaporitic sedimentation is represented by partly dolomitic, anoxic basinal limestones (Rhaetavicula Limestones auct.; Fazzuoli et al., 1985 and references therein).

A widespread carbonate platform environment existed during the earliest Jurassic (Hettangian) over the whole Tuscan and Umbria- Marches domain ('Calcare Massiccio' and 'Marmi' Formations). In the Sinemurian the basin sank and a bathyal and pelagic sedimentation was established ('Rosso Ammonitico' Fm.). Two episodes of limestones with cherty nodules (Calcari Selciferi), separated by a Posidonomia Marls level, followed these first pelagic sediments.

A cherty deposition occurred from Bathonian-Callovian to Tithonian, as in the oceanic realm. Micritic limestones ('Maiolica'F.) replaced the cherts in the Berriasian.

From the Valanginian to the Oligocene in the western Tuscan Sequence (Tuscan Nappe and Apuane Metamorphic Complex), to Lower Miocene in the eastern Tuscan Sequence (Cervarola Nappe), and to Middle Miocene in the Umbria-Marches Sequence, a slaty-marly-carbonate pelagic deposition characterized the bathyal plane environment of the western Adria margin. From west to east the pelagic deposits are represented by the 'Scisti Policromi', 'Scaglia Toscana' and the group of the 'Scaglia Umbra'.

Thick, siliciclastic molasse-type graywackes replaced the pelagic sediments gradually in time from west to east (from Middle-Upper Oligocene to Middle Miocene). Three main turbiditic sequences correspond to the three major ensialic tectonic units. From west to east they are the 'Macigno', Mt. Cervarola, and 'Marnoso Arenacea' Formations (see Fig. 4).

DEEP STRUCTURAL FRAME OF THE NORTHERN APENNINES

In the literature there are abundant studies in which the structures of the Corsica-Tyrrhenian-Northern Apennine crustal area are interpreted on the basis of seismic and other geophysical data (Morelli et al., 1977; Lavecchia, 1988; Bartole et al.,1991, with references; Coli et al., 1991, with references; Minelli et al., 1991, with references).

Many authors (e.g., Locardi, 1988; Cassinis et al.,1991) consider the high velocity level located at depths between 20-25 km and 30 km below Elba island (Letz et al., 1977) as evidence of the presence of a European lithosphere dipping eastwards below the Adria lithosphere. This interpretation, reproposed recently by Minelli et al. (1991) in a synthesis based on a seismic refraction profile from Corsica to Ancona (profile C in Fig 11 of their work), in which a new ensialic west- dipping subduction plane is opposed eastwards by an 'Alpine' (fossil) east-dipping subduction, is nevertheless the widely accepted 'classic' geodynamic framework for the Northern Apennines (e.g. Boccaletti and Guazzone, 1974).

Treves (1984), and Principi and Treves (1984), from stratigraphic and palaegeographic arguments, exclude the presence in the Cretaceous- Eocene of an east-dipping subduction plane. The synthesis by Bartole et Al. (1991) for the Tyrrhenian zone based on single and multichannel seismic reflection profiles shows the presence between Corsica and Tuscany of an old Cenozoic-Tertiary compressive imbricate wedge that was later affected by extension, starting probably from the late Burdigalian. The structural-stratigraphic framework is perfectly consistent with that recorded from Elba and Western Tuscany.

The discovery (Bartole et al., 1991) of a widespread Calcschists with Ophiolites metamorphosed complex representing the uppermost unit of the Tyrrhenian east-vergent wedge is important. This unit is completely underwater with the exception of Gorgona Island, Giglio Island and, probably, the Mt. Argentario Peninsula. The areal extension is like that of the west-vergent Schistes Lustrés Unit of Corsica.

In the Tyrrhenian area the extensional Neogenic tectonics produced listric faults dipping

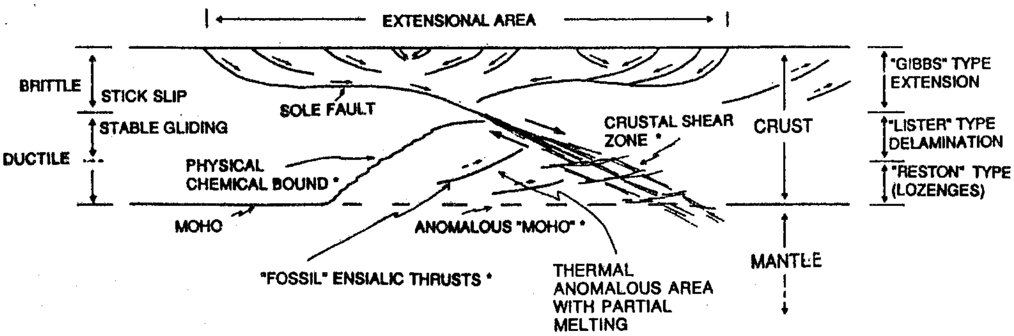


Fig. 9 - Proposed composite model of extensional tectonics (from Coli et al., 1991).

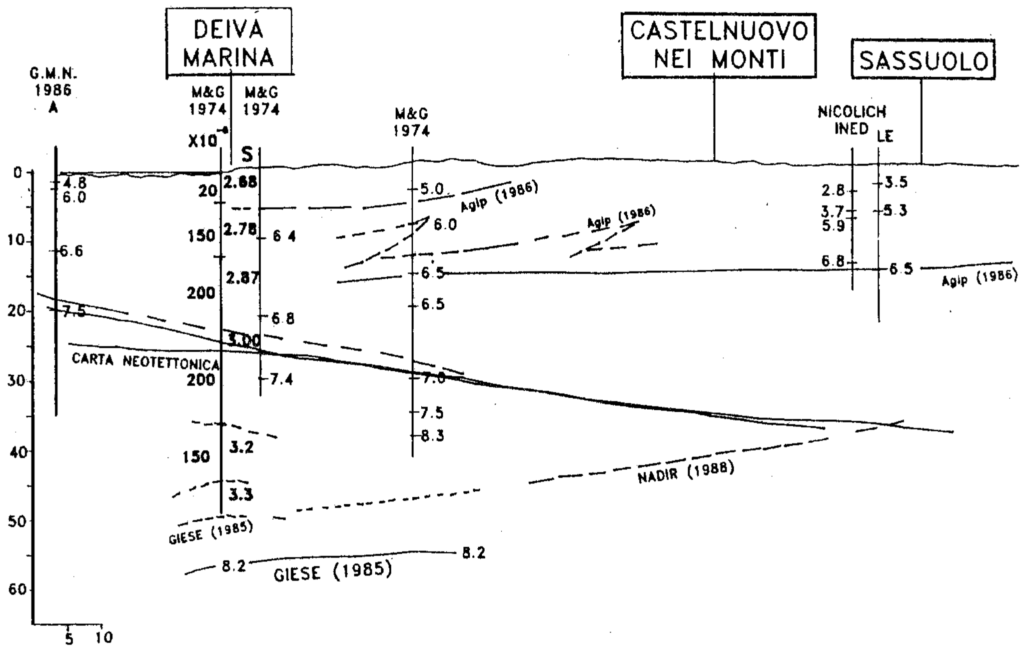


Fig. 10 - Synopsis of the available geophysical data along the studied profile between the A-LE shock points (from Coli et al., 1991).
Key: G.M.N. 1986 - Vp, after Ginzburg et al. (1986); M. & G. 1974 - magnetic susceptibility, density and Vp (from left to right) after Morelli et al., (1977); Nicolich ined. - Vp data; Agip 1986: after Cassano et al. (1986), continous line - top of magnetic basement; long dashes - top of magnetic metamorphic basement; short dashes - top of the Mesozoic carbonate sequence. Giese (1985), Nadir (1988), Carta Neotettonica (C.N.R., 1983): different Moho locations according to the respective authors (references in Coli et al., 1991).

westwards. In particular Bartole et al. (1991) interpret the Moho step below the Pianosa Island ridge, from 30 km in depth in the west to 20 km in the east, as an effect of a west-dipping lithospheric detachment.

For the Tyrrhenian extension there are many structural and kinematic models (Boccaletti and Guazzone, 1972; Boccaletti et al., 1982 with references therein; Lavecchia, 1988 with references therein). Recently Coli et al. (1991) discuss some structural and rheologic models (Fig. 9), based on the data from a new seismic reflection line, extending from the Deiva Marina offshore to Parma, and on those available in the literature (see synopsis in Fig. 10). According to them the tensional field west of Mt. Orsaro is the result of a composite lithospheric delamination.

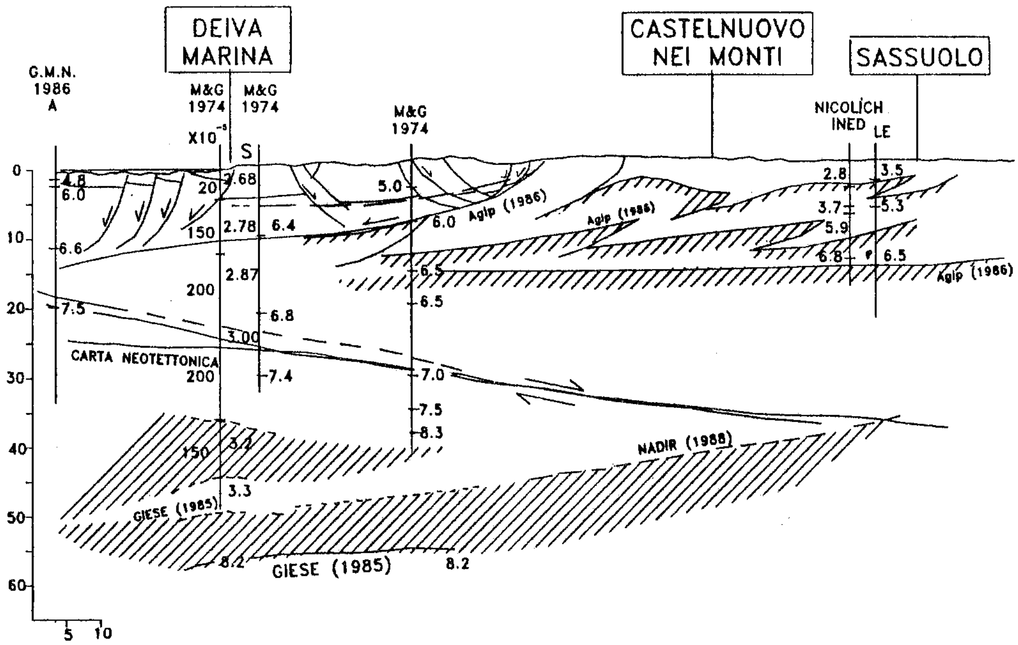


Fig. 11 - Interpretation of the studied profile in the light of the extension model (from Coli et al., 1991).

Their model assumes a pure-shear behaviour for the upper crust and a simple-shear model (Lister et al., 1986) for the lower crust, that changes to a lozenge geometric pattern (Reston, 1988) at the crust-mantle boundary.

The Coli et al. (1991) model of the Northern Apennines deep structure is shown in fig. 11. From the surface down, we see:

a) pure shear extensional faults on the Tyrrhenian side of the Northern Apennines overlying a west-dipping master fault (cropping out the western side of Mt. Orsaro), the subhorizontal listric sole of which is located at the brittle-ductile boundary;

b) an eastward-dipping crustal shear zone that marks the transition between the extensional structures of the upper crust and those of the lower crust;

c) a lozenge-shaped geometric pattern created by cross-cutting shear surfaces that transfer extension from the crust to the upper mantle;

d) the multiple reflectors below the east dipping shear zone that may be regarded as relics of old compressional structures.

History of the major sedimentary, palaeogeographic and kinematic events

The Northern Apennines tectonic evolution can be divided into three main stages: a rifting stage, an ocean spreading stage, and an orogenic stage. The latter can be divided into a Ligurid phase and an ensialic phase.

Rifting stage

Inception of the post-Hercynian sedimentary cycle in the continental basement of the future Northern Apennines started in the Middle-Upper Triassic with the transitional facies of the Verrucano Fm. and with basal evaporites. This is the sedimentary effect of a subsidence caused by a generalized distensive phase affecting the area between the Africa and Europe plates. Magmatic products related to this rifting stage are documented in Punta Bianca, La Spezia,

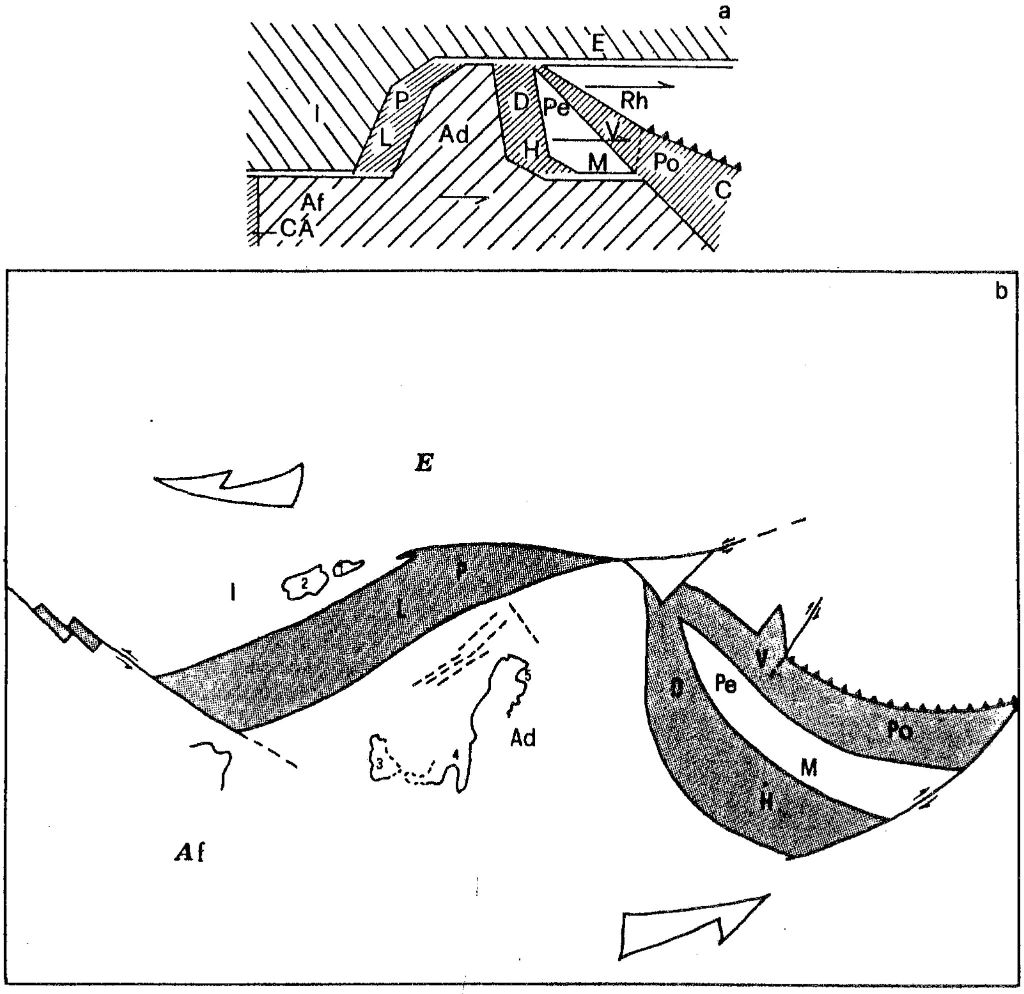


Fig. 12 - Continental block and oceanic basins in the mediterranean area at about 160 Ma (from Abbate et al., 1986), assuming that Adria moved bodily with Africa, and that the Pelagonian-Menderes plate drifted independently to the east.
a - Plate kinematics. E: Europe; I: Iberia; Af: Africa; Ad: Adria; CA: Central Atlantic; Pe: Pelagonian massif; M: Menderes; L and P: Liguria-Piedmont (oceanic domain) ; D and H: Dinarid-Hellenic; V: Vardar; C and Po: Caucasian and Pontic; Rh: Rhodope.
b - Paleogeographic reconstruction. White: continental plates. Grey: ophiolite basins. Letters as in a -. Dashed lines on Adria indicate isopic lines.

for the Northern Apennines (Ricci and Serri, 1975).

Both the geodynamic mechanism responsible for the rifting and the role played by the Adria and Pelagonian-Menderes microplates (Abbate et al., 1986, and references therein) are still debated.

The evolution of the sedimentary environments at the beginning of the Jurassic, from a shallow basinal (mainly anoxic) to carbonate platform is a record of a world-wide regressive event.

The widespread and sudden transition in the Sinemurian from a shallow sea environment (carbonate platform) to a pelagic basin ('Rosso Ammonitico' Fm.) represents the first apical stage of the extensional tectonics which will cause, at the Middle-Upper Jurassic boundary, the final continental breakup and the birth of the Western Tethys ocean.

Ocean spreading stage

The ocean spreading (Fig. 12) seems to be confined to the Upper Jurassic during the earlier

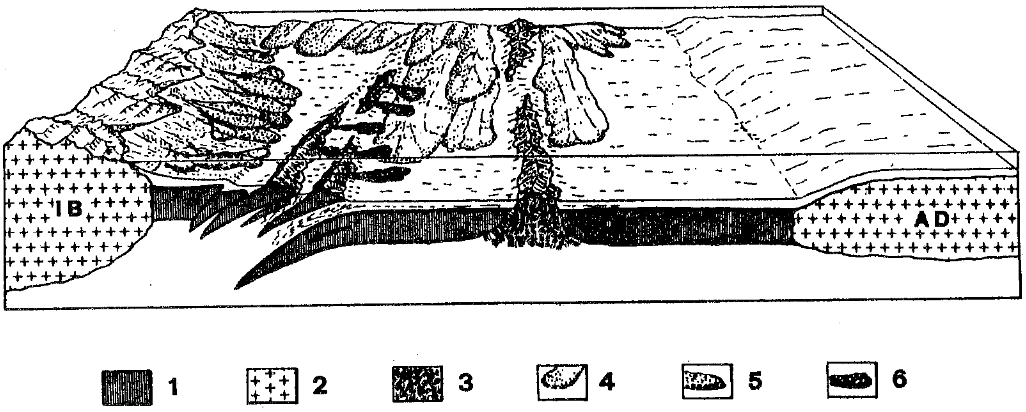


Fig. 13 - Oceanic crustal subduction and turbidite deposition during the Late Cretaceous (from Principi and Treves 1984b, redrawned).
1: oceanic crust; 2: continental crust; 3: serpentinite diapir; 4: calcareous turbidites coming from north (e.g. Helminthoid Flysch); 5: silicoclastic turbidites, coming from the west (e.g. Mt. Gottero Sandstone); 6: intrabasinal ophiolitic sandstones and breccias.

phase of the radiolarian sediment deposition that occurred both in oceanic and continental margin basins (Mt. Alpe Cherts in the Liguride domain; Diaspri and 'Calcari Diasprini' in the Tuscan continental domain).

The best recorded tectonic events occurred in the oceanic domain where the peridotitic-gabbroic basement is metamorphosed and deformed (at decreasing temperature and pressure) in a mid-ocean ridge and/or transform environment (see before and Fig. 7).

The tectonic activity produced a rough morphology, as documented by the presence of mono- and polygenic ophiolitic breccias, mixed with pelagites directly deposited on metamorphosed deep rocks of oceanic basement, by the discontinuity of the basalt blanket and by the strong differences in thickness and stratigraphy of the ophiolitic sedimentary cover (Fig. 5).

The formation of these ophiolitic sequences in a transform fault domain is proposed by Galbiati et al. (1976), Gianelli and Principi (1977), Abbate et al. (1980b), Cortesogno et al. (1987).

The lack of any lenses of "normal" oceanic sequence in the Northern Apennines Ophiolites represents the main objection to this model. Such a model, in fact, envisages the presence of wide zones of normal oceanic crust in the Jurassic ocean (Fig. 8). To explain this absence, Abbate et al. (1980b) hypothesized that the Cretaceous subduction mechanisms (see below) selected slices of transform fault "anomalous" crust, composed of serpentinitic ridges, while the "normal", thinner and more rigid crust was completely subducted. The general geodynamic framework could be that sketched in Fig. 13.

During the sedimentation of the Mt. Alpe Cherts, Calpionella Limestone and Palombini Shales (from the Tithonian to the Albian- Aptian), the tectonic activity was relatively minor. Nevertheless, the intra-basinal turbiditic character of many beds of cherts and Calpionella Limestones may indicate that the ophiolitic basin was still affected by a feeble tectonism. Therefore the presence in the oceanic domain of abundant argillitic and siltitic material from the Berriasian (Nisportino Formation) up to Albian and later (Palombini Shales) might be connected with tectonic (orogenesis?) activity in far continental areas. It is in fact very interesting to note that the Nisportino formation is coeval both with the earliest Alpine high pressure metamorphism (ca. 130 m.a.) and with the Dinarid orogenesis.

Orogenic stage

a) Ligurid phase

From the Upper Cretaceous to the Eocene the complete consumption of the Liguria Ocean occurs. The stages in the western Tethys closure are well documented by the ages of the turbiditic sedimentations of the Ligurid Units (see Fig. 4). In particular they are marked by the ages of the tops of the turbidites. As is seen in Fig. 4 the orogenic deformations, prograde from west to east.

Both the siliciclastic and carbonatic turbidites of the Upper Cretaceous-Paleocene are related to the early orogenic phase of the Northern Apennines (coeval with the Eoalpine orogeny in the Alps, e.g. Polino et al.,1990). In particular, many constraints, such as the western provenance of several siliciclastic turbidites of the Internal Ligurids, the palaeogeographic distribution of deposition depth with respect to CCD level, the pelagic environment for the coeval, more eastern sedimentation, show that the European Margin was during this period the active (uplifting) one, and that the probable position of the trench was near this margin (see Fig 11) . Also the migration, both in space (eastwards) and in time (from Upper Cretaceous to Eocene), of the deformations and post-deformation sediments (see Fig. 4) of the Ligurid Units supports this. On the other hand, the late occurrence of turbidites in the External Ligurid sequences (Eocene) and the long lasting persistence of pelagic facies on the Tuscan Adriatic margin (Scisti Policromi Fm.), seem to exclude an active role for this margin in the Upper Cretaceous (Principi and Treves, 1984a, and references therein).

This is all in contrast with previous kinematic models of the Corsica-North Apennines orogens (e.g., Boccaletti et al, 1971; Haccard et al., 1972; Elter and Pertusati, 1973; Boccaletti et al., 1980) that considered as Alps the Corsica Alpine chain, developed during the Eoalpine phase, and only as a post-Eocene chain the Northern Apennines orogen. The presence of Middle-Late Paleocene and Middle Eocene post- deformation sediments on top of the Ligurides of the Northern Apennines, that predate their deformations, and, on the other hand, the presence of Middle-Eocene autochthonous sediments beneath the Corsica Alpine thrusted nappes, that postdate their tectonic emplacement, are in contrast with those previous kinematic models (see Principi and Treves, 1984 with references therein).

Dieni and Massari (1982) support the validity of a classic 'Alpine' model on the basis of the presence of grains of glaucophane in an autochthonous Maastrichtian sediment in Eastern Sardinia. In my opinion these glaucophanitic grains, together with the siliciclastic ones, may be erosional records of the Caledonian suture, as known in the many European massifs from Iberia to Alps.

From the data in Fig. 4 we see the following:

- the ophiolitic sequences of Alpine Corsica (Glom, 1977) and of the Sestri Voltaggio Zone (e.g., Cortesogno and Haccard, 1984) previously not included in the Northern Apennines domain, were accreted and metamorphosed during the Upper Cretaceous (e.g. Cohen et al., 1981, and Cortesogno and Haccard, 1984, with references therein);

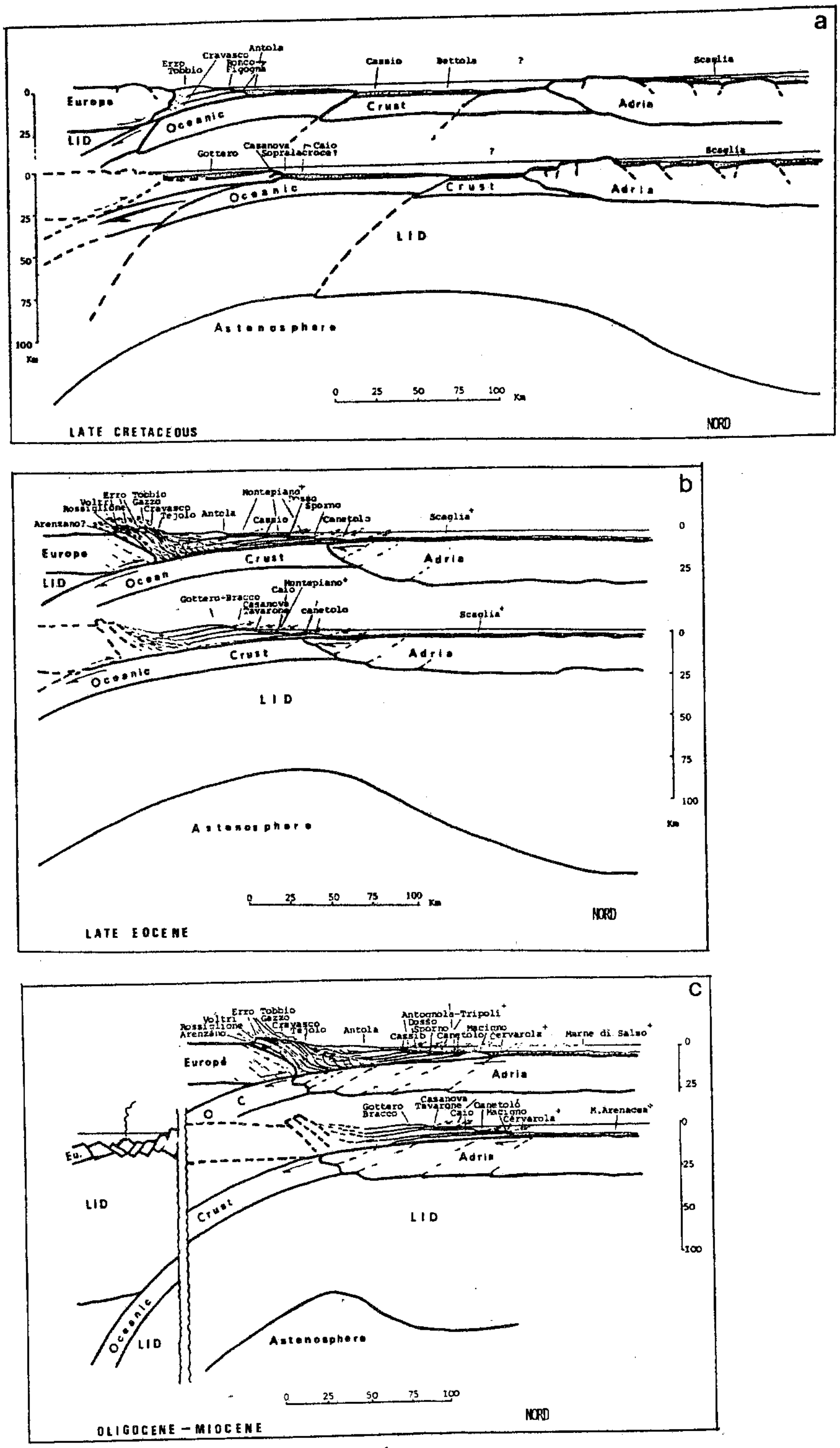
- the Internal Ligurids were accreted in the embrional Apenninic accretionary wedge during the Lower Paleocene (before deposition of the Giariette shales and Lanciaia Fm.).

The External Ligurids were accreted in the Lower-Middle Eocene before (and during) deposition of the Montepiano Marls.

The complete closure of the Appenninic basin occurred between the end of the External Ligurids sedimentation (Middle Eocene) and the beginning of the ensialic phase (Upper Eocene-Oligocene). During this event, in the internal zone of the accretionary wedge, both the metamorphic units of the Schistes Lustrés of "Alpine Corsica" and the Apennine-vergent Calcschists with Ophiolites Unit of the Northern Tyrrhenian Sea (CaO in Fig. 2b) were emplaced, respectively, on the European and Tuscan (Adria) margins. This fact is supported for the Schistes Lustrés by the age of the autochthonous sediments underlying the Alpine Corsica Units (Durand Delga, 1984; Nardi et al., 1987), and, for the Calcshists with Ophiolites, by the presence of a Paleocene-Eocene Unit (PEF in Fig. 2b) overlying the Vara Supergroup on Elba.

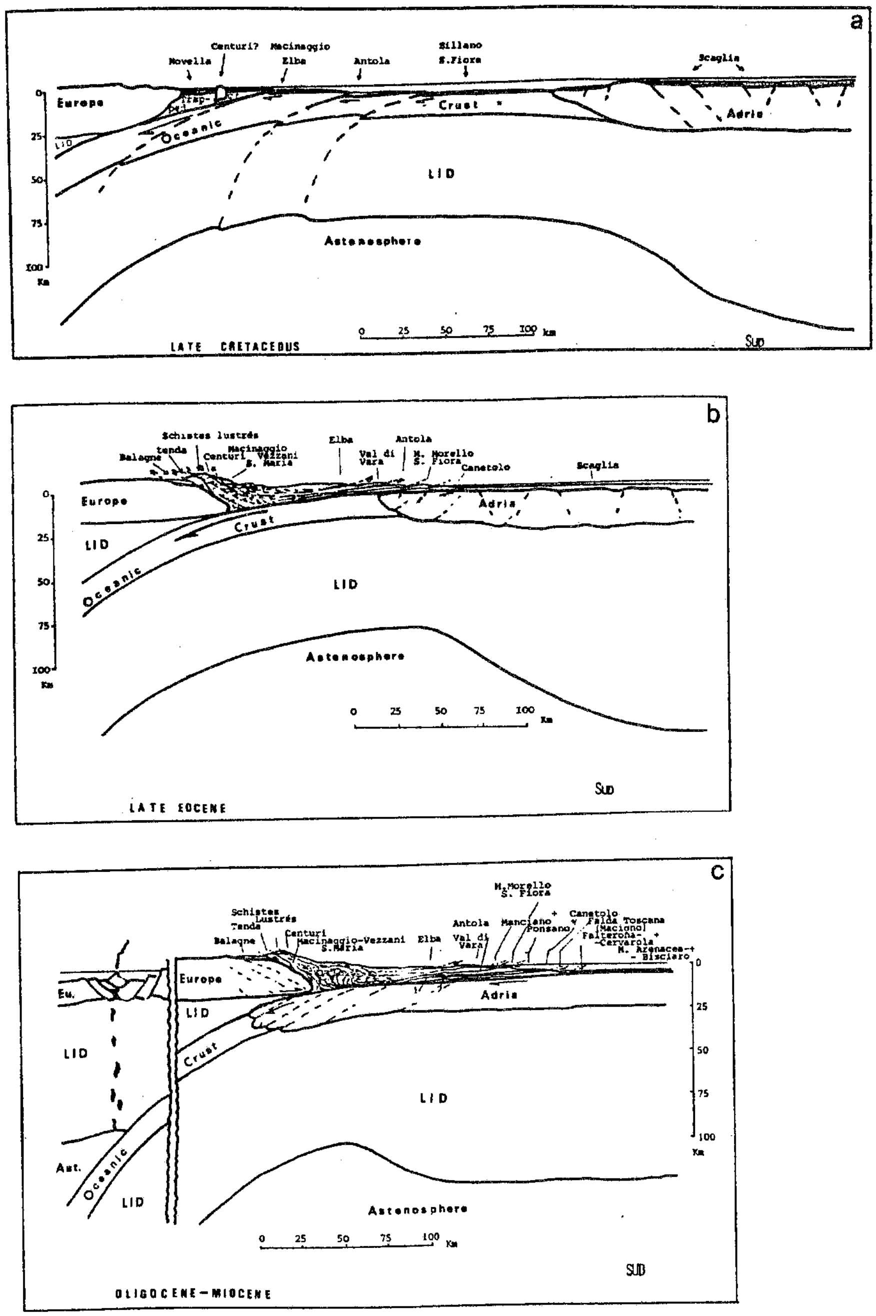
These metamorphic units were probably exhumed during the collision between the European and Adriatic plates (Fig. 14, steps b).

- The Subligurid Unit accreted between the Middle-Upper Eocene and the Lower-Middle Oligocene, and probably occupied an intermediate paleogeographic position with respect to



A

Fig. 14a - The Northern Apennine basin evolution during the Late Cretaceous, Late Eocene and Oligocene-Miocene boundary (from Principi and Treves, 1984a): Voltri Group-Piacenza Apennines (the higher section) and Ligurian Sea-Liguria Parma Apennines.



B

Fig. 14b - The Northern Apennine basin evolution during the Late Cretaceous, Late Eocene and Oligocene-Miocene boundary (from Principi and Treves, 1984a): Corsica - Tuscan Apennines.

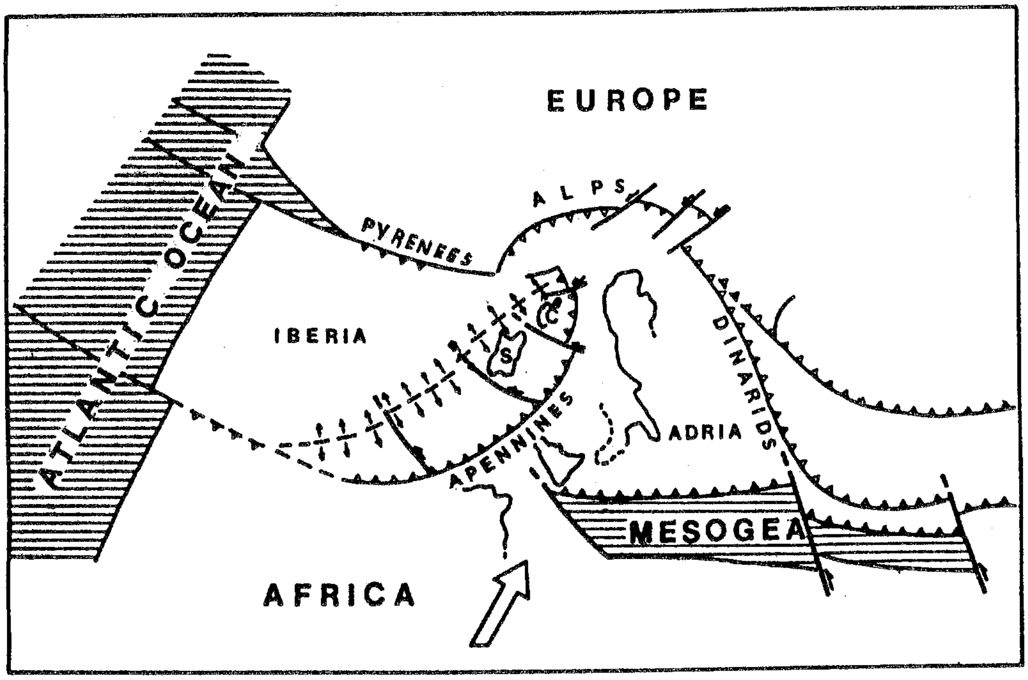


Fig. 15 - Palaeogeography of Adria and sourrounding plates during the Oligocene (from Abbate et al., 1986).

the oceanic and continental realms. Hence its accretion marks the beginning of the ensialic orogenic phase of the Northern Apennines.

b) Ensialic phase

This phase also is characterized by an eastwards progradation, in space and in time, of the turbiditic trough, and by the eastward vergence of accretionary wedge slices (see Fig. 4).

Important ensialic shear (e.g. Apuane Alps) took place during this phase in the Tuscan Metamorphic Unit palaeogeographic area (possibly as an abortive ensialic subduction). The metamorphic climax in the Apuanian Alps was at 27 Ma (Kligfield et al., 1986) which is also, approximately, the age of the end of sedimentation in the overlying Tuscan Nappe sequence.

The presence of (tectonic/karst or sedimentary) breccia levels (Versilia Breccias) between the Tuscan Nappe and Tuscan Metamorphic Unit is a matter of debate, especially regarding their age and genesis (Abbate and Bruni, 1987, with references therein; Carmignani and Kligfield, 1990).

Accretion of the more external continental units of the Northern Apennines continued during the Miocene and after. The compressive fronts are now buried under the Po Valley and Adriatic Sea.

From the Middle-Upper Miocene onwards an extensional front and magmatic activity began in the internal (Tyrrhenian) zone (Abbate et al, 1970; Boccaletti et al., 1985; Coli et al. 1991; Serri et al., 1991, with references therein). The extensional front migrated eastwards following the compressional front, at a distance of about one hundred km and with a time delay of approximately 10 Ma. Magmatism began in the Miocene, with granitic, granodioritic and quartz-monzonitic masses in the Tuscan Archipelago and in Western Tuscany, near Elba. In the Plio-Quaternary, it becomes active in the eastern belt with extrusive acid and/or intermediate products (Peccerillo et al. 1987; Conticelli and Peccerillo, 1990).

For the origin of the magmas there are contrasting opinions ranging from a metasomatized mantle beneath a thinned (passive rifting) Tyrrhenian lithosphere (Lavecchia and Stoppa, 1990, 1991) to a supra-subduction mantle in an ensialic subduction phase (e.g., Peccerillo et al., 1987; Conticelli and Peccerillo, 1990; Serri et al., 1991). Both consider mixing with mantle sources and crustal anatectic magmas.

If we consider the deep crustal structures shown in Fig. 11 as representative of the whole Apennine chain, the west-dipping deep Moho- line traced to the east in Fig. 10 may be the track of the ensialic compressional events, perhaps still active.

If we assume a supra-subduction mantle as the source of the Miocene-Quaternary Elba-Tuscany magmatism , this mantle must be that of the Adriatic Plate lithosphere, because the supra-subduction mantle of the Ligurid phase (according to the models of Fig. 14) remains under Corsica Massif, where it produced, behind this massif, in the Oligo- Miocene boundary, a calcalcaline magmatism (Fig. 14, c) and the inception of the opening of the Western Mediterranean Sea (Fig. 15). Hence, if this is true, it follows that during the ensialic phase a new subduction plane was produced eastwards inside the Adriatic Plate. The Apuane Alps shear zone could represent either an abortive inception of this ensialic subduction plane or one of the first ensialic accreted slices. Now this ensialic subduction plane emergence is buried in the Po plane and Adriatic deposits and is regionally correlatable with the Bradanic-Calabrian arc.

During the Late Eocene to Early Miocene the Ligurid accretionary wedge would have become a fossil structure whose last events could have been the formation of the Late Eocene west-vergent Corsica Alpine nappes and the east-vergent Calcshists with Ophiolites Unit emplacement accompanied by a new arrangement of the other Ligurid Units.

The recent extensional phases, with the complex rheology of the Adriatic lithosphere as shown in Fig. 11, and the magmatic intrusions, have strongly disturbed the primitive Ligurid accretionary pile in Tuscany and in the Tyrrhenian Sea.

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