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ORIGIN OF THE TYRRHENIAN SEA AND CALABRIAN ARC

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RIASSUNTO

Il Tirreno è un bacino di tipo oceanico che separa, tra la Corsica e la Calabria, frammenti della catena eo-Alpina, paleogenica ed Europa-vergente. La frammentazione della catena Alpina e l'apertura della piana abissale tirrenica sono legate ad un rift di età miocenica medio-superiore che ha interessato la fascia di deformazione Alpina ad est della Corsica-Sardegna, accompagnato da una rotazione antioraria dell'Appennino e da una contemporanea trascorrenza orientale delle Maghrebidi tunisino-siciliane.

La Fig. 3 descrive l'evoluzione tettonica ipotizzata delle catene eo-Alpina ed Appenninica e del Tirreno attraverso una serie di sezioni palinspastiche semplificate tra la Sardegna e la Puglia dal Trias all'attuale.

ABSTRACT

The Tyrrhenian Sea is a Neogene-Quaternary extensional area separating, from Corsica to Southern Italy, fragments of the Paleogene Europe-verging eo-Alpine chain.

The fragmentation of the Alpine chain and the opening of the Tyrrhenian Abyssal Plain are related to a Late Miocene rifting in the Alpine belt east of Corsica-Sardinia, accompanied by anticlockwise rotation of the Apennines and simultaneous eastward lateral displacement of the Tunisian-Sicilian Maghrebides.

Fig. 3 describes the hypothesized tectonic evolution of the eo-Alpine and Apennine chains and of the Tyrrhenian Sea, by simplified palinspastic cross sections between Sardinia and Apulia from Triassic to the present.

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The Tyrrhenian Sea is the deepest and the poorest in sediments of all the young basins of the Western Mediterranean Sea. Physiographically it consists of a triangular-shaped bathyal plain bordered by a more or less steep circum-tyrrhenian slope that includes several narrow basins which are elongate roughly parallel to the surrounding land (Corsica-Sardinia, Sicily and the Apennines). Some seamounts which are partly volcanoes, partly made up of crystalline rocks, rise up from the bathyal plain and from the circum-tyrrhenian slope. A calc-alkaline island arc emerges in the southeastern Tyrrhenian Sea, between the Calabrian-Sicilian coast and the bathyal plain.

Recently some researchers (BOCCALETTI & GUAZZONE, 1972; BARBERI *et al.*, 1973; BOCCALETTI *et al.*, 1976) have interpreted the Tyrrhenian Sea as a marginal basin: subduction of the Ionian plate beneath the Calabrian Arc might have been responsible for the south-eastward arc-trench system migration, with the consequent opening of the Tyrrhenian Sea. The location of the metamorphic Calabrian Arc bordered along the inner side by the calc-alkaline Aeolian Arc, the occurrence of mafic volcanism on the bathyal plain, the high heat flow, the thin crust and the "hot" mantle underneath the bathyal plain, the deep focus earthquakes in the southeastern area, were all accepted as confirmation of this hypothesis.

In my opinion another model may be proposed, which better fits the available geological and geophysical information: the

Tyrrhenian Sea originated by rifting of a deformed belt marking the Alps-Apennine collision suture zone, accompanied by anticlockwise rotation of the Apennines and eastward shifting of Sicily.

I shall summarize in broad outlines the geological features in Corsica-Sardinia, Sicily and the Apennines (fig. 1), in order to find a correlation between the geological history of the Tyrrhenian Sea and the simultaneous evolution of the surrounding lands.

Corsica and Sardinia constitute part of a slightly deformed European continental element which during the Paleogene played the rôle of Alpine nappe foreland. Alpine nappes are today exhibited only in the northeastern area (Corsica), but originally they must have been connected in the north with the Western Alps and in the south with the Calabria Alpine belt (HACCARD *et al.*, 1972). Lower Miocene clastics indicate the upper chronological boundary of the orogenic transport with vergence toward Europe in this sector of the Alpine chain. In Western Sardinia an ancient volcanic are is developed, represented by calc-alkaline lava flows and ignimbrites, ranging in age from Late Oligocene to Middle Miocene. Plio-Pleistocene continental basalts witness younger tensional environments. Extensive Tertiary anticlockwise rotation of the Corsica-Sardinia "microplate" is commonly admitted by many scientists (DE JONG *et al.*, 1969; ZIJDERWELD *et al.*, 1970; DE JONG *et al.*, 1973; ALVAREZ, 1972), although it is excluded by others (LAUBSCHER, 1975; COULON *et al.*, 1974).

The Apennines form a mountain belt with a NW-SE direction, consisting of Neogene nappes overthrust upon the Apulia foreland. The greatest part of the tectonic

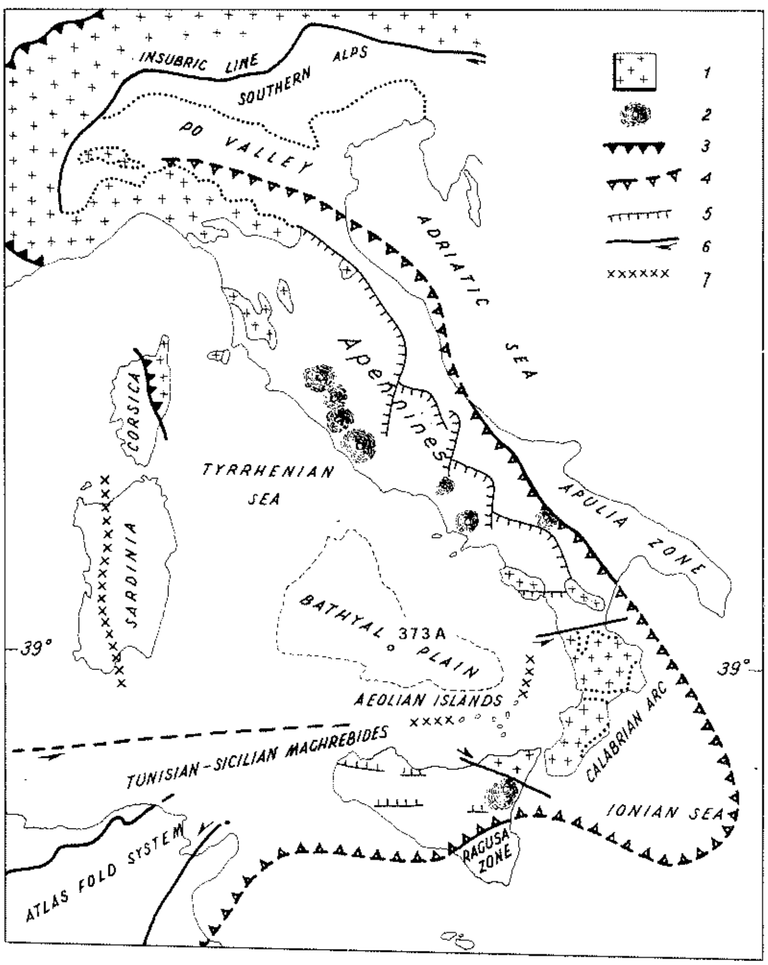

Fig. 1 - Tectonic sketch of the land masses surrounding the Tyrrhenian Sea.

1. Paleogene and Neogene Europe-verging Alpine chain; 2. main Upper Tertiary-Quaternary volcanoes; 3. European front of the Alpine chain; 4. Neogene compression front along the foreland of the Apennines and of the Maghrebides (in the Ionian Sea: front of the Calabrian "ridge"); 5. front of the carbonate units in the Apennines and in Sicily; 6. transcurrent faults; 7. volcanic arcs of Sardinia and Aeolian Islands.

units building up the chain consists of sedimentary décollement nappes, but palinspastic restorations allow one to estimate crustal shortening of some hundred kilometres (SCANDONE *et al.*, 1974). In the north the Apennines plunge beneath the Ligurian nappes (ELTER & PERTUSATI, 1973), which are considered in this paper elements of the Alpine chain. At the northern apex of the Tyrrhenian Sea, between Tuscany and Corsica, the Alps-Apennine boundary is marked by Miocene-Quaternary magmatism. In the south the Apennines plunge beneath the Calabrian crystalline nappes, which belong to a large fragment of the Alpine chain overthrust *in toto* upon the Apennines. Ligurian, Pennine and Austroalpine elements make up this intriguing sector of the eo-Alpine chain which in Paleogene time verged toward Europe. The overthrust of the Calabria-Peloritani belt upon the highest Apennine units dates back to the Burdigalian. The picture is complicated by the presence of "Insubric" Africa-verging Paleogene elements, tectonically placed between the Europe-verging Paleogene Alpine nappes and the Africa-verging Neogene Apennine-Maghrebian nappes.

The Tunisian-Sicilian Maghrebides form a sector of the Neogene Africa-verging chain, having a W-E direction. The general structure, as well as the tectonic units of the Maghrebides, can be compared to those of the Apennines, and both chains may be considered deformed portions of the Africa plate margin (SCANDONE *et al.*, 1974), having different direction (W-E the former, originally N-S the latter). In Eastern Sicily the Maghrebides plunge beneath the Calabria-Peloritani Arc, so that they should connect with the Apennines below the crystalline nappes.

From general considerations on the geological setting of the Tyrrhenian area and surrounding land masses, we can fix the following points, that no model can leave out:

— at the northern apex of the Tyrrhenian Sea two chains with opposite vergence face each other: the Alpine chain, Paleogene in age and verging toward the European foreland, and the Apennine chain, Neogene in age and verging toward Apulia (that is, toward the Africa foreland). The former partially overthrusts the latter;

— along the Corsica-Sardinia border the Neogene compression did not affect strongly the European foreland. This means that at that time Europe did not take part in the subduction along this segment;

— north of Corsica the Alpine chain also consists of Neogene nappes of European origin. This means that here Europe took part in the subduction during that time;

— the Apennines and the Maghrebides wholly consist of nappes originated from the African continental margin. This means that during Neogene the Apulia and the Ragusa margins took part in the subduction;

— in Calabria the Paleogene Europe-verging Alpine chain was already partially overriding the highest Apennine elements during Burdigalian. In fact the Alpine nappe building overthrust Aquitanian-Burdigalian Apenninic terranes, and a Langhian wildflysch unconformably overlies both Alpine and Apennine nappes;

— the Tyrrhenian Sea is a recent extensional feature, and does not represent a relic of ancient oceanic crust. Its oceanization occurred between Middle and Late Miocene, as suggested by the Messinian evaporites and by the Pliocene-Quaternary sedimentary column overlying the bathyal plain, as well as by the radiometric ages around 6 MY of the abyssal tholeiites drilled at Site 373 A (BARBERI *et al.*, 1977);

— the Alpine chain from the Western Alps to Corsica, to Southern Italy appears split up, and the single fragments are separated by recently oceanized areas (ALVAREZ *et al.*, 1974).

All these facts make the explanation of the Calabrian Arc following classical arc-trench system migration models difficult to accept. There is no time relation between the assumed arc-trench migration (which happened before Messinian) and the present calc-alkaline arc of the Aeolian Islands. Still more difficult to accept is the hypothesis of a Calabria-Peloritani microplate drift (ALVAREZ *et al.*, 1974; ALVAREZ, 1976) starting from Corsica-Sardinia and reaching the present position in recent times, because the Calabria Alpine nappes ovrthrust Apennine elements already during the Burdigalian.

Let us try, therefore, to reconstruct the main lines of the Neogene geological history of the whole area, starting with a palinspastic map of the region which eliminates the effects of the Neogene compression in the mountain belts and of the Miocene-Quaternary extension in the Tyrrhenian area. First we must fix the position of the Corsica-Sardinia element and of stable Europe. A possible small rotation of the former is a second-order problem, which may be left out in a first approach. The second operation is to trace the Paleogene chain, in order to locate the position of the compression fronts at that time. Fig. 2 represents an attempt at completing in the south a recent restoration by LAUBSCHER (1975), with some small modifications.

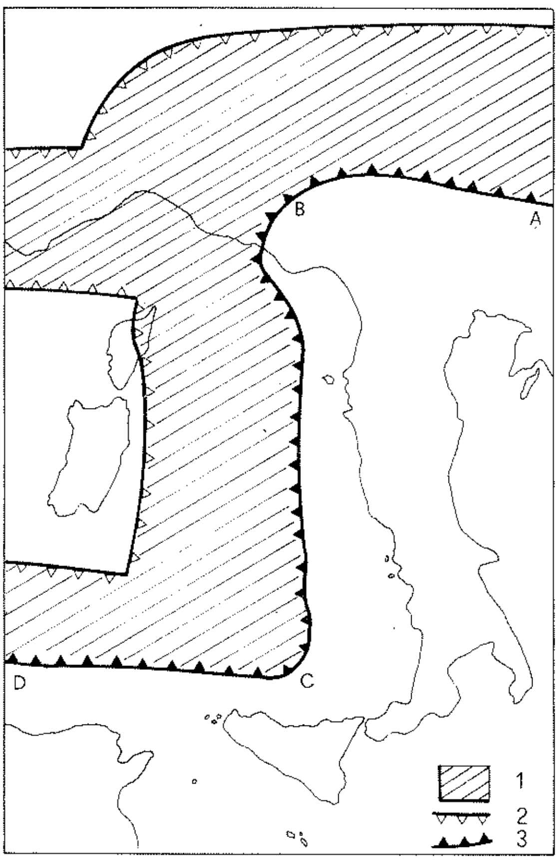

Fig. 2 - Palinspastic restoration of the Corsica-Sardinia and Apulia margins at the end of the Paleogene.

1. nucleous of Paleogene deformation between the European and the African forelands; 2. front of the Europe-verging Paleogene nappes; 3. front of the Africa-verging Paleogene nappes.

In agreement with the geological data and the available information of the Atlantic history at that time (PITTMAN & TALWANI, 1972), the Neogene compression pattern in the central Mediterranean area may be roughly represented by two N-S and E-W stress axes, sometimes with the former acting, sometimes the latter. In fig. 2 three E-W, N-S and E-W segments, which played different kinematic rôles, have been indicated:

— along the E-W belt AB at the northern margin of Apulia the amount of the N-S compression was absorbed mainly by subduction of European lithosphere, with the consequent building up of the Helvetic nappes and the development of the Jura folds; subordinately it was absorbed by subduction of African lithosphere, with the consequent generation of the south-Alpine thrusts (CASTELLARIN, 1978). The effects of the E-W compression could be recognizable by lateral translations along the dextral transcurrent Insubric Fault (LAUBSCHER, 1970);

— along the E-W belt CD at the northern margin of Sahara, the amount of the N-S compression was absorbed mainly by subduction of African lithosphere, with the consequent building up of the Tunisian-Sicilian Maghrebian nappes and the development of the Atlas fold system. In the west, Europe took part in the subduction as well, and absorbed a considerable amount of compression. This fact is witnessed by the simultaneous development during Neogene of the Africa-verging Maghrebian nappes and of the Europe-verging Pre-Betic nappes, today facing each other on the opposite sites of the Alboran Sea;

— along the N-S belt BC at the western margin of Apulia the whole amount of the E-W compression was absorbed in the north by subduction of European lithosphere, with consequent deformation in the Dauphinois domains; by subduction of the African lithosphere south of the Po Plain, with consequent building up of the Apennines.

According to this picture, the andesitic arc of Sardinia would lie parallel to the N-S front of the E-W compression, while the andesitic belt of Northern Africa and Southern Spain would lie roughly parallel to the E-W front of the N-S compression.

Obviously in this interpretation a lot of continental lithosphere must have been involved in the subduction (LAUBSCHER, 1970, 1974; SCANDONE *et al.*, 1974; SCANDONE, 1975), this in manifest contrast with the classical opinion expressed by more popular models which admit subduction of oceanic lithosphere only.

In fig. 3 I shall try to describe my conception of the geologic evolution of the Alpine and Apennine chains and of the Tyrrhenian Sea, by a succession of qualitative palinspastic cross sections at a latitude of about 39°, in a very semplified two-dimensional model.

Fig. 3a shows the Sardinia-Apulia sector of the undivided continental lithosphere during Late Triassic, before the opening of the Atlantic and Tethys oceans. Fig. 3b represents the European and the African continental margins, as well as the Tethys ocean, during Jurassic. Probably during Middle Cretaceous the Atlantic-type African continental margin changed into a Pacific-type one, and Tethys began to be destroyed. It is interesting to point out, following LAUBSCHER (1970), that the African continental margin took part in the subduction as well, with the consequent generation of the Austroalpine nappes. Another important fact is that within the described area the whole oceanic lithosphere was consumed in Cretaceous-Eocene times, so that any younger subduction consisted of continental lithosphere sinking into the mantle, with the one exception, perhaps (LAUBSCHER & BERNOULLI, 1977; HSU, 1977; HSU & BERNOULLI, 1977), of the Ionian area. Fig. 3c (Late Eocene) shows the Cretaceous-Eocene Pennine, Ligurian and Austroalpine nappes overthrust upon the European foreland, while the African continental lithosphere is subducting beneath the European foreland. The Alpine nappes are *flakes* verging toward the same direction as the corresponding subducting lithosphere. Between Late Eocene and Late Oligocene the vergence changed, but the nappes still derived from the African margin. They are *wedges*, therefore, verging towards a direction opposite to the dip of the corresponding lithosphere (fig. 3d). Within the European foreland a volcanic calc-alkaline belt developed during Late Oligocene, related to the active Benioff zone. During Early and Middle Miocene the eo-Alpine Cretaceous-Paleogene Europe-verging building and the Paleogene Africa-verging "Insubric" nappes overthrust *in toto* that part of the African continental margin which later generated the Apennines. We can reconstruct the following belts from W to the E, as they were about 19 MY ago (fig. 3d):

— Corsica-Sardinia element (which at this time is part of the Iberian plate), foreland of the Alpine chain in this sector, with an active volcanic arc;

— Paleogene Alpine chain, joined to the European foreland, back-thrust upon the Paleogene Africa-verging "Insubric" nappes;

— Paleogene Africa-verging "Insubric" nappes overthrust upon the highest Apennine elements;

— Apenninic domains, not yet reached by the compression front;

— Apulia platform, future foreland of the Apennines.

Between Serravallian and Tortonian, at a time which cannot be precisely stated, the rifting of the Tyrrhenian Sea began. Two models may be postulated: vertical oceanization or spreading. The present position of the Calabria Alpine nappes, very far from the European foreland, may be better explained by the spreading model (fig. 3e), assuming a N-S rifting within the BC belt of fig. 2, followed by anticlockwise rotation of the Apennines around a pole located farther north of Elba Island, and by simultaneous eastward drift of the Tunisian-Sicilian Maghrebides along a sinistral transcurrent fault passing between Sardinia and Sicily. In this way the Corsica-Sardinia eastern border developed as a passive-type margin, and the volcanic arc became inactive; along the outer border of the Apennines and of the Maghrebides, on the contrary, subduction of African lithosphere began again, and a new volcanic arc developed in recent time (fig. 3f). The Aeolian Arc, as well as the Calabrian Arc, lies in correspondence to the maximal distortion of the system, where the loci of the deep earthquake foci do not suggest a planar surface, but a funnel-shaped one, dipping NW (CAPUTO *et al.*, 1972).

The kinematic mechanism I propose in order to explain the rifting of the Tyrrhenian area, the rotation of the Apennines, the lateral shifting of the Maghrebides and the splitting of the chains, requires two main lines of lateral displacement: a dextral one, passing north of the Apennines, and a sinistral one, passing north of the Maghrebides and south of Sardinia. The first line may be identified with the Insubric Fault; the second one appears, at present, as a *"deus ex machina"*, which moreover induces first-order kinematic implications in the west, in the direction of Gibraltar. I am aware of these problems, and I realize that only a very scrupolous kinematic analysis in the Maghrebides and the Betic chains will check the geological consistency of the proposed model.

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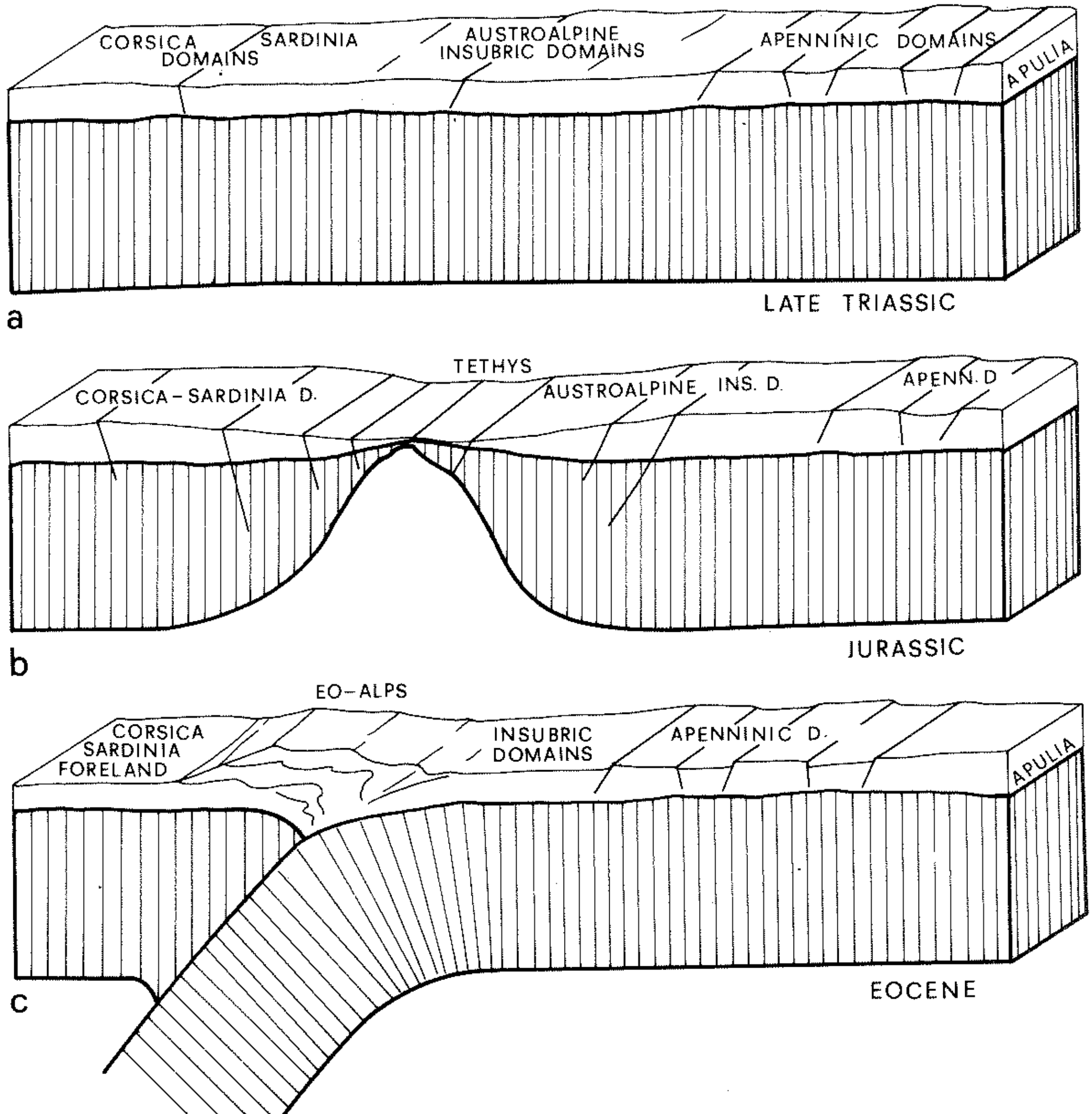
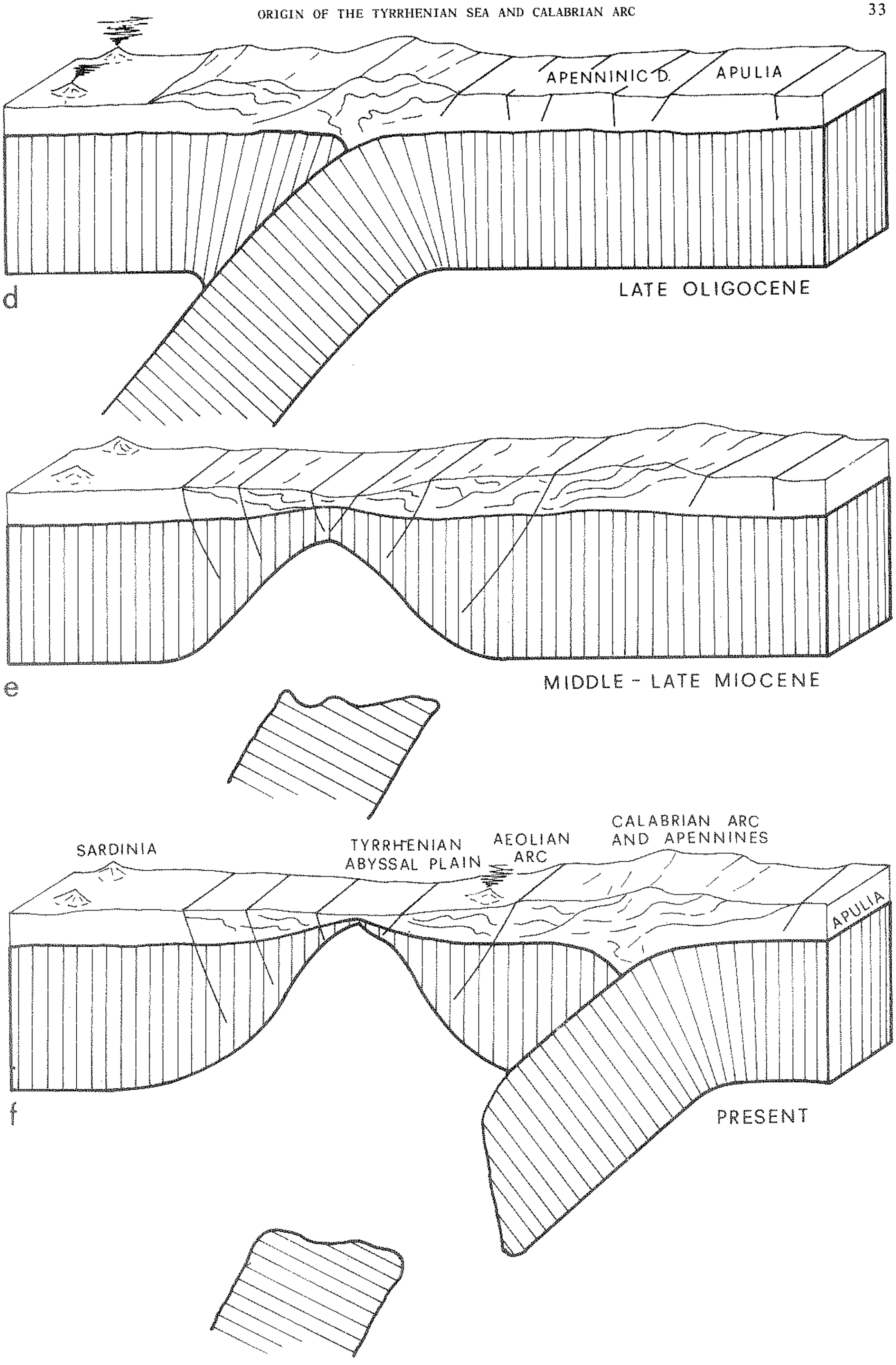


Fig. 3 (a, b, c, d, e, f) - Palinspastic cross sections between the Sardinia and the Apulia "blocks" from Triassic to the present.


APENNINIC D.
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d
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SARDINIA
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ABYSSAL PLAIN
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CALABRIAN ARC
AND APENNINES
APULIA
f
PRESENT

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