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Distribution of Messinian sediments and erosional surfaces beneath the Tyrrhenian Sea: geodynamic implications

Tyrrhenian Sea
Messinian acoustic facies
Erosional surfaces
Subsidence rates

Mer Tyrrhénienne
Faciès acoustiques du Messinien
Surfaces d'érosion
Taux de subsidence

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ABSTRACT

The study of more than 10 000 km of seismic reflection profiles led to the identification of four acoustic facies, interpreted as Messinian in age: 1) an evaporitic sequence previously described in the Western Mediterranean; 2) a non-coherent, undulating, irregular group of reflectors, interpreted as evidence of alluvial, possibly in part subaerial, deposition; 3) a horizontally bedded reflector with extensive lateral continuity, interpreted as subaqueous, maybe lacustrine, sediments; 4) a rough horizon dissected by channels possessing a dendritic basin-directed drainage pattern, interpreted as evidence of Messinian erosion and non-deposition.
The presence of erosional surfaces and backstripping calculations for sediment loading and thermal subsidence point to: *a*) an overall pre-Messinian (Tortonian-Serravallian) age for the Tyrrhenian basin; *b*) a substantial relief (2 000 m approximately) between the evaporitic basin and its surroundings in Messinian time.

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RÉSUMÉ

Répartition des sédiments et des surfaces d'érosion du Messinien en mer Tyrrhénienne : implications géodynamiques

L'étude de plus de 10 000 km de profils de sismique-réflexion a permis de distinguer quatre faciès accoustiques interprétés comme étant d'âge Messinien : 1) une séquence évaporitique déjà décrite en Méditerranée occidentale; 2) un groupe de réflecteurs irréguliers, discontinus et ondulés, interprétés comme étant un dépôt alluvial, peut-être subaérien; 3) un réflecteur parallèle, horizontal, s'étendant latéralement, interprété comme des sédiments subaquatiques, voire lacustres; 4) un horizon de ravinement entaillé par des chenaux (drainage dendritique de bassin), interprété comme la preuve d'une érosion et de lacune du Messinien.
La présence de surfaces d'érosion et les calculs de la subsidence liée à l'accumulation des sédiments et à la subsidence thermique, nous amènent à envisager : *a*) un âge pré-Messinien (Tortonien-Serravallien) pour le bassin Tyrrhénien; *b*) un relief important au Messinien (approximativement 2 000 m) entre le bassin évaporitique et ses bordures.

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The Tyrrhenian Sea is considered as a back-arc basin in the Western Mediterranean internal to the Apennine, Calabria and Maghreb orogenic belts of the Alpine system (Boccaletti, Guazzone, 1972; Bousquet, 1972). The Tyrrhenian Sea contains less sediments and its floor lies deeper than its Balearic Sea counterpart west of

Corsica and Sardinia (Finetti, Morelli, 1973). It is characterized by a shallow crust-mantle boundary (up to less than 10 km deep; Giese, Morelli, 1973), a low velocity upper mantle (Bottari, Lo Giudice, 1976; Panza, Calcagnile, 1979), positive Bouguer gravity anomalies (up to +250 mgal; Finetti, Morelli, 1973), and high heat flow (Erickson et al., 1976; Della Vedova, Pellis, 1979). In its southeastern corner seismicity is aligned on a funnel-shaped E-NE dipping Benioff plane (Caputo et al., 1972; Papazachos, 1973) descending beneath a calc-alkaline island arc (Barberi et al., 1973; Di Girolamo, 1978). Two drillsites of the Deep Sea Drilling Project provided valuable information on the actual composition of the sedimentary column in the last 5 MY (site 132, western Tyrrhenian rise; Ryan et al., 1973), and on the nature and age of the volcanic basement (site 373, southeastern abyssal plain; Hsü et al., 1978). In the latter, tholeiitic basalts whose maximum age is 7.5 ± 1.3 MY (Barberi et al., 1978) were recovered, while dredging results (Heezen et al., 1971; Selli, 1974) show the existence of Hercynian metamorphic rocks on ridges and horst blocks in the western and central parts of the basin.

Two main hypotheses have been put forward concerning the evolution of the Tyrrhenian Sea. One considers the submerged region to be a very young geological feature, created by foundering that commenced in the Mid-Pliocene (Selli, Fabbri, 1971; Curzi et al., 1980) or since Messinian time (Bousquet, 1972; Viaris de Lesegno et al., 1978). The second hypothesis argues that a deep-sea basin was already in existence in Late Miocene times (Ryan et al., 1973; Ryan, 1973; Hsü, 1977; Barberi et al., 1978; Panza, Calcagnile, 1979; Scandone, 1980) before the onset of the Messinian pan-Mediterranean salinity crisis (Hsü et al., 1973). Different combinations of the two hypotheses have been also proposed (Finetti, Morelli, 1973; Alvarez et al., 1974; Boccaletti et al., 1974; Fabbri, Curzi, 1980).

To discriminate between these hypotheses and to reconstruct a paleogeographic picture of the embryonic basin, we studied a network of seismic reflection profiles obtained by Italian and US research vessels since 1969. We calibrated identifiable subsurface units to the stratigraphic column provided by drilling and then mapped these units on a regional base. We chose to place particular attention on the distribution of Messinian evaporitic and clastic sediments and erosional surfaces created during the Mediterranean drawdown (Barr, Walker, 1973; Ryan, 1978; Ryan, Cita, 1978; Barber, 1980). The data studied by us (Fig. 1) consist of about 2 900 km multichannel (12 and 24 fold) reflection profiles obtained by scientists of Osservatorio Geofisico Sperimentale, Trieste, using a Flexotir explosive sound source, about 6 500 km single channel lines obtained by researchers of Laboratorio di Geologia Marina of Consiglio Nazionale delle Ricerche, Bologna, with a 24 kJ Sparker sound source, and about 1 000 km single channel profiles obtained by the USA research vessels Robert D. Conrad and Glomar Challenger using a 400 cm³ Airgun sound source.

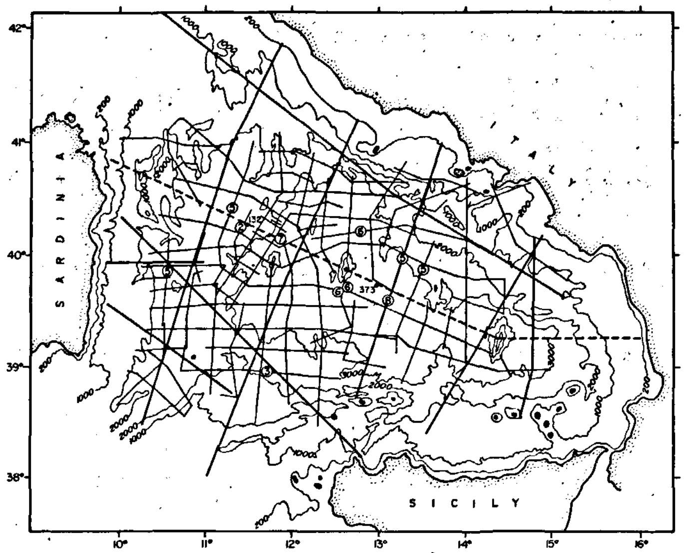

Figure 1

Location map. Dots, sites 132 and 373 of DSDP; thin lines, single channel LGM profiles; thick lines, multichannel OGS profiles; dashed thick line is multichannel OGS profile MS-1, discussed in the text. Circled numbers correspond to Figure 2, 3, 5, 6, 7, 8 profiles and show their location. Contours in meters.

ACOUSTIC STRATIGRAPHY OF THE MESSINIAN

Description

Four different acoustic facies, expression of the Messinian salinity crisis, were identified and traced throughout the whole central Tyrrhenian basin beneath a Plio-Quaternary cover.

1) Messinian seismic sequence similar to that already described in the Balearic basin (Montadert et al., 1978), being composed by the following units, from the top to the bottom: 1 *a*) well-stratified, strong-reflecting, multiple (up to 10 discrete reflectors) interval previously described in the Mediterranean Sea (M-horizons of Ryan et al., 1966; horizon Y of Selli, Fabbri, 1971; horizon A of Finetti, Morelli, 1973); its thickness is quite uniform (100-200 msec.); 1 *b*) an acoustically transparent interval, which is generally associated with diapiric structures. Its thickness – unlike that of unit 1 *a* – is highly variable. The transparent layer pinches out on the edges of the bathyal plain, where facies 1 is composed by units 1 *a* and 1 *c*, which form a single interval; 1 *c*) a single (sometimes multiple) strong-reflecting horizon which marks the base of interval 1 *b*. This complete seismic sequence near DSDP site 132 is illustrated in Figure 2.

2) A non-coherent, irregular, undulating group of chaotic reflectors which display an overall good reflectivity.

3) A layered horizon with extensive lateral continuity and slight reflectivity.

4) A rough surface incised by wide channels (Fig. 3).

Attribution of Messinian age to acoustic facies 1 is straightforward. It has been repeteadly drilled by D/V Glomar Challenger in the Mediterranean (Ryan et al., 1973; Hsü et al., 1978) and the acoustic sequence has been calibrated in the Tyrrhenian at site 132. Unit 1 *a* is composed by interbedded sulphates, dolomitic muds and

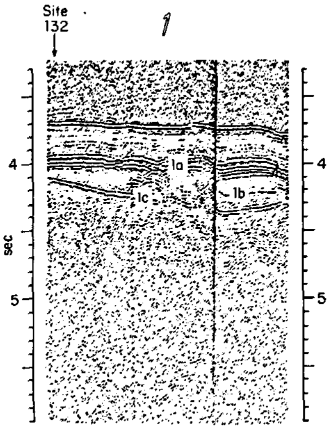

Figure 2
Messinian acoustic facies 1, close to DSDP site 132. Units 1 a, 1 b and 1 c are shown. Location in Figure 1.

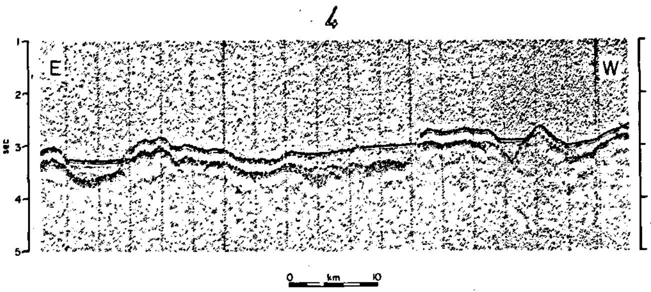

Figure 3
Messinian acoustic facies 4 (dotted horizon). Wide valleys are incised in an acoustic basement. Location in Figure 1.

some clastic sediments and corresponds to the "Upper Evaporites" of Montadert *et al.* (1978), which were deposited during the later part of the Messinian salinity crisis. Unit 1 *b* is interpreted as a halite layer (Auzende *et al.*, 1971), and unit 1 *c* as representing a sudden velocity change, expression of the beginning of salt deposition. Figure 4 is an isopach map of unit 1 *b*, assuming for it a sound velocity of 4.2 km/sec. (Schreiber *et al.*, 1973). Since its upper boundary is more or less flat (except for diapirs) it can be noted that the lower boundary is very irregular, and that salt is found in several deep troughs.

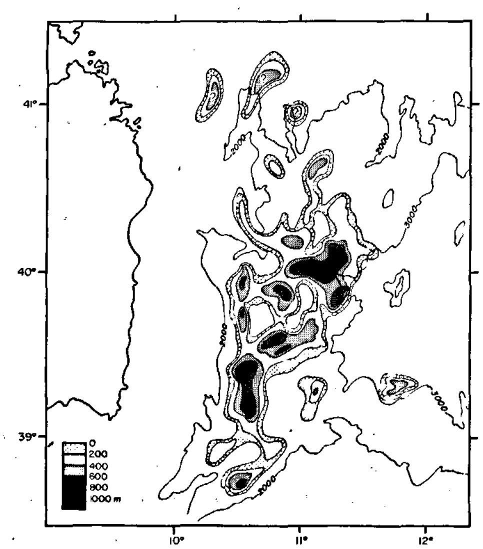

Figure 4
Isopach map of the salt layer (unit 1 b), assuming an interval sound velocity of 4.2 km/sec. Present-day seafloor bathymetry is shown too.

Correlations

Attribution of Messinian age to acoustic facies 2, 3 and 4 has been possible by correlation with facies 1. Correlation between facies 1 and 2 is shown in Figure 5. They are similar in acoustic reflectivity and are overlain by a transparent interval lacking internal reflectivity.

Facies 3 is a turbiditic horizon, and is found only in the deepest troughs of the southeastern abyssal plain, where the sediment thicknesses are greatest. Its acoustic characteristics are similar to those of the younger overlying sediments, in contrast to the previous cases. Correlation for this acoustic facies is shown in Figure 6. Better reflectivity of this horizon can be seen in multichannel profiles (Fig. 7) and in profiles such as those made by Glomar Challenger, recorded at relatively high frequency without Authomatic Gain Control, where it can be seen to be also overlain by a transparent interval,

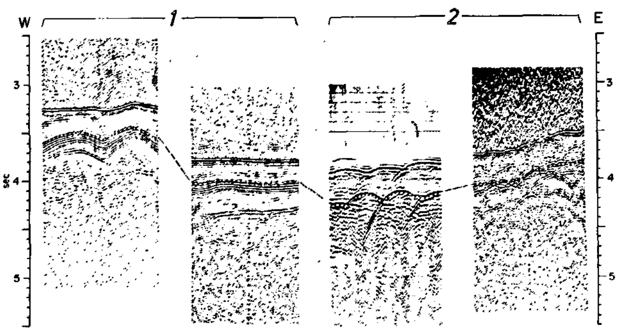

Figure 5
Correlation between Messinian acoustic facies 1 and 2 (dotted horizons). Location in Figure 1.

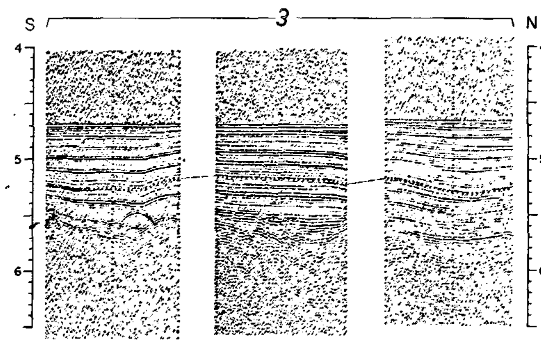

Figure 6
Correlation of Messinian acoustic facies 3 (dotted horizon) in single channel LGM Sparker profiles. Location in Figure 1.

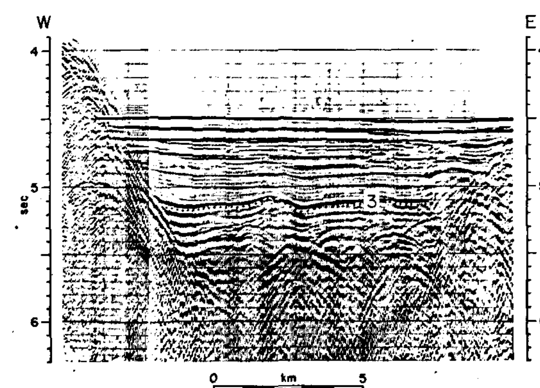

Figure 7
Good reflectivity of Messinian acoustic facies 3 (dotted horizon) displayed by a multichannel OGS profile. Location in Figure 1.

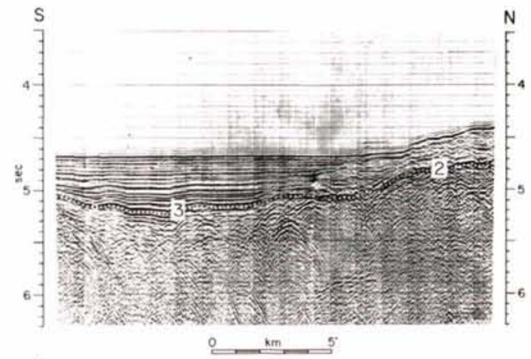

Figure 8
Lateral change between Messinian acoustic facies 2 (on the right) and 3 (on the left). Location in Figure 1.

as already remarked for acoustic facies 1 and 2. Moreover, some other profiles show lateral change between facies 2 and 3 (Fig. 8). This suggests that their age is the same whereas their depositional environment was different.

Along the edges of the basin facies 1 and 2 pass laterally to facies 4. A Messinian age can be attributed to it for the same reasons above mentioned. Facies 4 exhibits lateral equivalence to the other facies of known or inferred Messinian age, and good reflectivity. It is overlain by a similar sedimentary cover.

Interpretation

Figure 9 shows the space distribution of the four mentioned Messinian acoustic facies. Facies 1, the typical evaporitic suite, is developed in the western part of the Tyrrhenian Sea, where present-day seafloor is shallower than 3 000 m (see Fig. 1). Facies 2 and 3 are instead found in the deeper central and eastern part. Facies 2 surrounds facies 3, which is typically developed in the deepest troughs. Facies 4 is widespread on the continental slope and surrounds in turn all the former acoustic units.

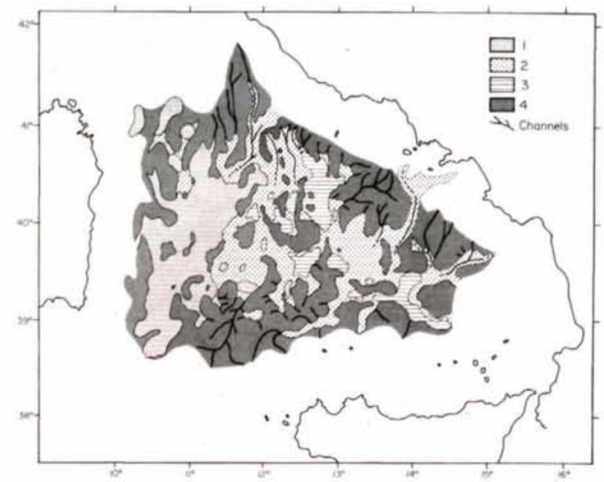

Figure 9
Space distribution of the four Messinian acoustic facies discussed in the text. Central Tyrrhenian seamounts are included in facies 4.

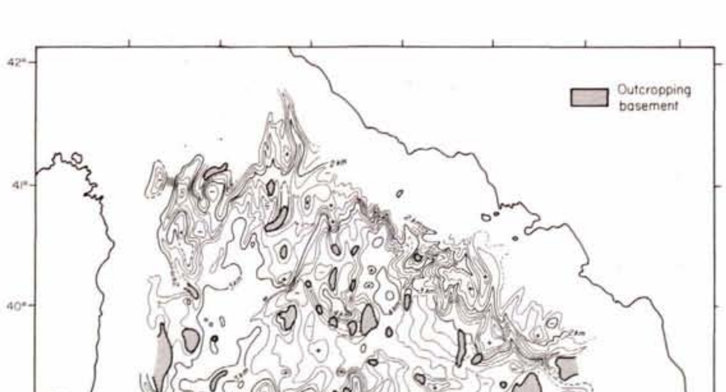

Figure 10
Depth beneath the sea level of the four Messinian acoustic facies, i. e. of the inferred Messinian horizon in the Tyrrhenian Sea. Contour interval 200 m.

Figure 10 shows the depth (below sea level) of the four Messinian age acoustic facies. Seismic velocities of 1.5 km/sec. for the water layer and 1.8-2.0 km/sec. for the Plio-Quaternary sediments have been considered. While facies 1 and 3 are more or less flat-lying at uniform depths (about 3 000 m for facies 1 and about 4 000 m for facies 3), the surface of facies 2 slightly dips towards the deepest troughs where facies 3 is developed. Facies 4 displays a similar but stronger dip and basin directed dendritic drainage patterns, which are also depicted in Figure 9.

The acoustic characteristics, the regional distribution and the overall morphology of the Messinian acoustic facies allow us to offer an explanation of the materials that are likely to correspond to them and of the processes that have concurred to their formation. Interpretation of facies 1 has already been described. Facies 4 is interpreted as an erosional surface. As previously remarked, it is a strong and irregular horizon dissected by several channels and dipping (approximately 3°) towards the basin, where coheval sediments were deposited. No reflections can be identified beneath it, because either of the nature of the materials incised or of the roughness of the erosional surface, which scattered the acoustic energy preventing further penetration.

An interpretation of the inferred Messinian-age acoustic sequence that differs from that presented here has been recently proposed by Fabbri and Curzi (1980), the data base being largely the same. These authors depict Messinian evaporites including the salt layer and indicate diapiric structures in the southeastern Tyrrhenian between Vavilov and Issel seamounts (Fabbri, Curzi, Plate IX). However, we do not think that acoustic facies 2 and 3 merely represent evaporitic sedimentation, because of their acoustic characteristics. Facies 2 does not show the typical layering of the M-horizons and reflectivity of facies 3 looks too low. The difference in acoustic characteristics is clearly visible in seismic line FC 11, illustrated by Fabbri and Curzi (1980) in their Plate VII. The layered nature of the Messinian acoustic unit on the western side (our acoustic facies 1) strongly contrasts with the chaotic nature of the Messinian horizons to the east (our facies 2). According to us, acoustic facies 2 and 3 represent mainly clastic sediments derived from extensive erosion of the regions surrounding the basin during the evaporitic drawdown. Roughness of facies 2 could be due to subaerial processes, and it should represent alluvial deposits. They have a low dip (2° approximately) towards uniformly bedded lacustrine strata, deposited in a subaqueous environment and represented by facies 3. Lacustrine Messinian sediments have been reported after the seismic record also by Aleria (1979) in the Corsica channel.

GENERAL DISCUSSION

Messinian paleogeography of the Tyrrhenian Sea

The Tyrrhenian Sea during Messinian time can be subdivided into a western part and a southeastern part. In the western part, influence of brine coming from the west was prevalent, and evaporites were deposited. In the southeastern part evaporites are not clearly recognized (as remarked also by Alvarez *et al.*, 1974), and the supply of terrigenous materials in the stream bed loads derived from the erosional areas seems to predominate over chemical sedimentation.

The paleogeographic relationship between the two parts of the basin is not clear. In a simple basin desiccation model (see for instance Hsü *et al.*, 1973) salt is expected to deposit in the deepest region, so that one might suppose that the present-day bathymetry of the Tyrrhenian Sea had to be reversed in Messinian time; that is, the western basin, which has a thick (see Fig. 4) salt layer, would have been deeper than the southeastern part of the Tyrrhenian, where alluvial (facies 2) and lacustrine (facies 3) deposition is believed to have taken place.

However, the topography of the Tyrrhenian basin might also have been similar to the present one. Drawdown of the sea level may only have been able to desiccate the western region due to a fresh water input from the wide surrounding water shed, which kept the deeper southeastern part more or less continuously flooded. This region remained as a group of several lakes surrounded by alluvial fans and interrupted by emergent volcanic and metamorphic hills. A strikingly similar paleogeographic setting has been described by Rizzini and Dondi (1979) for the Po plain, in northern Italy: Messinian clastic sediments up to 700 m thick are present in the subsurface, and are associated with brackish water faunas. These sediments are interpreted as deposited in a subaqueous, non-marine environment. Desiccation and evaporitic deposition could occur just in satellite basins along the perimeter of this non-marine basin.

The two parts of the Tyrrhenian basin are presently separated by a tectonic lineament which approximately strikes NE-SW and follows the 3000 m isobath on the western side of the abyssal plain, the so-called "Faglia centrale" of Selli (1970). As previously remarked, top of the Messinian lies at approximately 3000 m in the western basin, where facies 1 is developed, and down to 4000 m in the southeastern basin, where facies 3 can be found. An apparent vertical throw between the Messinian horizons of up to 800 m can be recognized along the fault. This lineament could therefore mark the faulted edge along which the southeastern Tyrrhenian foundered relative to its western part in post-Messinian times. This would agree with the first paleogeographic picture proposed.

On the other side, the Messinian acoustic facies change which can be always recognized crossing this lineament (acoustic facies 1 to the west, 2 and 3 to the east) suggests that it was already in existence during Messinian time. This is in agreement with recent studies (Fabbri *et al.*, 1980) which recognized pre-Messinian (Tortonian) activity along this fault. Moreover, basement ridges corresponding to the fault could act as a morphological bareer between the two basins, supporting the second paleogeographic hypothesis mentioned.

Age and Messinian bathymetry of the Tyrrhenian Sea

Our data indicate that the Tyrrhenian Sea had to exist in Messinian time as a sedimentary basin – as shown by extensive occurrence of Messinian sediments – deep respect to its surroundings – as shown by the Messinian age erosional surfaces, which are related to a substantial relief between the basin and its margins (Ryan, 1973). The problem of Messinian erosional surfaces is controversial (see review by Ryan, Cita, 1978); multiple erosional episodes have been documented both on land (Rizzini, Dondi, 1978) and under the sea (Montadert *et al.*, 1978; Almagor, 1980). However, in the case in hand our data do not allow to identify eventual pre-salt erosional episodes. Our Messinian acoustic facies distribution map (Fig. 9) shows that erosional channels are typically developed in acoustic facies 4, but that they also extend into and incise the top of acoustic facies 2. Consequently we can safely infer that the erosional episode documented occurred in the latest part of the Messinian salinity crisis.

The Tyrrhenian Sea is usually considered as a back-arc basin (Boccaletti, Guazzone, 1972; Bousquet, 1972; Barberi *et al.*, 1973; Boccaletti *et al.*, 1974; Barberi *et al.*, 1978), but oceanization of a cratonic region (Selli, Fabbri, 1971; Selli, 1974) and rifting of the Alpine orogenic belt (Scandone, 1980) have been also proposed. We think that anyone of these processes can be best explained by horizontal extension. Horizontal extension has been proposed: 1) in a back-arc setting, where opening can be related to seaward trench migration due to sinking of the subducted plate (Moberly, 1972; Uyeda, Kanamori, 1979) when it becomes gravitationally unstable, i. e. old enough (Molnar, Atwater, 1978) and consequent stretching induced in the overriding plate; 2) in rifted margins, where substantial extension can be recognized (de Charpal *et al.*, 1978; Montadert *et al.*, 1979). Stretching first leads to considerable thinning of the continental crust by listric faulting in an upper brittle layer and flow in a deeper ductile one (de Charpal *et al.*, 1978; McKenzie, 1978) and then, if it proceeds, to formation of new oceanic crust. Other mechanisms proposed for crustal thinning, as erosion following uplift in a first rifting phase (Turcotte *et al.*, 1977), deep crustal metamorphism (Falvey, 1974), subcrustal erosion (Selli, 1974) are not considered of fundamental importance in creating the crustal thinning observed in the Tyrrhenian Sea. They will be disregarded in the calculations.

Thermally-driven subsidence (Sleep, 1971), due to cooling of hot asthenosphere upwelled during the extension phase (McKenzie, 1978), follows both on the continental margin (Watts, Ryan, 1976; Ryan, 1976; Steckler, Watts, 1978) and in the oceanic region (Parsons, Sclater, 1977). Cooling will proceed until equilibrium is reached, i. e. when the lithosphere reaches a depth where it loses heat upwards as much as it receives from the asthenosphere below (Crough, 1975).

We therefore propose that the Tyrrhenian Sea was created by horizontal extension and consequent subsidence. Subsidence is due to crustal thinning and thermal cooling in the stretched continental crust portion of the basin (McKenzie, 1978) and to thermal cooling in the part which is supposed to be floored by oceanic crust (Parsons, Sclater, 1977).

Since thermal cooling is a time-depending process, quantitative estimates of the timing of extension in the continental region and of creation of new crust in the oceanic one can be attempted and have already been carried out in the Tyrrhenian Sea (Panza, Calcagnile, 1979). Quantitative models which consider the variation of the seafloor bathymetry and heat flow versus time both in continental stretched crust (McKenzie, 1978) and in new-formed oceanic crust (Parsons, Sclater, 1977) are available. The former model is illustrated in Figure 11. At $t=0$ a thermally equilibrated lithospheric slab is suddenly extended by a factor β: isostatic subsidence, which accounts for crustal thinning and elevation of the lithosphere-asthenosphere boundary, immediately occurs, and thermal subsidence, due to thickening of the lithosphere, follows. Equilibrium is reached at $t=\infty$. A very similar sequence of events is actually reported by Montadert *et al.* (1977), de Charpal *et al.* (1978) and Montadert *et al.* (1979) for the Biscay passive Atlantic margin. Rifting in an epicontinental area led to 2 500 m depth in Aptian time, which could be accounted to the isostatic process, and to 4 000 m of consequent further subsidence, which is accounted to a thermal process. This happens in the most stretched zone, where present-day continental crust thickness is reduced to 4-5 km, showing that substantial amounts of crustal thinning can be reached before oceanic crust is created. It is also shown that the amount of post-rifting (thermal) subsidence depends on the crustal thinning, as it is expected in McKenzie's (1978) model.

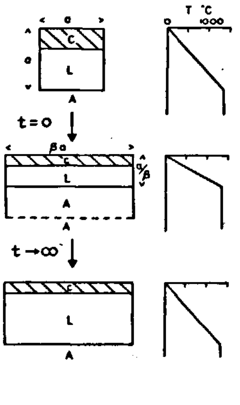

Figure 11

Stretched continental crust model (after McKenzie, 1978). C=crust, L=lithosphere, A=asthenosphere. The diagram on the right shows the temperature pattern in the slab. Discussion in the text.

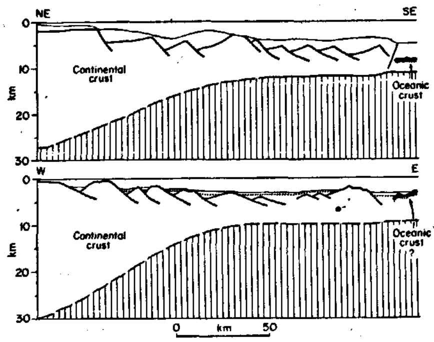

Figure 12

Comparison between crustal sections on the Biscay Atlantic margin (top, after Montadert et al., 1979) *and on the Sardinia Tyrrhenian margin, along OGS multichannel profile MS-*1 *(bottom; Finetti, Morelli,* 1972). *Dotted horizon in the Tyrrhenian section is the inferred Messinian reflector. Transition to oceanic crust in the Tyrrhenian section after Fabbri* et al. (1980).

An overall structure very similar to that of the Biscay margin can be recognized along OGS profile MS-1, entirely published by Finetti and Morelli, 1972 (in their Figures 6 *a* through 6 *h*) on the Sardinia margin (Fig. 12; for location of OGS profile MS-1, see Fig. 1). Half-grabens are encompassed by listric blocks, and inferred crustal thinning is supported by gravity measurements (Giese, Morelli, 1973; Malinverno, in press).

In a previous work (Malinverno, in press) both quantitative models have been tested with regard to basement depths and heat flow measurements. The results will be briefly summarized here. The continental crust model was expected to give the best results on the margins and in the western part of the Tyrrhenian, where Messinian acoustic facies 1 is developed and where recent studies have shown continental crust to exist (Fabbri *et al.*, 1980). The oceanic crust model instead was applied in the southeastern part of the basin, where oceanic crust is believed to occur (Giese, Morelli, 1973; Barberi *et al.*, 1978). Both models must anyway give the same age estimate, if the whole basin has been created during the same extension phase.

Both models in fact point to a 10-14 MY age for the Tyrrhenian basin, i. e. Tortonian-Serravallian stages of Upper-Mid Miocene (Ryan *et al.*, 1974). Figure 13 shows the application of McKenzie's (1978) model to multichannel profile MS-1 of OGS, Trieste (see Fig. 1 for location). Whereas it looks inadequate to explain the bathymetry of the eastern margin and it does not allow time considerations on the western one, basement depth in the evaporitic (Messinian acoustic facies 1) basin (120-140 km) is accounted by an age of approximately 14 MY. A younger Tyrrhenian would be about 500 m shallower. Figure 14 instead depicts basement depths in the central oceanic area and their average compared to basement depth computed after Parsons and Sclater (1977) expression. Again, a Tyrrhenian younger than 10-14 MY would be expected to be sharply shallower.

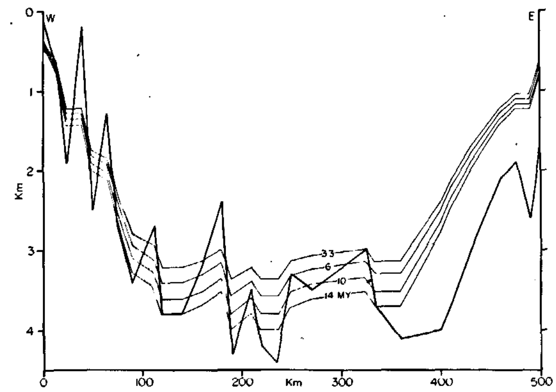

Figure 13
Comparison between actual basement depth (thick line) and computed basement depth 3.3, 6, 10, 14 MY after the extension, according to McKenzie's (1978) model along multichannel OGS profile MS-1 (location in Fig. 1).

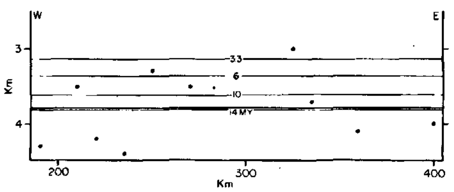

Figure 14
Actual basement depths (dots) and their average (thick line) compared to theoretical basement depths (thin lines) computed after Parsons and Sclater's (1977) expression for the lithospheric ages indicated in the central Tyrrhenian area along multichannel OGS profile MS-1 (compare to Fig. 13).

The models therefore allowed time considerations even in a very short time span, and they never show as likely a post-Messinian tectonic phase. This supports an overall pre-Messinian age for the Tyrrhenian basin (Ryan *et al.*, 1973; Hsü, 1977; Panza, Calcagnile, 1979; Scandone, 1980), and it discards post-Messinian tectonic foundering (Selli, Fabbri, 1971; Curzi *et al.*, 1980). Our interpretation differs from that recently proposed by Fabbri and Curzi (1980), who recognized: 1) opening of the Tyrrhenian in Tortonian time; and 2) sinking during several Plio-Quaternary tectonic phases. We think that crustal thinning and subsidence are related to substantial horizontal movements (McKenzie, 1978) and consequently that sinking is directly related to opening according to the isostatic and thermal processes described above. Absolute amount and velocity of Plio-Quaternary subsidence in the Tyrrhenian as described by Fabbri and Curzi (1980) do not agree with these worldwide recognized processes (Ryan, 1973) and are not explained otherwise.

As a next step, paleodepth of the pinch-out of the evaporites along the Sardinia continental slope, corrected for sediment and water loading and for post-Messinian subsidence, has been computed (Malinverno, in press). It turns out to be 1 850-1880 m, strikingly similar to the 1 900 m computed with identical assumptions by Ryan (1976) in the Gulf of Lion for the Messinian strand line and shown as significant in the whole Balearic basin. This does not look a mere coincidence. An overall paleogeographic picture for the whole Western Mediterranean can be drawn. Evaporites were deposited exactly at the same depth in the Balearic basin and in the western Tyrrhenian. The reason for this to happen is still not clear, since the two basins do not seem directly connected in Messinian time. Anyway, repeated transgressions could have crossed the low bareer between the two basins south of Sardinia and subsequent desiccation could have led to evaporite deposition at the same depth. Our results from quantitative modeling clearly discard any inversion of the Tyrrhenian Sea bathymetry after Messinian time. The existence of a southeastern deep trough where supposed alluvial and lacustrine sedimentation prevailed is therefore supported. As already mentioned, vicinity of wide erosional areas and narrowing of the basin towards the east could have created a puzzling paleogeographic situation which exceeds a simple basin desiccation model, but that can and must be explained in terms of a deep Tyrrhenian in Messinian time.

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