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Review

Changing perspectives in the concept of “Lago-Mare” in Mediterranean Late Miocene evolution

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Abstract

The Cenozoic Alpine orogeny caused the partition of Tethys into several basins. During the Late Neogene, the Mediterranean attained its final configuration, whereas, eastwards, the Paratethys, isolated from the World Ocean, disintegrated progressively into a series of smaller basins. As a result, an endemic fauna developed in these basins, mainly composed of brackish to freshwater faunas, indicating an environment affected by changes in water salinity. These small basins of the Paratethys were named “Sea-Lakes” by Andrusov [Andrusov, D., 1890. Les Dreissenidae fossiles et actuelles d’Eurasie. Geol. min. 25, 1–683 (in Russian)]. Subsequently this name was translated into “Lac-Mer” [Gignoux, M., 1936. Géologie stratigraphique, 2°édition, Masson, Paris].

In the Mediterranean isolated from the Atlantic at the end of the Miocene (Messinian), thick evaporites deposited, consisting of a marine Lower Evaporite unit and an Upper Evaporite unit, mainly of continental origin. Ruggieri [Ruggieri, G., 1962. La serie marine pliocenica e quaternaria della Val Marecchia. Atti Acad. Sci. Lett. Arti. Palermo, 19, 1–169.] used the term “Lago-Mare”, to characterize the brackish to fresh water environment which occurred within the Mediterranean at the end of the Messinian.

During recent decades, numerous scientific investigations concerning the history of the Messinian within the Mediterranean were devoted to the understanding of conditions prevailing after the deposition of the marine evaporites. Brackish to freshwater faunas are found in several outcrops and boreholes in the Mediterranean, both in the uppermost beds of gypsum and inter-bedded within the clastic sediments of the Upper Evaporite Unit, immediately preceeding the flooding by the marine Pliocene waters. These faunas, because of their similarities with the fauna described in the Paratethys, were named “Paratethyan”, or “Caspi-brackish” fauna, this leading some authors to imply a migration of these fauna from Paratethys to the Mediterranean. However, others refute this hypothesis.

New data induced some researchers to consider that exchanges existed between the Mediterranean and the Eastern Paratethys and also between the Mediterranean and the Atlantic Ocean at the Miocene–Pliocene transition. These investigations now take advantage of the accurate time scales established by authors (biostratigraphy, cyclostratigraphy, magnetostratigraphy), allowing good stratigraphic correlations between the Mediterranean and the Paratethys, and precisions on the geodynamic evolution of this area.

Furthermore, sediments at the base of the Zanclean (MPl1), locally containing brackish to fresh water faunas conducted authors to attribute this formation to an infra- or pre-Pliocene and also to a Lago-Mare “event”.

Thus, the “Lago-Mare” concept drifted from its original meaning, and is evolving because of progresses in the understanding of the Mediterranean geodynamics and the adjacent areas during the Miocene–Pliocene transition.

Keywords: Neogene; Messinian; Mediterranean; Paratethys; Lago-Mare; Brackish environments

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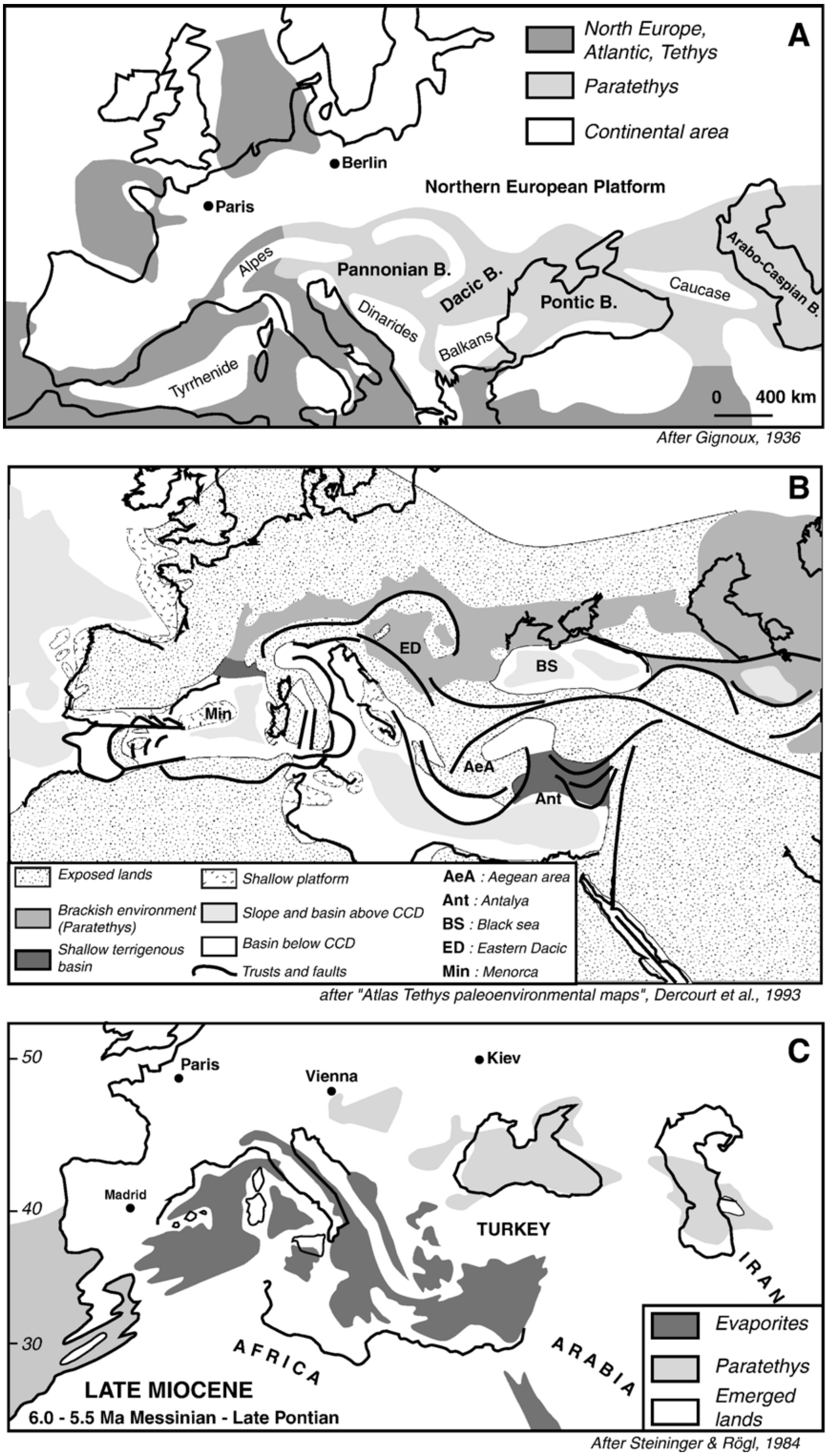
1. Introduction

During the Neogene, the Tethys was split into the Mediterranean and Paratethys as a result of the Alpine orogeny. Thus, since the Serravallian, Paratethys became isolated from the Global Ocean and evolved into internal seas, as it is indicated by maps established by Steininger and Rögl (1984), Rögl and Steininger (1984), Dercourt et al. (1993), (Fig. 1B, C), Rögl (1998), Sprovieri and Sacchi (1999), Popov et al. (2004). Consequently, an endemic, brackish to fresh water molluscan faunas association flourished within the various basins of the Paratethys realm. During the Messinian, the connections between the Mediterranean and Atlantic were (partly ?) interrupted, leading to thick deposits of salt, during the so-called Messinian Salinity Crisis (MSC). The connections between the Mediterranean and Atlantic were re-established at the beginning of Pliocene.

The vestigial seas of the Paratethys were inhabited during Pontian times by a brackish to fresh-water fauna leading Andrusov (1890) to consider that the different areas inhabited by these faunas were no longer seas, but constituted a "sea-lake" (in Russian), which was translated "Lac-Mer" by Gignoux (1936) (Fig. 1A). The Miocene–Pliocene boundary in the Mediterranean is also marked, at the end of the MSC, by the development of an environment dominated by brackish and freshwater conditions. The "Lac-Mer" was translated by Ruggieri (1962, 1967), and Ruggieri and Greco (1965) into "Lago Mare", to describe the "Melanopsis beds which lived in sea lakes" and represented restricted alkaline and saline waters in the Mediterranean at the end of Miocene. The term "Lago-Mare" is now employed unanimously by geologists to designate the brackish to freshwater environment ending the Messinian time prior to the marine Pliocene re-flooding. In recent decades, the Messinian time stratigraphy was revised, these new data permitting better knowledge of the interval following the evaporite deposits (Salinity Crisis) and preceding the marine re-flooding of the Mediterranean, concurrent with the (questionable) connections of the Atlantic, Mediterranean and the Paratethys realm near the end of Miocene.

The evolution of the Mediterranean during the Messinian is shown by a generalised sedimentary



After Gignoux, 1936

after "Atlas Tethys paleoenvironmental maps", Dercourt et al., 1993

After Steininger & Rögl, 1984

Fig. 1. A. Location of the Pannonian, Dacic, Pontic and Arabo-Caspian basins, the vestigial "sea-lakes" of the Paratethys (after Gignoux, 1936). B. During Tortonian, while the Mediterranean and the Atlantic Ocean are still connected, the Central Paratethys begins to disintegrate into smaller basins in which a brackish environment is setting (after Dercourt et al., 1993). C. During the Late Miocene (Messinian, Late Pontian), the connections between the Mediterranean and the Paratethys are severed; evaporites deposited in the Mediterranean. The Eastern Paratethys is now subdivided into smaller basins in which endemic fauna developed (Steininger and Rögl, 1984).

succession (Fig. 4B), observed commonly in the Mediterranean basins. This general pattern was documented initially in Sicily and observed subsequently in the Western and the Eastern Mediterranean.

In Sicily, it consists classically of 3 main units: a–a pre-evaporitic unit (the "Tripoli" in Sicily, for example); b–a massive Lower Gypsum formation of marine origin, and c–an Upper Gypsiferous unit comprising 6 to 7 gypsum layers inter-bedded with marls, carbonates and capped by detrital formations. In the deep basins, seismic profiles indicate that about 1000 m of salt were deposited. Several models are currently proposed to explain the MSC.

For many authors this salt is interpreted as a deep basinal lateral equivalent of the marginal Lower Evaporites (Cita et al., 1978a,b; Rouchy, 1982; Cita and McKenzie, 1986; Cita et al., 1990; Rouchy and Saint Martin, 1992; Krijgsman et al., 1999b; Rouchy and Caruso, 2006-this issue). For Clauzon et al. (1996) the main salt deposit is contemporaneous with an important drop of sea level which was responsible for the erosion of the Lower and also the Upper Gypsum (deposited in marginal basins). For Butler et al. (1995), the erosional phase occurred between the Lower and Upper Gypsum, while for Riding et al. (1998), a major Late Messinian erosion surface between 5.9 and 5.5 Ma represents the Mediterranean evaporative drawdown, before the deposition of gypsum, in the Sorbas basin (see discussions on this topic in Rouchy and Caruso, 2006-this issue). Thus the pertinence of the new data concerning the Lago-Mare should be taken into consideration, insofar as Lago Mare is a key to the understanding of the geodynamics of the Mediterranean: depth before and after the MSC, connections with Atlantic and Paratethys domains, significance of the erosional phases observed during the Messinian.

In the first part of this paper, we will return to the primary meaning of the so-called "Lago-Mare", broadly used by the scientific community, and to the examination of the interpretations, by authors, of some features observed during this time. During these last decades, thanks to numerous scientific articles and data, this concept is enlarged, leading to a reassessment of the isolation of the Mediterranean from the Paratethys and the Atlantic Ocean at the end of the Messinian. To re-evaluate the situation, the stratigraphic correlations are now better constrained between the different parts of the Paratethys on one hand and, on other hand, between the Paratethys and the Mediterranean during the Neogene (particularly the accurate astronomical time scales, magnetostratigraphic studies, etc…).

2. "Lago-Mare": what does the term mean

The "Lago-Mare" in the Mediterranean realm was used initially to describe a brackish to freshwater environment characterized by a fauna of molluscs ("*Congeria* beds", or "*Melanopsis* beds", Ruggieri, 1967) in sediments deposited ending the MSC immediately prior to Pliocene marine re-flooding.

2.1. A case study: the Lago-Mare in Cyprus

Many papers have described the Lago-Mare, as observed both in outcrops as well as in DSDP-ODP cores

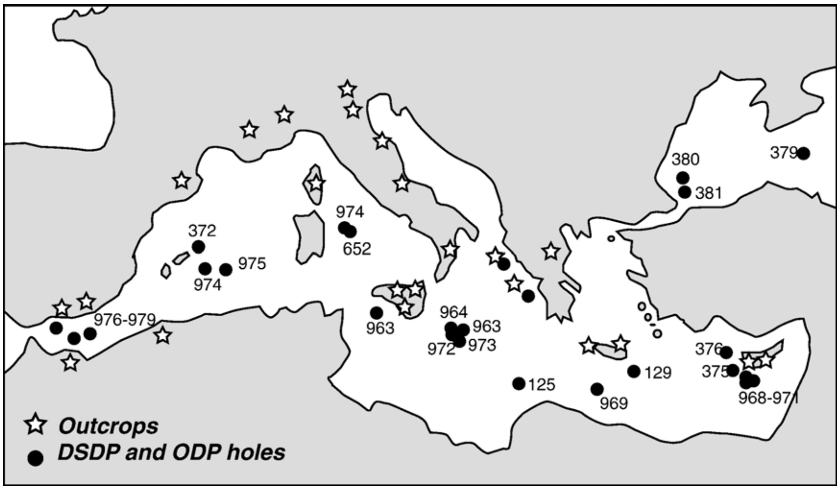


Fig. 2. Map of the Mediterranean with the location of outcrops and DSDP and ODP sites in which the brackish to fresh water fauna of the Upper Evaporite Unit ("Lago-Mare") are observed.

(Figs. 2 and 3). In the eastern Mediterranean several detailed studies of the Pliocene–Miocene boundary in Cyprus were carried out in the Polemi, Pissouri and Psematismenos basins (Weisgerber, 1978; Orszag-Sperber and Rouchy, 1979; Rouchy et al., 1980; Dupoux, 1983; Elion, 1983; Orszag-Sperber et al., 1989; Di Stefano et al., 1999; Orszag-Sperber et al., 2000; Rouchy et al., 2001).

Sections measured in the Pissouri and Polemi basins (South Cyprus) (Fig. 4) are utilised in this paper as a base for defining the different units and facies of the sediments marking the end of the Miocene period in the Mediterranean. They are very similar to those of the well known and often published Central Sicilian basin, which is considered as a deep basin by many authors (Decima and Wezel, 1973; Hsü et al., 1978; Rouchy, 1982, among others). Also of interest are the sites drilled southward (ODP sites 966, 965, 967, Eratosthenes Rise) and westward (Florence Rise, DSDP sites 375, 376) of Cyprus which complement the data obtained from outcrops.

We summarise the sections situated at the transition Messinian–Pliocene, i.e. the Upper Gypsum unit (details in Orszag-Sperber et al., 2000; Rouchy et al., 2001).

In the Polemi basin (Fig. 4A, C1), this unit consists of 6 beds of gypsum inter-bedded locally with varved marls. Sands and conglomerates appear between the 5th and 6th beds of gypsum. These gypsum beds are composed of whitish laminated gypsum to gypsarenite, the laminated gypsum corresponding to gypsified microbial laminites and stromatolites.

Both marls and gypsum beds contain a fauna of molluscs, including *Limnocardiidae*, *Melanopsis*. Marls also contain *Ostracoda* (*Cyprideis* sp.), abundant fragments of *Clupeidae*, marine fish tolerant to variations of the salinity (Gaudant, pers. com.), *Ammonia beccarii*, typical of a brackish environment are also observed in the marls.

The uppermost Gypsum bed is eroded and locally disappears. This bed is overlain by dark sandy marls containing *Melanopsis*, *Melania*, *Cyprideis* sp., *Planorbis*, oogonia of *Characea*, plant fragments and reworked Cretaceous to Miocene foraminifers. Locally (Giolou section), these dark marls contain pulmonate gastropods, root moulds and caliche-like concretions. A thick (1 m) level of conglomerate is also observed.

In the Pissouri basin (Fig. 4A, C2), the uppermost gypsum bed was karstified during breaks in sedimentation, as it is indicated by the progressive filling of the ensuing cavities by marls, and conglomerates, and by the

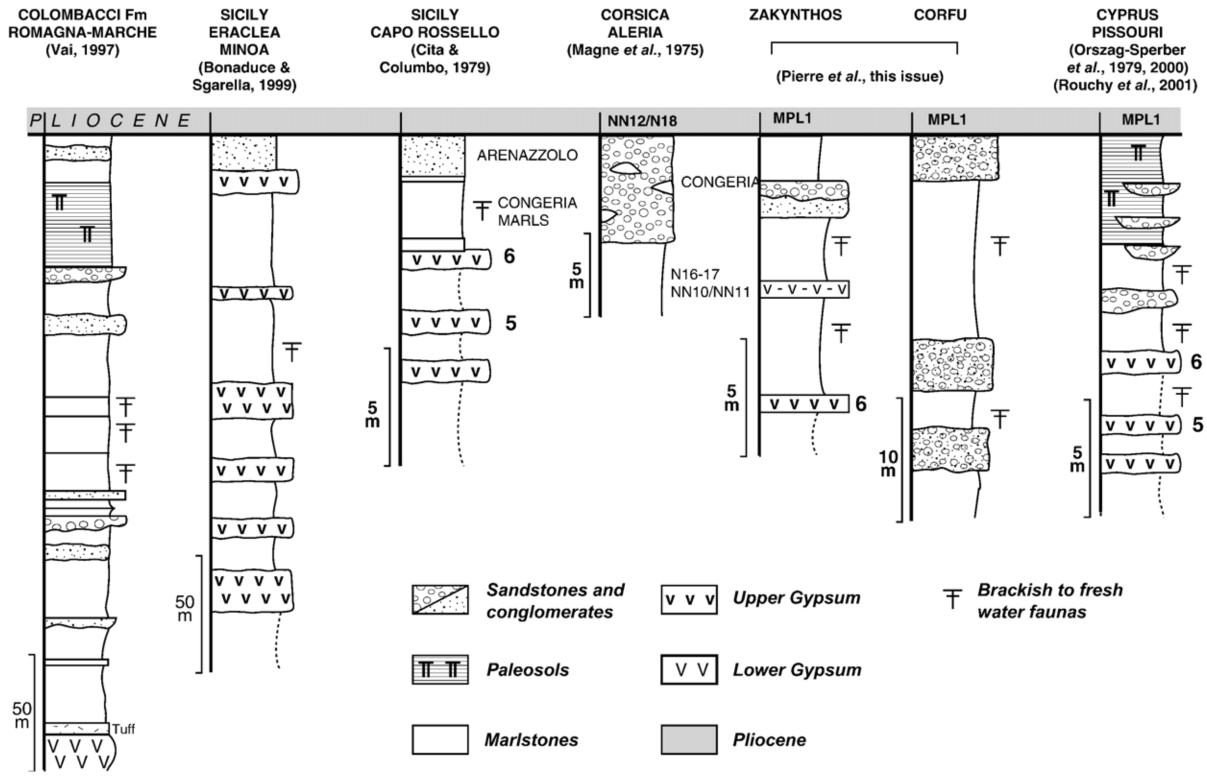


Fig. 3. Representative sections in the Mediterranean where the Upper Evaporite Unit is described. The Early Pliocene is well dated (MPl1). The presence of paleosols in several sections is of interest, showing periods of emersion.

presence of large blocks of gypsum. Above this bed, marls contain a brackish fauna similar to that described in the Polemi basin. Of interest is the presence of 4 levels of conglomerates alternating with marls containing the brackish fauna as well as marls exhibiting local paleosols, indicating periods of emersion. Marine influence is demonstrated by a layer containing a scattered dwarfed microfauna with the Messinian *G. mediterranea* and

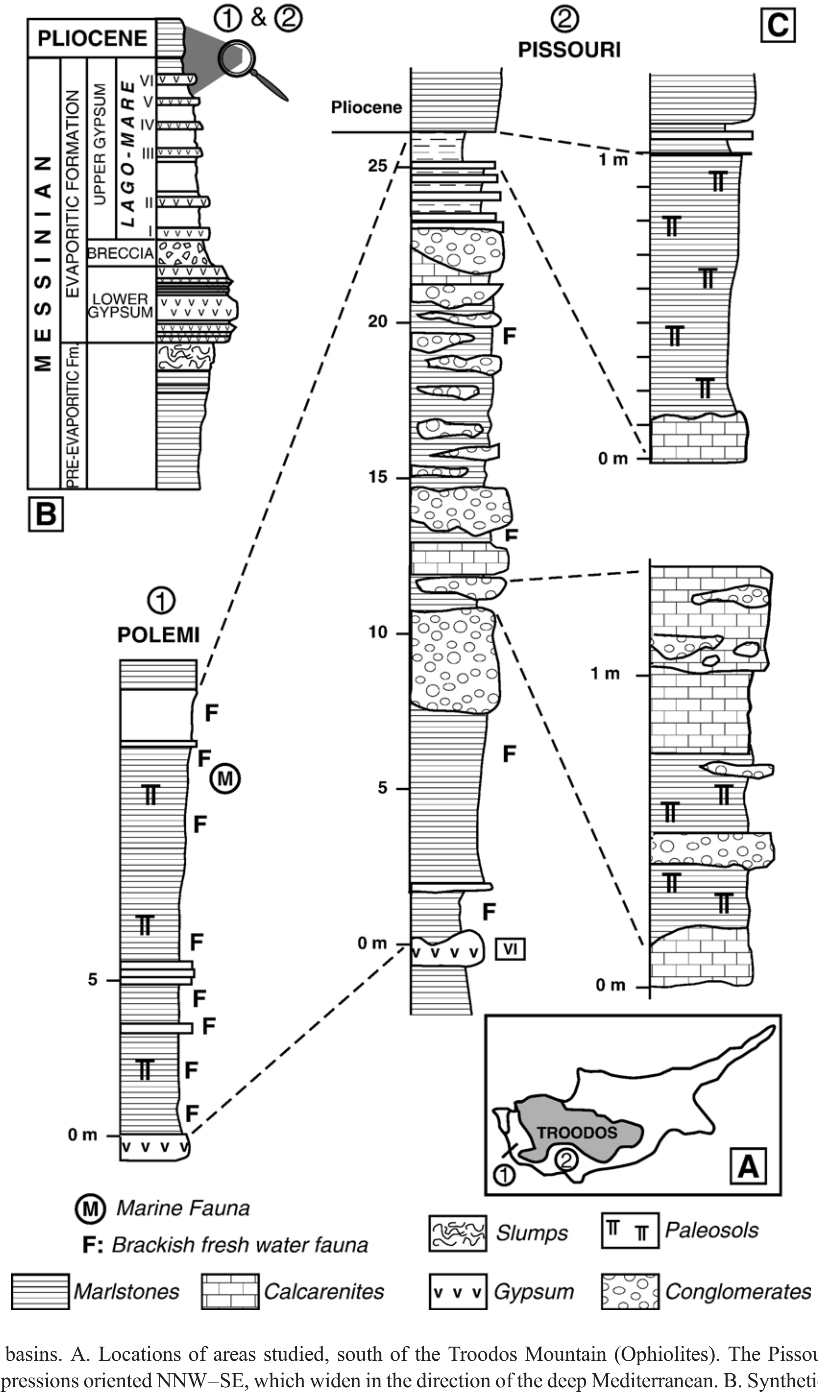


Fig. 4. Southern Cyprus basins. A. Locations of areas studied, south of the Troodos Mountain (Ophiolites). The Pissouri and Polemi basins are tectonically controlled depressions oriented NNW–SE, which widen in the direction of the deep Mediterranean. B. Synthetic section of the Messinian in Cyprus in which the 3 main units of the Messinian are present. Each unit is separated from the other by an erosion phase. C. The Upper Gypsum Unit in Polemi (1) and Pissouri (2) basins. Above the last bed of Gypsum (VI) and before the earliest sediments of Pliocene (in Pissouri), the sequence includes alternations of conglomerates and marls within paleosols (Pissouri) and continental fauna (Polemi) are observed. Brackish to fresh water fauna occur in both sections.

G. humerosa and, before the Trubi of the Pissouri section, a microfauna (*G. trilobus, G. obliquus* and *G. sacculifer*) indicating shallow marine conditions related to transitional conditions (Elion, 1983).

The isotopic signature of the sulphate of the upper gypsum indicates a significant meteoritic water contribution, while the gypsum of the Lower unit is of marine origin (Pierre et al., 1998). An alternation of dry and humid seasons is documented by the successions of gypsum and strata of marls containing typical fauna and pollen assemblages (*Pistacia*, *Pinus*, *Olea*).

Tectonic movements are documented by sedimentary features (slumps, for example) and by conglomeratic discharges, which includes pebbles from emergent Troodos and its sedimentary cover. In both basins, the contact with the Early Pliocene (MPL1) is very sharp (Bizon, in Orszag-Sperber and Rouchy, 1979; Di Stefano et al., 1999).

West of Cyprus, at sites 375–376, on the Florence Rise, siltstones, sandstones and marlstones overlie a gypsum sequence and these contain a fauna with *A. beccarii* and *Cyprideis pannonica*. Horizons with marine foraminifers possibly indicate occasional marine influxes within the Lago-Mare sediments, discussed by the researchers of the DSDP team, while it was already shown that the shallow brackish to fresh water fauna was clearly in situ (Cita et al., 1978a,b). The salinity of the water was only 10‰ (Mélières, 1978).

The ODP leg 160 (sites 966, 965, 967, 968) recovered sediments at the Miocene–Pliocene boundary along a north–south transect of the Eratosthenes Seamount, south of Cyprus. Eratosthenes Seamount is considered to be an isolated carbonate platform, situated above the desiccated deep basins, during the Late Messinian (Major and Ryan, 1999). Sediments and gypsum at site 968 are related to the Lago-Mare type-facies (Robertson, 1998), which is confirmed by the presence in marls of *Ammonia* sp. and *Cyprideis* sp. (Blanc-Valleron et al., 1998). The gypsum with a marine isotope signature and containing nannofossils is considered to be reworked from onshore basin (Blanc-Valleron et al., 1998). At site 965, at the Messinian–Zanclean boundary, clays contain a sparse fauna of ostracods, together with carbonate nodules, which are related to paleosols. An emersion is also documented at site 968 by the presence of a pulmonate gastropod in sediments (Blanc-Valleron et al., 1998). Caliche and paleosols accumulated on the Eratosthenes Seamount upper slope (Site 965) as it is demonstrated by the stable isotope composition of the carbonate (Böttcher et al., 1998).

Thus, in the Cyprus region, the sediments at the M/P boundary, whether investigated on outcroping deposits or on drill-cores from the DSDP-ODP sites to the south and to the west of the island, record similar environmental indicators, calling for the same re-appraisal : shallow water depth as indicated by the faunas, questionable effects of tectonics, origin of the gypsum deposits, periods of emersion, puzzling marine incursions in a brackish to fresh water environment (connection with the Atlantic?), origin of the faunas (connections with the Paratethys?).

2.2. Outstanding features: Lago-Mare in the other Mediterranean basins

Several studies were carried out in the Mediterranean, as shown on the map (Fig. 2), and similarities with the Cyprus sections are obvious (Fig. 3).

The totality, or at least, a part of the cyclic pattern (6 to 7 gypsum beds associated with marls and conglomerates and containing a fresh water to brackish fauna) are observed in most sections especially in Italy (including Sicily), Spain, Greece (islands of Corfu, Zakyntos, Crete), Morocco, Tunisia, South of France, Corsica. The Colombacci Formation in Romagna, in which 8 cycles of carbonates and marls containing a brackish to freshwater faunas, is considered to be the equivalent of the Upper Gypsum Unit (Casati et al., 1976; Colalongo et al., 1978; Vai, 1997; Krijgsman et al., 1999a).

The Upper Evaporites of the deep basins have been recognized on seismic records both from the Eastern and the Western Mediterranean (Montadert et al., 1978) and cored during the DSDP-ODP legs.

Several DSDP-ODP sites (Fig. 2), also documented the "Lago-Mare" interval in the deep sea basins. The ostracod *Cyprideis* has been found at several sites in the Mediterranean. Benson (1973), in the Leg 13, already has indicated the presence of a "*Melanopsis–Cyprideis* zone of the Upper Messinian Lago-Mare continental alkaline lakes". A brackish fauna is described in different ODP sites, particularly at sites 974 (Tyrrhenian sea) and 975 (Balearic basin) in the Western Mediterranean (Iaccarino and Bossio, 1999), and, as mentioned above, at sites 375 and 376 on the Florence Rise and 967 and 968, on the Cyprus lower slope, in the Eastern Mediterranean (Blanc-Valleron et al., 1998; Robertson, 1998; Major and Ryan, 1999). Records of the Lago-Mare environment in the deep basins of the Western Mediterranean were already described at site 652, eastern Sardinia (Cita et al., 1990) and at site 372 on the Minorca Rise (Benson, 1978).

Thus, the Lago-Mare type-facies is present in the Mediterranean both in the exposed basins and in the deep parts of the Mediterranean, above the marine evaporites and just beneath the marine Zanclean reflooding.

Some features observed in the different localities in the Mediterranean deserve additional comments.

2.2.1. The gypsum deposits

The Upper Gypsum Unit consists of a cyclical sedimentary sequence and its distribution is larger than that of the Lower Gypsum unit. The gypsum beds are composed of laminated, selenite and clastic gypsum. Some layers (5 and 6 of the Polemi basin) are composed of microbial laminites and stromatolites which indicate a restricted water environment. Halite lenses are present at sites 134 (Balearic basin) and 376 (Florence Rise). By contrast with the marine "Lower Gypsum Unit", the precipitation of the gypsum from the upper unit, deposited in continental settings, was influenced by continental meteoric waters as evidenced by the isotope composition of the sulfate (Pierre, 1982; Pierre et al., 1998; Longinelli, 1979; Iaccarino et al., 1999b). The low oxygen and carbon isotopic ratios indicate inputs of meteoritic waters diluting the brines of these lakes in holes 968A, 969A and 969B (Pierre et al., 1998).

These gypsum deposits are considered to result from the recycling of the Lower gypsum (Butler et al., 1995; Cita, person. com.).

2.2.2. Fauna

What was originally considered as Lago-Mare was the last detrital formation containing brackish to freshwater faunas (for example the Arenazzolo Formation in Sicily (Fig. 3), which overlies the Upper Gypsum. However, it is also clear that the period corresponding to the Lago-Mare includes the Upper Gypsum in which brackish to fresh water faunas occur throughout the formation.

The similarities between the Paratethys and the Mediterranean faunas during this period led to the terms "Paratethyan" or "Caspi-brackish" and this leads authors (Hsü et al., 1977; Hsü, 1978; Cita et al., 1978b), to propose these faunas emigrated from the Paratethys into the Mediterranean via aquatic ways. These assemblages indicate very shallow brackish to fresh water environments as shown by many authors: molluscs such as *Congeria*, *Melanopsis*, *Melanoides* or *Limnocardium*, live around a depth of 0 to 10 m, and tolerate only a very slight salinity. Ostracoda are observed until the depth of 50 m, in waters in which the salinity can vary from fresh water up to 100‰. These ecological data together with the very thin laminated sediments in which they locally occur, may indicate lacustrine conditions with seasonal changes: during periods of inundation brackish to freshwater fauna thrived while periods of progressive desiccation favoured gypsum deposition.

2.2.3. Detrital deposits

The 4–5 m thick sandy layer capping the Upper Gypsum of Sicily, the so-called "Arenazzolo Formation" contain scattered broken valves of *Cyprideis* and sedimentary features indicating a high energy environment related to the littoral edge of a lake (Cita and Colombo, 1979), with fresh water conditions (Fig. 3). This formation capping the Upper Gypsum unit, through a level of claystones, is observed only in Sicily.

Detrital sediments related to a more humid climate are described in Corfu, in the Agios Stefanos section (Vismara-Shilling et al., 1976; Heiman, 1978; Pierre et al., 2006-this issue). In the Colombacci Formation, conglomerates and sands reflect a deltaic environment (Farabegoli and Ricci Lucchi, 1973; Carloni et al., 1975). In Corsica, the Aleria Formation (Magné et al., 1975; Orszag-Sperber and Pilot, 1976; Ferrandini et al., 2004) which consists of conglomerates containing lenses of marls is also related to a deltaic environment: the presence of *Dreissena,* diatoms, ostracods, Limnocardiidae in some of these lenses suggests that small marshes were setting at the freshwater–salt water transition, exhibiting a salinity gradient controlled by the distance to the sea. These deposits are situated between the Late Tortonian–Early Messinian and the Early Pliocene (Fig. 3).

Elsewhere, the conglomeratic discharges observed in Cyprus basins have been related both to tectonic pulses, i.e. the Troodos uplift and more humid conditions (Orszag-Sperber et al., 1989, 2000; Rouchy et al., 2001). The "Conglomerates of Palena", observed in the Central Apennines are also related to a tectono-sedimentary event that affected the Le Vicenne area (Cipollari et al., 1999). Federici et al. (2004) consider that the thickness of the Messinian Lago-Mare clastic sediments drilled in the Tyrrhenian bathyal basin (ODP 652) and in the Garigliano plain (Mondragone 1 well) is strongly controlled by a syn-rift extensional tectonics. Coarse-grained sedimentation also suggests tectonic activity in South Calabria (Cavazza and DeCelles, 1998).

2.2.4. Climate

During the Lago-Mare time, an alternation of dry and more humid seasons may logically explain the annual or seasonal fluctuation of brine concentration (Orszag-Sperber et al., 2000). Pollen indicate moist, subtropical to warm temperate conditions in the Piedmont and Emilia–Romagna regions (Bertini and Martinetto, 2004) where trees, like *Sciadopitys*, that are present in the Colombacci Formation, require almost 6 months of rain (Bertolani Marchetti and Marzi, 1988). The predominance of smectite and kaolinite in Messinian clays also reflects a relatively warm and wet climate (Chamley et al., 1977).

The occurrence of conglomerates in Cyprus sections implies the setting of a fluvial network during humid seasons, whereas, a dry season favoured the deposit of gypsum. The gullied surface at the top of the Eratosthenes seamount is related to a period of drainage (Major and Ryan, 1999). This alternation of dry and humid periods is also observed by Griffin (2002) for whom the cyclicity of the Upper Evaporites (gypsum alternating with clastics) is related to the earth precession (21 Ky) as postulated by Krijgsman et al. (1999a,b, 2001). Analogies with the cyclicity of the gypsum deposits in the Pleistocene salina on the Egyptian Red Sea coast induced Orszag-Sperber et al. (2001) to question the influence of a monsoon system.

2.2.5. Periods of emersion

They are clearly evidenced by paleosols intercalated in the conglomerates in Cyprus basins, already described in this paper. Periods of emersion are also observed in Spain, notably the paleosols in the Sorbas section (Ott d'Estevou, 1980), presence of *Characea* at Cuevas del Almanzora (Geerlings et al., 1980).

At site 974B (Iaccarino and Bossio, 1999), the interval attributed to the Lago-Mare consists of variegated clay and silty to sandy clays with ripple-cross structures consistent with lacustrine sedimentation (Comas et al., 1996). At site 965, a soil horizon present on the flank of the Eratosthenes Seamount provides additional evidence for sub-aerial exposure (Major and Ryan, 1999). At ODP site 968, Blanc-Valleron et al. (1998) note the presence of a pulmonate gastropod.

2.2.6. Duration of the Lago-Mare period

According to Vai (1997), the Colombacci Formation represents the Lago-Mare-type Messinian interval, equivalent to the Sicilian "Gessi Superiori" (Upper Gypsum). It comprises eight cycles enclosed within the C3r reversed chron (which bridges the Messinian–Pliocene boundary). The Ar^{40}/Ar^{39} investigations by Odin et al. (1997) of the volcanic ashes situated beneath the first Colombacci bed provide an age of about 5.50 Ma and the Pliocene–Messinian boundary being dated 5.33 Ma (Gautier et al., 1994; Odin et al., 1997). The sedimentary cycles of the Colombacci appears to be controlled by precession (Krijgsman et al., 1999a). This is in good agreement with the studies in Sicily and Spain by Krijgsman et al. (1999b, 2001) who consider that the non-marine sediments were deposited in a large Lago-Mare between 5.50 and 5.33 My. The duration of the Lago-Mare period is very short: 175 kyr for Krijgsman et al. (1999a,b) or 250 kyr for Vai (1997).

3. The Atlantic–Mediterranean–Paratethys connections revisited

3.1. Recent data

The deposition of Messinian evaporites in the Mediterranean implies that the connections with the Atlantic were severed during this time. It was suggested also by most authors (Rögl and Steininger, 1984; Popov et al., 2004) that the vestigial sea-lakes of the Paratethys were isolated from the Mediterranean, before the Messinian. However, authors and especially those which studied the Paratethyan domain, already suspected a possible connection between the Mediterranean and the Pannonian and Euxino–Caspian basin. In the Pannonian basin, since the Maeotian (Tortonian), marine incursions are shown by the presence of supposedly marine dinocysts associations (Suto, 1995; Popov et al., 2004), while molluscs and ostracods reflect a brackish lacustrine environment (Müller et al., 1999). In the Euxino–Caspian basin, inhabited by brackish faunas, ephemeral marine incursions took place during the entire Maeotian, documented by marine molluscs (Ilyina et al., 1976; Ilyina, 2000). Marunteanu and Papaianopol (1995, 1998) found calcareous nannoplankton, at different levels, in the Middle Miocene–Pliocene deposits of the Dacic basin (Fig. 5).

In the Northern Aegean regions, sediments with Limnocardiids and Dreissenids have been described by Gillet (1937), Dermitzakis et al. (1985/86), Karistineos and Ioakim (1989), Syrides (1995, 1998, 2000), Popov and Nevesskaya (2000). Marine invasions indicated by molluscs in the Strymon basin are described by Syrides (2000) who summarises the successive steps of the stratigraphic revisions of these marine deposits. The stratigraphic correlations between the Mediterranean and the Paratethys via the Aegean basin are discussed in Popov and Nevesskaya (2000).

In recent years, the stratigraphic accuracy has advanced considerably, mainly thanks to magnetostratigraphy, that permitted a chronological framework for the Pontian and Dacian stages in the Paratethys area and thus, enabled correlation with the biozones of the Mediterranean. However there remain some discrepancies between the scales of Snel et al. (2000) and Vasiliev et al. (2004) as it is shown on the Fig. 5.

Calcareous nannoplankton assemblages belonging to the NN11 and NN12 zones (i.e. Portaferrian–Bosphorian) occur in the Romanian Dacian basin (Marunteanu and Papaianopol, 1995; Snel et al., 2000) facilitating good correlations between the stratigraphic scales of the Dacian basin and the Mediterranean. In the Northern

Aegean (Orphanic Gulf–Strymon basin, Greece) temporary marine incursions are documented by the same assemblages, and their age (Upper Messinian, NN12 zone) is also supported by paleomagnetic data (Snel et al., in press)(Fig. 5).

These marine incursions in the Dacian basin are taken into account by Clauzon et al. (2005) who suggest, moreover, that a double cross exchange at high sea level occurred between the Dacian basin and the Mediterranean at 5.52 My (isotopic stage TG11) and 5.33 My (isotopic stage TG 5).

3.2. The gate-ways

These new data are not in agreement with previous interpretations of closure of the communications between the Mediterranean and the Paratethys since the Serravallian (Steininger and Rögl, 1984; Rögl and Steininger, 1984; Dercourt et al., 1993; Sacchi et al., 1997; Orszag-Sperber et al., 2000; Rouchy et al., 2001) and stimulate the search for these passages.

A proto-Bosphorus passage was first discarded (Percival, 1978; Schrader and Gersonde, 1978), but again considered (Kojumdgieva, 1987; Marinescu, 1992). A passage via the Black sea suggested by Hsü and Giovanoli (1979), rejected (Carbonnel, 1980) and discussed (Gillet, 2004). Çagatay et al. (2004, 2006-this issue) have excluded an exchange between the Mediterranean and the Sea of Marmara from the Late Serravallian to Late Pliocene, but not a connection between the Paratethys and the Sea of Marmara.

Sakinç and Yaltirak (2005) consider that two seas, separated by the present day Gelibolu Peninsula (which was a shallow sill) were present in the Aegean region during the Late Miocene, one being a branch of the Mediterranean occupied the Aegean corridor (Saros bay) and the other was a lagoonal bay of the Paratethys located in the present day Marmara Sea. These authors

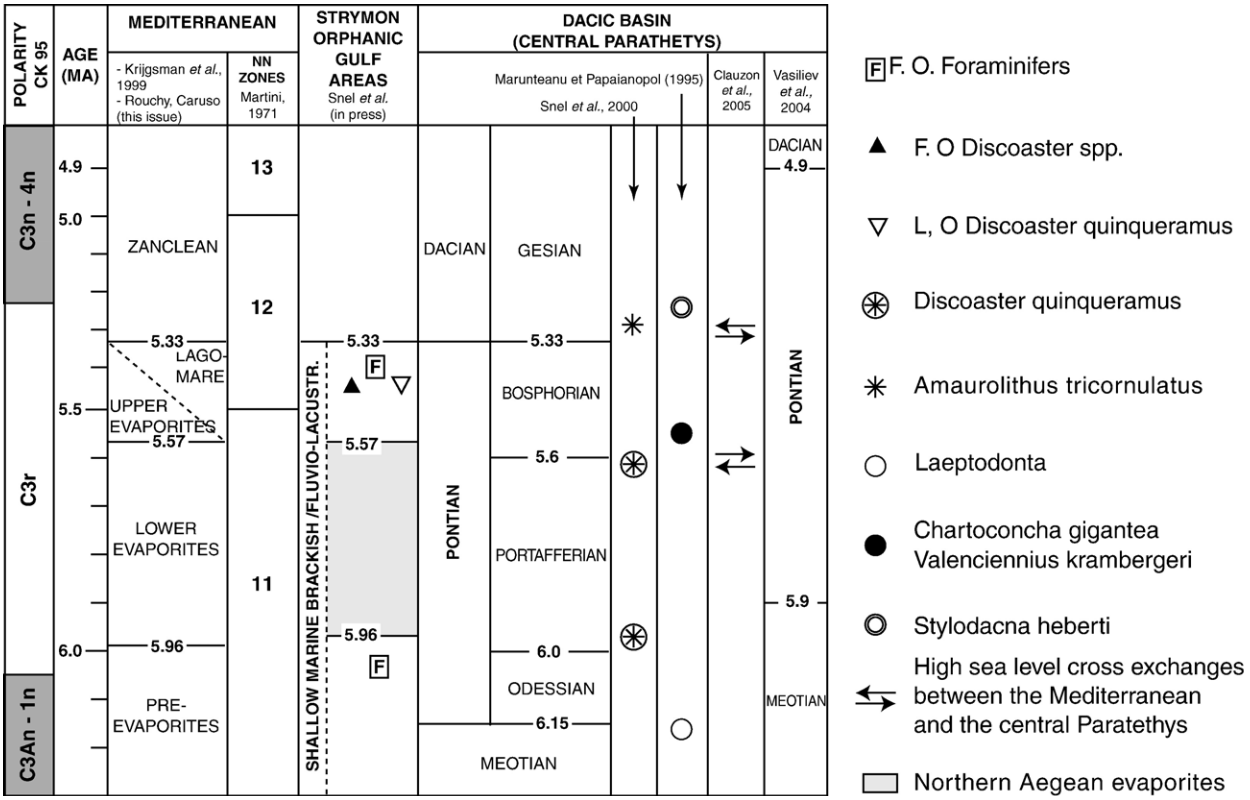


Fig. 5. Stratigraphic correlations between the Mediterranean, the Strymon and Orphanic Gulf area and the Dacian basin (Central Paratethys basin), after various authors. Evaporites in the Mediterranean occur between 5.96 and 5.33 My. The Northern Aegean evaporites are considered to be the equivalent to the Mediterranean Lower Evaporites, since they are dated between 5.96 and 5.57 My. The Lago-Mare period corresponds to a fluvio-lacustrine environment. The high sea level exchanges between the Mediterranean and the Dacian basin indicated by Clauzon et al. (2005) correspond to the isotopic stages respectively TG 15 (5.7 My) and TG 5 (5.33 My). There are some discrepancies between the data of Snel et al. (2000, in press) and Vasiliev et al. (2004), particularly concerning the Pontian–Dacian boundary, thus leading to discuss the connection between the Paratethys and the Mediterranean.

observed an alternation of sediments containing a marine Mediterranean fauna (*Ostrea*, *Pecten*) and Paratethyan faunas in the area of the sill (Intepe section). The presence of the endemic Paratethyan faunal assemblages (Ostracods, *Limnocardiidae*, *Dreissena, Melanopsis*) throughout the Northern Aegean indicates a brackish-water supply from the Paratethys, via the Marmara sea.

The Northern Aegean successions in the Orphanic Gulf area and the Strymon basin show the influence of both the Mediterranean and the Paratethys (Syrides, 1998; Popov and Nevesskaya, 2000; Snel et al., in press). Thus, the Aegean domain seems to be the main gate-way between the Paratethys and the Mediterranean, via the Dacic basin. An Aegean gulf was already considered by Cvijic (1911), Gillet (1937), Guernet (1978), among others.

4. Discussion

Because the significance of some features remains uncertain, several recurrent questions imply further discussion.

4.1. Paratethyan and Mediterranean connections

For Hsü et al. (1977), Hsü (1978), Cita et al. (1978a,b), Cita and McKenzie (1986), an invasion of Paratethyan immigrants followed the capture of high-standing Paratethyan lakes by headward erosion and canyon cutting during a time of drawdown of the sea. Numerous studies of the fauna have enabled Iaccarino and Bossio (1999) and several others to assess that the Mediterranean region "experienced fresh-water invasion from the Paratethys, due to tectonic and climatic variations that changed the drainage".

However, paleogeographic data suggest the separation between the Mediterranean and the Paratethys (Steininger and Rögl, 1984; Rögl and Steininger, 1984; Dercourt et al., 1993). The Paratethyan faunas may be also interpreted as an adaptation to Mediterranean brackish environments or/and a migration and the possibility of transport by air, leading others (Benson and Rakic-El Bied, 1991) to consider that a connection and an aquatic transport was not necessary to explain the presence of a brackish to fresh water fauna in the Mediterranean. For Cita and Ryan (1973), De Deckker et al. (1988), Bonaduce and Sgarella (1999), Orszag-Sperber et al. (2000), Rouchy et al. (2001), it was assumed that the faunas inhabited in shallow lakes, located within depressions of the contrasted Mediterranean morphology. These lakes were seasonally dried (deposition of evaporites) and subsequently filled by meteoritic water as it is indicated by the fauna and the $\delta^{18}O$ and $\delta^{13}C$ values of the carbonates (Pierre et al., 1998; Iaccarino et al., 1999a). These observations have bearing on the depth of the Mediterranean throughout the Messinian time. As already mentioned, Late Tortonian–Early Messinian and Early Pliocene sediments are considered to have been deposited in waters as deep as 1500 m, as indicated by foraminifer assemblages. By contrast, the Lago-Mare sediments were deposited in very shallow, sometimes emergent environments. Bassetti et al. (2006-this issue) in their study of the Nijar basin (Spain) suggest that the base level of the Lago-Mare was not significantly lower than the ocean. However Maillard et al. (2004), in the Valencia trough, relate two major erosion surfaces at the beginning and the end of the Messinian, the later affecting the top of the Upper Gypsum Unit. These suggest a decrease of oceanic input and an increase of run-off, responsible for the creation of shallow, episodically desiccated lakes situated below global sea level. This conception of the deposition of the Upper Gypsum Unit within shallow lakes situated in a deep Mediterranean basin questions a possible connection with the vestigial seas of the Paratethys. For Vasiliev et al. (2004), based on their high resolution magnetostratigraphy (Fig. 5) of the Upper Miocene to Pliocene sedimentary succession of the Romanian Carpathian foredeep, there is no evidence for water exchanges between the Mediterranean and the Eastern Paratethys during the Late Miocene.

As the connections between the Paratethys and the Mediterranean were based mainly on the possible migration of faunas versus endemic faunas, it is of interest to re-examine the studies relative to this topic, some of which showing that the interpretations are not conclusive.

4.1.1. Molluscs

Archambault-Guezou (1976) demonstrated, thanks to the very precise observations made by naturalists some centuries ago, the very rapid extension of the distribution of the species *Dreissena polymorpha* which, in one century, propagated from the Ponto–Caspic area (where this species is observed since the Early Pliocene), until Western Europe, probably via rivers; it was observed in Danube in 1769, in Belgium and Great Britain in 1824, and finally in the South of France in 1865–1866. Modern *Congeria* has propagated rapidly in Europe through rivers and channels, after their arrival from Africa, attached to the bottom of ships. These examples show that faunal colonization can be very rapid and their adaptability very efficient.

The Paratethyan origin of the mollusc *Dreissena rostriformis* and representatives of the subfamily

Limnocardiidae is also considered by Esu (1997) and Nevesskaya et al. (2002). For Magyar (2004), *Limnocardinae* appeared in the Pannonian basin during the Tortonian, and subsequently in the Euxinian basin during the Early Pontian (Early Messinian) and in the Aegean area during the Late Messinian. However, some species in the Northern Aegean, considered as typical of Mediterranean Messinian brackish waters are unknown in the Paratethys domain (Popov and Nevesskaya, 2000). For Popov et al. (2004), the origin of the molluscs assemblages was probably connected with more ancient Pannonian (Tortonian)–Paratethys biota which, subsequently, evolved independently.

The question of the passive dispersal possibilities (birds) to explain a transport of molluscs and foraminifers, is considered in studies on recent *Potamid* faunas currently found in lakes of South Algeria where they are associated with a thalassoid malacofauna dominated by Cardium *Ceratodesma glaucum*, in association with Foraminifers (especially *A. beccarii*) and Ostracods (*Cyprideis*). These lakes are located 250 to 900 km from the closest modern shore line (Plaziat, 1993).

4.1.2. Ostracods

Studies of ostracods offer a variety of interpretations. Concerning *Loxoconcha djaffarovi*, Carbonnel (1978) accepts the idea of Paratethys waters emptying into the Tethys. However, he considers that this cannot explain the distribution of *Cyprideis* of the DSDP holes (Legs 13, 42A, 42 B) from which desiccated eggs can be transported by birds. This is also reported by Benson and Rakic-El Bied (1991) who indicate that *Cyprideis salebrosa* lives in saline ponds in Kansas at least 1000 km from its primary habitat along the Texas coast. However, this is disputed by De Deckker et al. (1988), who demonstrate that *Cyprideis* requires permanent water to reproduce because its eggs, “unlike those of most lacustrine ostracodes, cannot withstand desiccation”.

Gliozzi et al. (2004) agree with an aquatic migration of the Paratethyan ostracods to the Mediterranean during the Messinian. However they indicate that during the Late Tortonian, an initial migration of ostracods in the Mediterranean was necessary effected via passive dispersal by birds, because the antagonistic salinity prevailing between Paratethys and the Mediterranean, at this time, did not allow the survival of these faunas in the Mediterranean.

Bassetti et al. (2003), following studies of ostracod assemblages referable to *Loxocorniculina djaffarovi* from the Umbro-Marchean Apennines, reveals an interesting difference between the Western and Eastern Mediterranean basin. Most ostracods in the Apennines seem to be restricted to the Western Mediterranean. Moreover, although Pontian and Dacian ostracod assemblages of the Pannonian and Dacian basins are certainly similar to the *L. djaffarovi* fossil assemblages, only a few species are common to both Western Mediterranean and Paratethys basins. For Bassetti et al. (2006-this issue), it is probable that the lakes of the Western Mediterranean were inhabited by endemic faunas.

Bonaduce and Sgarrella (1999) concluded their study of the ostracods of the Columbacci Formation by redefining the generalized term of “Lago-Mare” with the distinction of two different facies: a hyperhaline environment in which only a monotypic population of *Cyprideis* survived, and a brackish hyposaline environment (as recorded in the Arenazzolo Formation) characterized by numerous species of the *L. djaffarovi*. These two facies are recognized both in marginal and deep basins.

4.1.3. Dinocysts

The Paratethyan dinocysts (*Galeacysta*, *Impaginum*, etc.) are found in the Mediterranean (Corradini and Biffi, 1988; Bertini et al., 1995; Londeix, 2004; Popescu, 2004; Clauzon et al., 2005). It is pointed out that they require an aquatic transport. For these authors, the presence of *Galeacysta etrusca* in the Mediterranean is an important evidence of connections between the Paratethys (Dacic basin) and the Mediterranean (Popescu, 2004). Bertini et al. (1995) have doubts about a migration of *Galeacysta* from the Paratethys into the Mediterranean, preferring an endemism of this species, based on phylogenetic relationships between different morphologies of *Galeacysta* in both the Paratethys and Mediterranean basins. However, dinoflagellate cyst morphologies with unusual ornamentation and/or body shape are thought to be influenced by subnormal water salinity (Wall et al., 1973; Dale, 1996; Lewis et al., 1999). These intraspecific peculiarities lead some authors to recommend caution when attributing such morphologies to specific variations (Lewis et al., 1999; Londeix, pers.comm.).

4.2. Mediterranean–Atlantic connections

The presence of nannoplankton in the Northern Aegean and the Dacic basin implies brief marine incursions during the Lago-Mare interval (Fig. 5).

In the Mediterranean, marine influences in the sediments of the Lago-Mare are documented by the presence of coccospheres and planktonic foraminifers (ODP Sites 968 and 967, Blanc-Valleron et al., 1998;

ODP sites 974, 975, 978, Iaccarino and Bossio, 1999). Marine foraminifers also are present in the sediments cored during Legs 42 and 161 in the Balearic basin, especially at the top of Lago Mare facies (Iaccarino et al., 1999a), where dwarfed planktonic foraminifera associated with brackish benthic foraminifer assemblages occur in laminated sediments underlying the Pliocene marls. Marine influences also are reported by Cita et al. (1978a,b), Elion (1983), Spezzaferri et al. (1998), among others. Calcareous nannoplankton found within the laminated gypsum in Sicily (Rouchy, 1976) belong to a monospecific assemblage, and the foraminifers assemblages (Cita et al., 1978a,b; Iaccarino and Bossio, 1999) also are composed of dwarfed specimens.

The presence of the marine microfossils in the Upper Gypsum Unit, is puzzling, and it questions their significance: ephemeral incursion of the sea in the Mediterranean, allochtony of these organisms, adaptation in very drastic changes of the salinity? The autochtony of foraminifers in the Lago-Mare sediments was already questioned by the teams of the DSDP drilling (Cita et al., 1978a,b). It was observed that the continuously cored post-evaporite interval with typical Lago-Mare assemblage of *C. pannonica*, was alternating with strata locally very rich in Myogypsines or in planktonic foraminifers. This marine fauna was considered as reworked by part of the team, whereas another researchers thought that they documented a marine influx.

Iaccarino and Bossio (1999) are also convinced that, at least for the fauna of the Hole 978 A, both foraminifers and calcareous nannofosils are reworked, while only the ostracod assemblage reflects the original environment, due to their fragility. Spezzaferri et al. (1998) relate the presence of planktonic foraminifers associated with brackish ostracodes in Hole 967A to a “temporary incursion of Atlantic waters into a fully Lago-Mare environment”.

Thus the existence of marine fauna as documented by the presence of calcareous nannoplankton in the Aegean area needs a marine influx from the Atlantic and one must consider that very short marine incursions occur during the Lago-Mare interval, as they are described in several sections.

4.3. Depth and tectonics

The bathymetry of the Mediterranean before and after the MSC has been documented mainly by foraminifers and psychospheric ostracods indicating deep water conditions (1000 up to 2000 m). The setting of the Upper Messinian lakes inhabited by a shallow water fauna (0 to 50 m) at different topographic levels, questions the possible role of tectonics.

Although shown that tectonics certainly evolved during the entire Neogene in the Mediterranean (see Jolivet et al., 2006-this issue) it is difficult to demonstrate its direct effects on the scale of our observations other than sedimentary features (water escapes, slumps, in Orszag-Sperber et al., 1989). However, several papers concerning the evolution of the Eastern Mediterranean are devoted to this pattern. Among them, Chaumillon and Mascle (1997) stress an important event initiated at 5–6 Ma. which has induced a differentiated paleogeography of Messinian evaporites.

The lakes of the Lago-Mare in which the brackish to fresh water sediments were deposited were obviously shallow. As they are now observed both in marginal basins and deep Mediterranean basins, this implies either vertical movements after the deposition of sediments with shallow water fauna (i.e. collapse of former shallow basins to their present deep level) or the existence of shallow free basins, arranged in tiers, at different topographic levels, within a significantly lowered Mediterranean.

Sites 967 and 968, located on the slope of the Eratosthenes Sea-Mount (South of Cyprus), in which Lago-Mare facies sediments have been met with, have a differential depth of 1000 m (Robertson, 1998; Major et al., 1998) and also differ from the Lago-Mare as described in the marginal basin of Pissouri (Orszag-Sperber et al., 2000; Rouchy et al., 2001). Moreover, Major and Ryan (1999) explained the presence of Tortonian shallow-water carbonate (coralgal sediments) and Pliocene deep water pelagic oozes on the top of the Eratosthenes seamount by a significant subsidence of the seamount during the Messinian, superimposed on the drawdown and refill phenomena.

4.4. The marine re-flooding of the Mediterranean

The marine refilling at the beginning of the Zanclean is considered to have been very rapid. For Hsü et al. (1973), the re-flooding was evaluated at “probably less than 10 000 years”. It is considered as a “catastrophic deluge” for Cita et al. (1978a), instantaneous through the Mediterranean basin (Hilgen and Langereis, 1988). Blanc (2002), who takes into account both the present exchanges of water between the Atlantic ocean and the Mediterranean Sea and the morphology of the Gibraltar Strait area, estimates that only 36 years are needed “to fill an empty Mediterranean, even when taking into account the evaporation”. The velocity of the flow refilling the Mediterranean from the Atlantic through the Gibraltar Strait is evaluated by this author at several tens to more than 100 m s^{-1}, and termed “cataclysm”.

4.5. Brackish to freshwater faunas at the base of Pliocene?

The presence of brackish to freshwater fauna is documented within sediments assigned to the Pliocene, just before the appearance of the foraminifers usually considered as indicating the earliest Zanclean: they were attributed to an "infra-Pliocene" time by Ballesio (1971) in the Rhône Valley (France), considered as indicating a progressive change from continental to marine environments at Cava Serredi section (Tuscany, Italy) by Corradini and Biffi (1988) and mentioned as "pre-Pliocene" when associated with epi-pelagic foraminifer assemblages, lacking stratigraphic markers in the Cyprus sections by Rouchy et al. (2001). For Di Stefano et al. (1999) the rare specimen of *Cyprideis* sp. found in the very basal Pliocene are reworked from the underlying Messinian continental sediments.

Suc and Clauzon (2004) and Clauzon et al. (2005) relate the presence of brackish to fresh water fauna in deposits interpreted as equivalent to the earliest Zanclean to a "Lago-Mare event" that would be Pliocene in age.

The presence of brackish micro-organisms is considered to be the consequence of the mixing of faunas due to an exchange of water masses during the very rapid transition from continental to marine conditions at the Messinian–Zanclean boundary (Iaccarino et al., 1999a; Cita, person.com.). Several negative shifts of the δ^{18}O values occur at several sites in the earliest Pliocene deposits, indicating the contribution of less saline waters (Di Stefano et al., 1999; Pierre et al., 2006-this issue). Corradini and Biffi (1988) put forward a rapid but progressive deepening of an environment unfavourable for marine organisms to clearly open marine conditions. The small size of the first immigrants and composition of their assemblages at sites 974B (Tyrrhenian basin) and 975B (Balearic basin) suggest that at the base of the Zanclean the bottom waters were poorly oxygenated (Iaccarino et al., 1999b).

The benthic foraminifers progressively re-populated the Eastern Mediterranean sea floor during the biozone MPl1 (Spezzaferri et al., 1998) and the fully open, deep-water, benthic communities from the Atlantic appear at the MPl1/MPl2 boundary, showing that the substitution of shallow waters of the continental Lago-Mare by deep Atlantic waters required a very short time, estimated to less than one cycle of astronomical precession (20 kyr) for Hilgen and Langereis (1988). At sites 652 (Tyrrhenian Sea), both eustatic sea level rise and tectonic movements results in the full restoration of normal marine conditions in the Mediterranean, approximately 250 000 yr after the earliest Pliocene marine flooding (McKenzie and Sprovieri, 1990).

Furthermore, according to McKenzie and Sprovieri (1990) the different depths between the Tyrrhenian and Balearic basins could be responsible for the slight differences in time necessary for the arrival of the benthic foraminifera at the beginning of Pliocene, while the reflooding is also considered to be very rapid but synchronous throughout the Mediterranean (Krijgsman et al., 1999b).

4.6. The drifting of the meaning "Lago-Mare"

The meaning of "Lago-Mare" necessarily evolved with a better knowledge of the Messinian/Pliocene transition. From its original definition based on the paleogeography of a Paratethys isolated from the global ocean since the Maeotian/ Sarmatian (Serravallian pro-parte-Tortonian) and having evolved in separated internal seas, "Lago-Mare" was later applied to the brackish fauna and sedimentary facies which accumulated at the end of Messinian in the Mediterranean area. Finally, the concept of Lago-Mare has been enlarged to include the Upper Gypsum Unit in which evaporites alternating with marls contain this so-called Paratethyan fauna (Cita and McKenzie, 1986; Orszag-Sperber et al., 2000).

The brackish to fresh water fauna found within the marine sediments of the very base of the Pliocene, together with the influence of continental waters in the basal part of the MPl1 (as indicated by the oxygen isotopic composition of the carbonates), should not be included in the term Lago-Mare because a major change coincides with the Miocene–Pliocene boundary. It is shown by: *i*, a very sharp contact between the Messinian and Zanclean sediments as it is observed in most sites, *ii*, an important shift of the rate of carbonates from the Messinian to the very Early Pliocene (Spezzaferri et al., 1998; Pierre et al., 1998), *iii*, the repopulation of the environment by the benthic communities since the very early Zanclean.

It is logical to reserve the term "Lago-Mare" to its closest original meaning: as such it should be applied to the brackish to fresh water environment which existed just after the Lower Gypsum deposits and just prior the marine Pliocene reflooding in the Mediterranean. This implies an environment, mainly brackish to fresh water, an Upper Messinian age and a duration of about 200 kyr.

5. Conclusion

Active research with important advances in the understanding of the so-called Lago-Mare led to a better knowledge of the Mediterranean geodynamics during the Messinian. The "Lago-Mare" concept evolved by taking into account the data collected by different teams at the transitional Messinian–Pliocene boundary. The Lago-Mare "facies", "fauna" or "event", represent the very short time separating the marine Lower Evaporite unit from the marine Pliocene refilling, and characterized mainly by brackish to fresh water environment. The short interval at the beginning of the marine Pliocene, showing continental influxes, and which cannot be dated precisely, because of the lack of biostratigraphic markers, does not result from the same geodynamical evolution. Thus, it may now be convenient to extend the use the name Lago-Mare to the Upper Gypsum Unit only, this being close to the original meaning.

The accurate stratigraphic scales established both in the Paratethyan and Mediterranean basins, even if they are still being debated, allow now to better correlate the events at the Miocene–Pliocene (Mediterranean) and the Pontian–Dacian (Paratethys) boundaries. However, some recurrent questions remain. The questionable connections between the Mediterranean and the Paratethys imply to reconsider the significance of some features: particularly, the recent studies of the brackish to fresh water faunas show that their migration and/or endemism is not yet clear and their distribution in both the marginal and deep basins in the Mediterranean is still uncertain. Questionable also is the depth of the Mediterranean during the Lago-Mare time where the shallow water sediments deposited, sandwiched between the deep marine sediments of the Tortonian and Zanclean. The role of the tectonic in the distribution of these shallow lakes at different topographic levels is not well established.

The presence of marine micro-organisms in the Aegean and Dacic regions, during the "Lago-Mare" period, implies (episodic) connections between the Atlantic Ocean, the Mediterranean and the Paratethys, that strongly need more studies.

That being, the recent data collected at the Miocene–Pliocene transition, both in the Mediterranean and the Paratethys area points to the Aegean domain and the Dacic Basin as a key region for further investigations.

Thus, during the very short Lago-Mare time interval, at the end of the Messinian Salinity Crisis, just before the marine Pliocene reflooding of the Mediterranean, several major events took place. These events determined up to the present the configuration of the Mediterranean and the adjoining areas.

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