# Chronology of the Messinian events and paleogeography of the Mediterranean region *s.l.*

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## Abstract

After an intense effort in chronology (magnetostratigraphy, biostratigraphy), the effects of the Messinian Salinity Crisis have been explored all around the Mediterranean Sea and its appendix, the Eastern Paratethys. The respective influence of regional tectonics and global climate has been estimated, the role of the latter cannot be neglected. The Messinian Erosional Surface cuts everywhere the marginal evaporites and correlates to the halite in the central deep basins, an observation that led to the two-step scenario of the crisis (Clauzon *et al*., 1996). The Lago Mare biofacies results from various paleogeographic conditions, reproduced several times: Mediterranean–Paratethys exchanges during high sea-levels, dilution by river input at the end of the evaporitic phase. Henceforth, Lago Mare cannot have a chronostratigraphic value. This dense

study results in a detailed chronology of the Messinian Salinity Crisis and in the paleogeographic reconstruction of the region, showing that the crisis cannot be reduced to a simplistic scenario.

## Introduction

Since Gautier *et al.* (1994) first published a magnetostratigraphy of deposits encompassing the Messinian Salinity Crisis, systematic biostratigraphic studies (nannoplankton and planktonic foraminifers) carried out around the Mediterranean and adjacent basins (Eastern Paratethys) have enabled the development of a detailed succession of Messinian events and associated paleogeographic changes.

These aspects are discussed below along the following development: climate, erosion, and "Lago Mare" events as a basis of the two-step scenario (Clauzon *et al.*, 1996), followed by a discussion of chronology and paleogeography.

## 1. Climate

Pollen records have established that drastic climatic change was not the cause of the desiccation of the Mediterranean Sea (Suc and Bessais, 1990; Fauquette *et al.*, 2006). However, the influence of cooling cannot be discarded as done by Krijgsman *et al.* (this volume). It may have caused, in conjunction with the tectonic narrowing of the Rifian Corridor (Figure 1; Warny *et al.*, 2003; see also Drinia *et al.*, 2007), a context of minor sea-level fall in the Mediterranean, which was prevalent in the marginal basins because of their relative isolation by sills. At Bou Regreg (i.e. the Atlantic outlet of the Rifian Corridor), the large fluctuations in abundance of *Operculodinium israelianum*, a neritic dinoflagellate cyst, indicate that glacio-eustatic variations mostly controlled the water-depth changes in the Rifian Corridor before and after the Antarctic glacials TG 22 and TG 20. These conditions continued up to 5.6 Ma, i.e. during the narrowing of the corridor, indicated not only by increasing neritic conditions according to dinocysts but also by the transition from distal to coastal conditions according to a severe decrease of *Pinus* in the pollen record (Figure 1; Warny *et al.*, 2003).

The newly exposed coastal regions around the Mediterranean Sea probably experienced very dry conditions, as expressed by the migration of subdesertic plants from Sicily, which is 4° to the

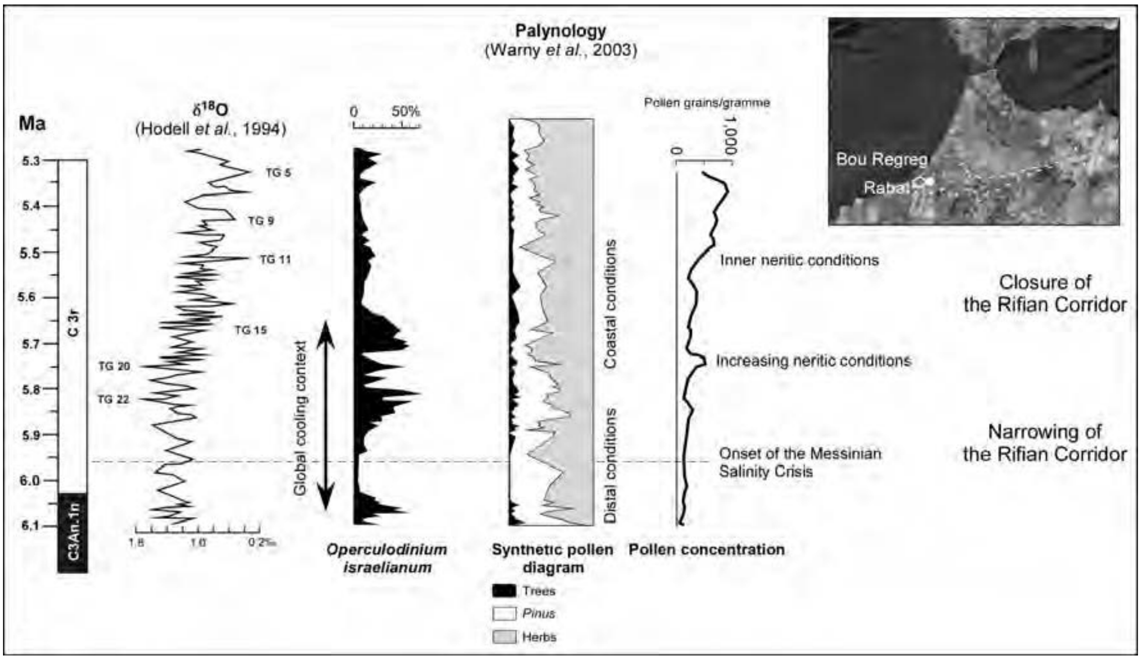


Fig. 1. Palynology at Bou Regreg (Morocco) documents the global and local conditions during the narrowing of the Rifian Corridor leading to its closure.

Palynological data and $\delta^{18}O$ from foraminifers are taken from the same samples.

The Rifian Corridor is indicated by a doted line on the map.

south (Fauquette *et al*., 2006; Popescu *et al*., 2007). Steppic elements are also shown to increase in pollen records from the earliest Zanclean of the Black Sea (Popescu, 2006).

## 2. Erosion

Only the erosional surface which cuts the uppermost marginal evaporites (Figure 2) is the Messinian Erosional Surface overlain by Zanclean deposits and corresponds to the peak of the Salinity Crisis, i.e. deposition of evaporites in the almost desiccated central basins (Clauzon *et al*., 1996; see also Lofi *et al*., this volume). This feature has been observed everywhere around the Mediterranean (for example: Clauzon, 1973; Chumakov, 1973a; Delrieu *et al*., 1993; Poisson *et al*., 2003) and also in the Eastern Paratethys (Dacic Basin: Clauzon, pers. comm.; Black Sea: Gillet *et al*., 2003, 2007). In Sicily, an erosional phase is intercalated between the Lower and Upper Evaporites and is often considered as the Messinian Erosional Surface (Butler *et al*., 1995; Krijgsman *et al*., 1999c). As this erosion is expressed at the foot of the Nebrodi Mountains, in a

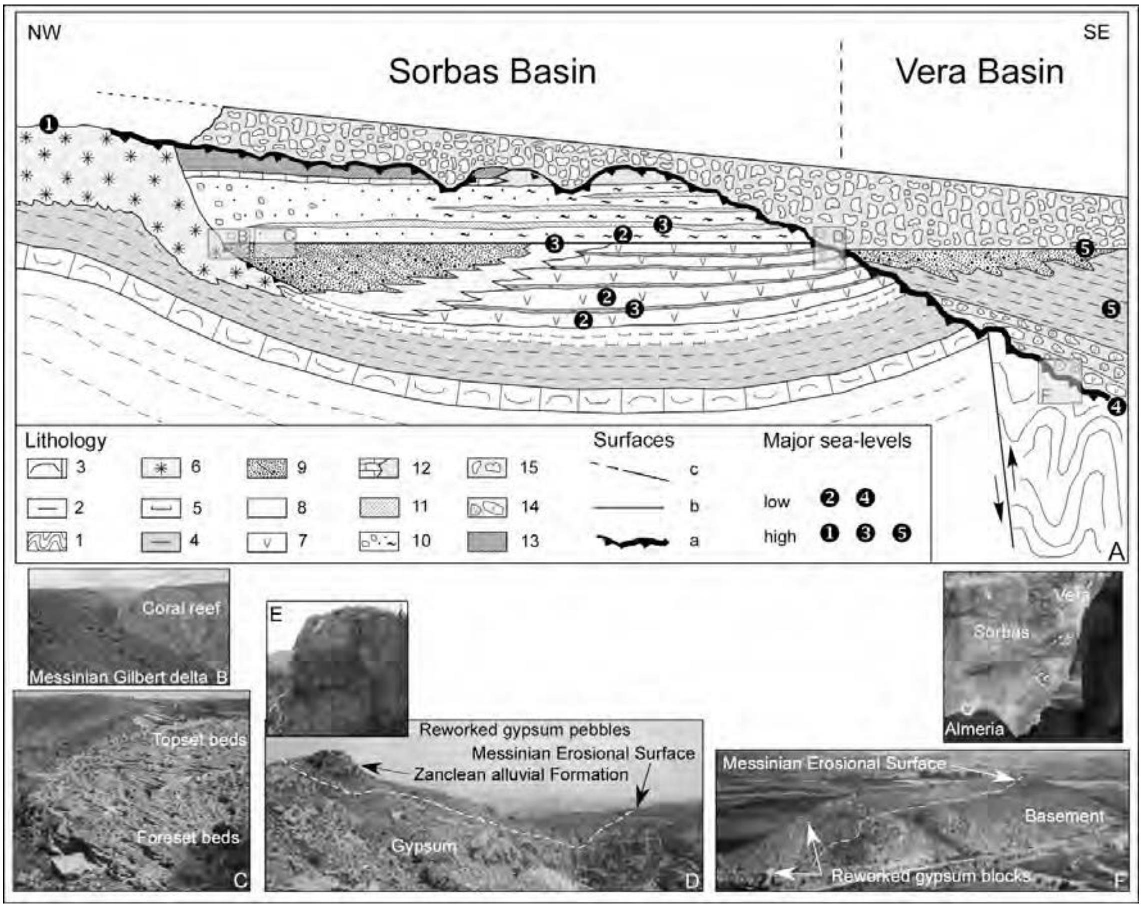


Fig. 2. Restituted Sorbas and Vera basins (Spain).

**A:** Synthetic cross-section.

Sorbas: **B:** Messinian Gilbert delta overlying coral reef with erosional contact; **C:** Marine-continental transition of Messinian Gilbert delta; **D**: Late Messinian valley infilled by Zanclean alluvial deposits; **E:** Detail of Zanclean alluvial deposits including reworked gypsum pebbles.

Vera: **F:** Block formation including reworked gypsum overlying the Messinian Erosional Surface.

Lithology: **1:** Betic basement; **2:** Tortonian clays; **3:** Earliest Messinian (=M) calcarenite; **4**: Messinian and Zanclean (=Z) clays; **5**: Diatomites (M); **6**: Carbonated constructions (coral reefs, Terminal Complex: M); **7**: Gypsum (M); **8**: Silts with gypsum (M); **9**: Fluvial conglomerates Gilbert deltas (M, Z); **10**: Red continental pebbles (M); **11**: White clays (M) with marine fossils; **12**: Continental clays and limestones (M); **13**: Paleosoils; **14**: Subaerial formation with reworked gypsum blocks; **15**: Continental pebbles. Surfaces: **a**: Erosional surface; **b**: Marine-continental transition within Gilbert deltas; **c**: Pliocene abandonment surface.

Major sea-levels: **1**: Ante-crisis coastline; **2**: Cyclic low sea-levels during the first step of the crisis (deposition of marginal evaporites); **3**: Cyclic high sea-levels during the first step of the crisis; **4**: Sea-level drop of the second step of the crisis (deposition of evaporites in the central basins); **5**: Zanclean high sea-level.

similar relief context as in Tunisia (El Euch – El Koundi *et al*., in press) where it is overlain by the Messinian Erosional Surface itself, we consider that it has been caused by tectonic uplift and has only a local significance. Some marginal localities simulate an apparent continuity between Messinian and Zanclean deposits but show in fact a clear discontinuity caused by a weak erosion in an interfluvial context: Cava Serredi in the Livorno region and Eraclea Minoa in Sicily (Popescu *et al*., in press), Intepe in the Dardanelles Strait (Melinte-Dobrinescu, pers. comm.; see also Çağatay *et al*., this volume).

In many places (Sorbas: Figure 2; Vera, Dardanelles Strait, Orb Valley), an older erosional surface coeval with the marginal evaporites is evident, and this surface corresponds to the first step of the crisis (Clauzon *et al*., 1996). Contrary to the assumption defended by Krijgsman *et al*. (this volume) the marginal evaporites significantly preceded the central deep basin ones.

## 3. "Lago Mare" events

Two "Lago Mare" events correspond to exchanges between the Mediterranean and Eastern Paratethys during high sea-level episodes just preceding and following the peak of the Salinity Crisis, respectively (Clauzon *et al*., 2005): Paratethyan congeria, ostracods and dinoflagellates invaded the Mediterranean, while Mediterranean calcareous coccoliths, foraminifers and dinoflagellates entered the Eastern Paratethys (Figure 3).

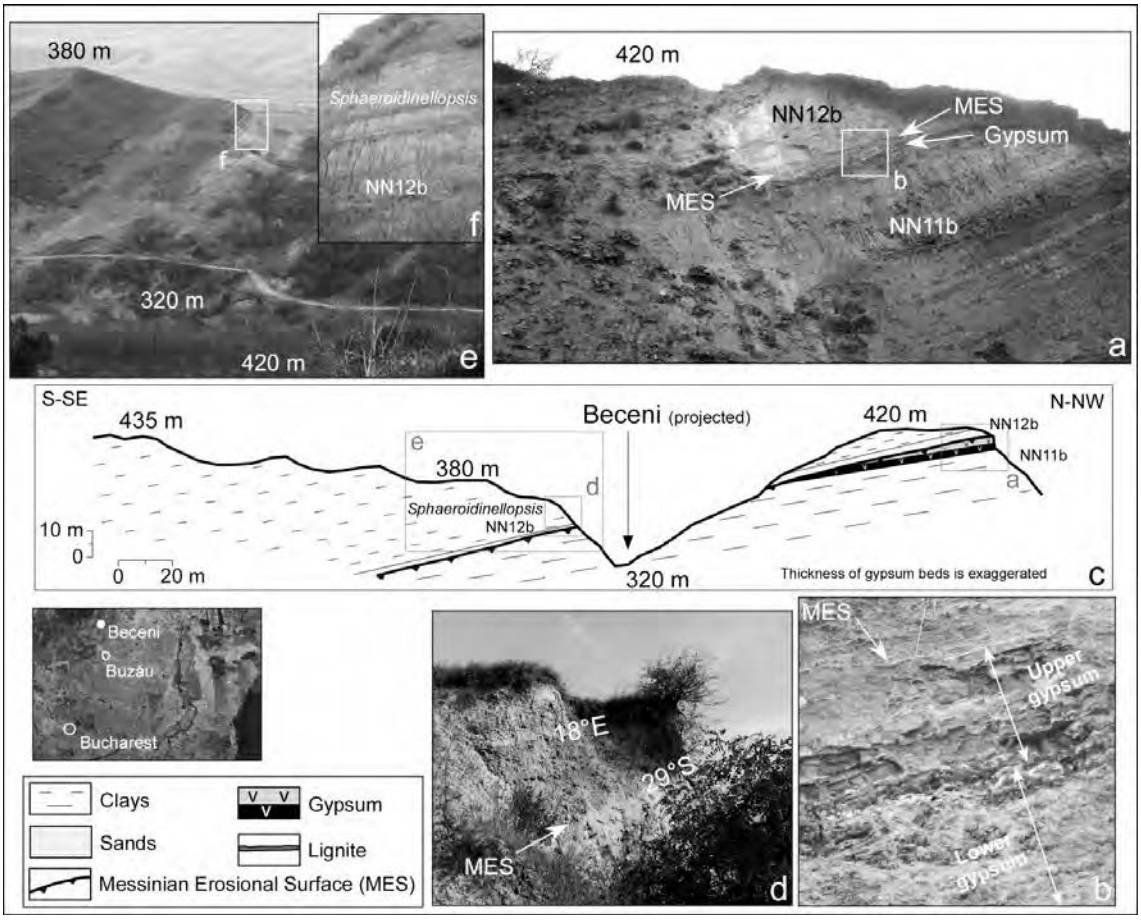


Fig. 3. The Messinian–Zanclean succession at Beceni (Romania, Eastern Paratethys).

**a**: General view of the Messinian gypsum layers overlying clays, truncated by the Messinian Erosional Surface; **b**: Detail of the gypsum; **c**: Cross-section in the Beceni area; **d**: Messinian Erosional Surface overlain by Zanclean clays; **e**: Zanclean deposits channelled within the Messinian ones; **f**: Detail of the earliest Zanclean clays.

Note the two successive influxes of Mediterranean marine waters below and above the Messinian Erosional Surface indicated by nannoplankton and foraminifers, and corresponding to the two high sea-level "Lago Mare" events in the Mediterranean.

For example, on both sides of the Tyrrhenian Sea, the "Lago Mare" of Aleria (Corsica) belongs to Zanclean while that of Cava Serredi (Livorno, Italy) belongs to Messinian. In the Adriatic perched area, the Colombacci Formation (a "Lago Mare" biofacies) and the immediately underlying sediments are earliest Zanclean in age (Popescu *et al*., 2007). At Eraclea Minoa (Sicily), the Lago Mare Formation belongs to Messinian but the overlying Arenazzolo Formation (separated by the Messinian Erosional Surface) shows a "Lago Mare" biofacies which is attributed to the earliest Zanclean (Londeix *et al*., 2007; Popescu *et al*., in press).

Another "Lago Mare" event marked by ostracods only was exclusive of the almost desiccated central Mediterranean basins, probably corresponding to freshwater inputs (Rouchy *et al*., 2001) maybe caused by stream piracy of rivers with a large drainage basin at the end of the crisis peak, the Ebro (Babault *et al*., 2006) and Sahabi rivers (Griffin, 2002).

## 4. Chronology

The resulting detailed chronology is given in Figure 4. In many places (Marches: Popescu *et al*., 2007; Sicily: Popescu *et al*., in press; northern Morocco: Cornée *et al*., 2005; Dacic Basin: Clauzon, pers. comm.; Dardanelles Strait: Melinte-Dobrinescu, unpublish. data), the Zanclean reflooding precedes the "official" base of Zanclean. This is also supported by two superposed "foreset-topset bed" sequences in some Gilbert deltas (Roussillon, Skopje). Zanclean reflooding seems to have occurred in two steps (collapse of the Gibraltar Strait at 5.480 Ma, widening of the Gibraltar Strait at 5.330 Ma; Figure 4).

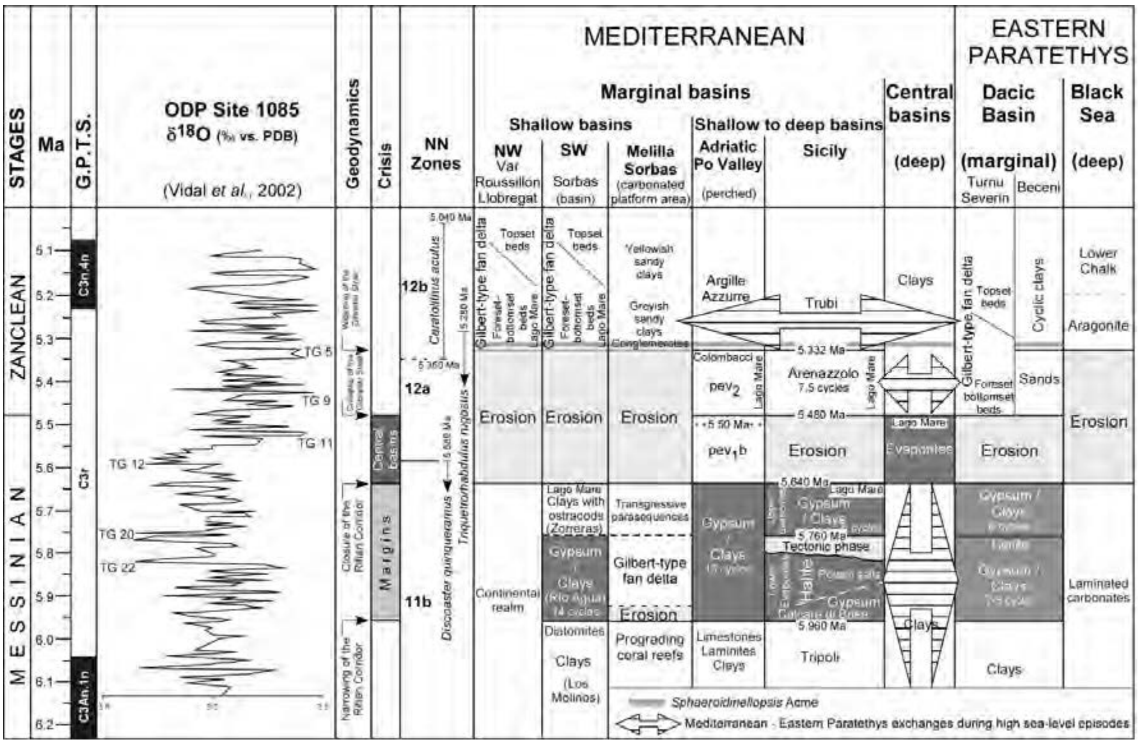


Fig. 4. Chronology of the Messinian–Zanclean events in the Mediterranean and Eastern Paratethys.

## 5. Paleogeography

A continuous paleogeographical development is shown on Figure 5, which focuses on five critical periods. Among the most important new evidences one notes:

- the pre-crisis activity of the corridor between the Aegean Sea and the Dacic Basin which connected these basins during high sea-level episodes up to the Early Pliocene, and its western branch as a link with the Panonian Basin which was active before the crisis (Popescu *et al*., in press);

- the absence of direct connection between the Aegean Sea and the Black Sea through the Marmara Sea area and the resulting Messinian canyon in the Dardanelles Strait area, the cutting of which provides a fine time-control to the passage of the North Anatolian Fault (Armijo *et al*., 1999);
- the continuous passage of Atlantic waters through the Gibraltar Strait before its collapse caused by regressive erosion (Blanc, 2002; Loget *et al*., 2005);
- the persistence of some perched freshwater (Adriatic-Po: Roveri and Manzi, 2006; Popescu *et al*., 2007; Dacic: Clauzon *et al*., 2005) basins with an almost continuous sedimentation during the peak of the crisis.

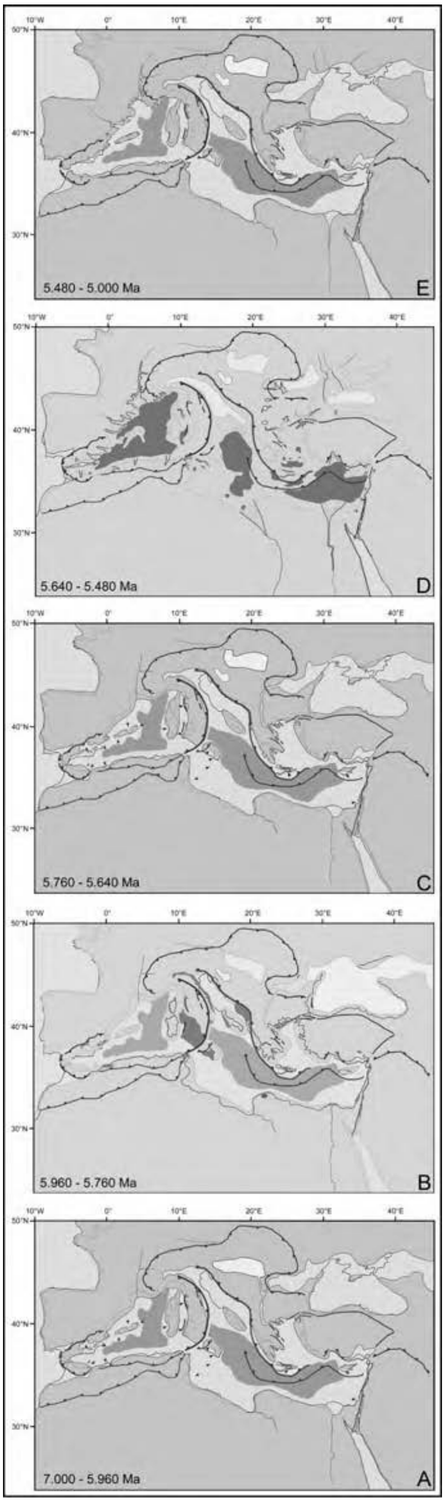


Figure 5. Palaeogeography of the Mediterranean *s.l.* region between 7 and 5 Ma.

Some of the modern sills (Gibraltar, Otrante, Sicily) were extant between 7 and 5 Ma. Marginal shallow basins are in light grey, central deep basins in dark grey, brackish to freshwater ones in very light grey. The architectural relief frame is indicated in black. Evaporitic rocks are in very dark grey, carbonated platforms in doted areas indicated by arrows.

**A**: 7.000–5.960 Ma, Ante-crisis situation; **B**: 5.960–5.760 Ma, First (marginal) step of the crisis; **C**: 5.760–5.640 Ma, High sea-level interval between the two evaporitic steps; **D**: 5.640–5.480 Ma, Second step (almost complete desiccation of the Mediterranean and Black seas; **E**: Zanclean “Deluge”.

Such a succession of major geographic changes strongly affected the fauna (fishes, molluscs, echinoids, bryozoans, crustaceans, foraminifers) and flora (dinoflagellates, calcareous coccoliths, diatoms) from marine and continental (rivers, lakes, groundwaters, lagoons) aquatic habitats. Processes which resulted in restoring the Mediterranean biota after the Messinian Salinity Crisis are still unknown. Isolation of basins followed by their re-connection, catchment of rivers, huge variations in salinity, etc. have drastically affected organisms, the marks of which could be still present in the present-day biodiversity. To study how much the crisis influenced modern biodiversity is an exciting challenge both for paleontologists and biologists.

## Conclusion

The Mediterranean region *s.l.* was marked by severe upheavals during the 6-5 Ma time-interval which encompasses the Messinian Salinity Crisis, forced both by tectonics and sea-level changes. Their deciphering depends on a finer chronological evaluation and more detailed paleogeographic reconstructions. To core the central basin evaporites is also an absolutely necessary target. In addition to these questions, a problem is to be answered: was the Black Sea almost completely desiccated too? The pre-existing connection with the Mediterranean is able to explain the beginning of the process up to the desiccation of the sill of the Skopje Corridor. And then? It could be considered that the desiccation of the Mediterranean caused a severe aridity in the nearby regions as suggested by pollen records (Popescu, 2006) that extended the process.