The Messinian Salinity Crisis in the offshore domain: an overview of our knowledge through seismic profile interpretation and multi-site approach

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Abstract

Most studies dealing with the Messinian Salinity Crisis (MSC) are based on outcrops located in peripheral Mediterranean basins (Morocco, Cyprus, Spain, etc.). These basins contain incomplete Messinian successions, making a full interpretation of this event a difficult challenge. Seismic profiles allow the exploration of the deep domain, which, contrary to the peripheral basins, registered the entire MSC event. We present here new results based on a comparative study of 13 areas located offshore, in the Mediterranean and Black Seas. The key seismic markers of the offshore MSC are erosion surfaces and depositional units. This work provides an overview of these markers and illustrates the potential of the multi-site seismic approach in increasing our understanding of the MSC. We also propose a new global and coherent terminology for MSC markers in the entire offshore Mediterranean area.

Following the workshops' conclusions, it appears that outcrops in Sicily and the Apennines may offer for the first time an onland analogue deep basins markers.

1. Introduction

Due to limitations in funding and data accessibility, most studies of the Messinian Salinity Crisis (MSC) are based on outcrops located onland (Morocco, Cyprus, Spain, Italy, etc.). A near-consensus now exists around an adaptation of the deep-desiccated basin model (Hsü and Cita, 1973), but several key points are still debated, including the detailed modalities of the crisis, the timing, duration and amplitude of the sea falls, and the significance, nature and relative relationships of Messinian deposits and erosion surfaces. This is essentially because the peripheral basins (where most detailed field observations come from) only contain incomplete Messinian successions, making a full interpretation of this event a difficult challenge. In addition, the observations from the offshore domain are only partly used in scenarii of the MSC because of scale integration problems and ambiguous labelling, leading to frequent ambiguities and misunderstandings (e.g. onshore and offshore “lower evaporitic unit”). Offshore studies have thus been less numerous than works onshore. However, the increasing quality of the geophysical seismic reflection data offers the advantage to image the Messinian markers much better than previously. It is now possible to study the spatio-temporal organisation of these markers from the inner shelf down to the abyssal plain. Seismic profiles thus allow exploring the deep domain, which, conversely to the peripheral basins, has registered the entire MSC event.

Since 2004, work on the MSC has been undertaken as part of the ECLIPSE French research programme, aiming to produce a seismic atlas illustrating the MSC markers in the Mediterranean offshore domain. Several study areas are considered, from the western Mediterranean to the Black Sea (Figure 1). We present here for the first time results based on a comparative study of these areas and highlight the potential of the offshore multi-site seismic approach in increasing our understanding of the MSC. Comparative study and multi-site approach allow analysing the impact of the MSC on margin segments and basins that have various structural, geodynamical and geological backgrounds.

During the crisis, while the margins were largely eroded, deep basins accumulated sediments under the form of thick evaporitic and detritic units. At the contact of both, in an area of highly variable extent, detritals are supposed to emplace and were until recently either missing or impossible to identify. The key seismic markers of the MSC in the offshore domain are thus erosion surfaces and depositional units.

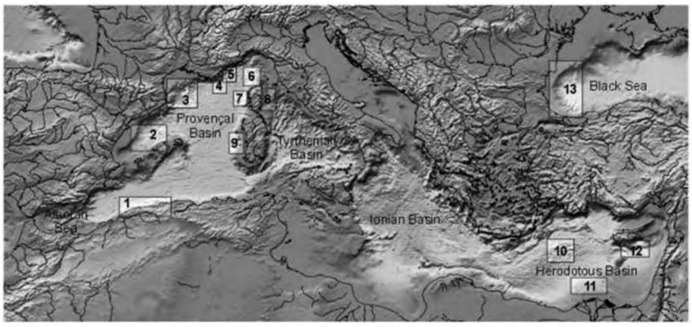

Fig. 1. Map showing the location of the 13 study areas used for the comparative study at the scale of the Mediterranean and Black Seas. The multi-site approach allows analysing the impact of the MSC on margin segments and basins that have various structural, geodynamical and geological backgrounds. Intermediate basins: Valencia Through (1) and Eastern Corsica (8); Narrow and steep margins: Provençal (4) and Ligurian (5) margins, Western Corsica (7), Western Sardinia (9); Large thick margins: Gulf of Lions (3), Nile (11), Romanian margin (13); Active areas: Algerian Margin (1), Florence ridge (10), Cyprus arc (12).

2. Messinian units in the offshore domain

2.1 Deep basin evaporites and deep basin trilogy

Messinian evaporites occupy most of the present-day Mediterranean domain. Two groups can be distinguished. The first concerns thick evaporites deposited in the large and deep/intermediate basins (mostly present-day deepest areas of the Mediterranean). The second refers to thinner evaporites accumulated in the peripheral basins (now located onshore and generally isolated from the deep basins). No stratigraphic or sedimentologic correspondences can be established between those two groups of evaporites because they are totally disconnected from a geographical and geometrical point of view.

The deep basin evaporites are generally evidenced on the seismic profiles, thanks to the transparent facies and the plastic deformation of the Messinian salt, creating listric faults and diapirs (Gaullier *et al.*, this volume). Seismic reflection studies report thicknesses up to 2,500 m in the oriental basin and up to 1,600 m in the occidental basin.

In the western Mediterranean deep basin, three distinct seismic units (Messinian trilogy) have been identified (Montadert *et al*., 1970). For a long time, they have been called Lower Evaporites, Salt, and Upper Evaporites. However, in order to avoid misleading use of these terms, we refer to them as the Lower Unit (LU) at the base, the mobile unit (MU) in the middle and the Upper Unit at the top (UU). In the eastern Mediterranean basin, the Messinian seismic trilogy (UU, MU, LU) has not been identified on the seismic profiles. In our data a thick Mobile unit is visible, but not bracketed by any LU and UU.

In the central part of the western Mediterranean basin, the "trilogy" is concordant at the base and at the top with the Miocene and the Plio-Pleistocene sequences, respectively. The absence of erosion surface in this sequence testifies to the permanent immersion of the deepest part of the abyssal plain during the "desiccation" phase. Therefore, the deep western basin has never been emerged and appears as a continuous recorder of the entire MSC. In more proximal areas, the deep basin trilogy is observed as a lateral onlap on margin foots. This peripheral onlap shows that, unlike the more distal areas, the registration of the MSC is incomplete. This onlap possibly reflects the progressive infilling of the abyssal plain by the Messinian deposits, as the subsidence apparently did not compensate the extremely high sedimentation rate in the basin (> 1,600 m in less than 300,000 years).

Only a very small part of the deep MSC sequence has been sampled during the ODP and DSDP legs (Hsü and Cita, 1973). The deep sea drilling holes failed to penetrate into the mobile unit. The halite and potash salts encountered in Holes 134, 374 and 376 all belong to top deposits. The greatest part of the Messinian evaporites (around 90%) is thus still unknown (Rouchy, 2004) and the lithology, stratigraphy and depositional environments can only be studied indirectly. Seismic profiles allow clarifying the internal structure of the deep MSC sequence.

2.1.1 Upper Unit (UU)

UU is the upper and most recent deep basin unit. It is generally 500-800 m thick in the occidental basin and is indicated by a group of parallel and relatively continuous reflectors. UU is aggrading and onlaps the margin foots. The top of this unit has been sampled during DSDP Leg XIII (Hsü and Cita, 1973) with the discover of the "pillar of Atlantis", made with dolomitic marls and anhydrite in layers. Stromatolites characterizing arid and shallow marine depositional environments (Sabkha) have also been observed, interbedded with marly levels rich in deep marine fauna, locally non salty. The top of UU has been labelled TES in this study. It is overlain by Plio-Pleistocene deposits.

UU has been evidenced in many areas all around the Northwestern-Mediterranean, where it is continuous, from the Gulf of Lions, to the Valencia Trough, Alboran and Algerian basins. However, this UU layer has not been seismically observed in the deep eastern Mediterranean (Levantine domain, Cyprus or Florence arcs of the Mediterranean Ridge). Only the thick salt unit (MU) is clearly visible on the seismic profiles, and we lack evidences for both UU and LU. In the Nile, the Rosetta Anhydrite Formation (Barber, 1981) is interpreted as the landward equivalent of the deep basin UU sampled during DSDP legs. Gypsum has been drilled in the Cretan basin and Florence rise. These deposits are either too thin (compared to the western basin) to be clearly evidenced on the seismic profiles or have been subsequently eroded by a late phase of erosion during the last stage of deposition in the eastern basin (Bertoni and Cartwrigth, 2007a).

2.1.2 Mobile Unit (MU)

This unit corresponds to the Messinian Salt and is evidenced by a characteristic transparent acoustic facies displaying plastic deformation. The reflection-free seismic facies has been interpreted as consisting dominantly of halite (Nely, 1994). MU is 600-1,000 m thick in the western basin and 1,500 m at least in the eastern one (e.g. Levantin Basin). Several internal discontinuous reflector packages are observed in the Eastern Mediterranean, separating several evaporitic sequences (Netzeband *et al*., 2006b; Bertoni and Cartwright, 2006; Hubscher *et al*., this volume; Ottes *et al*., this volume) possibly related to lithological and/or diagenetic differences. A strong erosion on top and on bottom of this unit has been observed in the Levantine Basin (Bertoni and Cartwright, 2006 and 2007a; Tahchi *et al*., 2004).

MU onlaps the Miocene margins. Listric faults linked to post MSC salt tectonics are currently observed passing progressively downslope to salt anticlines and diapirs in the more distal areas

(Loncke *et al*., 2006; Gaullier *et al*., 2006). Because the two Mediterranean basins are now disconnected, the lateral correlation between the observed MU is not possible and a synchronicity between those two units cannot be demonstrated.

2.1.3 Lower Unit (LU)

LU is 500-700 m thick and corresponds to a group of very continuous high amplitude reflectors. Recent seismic profiles suggest that LU onlaps some Miocene margins (Réhault, pers. comm.; Lofi *et al*., 2005) but this geometrical relationship is generally poorly imaged. This unit has been initially labelled “Lower Evaporites” by analogy with the Lower Evaporites of the Sicilian peripheral basin. However, this analogy is improper as no correlation is possible between those two units. In addition, the age, lithology and depositional environment of LU are still speculative, as it has never been drilled. Some authors propose that LU is entirely evaporitic and coeval from the peripheral lower evaporites (Krijgsman *et al*., 1999a). It would have deposited before 5.6 Ma. Others suggest that LU could contain a large part of clastic sediments accumulated at the beginning of the drawdown, after 5.6 Ma (Lofi *et al*., 2005). Ryan (2004) proposes a combination of those depositional environments.

2.2 Products of erosion

During the crisis, the margins were deeply eroded. Thanks to the increasing quality of the seismic data, one part of the products of this erosion is now regularly imaged in the downstream part of the main Messinian thalwegs. It corresponds to some fan-shaped accumulations labelled CU (Chaotic Unit) and also sometimes BU (bedded Unit).

The products of the margin erosion have been evidenced on many margins: Ligurian and Provencal margins (Savoye and Piper, 1991), Gulf of Lions (Lofi *et al*., 2005), Valencia basin (Maillard *et al*., 2006a), Valencia seamount flanks (Mitchell and Lofi, unpubl. data), Western Sardinia (Sage *et al*., 2006), Provencal margin (Obone Zue Obame *et al*., 2007) and on the Algerian margin (Déverchère *et al*., 2005). The Nile system is however the best documented because of the potential that these deposits represent in terms of reservoir (Rizzini *et al*., 1978; Barber, 1981; Ottes *et al*., this volume).

CU displays a characteristic chaotic seismic facies, more or less transparent. It can reach up to 1,000 m thick locally. CU is not observed on the upper slopes or on the margin shelves. It is essentially evidenced infilling the Messinian thalwegs and downslope at Messinian river mouths. It appears therefore as irregular in terms of lateral extent (and overall thickness). In some cases, CU is replaced by (Ligurian margin) or lays upon (Algerian margin) a bedded unit called BU. Downslope, CU displays a complex relationship with the other Messinian units: either beneath or above MU, and a lateral facies change to UU and/or MU is locally suspected.

Where it has been drilled (on the slopes), CU consists of sands and conglomerates intercalated with marly levels and overlain by early Pliocene deep marine sediments. These are interpreted as Messinian fluviodeltaic deposits (Rizzini *et al*., 1978; Estocade, 1978; Stampfli and Höcker, 1989; Savoye and Piper, 1991). Downslope, in its more distal part, CU may consist of subaqueous gravitary deposits resulting from an early erosion of the margin at the beginning of the drawdown (Lofi *et al*., 2005). The presence of thick resedimented deposits through gravitative processes into relatively deep waters has also been evidenced in the Apennine foredeep (Roveri *et al*., 2001).

3. Erosion in the offshore domain

Evidence for a substantial drop in sea level during the MSC has been collected from numerous records of deep erosional features in offshore areas (Ryan and Hsü, 1973). Several erosion surfaces have been evidenced on seismic data. They are labelled MES, BES, TES, IES. The MES is observed only on the margins and is systematically overlain by the Plio-Pliostocene sequence. The BES, TES and IES are observed only in the deep or intermediate basins, in association with Messinian units. These surfaces merge together upslope into the MES, generally at (or close to) the onlap point of the deep basin Messinian trilogy. The MES is thus only observed on the Miocene margin shelves and slopes.

3.1 Margin erosion surface (MES)

The MES is a widespread erosion surface generally quite well identified on the margins. It is a unique, complex poly-phased and polygenic unconformity, commonly interpreted as the result of subaerial erosion, essentially by river action and retrogressive erosion (Loget and Van Den Driessche, 2006). Onshore, the MES is characterised by the presence of deep narrow incisions ("canyons"), which correspond to the entrenchment of streams in response to the huge fall of sea level (Chumakov, 1973b; Clauzon, 1973). Offshore, numerous investigations have enabled reconstructions of the detailed paleomorphologies of the MES at several margins, revealing the existence of Messinian paleo-fluvial networks: Egyptian margin (Barber, 1981), Gulf of Lions shelf (Guennoc *et al*., 2000); Ebro margin and Valencia trough (Stampfli and Höcker, 1989). On large margins, subaquatic processes may also have contributed to the shaping of the MES at the beginning of the drawdown (Lofi *et al*., 2005).

The MES has been correlated with several exploration boreholes in the Mediterranean Sea but its existence has also been confirmed recently in the Black Sea (Gillet *et al*., 2007). Boreholes located on the shelves revealed only a discordance between Miocene and Pliocene deposits (or extremely incomplete successions). Subaerial erosional features (for instance desiccation cracks and stromatolite layering (DSDP, Leg 42), fossil meanders and fluvial terraces (Stampfli and Höcker, 1989) have been described from margin edges, supporting the interpretation of fluvial erosion.

The MES is overlain by Plio-Pleistocene deposits and extends downslope to the onlap point of the deep basin Messinian trilogy deposits. There it passes laterally to the BES, TES and IES, each of these erosion surfaces being defined based on their relationship to Messinian units downslope.

3.2 Bottom erosion surface (BES)

The BES is the basinward prolongation of the MES. It is an erosion surface separating pre-MSC deposits from MSC deposits. Thus on the Miocene slopes, the BES passes in the Messinian thalweg axis, beneath CU and/or BU (Nile, Gulf of Lions, Valencia Basin, Levantine margin, Ligurian margin, Algerian margin). The BES then extends out beneath the deep basin Messinian trilogy and both UU and MU clearly pinch out against this surface. The BES also possibly extends to the base of LU. It is however difficult to estimate how far this surface extends basinward because it progressively becomes conformable with the underlying strata. Where the BES is clearly erosional, it truncates the underlying reflectors and displays locally small discontinuous gully-type incisions such as in the Valencia and Eastern Corsica basins.

3.3 Intermediate erosion surfaces (IES)

The IES are erosional discordances that are only observed within UU. From a stratigraphical point of view, they were created after the BES and before the TES. Up to now, the IES have only been observed on the Northern Ligurian and Western Sardinia margins and in the Valencia and East Corsica basins. In these basins, MU is absent and UU thus is representative of the entire Messinian deposits between several distinct entrenched sub-units (Maillard *et al*., 2006b).

3.4 Top Erosion Surface (TES)

The TES consists of an erosion surface observed at the top of Messinian units. It separates the MSC deposits from the Plio-Pleistocene sequence. Thus, on the Miocene slopes, the TES passes in the Messinian thalweg axis, at the top of CU (e.g. Gulf of Lions, Valencia Basin, Nile). The TES extends to the top of the Messinian trilogy (top of UU). Its erosional character is clear in the Valencia basin where it consists of a very flat surface with a sinuous central paleo-valley and its tributaries (Escutia and Maldonado, 1992; Maillard *et al*., 2006a). These characteristics have also been clearly observed in the eastern Corsica basin at the top of UU (Thinon *et al*., 2004), on the Northern Ligurian and Western Sardinia margins, and more locally in the Gulf of Lions at the top of the CU and UU and in the Nile at the top of CU (Barber, 1981). It has also been evidenced recently on the Levantine margin, on top of the MU unique Messinian unit where this unconformity is interpreted as a subaerial exposure linked to a regression, occurring during the last stages of deposition of the Messinian unit (Bertoni and Cartwrigh, 2007a).

The TES extends towards the centre of the basins and progressively becomes concordant with the top of UU.

4. Discussion

Offshore, studies of the Messinian markers are limited by the lack of lithological and stratigraphical calibrations. In the absence of fully recovering deep boreholes, our knowledge about the nature and age of the deep evaporite sequence is weak, in particular concerning the Mobile and Lower units. Diving may bring invaluable information (e.g. cirque Marcel on the Ligurian margin, see Savoye and Piper, 1991 but they is limited because of sampling difficulties and because MSC deposits seldom outcrop in the Mediterranean Sea. Industrial boreholes could be very useful but the data are not easily accessible to the scientific community. Thus, considerable progress will be achieved when this sequence is drilled integrally. Until such time, only the seismic approach can be envisaged.

Offshore seismic studies are based on the recognition and interpretation of seismic facies. Because several lithologies can correspond to a unique seismic facies, we suspect that UU displays an important variability (in term of lithology and depositional environment) since it is recovered at river mouths (increased detrital fraction), in the centre of the deep basins (increased evaporitic fraction?) or in an intermediate basin (proportion of lacustrine fraction?). A definitive interpretation of the seismic facies requires direct well calibration.

The architectural complexity, the lateral changes in seismic facies, the deformations related to salt tectonics, volcanism or tectonics are among the factors that make interpretation difficult or equivocal at a local scale. For instance, the Messinian units found on the slope of the Ligurian margin cannot be definitely correlated with the abyssal plain units because of a major listric fault. In the same way, the MSC deposits of the eastern Corsica basin cannot be correlated with the rest of the western Mediterranean because of the presence of a volcanic intrusion at the outlet of the Messinian basin. As a last example, in the Eastern Mediterranean basin, geometry and thickness of MU have been modified by subsequent tectonics and the present day geometry does not reflect the initial deposition.

Correlation at a larger scale is limited essentially by the existence of topographic sills that disconnect the different Mediterranean basins and sub-basins. This is essentially true for the main Mediterranean basins. Although a mobile unit has been evidenced in both basins, their synchronicity is not obvious. Indeed, the principle of the communicating vessels suggests that it may exist a delay between the deposition of the MU eastern and western basins (Blanc, 2000). The knowledge of the paleo-geography of the Mediterranean and Paratethys during the MSC is also essential for restituting the paleo-connections among the basins during higher sea-levels (Clauzon *et al*., this volume).

The multi-site comparative study approach proposed here allows us to remove some of the problems discussed above and to bring new information regarding the MSC and some local and global triggering factors. The multi-site approach thus evidences the crucial impact of the initial geological-morphological context on the registration of the crisis. The response of the margin/basin is thus closely related to local triggering factors (morphology, dimensions and initial bathymetry of the area, lithology, dimension of the drainage basins and of the continental shelf, proximity and height of aerial relieves, tectonic context, subsidence, etc.). These factors will play a key role on the spatial and temporal organisation of the Messinian erosions, the location, the amount and the nature of the sediment eroded and the modalities of sediment transport and sedimentation toward/in the basins. Whatever the study area considered, we evidence a more or less complete association of characteristic seismic markers.

The MSC sea-level drawdown is testified by the erosion surfaces observed all over the Mediterranean and Black Seas. If only one erosion surface (Messinian in age) is observed on the margins, several are observed downslope. These surfaces must be clearly distinguished. We did label them according to our observations. The BES, TES and IES can be identified thanks to their relationship with the Messinian deposits. They all join each other and merge upslope into a single erosion surface, the MES, that can be traced landward. This illustrates the complexity of the MES, which appears as a diachronic and polygenic erosion surface representing the entire time interval of the crisis: Bottom erosion (BES), MSC deposits (LU, MU, UU, CU), and Top erosion events (IES, TES). The MES is also older on the upper parts of the margins than on the lower parts, as the shelves have been emerged before and over a longer period than the margin slopes.

The magnitude of the sea-level drop in the Western Mediterranean Sea can be estimated from the depth of the onlap of UU in the deep basin, corrected for the effects of post-Messinian vertical movements and compaction (Ben-Gai *et al*., 2005; Steckler *et al*., 2003; Tibor and Ben-Avraham, 2005). UU sampled south of the Balearic Islands contain stromatolites and anhydrite nodules characteristic of arid shallow-water depositional environments. This suggests that sea-level drop was at least as much as the depth of the depositional onlap of UU. This interpretation is reinforced by the existence of the TES and IES in the Valencia Basin, showing that sea-level changes occurred during a lowstand phase that persisted during deposition of UU. These multiple phases are interpreted as reflecting alternating episodes of the Atlantic advancing into and retreating from the Mediterranean (Escutia and Maldonado, 1992). These multiple phases could nevertheless also reflect small amplitude variations in the base-level due to climatic changes, that influence the different runoff in the basins. The TES may also be related to the so-called “Lago-Mare”, characterised by the presence of brackish shallow-water sediments in the uppermost MSC deposits (Rouchy *et al*., 2001). This event could also attest that lacustrine settings could have formed at different elevations in the depressions during the end of the MSC.

If a very lowstand or aerial erosion is clearly suspected at the end of the MSC (TES), the subaerial/subaqueous nature (and depth of extension) of the BES beneath the onlap of UU is still a matter of speculation. Here we lack crucial information concerning the nature of LU and the thickness of the water column before, during and after MU deposition (Lugli *et al*., this volume). This would allow us to assess how far the BES extended more basinward and how it formed in this area. A subaerial origin beneath the onlap of MU is not excluded. It would imply the formation of a subaerial erosion surface before the deposition of the Salt. In other words, the fall in sea level would have reached a maximum (greater than the onlap depth of UU) before salt precipitation in the basin.

The erosional character of the BES, IES and TES is much more visible in the Valencia Basin compared to other areas such as the Gulf of Lions. This illustrates the importance of basin paleo-depth and morphology in the registration of the erosion. In the Valencia basin, erosion is enhanced by the very low gradient of the basin floor that favoured the registration of very slight variations during the low-stand. This is also observed in the intermediate Eastern Corsica basin, which had a relatively gently sloping southward basin floor. Strong geometrical and morphological equivalence exists between those two study areas characterised by thin UU bracketed by the BES and the TES that are extremely well imaged. Only some seismic facies differences are observed, suggesting that climate may have partly controlled the deposition of UU. Their lateral equivalence however cannot be fully demonstrated in the absence of datation. However, because of their intermediate-depth, these basins could be key areas for constraining the precise timing of the Messinian events.

Regarding the erosion products, we find that CU and BU develop generally at river mouths and in the Messinian thalwegs. The internal spatio-temporal variability of CU and BU is important and the deposition of the entire detrital sequence appears as a non-synchronous event. The depositional environments (subaqueous gravitary/subaerial fluvial) may also differ significantly within the deposional unit. Such an internal variability has been evidenced in the Gulf of Lions (Lofi *et al*., 2005). It is also observed in the Nile where CU is overlain upslope by some marly Pliocene deposits and downslope by a Messinian anhydritic unit (Barber, 1981). In the Algerian margin (west of Algiers), characterized by high reliefs on land, steep slope, tectonic activity, and existence of abundant clastic sediments, CU (and BU, in a lesser extent) is very thick and spread over the margin foot. Because CU and BU often make the transition between the eroded slopes and the deep Messinian trilogy, the fine stratigraphic relationships between these markers on slope and the trilogy in the deep basin are complex. It appears that their spatio-temporal organisation presents a high variability from one margin to another. For instance, in the Gulf of Lions, CU extends beneath MU in its distal section, whereas in some smaller systems (Sardinia, Provence, Algeria), CU is clearly imaged above MU. Such a geometrical and temporal variability possibly results from the initial morphology, lithology and structure of the margin. Large, thick and clastic shelves favouring large-scale submarine instabilities during the drawdown, allow the deposition of one part of CU before MU deposition. On the other hand, narrow margins with thin sedimentary cover or shallow substratum depict much smaller and distributed drainage slopes, and may therefore be eroded more lately, once the maximum drawdown has been reached and river power is maximum. In such a case, CU is deposited after MU.

As a last point, a major difference exists between the western and eastern Mediterranean basins. When a clear deep basin trilogy is observed in the western basin, only the Mobile Unit is recovered on seismic data in the eastern basin (excepted maybe in the Ionian basin). Although an increase of the number of internal reflectors within MU is observed toward the top of the unit, the seismic facies is very different from UU. This suggests that the paleo-environmental changes or triggering factors during the crisis were different in the two basins. This interpretation seems supported by geochemical analyses of the Messinian deposits that reveal basic differences between the eastern, central and western Mediterranean basins during the last stage of the Messinian salinity event. The western and Ionian Basin were characterized by marine brines whereas the eastern basins were rather fed with brines of continental origin (Kushnir, 1982). The synchronicity of MU in both basins is also far from obvious.

5. Conclusion

This study proposes for the first time a global and coherent terminology for MSC markers in the entire offshore Mediterranean area. We also compare several study areas characterised by various structural and geodynamical contexts. This multi-site approach is based on seismic data interpretation. It allows us to document the way the MSC left its imprints in the offshore domain. The sedimentary and morphological response of the margin/basin depends of the local/global triggering factors. Thus it is important to know the evolution of the study areas since the achievement of the MSC and to redefine the initial morphology of the margins and the paleo-topography/bathymetry of the Mediterranean sub-basins (and their connections). This restitution must take into account the quantification of the successive deformations that are very contrasted in the Mediterranean. Whatever the study area considered, we observe a more or less complete association of characteristic seismic markers. Some global triggering factors and superimposed local trends can be discriminated, allowing us to discuss: (1) the existence of several erosion surfaces in the basins merging together upslope, as well as associated detritals; (2) the amplitude of sea-level fall during the crisis and evidence for sea-level oscillations at low-stand; (3) the importance of the initial Miocene geological-morphological context on the organisation of the Messinian markers in the basins.

Implications of Workshop conclusions

The new interpretation of Sicily as a locally deep basin (Roveri *et al.*, this volume) has strong implications for the geophysician community studying the MSC offshore. Indeed, interpretations of the Messinian seismic markers offshore are limited by the lack of lithological and stratigraphical calibrations. Outcrops in Sicily and in the Apennines may thus offer for the first time an onland analogue to the deep-water records located in the present day deep Mediterranean basins, thus allowing direct comparison. This approach may lead to a possible complete/partial temporal and lithological calibration of the deep basins markers.

Following the CIESM Workshop in Almeria, the main new points that we need to take in consideration are as follow: 1) In the Western deep Mediterranean basin, the seismic facies, the geometrical configuration and the possible lithology of the Messinian units presented in this study seem compatible with the interpretation from outcrops in Apennines and Sicily (Roveri *et al.*, this volume). Several analogies support a possible correlation between the Reworked Primary Gypsum and Halite observed onland (Roveri *et al.*, this volume) and the deep basin Lower and Mobile Units respectively. The possible correlation between the Upper Evaporites onland and the Upper Unit offshore needs to be clarified. 2) Ottes *et al.* (this volume) suggest that the lowest halitic sequence of the Mobile unit may be Tortonian in age. This major point must be confirmed from a biostratigraphic point of view. Indeed, such an age, pre-dating the onset of the MSC, would raise important questions concerning the depositional models in the Eastern Mediterranean basin and possible correlations with the Western basin.

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