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"The Messinian salinity crisis revisited-II"
Parma (Italy), 7th - 9th September 2006

CLASTIC VS. PRIMARY PRECIPITATED EVAPORITES IN THE MESSINIAN SICILIAN BASINS

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front cover:
panoramic view of the Upper Evaporites at Montagna Grande, east side of the Salso River Valley, Sicily

Foreword

The Messinian stratigraphy of Sicily has a particular importance for the comprehension of the Messinian salinity crisis as its successions bear the greatest similarity with those of the deep Mediterranean basins. Despite the large number of studies carried out in the last 30 years, we believe that the true time and genetic relationships between the different evaporitic and non evaporitic rock bodies are still not well established. This is probably due to the limited, partial view offered by the central Sicilian basin, despite its complete Messinian stratigraphic record.

Clastic and chaotic evaporitic deposits emplaced by tectonically-driven small to large-scale resedimentation processes form an important part of the MSC record of Sicily in the Belice and Caltanissetta basins. Facies characteristics of clastic evaporites, the stratigraphic relationships with the other Messinian deposits, their possible significance in the regional geological evolution and the implications at a Mediterranean scale will be discussed in the field. Attention also will be paid to primary precipitated facies of Lower and Upper Evaporites.

The main aim of this field trip is to visit and discuss, beside some of the classic localities of the Caltanissetta basin, other less known outcrops of western Sicily (Belice basin), in order to have a more complete regional geological framework of the MSC events in Sicily.

This will give the participants the opportunity to discuss many of the still open problems concerning the MSC. In this section we suggest some topics for discussion during the field trip.

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Parma, August 2006

Marco Roveri, Stefano Lugli,
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Clastic vs. primary precipitated evaporites in the Messinian Sicilian basins

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The Messinian salinity crisis of the Mediterranean: old and new problems

More than thirty years after the formulation of a unifying theory for the Messinian salinity crisis (MSC), the so called "deep-basin desiccation model" (Hsu et al., 1973), several aspects are still not fully understood (Hardie and Lowenstein, 2004). A crucial point is the nature and age of the giant salt deposits buried under the deepest Mediterranean basins, imaged by seismic data but never sampled by boreholes, except for their uppermost part (Hsü et al., 1973). These deposits have been classically subdivided into three seismostratigraphic units that from the bottom are: Lower Evaporites, Messinian Salt and Upper Evaporites; only the latter have been reached at its top by DSDP and ODP boreholes. The deep-desiccation theory considers that both the Lower Evaporites and Messinian Salt (total thickness > 3000 m) formed through direct precipitation from very shallow waters during the desiccation stage of the Mediterranean basin. This requires a sea-level fall in excess of 1500 m, leading to the widespread development along the continental margins of a subaerial erosional surface (MES) with deeply incised canyons in front of the main river systems (Ryan and Cita, 1978; Clauzon, 1982). Due to the lack of direct observation data from the Lower Evaporitic complex and the underlying deposits, their (deep vs shallow-water) nature as well as the chronology of Messinian events are object of speculations.

One of the main problems is the correlation of the deep basinal succession with the outcropping ones, because many of those also accumulated in shallow peripheral basins. In Spain (Betic basins), Italy (Apennine foredeep, Sicily) and Eastern Mediterranean (Crete, Cyprus), these successions are characterized by a lower evaporitic unit made up of cyclically arranged selenitic gypsum (up to 16 cycles recording periodic, precession-related, variations of marine water concentration), cut at the top by a subaerial erosional surface (MES, intra-Messinian unconformity) overlain by hyposaline deposits (Lagomare facies) which locally contains thin evaporitic horizons precipitated from marine waters with a strong continental input (Upper Evaporites of Sicily).

In order to fully understand the MSC, the relationships between the different Messinian units should be defined in detail within this time framework. One key for correlating deep and peripheral basin successions is to trace the MES to its correlative conformity basinward. On this base Clauzon et al. (1996) refined the desiccation model by proposing a two step development of the MSC (Fig. 1): the first one with primary evaporite precipitation only in peripheral basins; the second one, following a sea-level fall of more than 1500 m, characterized by shallow-water evaporite deposition (mainly halite) in the deepest Mediterranean depressions. In this model the MES is traced at the base of the deep Lower evaporites or, at least, of the Messinian Salt (Lofi et al., 2005). The threefold stratigraphic subdivision of Messinian evaporites can be recognized elsewhere in Mediterranean basins. However, where deep-basin Messinian successions have been uplifted and can now be observed in outcrop a quite different picture appears from what the general model predicts. In the case of the Apennine foredeep, the MES can be traced into a correlative conformity at the base of a clastic evaporite complex that was emplaced through gravity flows in fully subaqueous and relatively deep depositonal settings (Roveri et al., 2001, 2003, 2004; Manzi et al., 2005). This hypothesis, which discussed at a larger scale the true nature of basinal evaporites, was actually suggested by Lofi et al. (2005) for the origin of the Lower Evaporites of the Gulf of Lions; based on seismic data, during the initial sea-level fall, fully subaqueous processes could have transferred to the basin huge volumes of mixed, siliciclastic and evaporitic, sediments to the basin.

A non-clastic, shallow-water precipitated nature of most deep Lower Evaporites is the mostly accepted hypothesis within the scientific commu-

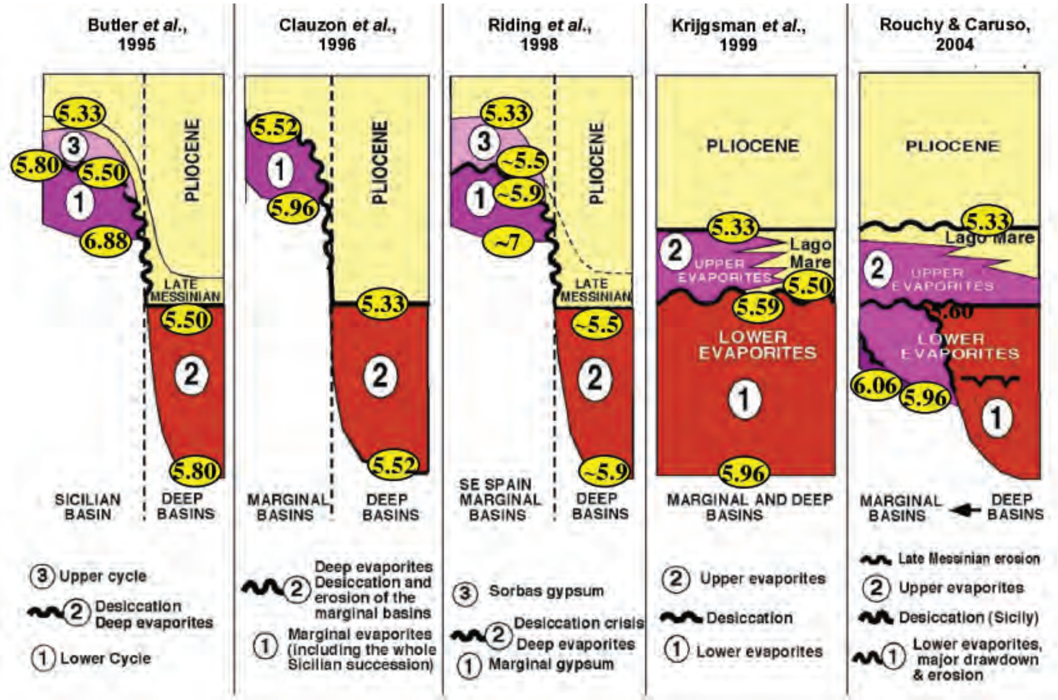

Fig. 1 – The different scenarios of the MSC (from Rouchy and Caruso, 2004).

nity; these deposits are generally considered to postdate marginal evaporites. A post-desiccation age has been also proposed for the primary evaporites of Sorbas (Yesares gypsum), thus implying the permanence of marine connections with the Atlantic throughout the MSC (Braga et al., 2006; Riding et al., 1998; Fig. 1). Only Krijgsman et al. (1999) proposed the synchronous character of the onset of all the Mediterranean evaporites, thus implying the possibly deep-water nature of basinal successions.

One crucial point which is generally overlooked is the role of drastic, pan-Mediterranean tectonics in controlling the Messinian stratigraphy and specifically the event related to the MES (Jolivet et al., 2006). The peri-Mediterranean area can be considered a single deformation complex related to the convergent boundary between the African and Eurasian plates; tectonostratigraphic studies document the occurrence of discrete phases of accelerated deformational processes in different geodynamic settings; the MSC occurs exactly in one of them, initiated since the Late Tortonian (Meulenkamp and Sissingh, 2003). This tectonic activity is considered responsible for the progressive closure and subsequent reopening of the Atlantic gateways and, as a consequence, of the MSC.

Notwithstanding a growing amount of evidence for its assiociation to angular discordances in the Apennines, Sicily, Spain and, more recently, even in the Gulf of Lions (Lofi et al., 2005), the development of the MES is usually coupled only with the exceptional sea-level fall related to the desiccation of deep Mediterranean basins. Besides the Apennine foredeep, a few evolutionary models for the MSC do take into account the regional geologic framework for the development of evaporitic successions; one of these instances concerns Sicilian basins. According to the sequence-stratigraphic model by Butler et al. (1995), evaporitic successions of Sicily predate those of the deep Mediterranean and formed diachronously in a series of small basins developed at increasing depths above the actively deforming the Maghrebian orogenic wedge during a long-term eustatic fall culminated with the desiccation of deepest basins.

Also, closely tied to the previous point, the common occurrence of deep-water resedimented evaporites in the Messinian stratigraphy of many basins is usually overlooked; their overall significance in the development of the MSC still waits to be fully recognized and accounted for in general scenarios.

The correct time relationships between the evaporitic rocks formed in marginal and deep basins is still controversial and this uncertainty is mirrored by the number of evolutionary models of the MSC proposed thus far (see Rouchy and Caruso, 2006 for a complete and updated review).

The record of Messinian events in Sicily

M. Roveri, S. Lugli, V. Manzi, B.C. Schreiber,
F. Ricci Lucchi

Because Sicily probably represents the most attractive area for trying to understand the big Messinian puzzle, this focus has strong and motivated roots. Like in the Northern Apennines, both the natural and human history of Sicily have been deeply affected by the heritage of the Messinian salinity crisis, which left so many signs in the physical, social and cultural landscape of this fascinating island laying in the middle of the Mediterranean, a crucial position for geologic and historical aspects.

The morphology of central Sicily is largely controlled by Messinian stratigraphy, with large- to small-sized gypsum or limestone hogbacks and cliffs emerging from a dominantly smooth and rounded landscape carved into a often chaotic mass of Tertiary clays and arenites. The Messi-

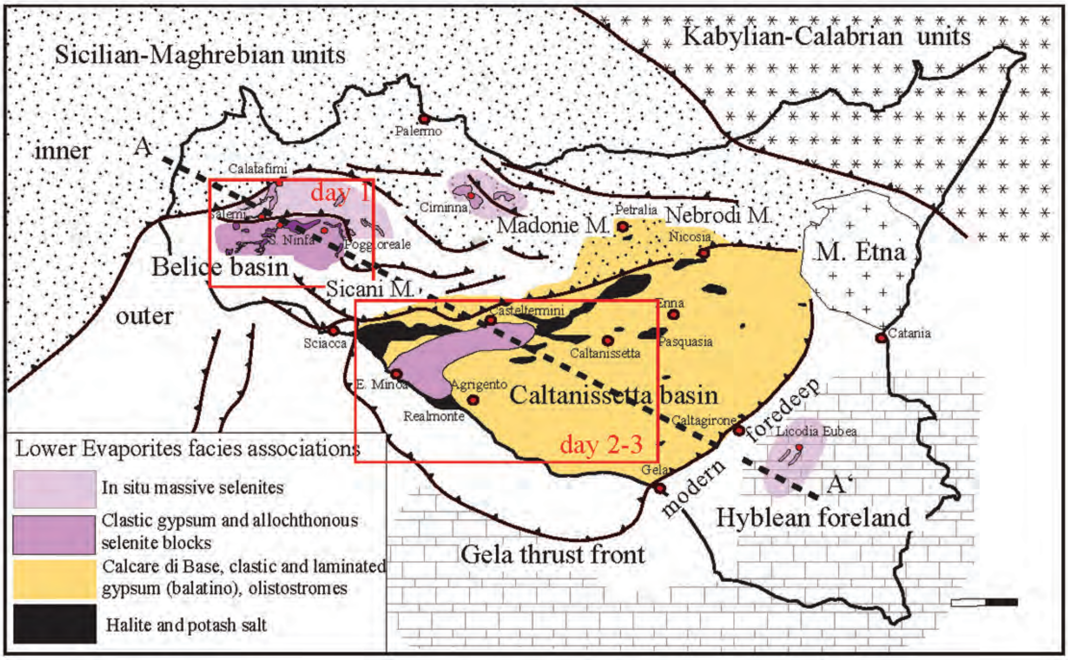

Fig. 2 – Schematic geologic map of Sicily with the distribution of the "Lower Evaporites". Upper Evaporites distribution is not shown in this map.

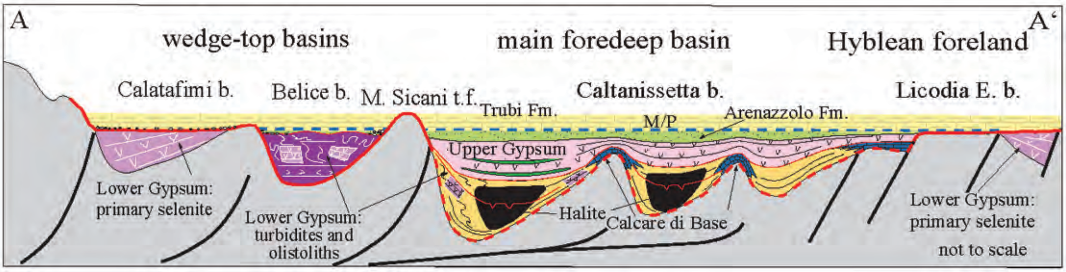

Fig. 3 – Schematic geologic cross-section across the Sicilian basin flattened at the base of Pliocene and showing the distribution of upper Messinian deposits (above Tripoli Fm.).

nian rocks allowed the development through time of a mining economy first focused on sulphur and then, more recently and still surviving, on potash salts and halite preserved in the subsurface. While driving or walking along these lands it is very common to see and touch the memory of such human history written by the sweat (and blood) of generations of miners.

The evaporitic succession of Sicily has long been considered an equivalent of the deep Mediterranean ones, uplifted in post-Messinian times following the evolution of the Sicilian-Maghrebian thrust belt. Now it is regarded to as a relatively deep peripheral basin containing the best analog Messinian succession of the deep Mediterranean basins (Rouchy and Caruso, 2006).

While the most continuous succession occurs in the central Sicilian basin (Caltanissetta Basin, see Rouchy and Caruso, this volume), Messinian deposits also crop out in other basins developed in different structural and depositional settings (Figs 2-3). These basins, with some exceptions, are usually less considered in the literature, probably due to the incomplete nature of their Messinian sedimentary record. We believe, on the contrary, that the stratigraphic features of such basins and their correlation with the central Sicilian basin could provide a much more complete scenario of the time and spatial development of the MSC in Sicily and hence more insights also at a Mediterranean scale.

We refer to the wedge-top basins of Calatafimi, Ciminna and Belice in northwestern Sicily, and to the Licodia Eubea basin formed in a foreland ramp setting on the Hyblean Plateaux.

Classic studies (Decima and Wezel, 1971, 1973), mainly carried out in the central Sicilian basin (the Caltanissetta basin), showed that the Messinian succession of Sicily consists of two main sedimentary cycles separated by an erosional surface with associated angular unconformity. The lower cycle (equivalent to the deep Mediterranean Lower Evaporites) comprises the Calcare di Base, the Lower Gypsum (massive selenite of the Cattolica Fm.) and the Salt unit. Salt bodies are distributed in a array of subbasins aligned in a broad belt within the Caltanissetta basin and attain maximum thicknesses of about 1000 metres. The upper cycle is characterized by the occurrence of interbedded gypsum (balatino and selenite) and marls (Upper Evaporites, Pasquasia Fm.) overlain by the Arenazzolo siliciclastic sediments.

The stratigraphic relationships of the Calcare di Base, Lower Gypsum and Salt within the lower cycle are not clearly defined. According to Decima and Wezel (1971, 1973; Fig. 4) and Decima et al. (1988), the Salt lies above the Cattolica Gypsum (massive selenites). Garcia-Veigas et al. (1995; Fig. 5) and Rouchy and Caruso (2006) suggested instead a lateral transitions between Salt, Lower Gypsum and Calcare di Base that would imply a virtually synchronous deposition of different facies in basinal, marginal and sill settings. Subsurface and outcrop data point indeed to complex genetic and stratigraphic relationships between salt bodies, limestones (often brecciated, both primary and derived from the diagenetic transformation of gypsum) and gypsum, both clastic and primary (Decima et al., 1988; Pedley and Grasso, 1993). Butler et al. (1995) suggested a strong tectonic control on the areal distribution and fractionation of Messinian deposits (Figs 6-7); within the larger-scale context of evaporitic basins developed diachronously above an active orogenic wedge during an overall relative sea-level drop, the Calcare di Base limestones would be deposited on top of thrust-related anticlines, while interbedded limestones and gypsum would be found on their flanks and salt in the deepest depressions of adjacent footwall synclines.

No unequivocal information exists concerning the lower boundary of the Lower Evaporites, as well as the nature and age of underlying units, at least as far as the deepest basinal areas are concerned, i.e. below the halite unit. Borehole data suggest the occurrence below the halite of a thin horizon of anhydrite and shale breccia, lying above mudstone deposits generically attributed to the Upper Tortonian-Lower Messinian. In outcrop successions the Lower Evaporites usually start with the Calcare di Base lying above basinal diatomites (Tripoli Fm.) or deltaic deposits (Terravecchia Fm.) (Butler and Grasso, 1993). Based on the age of the first Lower Gypsum or Calcare di Base bed, the onset of the MSC in Sicilian basins is considered fully diachronous

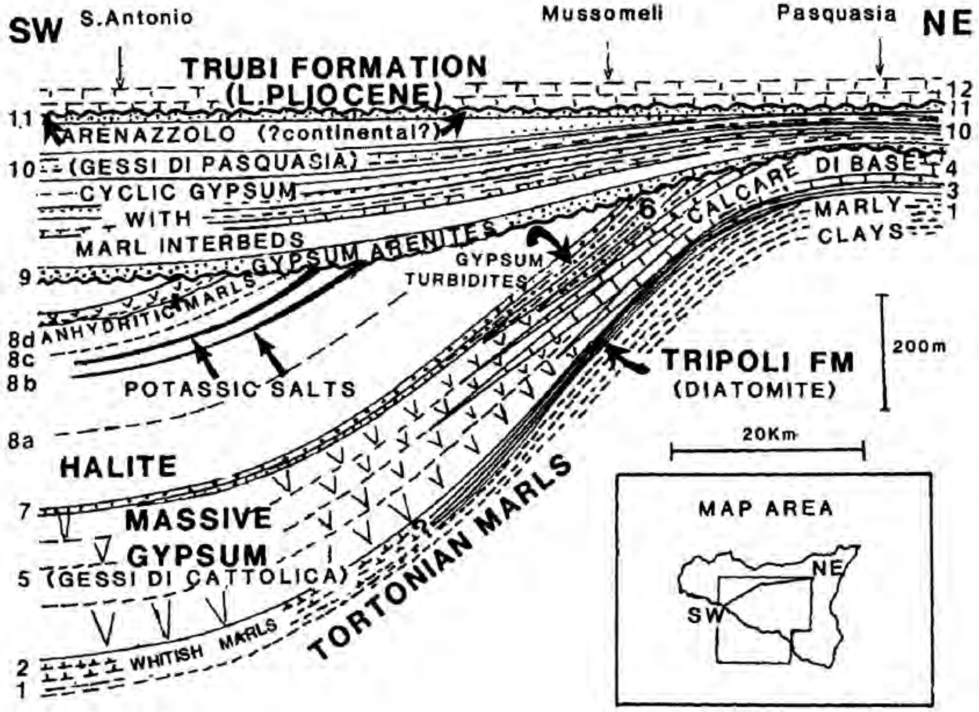

Fig. 4 – The stratigraphic model for the Messinian of Sicily of Decima e Wezel (1971), in Decima et al. (1988).

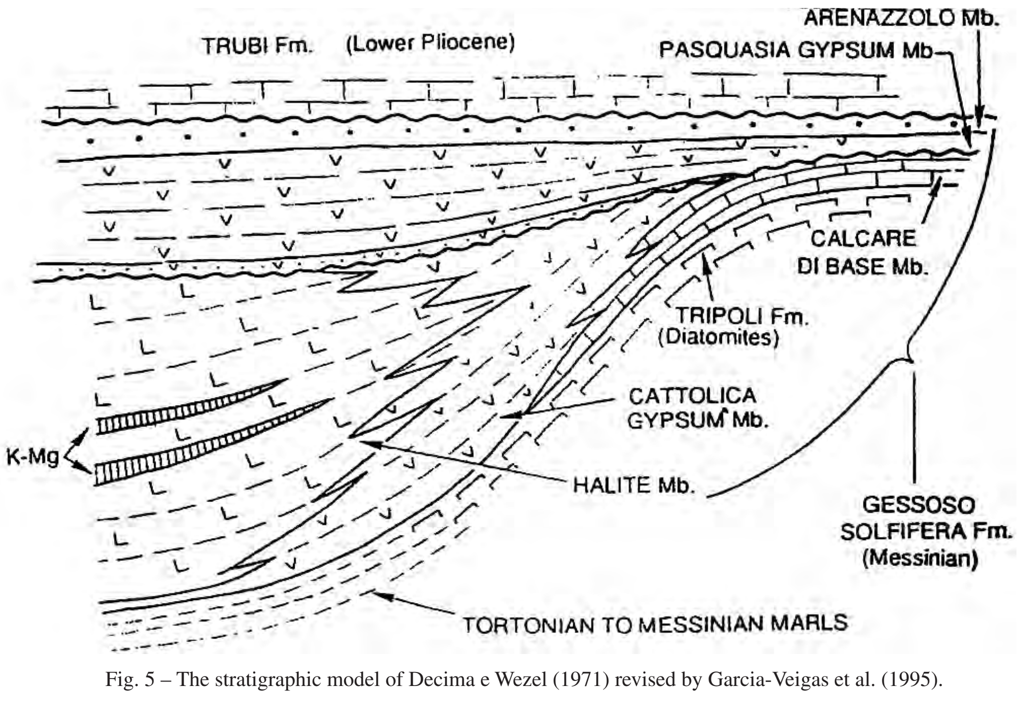

Fig. 5 – The stratigraphic model of Decima e Wezel (1971) revised by Garcia-Veigas et al. (1995).

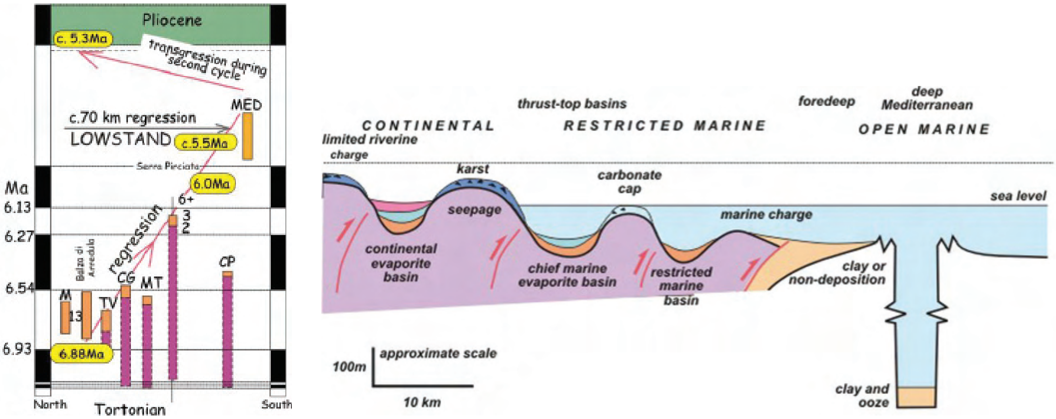

Fig. 6 – The stratigraphic model for the Messinian evaporites of Sicily proposed by Butler et al. (1995).

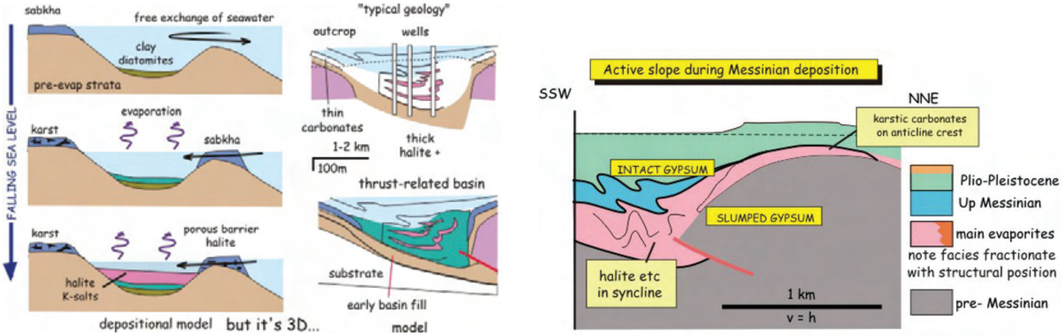

Fig. 7 – The fractionation of Messinian evaporites in Sicilian basins induced by structural setting and evolution (from Rob Butler's website "The Messinian salinity crisis" - http://earth.leeds.ac.uk/tectonics/messinian/).

(starting from 6.8 Ma, Butler et al., 1995), slightly diachronous (locally starting at around 6.1 Ma, Rouchy and Caruso, 2006) or synchronous (at 5.96 Ma, Krijgsman et al., 1999).

Like its equivalents of Sorbas and of the Northern Apennines, the Lower Gypsum of Sicily consists of cyclically interbedded massive selenites and thin shales; the number of cycles, their internal organization and the overall stacking pattern is remarkably similar to the other Lower Gypsum unit, suggesting a dominantly external control on their formation (see topic 3).

The detailed stratigraphy as well as the depositional features of salt deposits are only locally recognized; according to Decima and Wezel (1971) and Decima (1976), a regional-scale subdivision of salt deposits into four units characterized by different composition and halite content (among them one containing at least 6 kainite beds) can be established here and are separated by shale and/or breccia layers, thus implying a synchronous deposition in the different sub-basins. In the Realmonte mine two units deposited at different water depths have been recognized; the lower one formed in relatively deep waters and shows a shallowing-upward trend culminating in the development of an erosional surface with clear evidences of subaerial exposure (contraction-expansion cracks; Lugli et al., 1999); based on facies analysis, the upper one was deposited in very shallow waters. A similar surface has been recently discovered also in the Racalmuto mine (Lugli et al., 2006). The salt succession is characterized by a pervasive small-scale lithologic cyclicity given by the rhythmic alternation of a 2-3 to 10-20 cm thick halite-shale couplets. An annual or interannual periodicity for these cycles has been proposed by Bertini et al. (1998), clearly supported by depositional rates observed in modern salinas (Schreiber and Hsu, 1980) and this led to the suggestion that Sicilian salt formed in a very short time span (a few thousand years). The upper boundary of the Lower Evaporites is represented by the intra-Messinian unconformity, here clearly related, like in the Apennines, to an important deformational pulse of the Sicilian-Maghrebian chain.

This surface is overlain by deposits of the upper cycle, consisting of the Pasquasia Fm. (Upper Gypsum), made up of cyclically interbedded marls and selenitic gypsum (up to 6 cycles), and the overlying Arenazzolo Fm. The Upper Gypsum marly intercalations are characterized by fossil assemblages suggesting brackish to slightly hypersaline environments, while the Arenazzolo contains the typical freshwater faunal assemblages with paraTethyan affinity occurring in the latest phase of the MSC and indicating an important episode of dilution at the end of the Messinian (Lagomare; Bonaduce and Sgarrella, 1999). Above the Arenazzolo a sharp transition to deep marine deposits (Trubi Fm.) occurs, which represents the base of the Pliocene (Zanclean GSSP, Van Couvering et al., 2000; Iaccarino et al., 1999).

The Calatafimi, Ciminna and Licodia Eubea basins, despite their different tectonic settings, show a similar stratigraphy. The Messinian succession consists, at their base, of relatively shallow-water pre-evaporitic marls and reefal limestones; the lower cycle is represented only by the Lower Gypsum (massive selenites) showing the same facies and stacking pattern characteristics of the Cattolica Fm. This unit is normally cut by an erosional surface overlain directly by the Lower Pliocene Trubi or by a very thin and discontinuous veneer of continental deposits (conglomerates and sandstones, in the wedge-top basins or fossiliferous sandy siltstones with paleosoils in the Hyblean foreland) of possible latest Messinian age. The Upper Evaporites are always lacking, as well as the Salt and the Calcare di Base in the lower cycle. The Belice basin is characterized only by clastic gypsum deposits, with gypsum turbidites at the base and a chaotic complex made up of large selenite blocks and slumped marls and gypsarenite beds in the upper part, overlain by Trubi and locally by upper Messinian sandstones and conglomerates.

Open problems

(to be investigated and discussed)

M. Roveri, S. Lugli, V. Manzi, B.C. Schreiber

In this section we suggest some topics for discussion during the field trip.

Topic 1 – The origin of the Calcare di Base and its stratigraphic relationships with massive selenites (Lower Gypsum).

The term Calcare di Base is used to indicate a lithostratigraphic unit consisting of thin to thick beds of primary peloidal limestones cyclically interbedded with shales; limestones are often brecciated and deformed and commonly contain halite and gypsum pseudomorphs (Decima et al., 1988). Laminated gypsum (“balatino” and gypsarenites) is also commonly interbedded with the limestones. This unit ordinarily lies above the Tripoli Fm.; the transition is gradual as thin dolomitic limestones appear in the upper part of the Tripoli Fm. The CdB is widespread in the central Sicilian basin, where it is generally considered to record the onset of the MSC. The Calcare di Base is usually associated (laterally and vertically) with sulphur-bearing carbonate bodies, deriving from the diagenetic transformation of gypsum through bacterial reduction. Such secondary limestones, that probably should not be included in the CdB lithostratigraphic unit to avoid confusion, can be recognized on the base of sedimentological and geochemistry parameters (see detail in stop 3.2 and 3.3). The Calcare di Base is usually interpreted as formed in very shallow waters with strongly fluctuating salinities; the typical brecciated facies is related to autobrecciation processes induced by dissolution of halite and gypsum intercalations during phases of surface water dilution (Ognibe, 1963; Decima et al., 1978; Pedley and Grasso, 1993). However, in some cases, a origin as mass flow of some brecciated limestone bed is suggested by characteristic features, such as erosional bases with load casts, overall normal gradation, upward transition to gypsarenite divisions and clay chips (see stop 2.7); these observations cast some doubts on their origin and on their cyclic stacking pattern.

In the Decima and Wezel's (1971) stratigraphic scheme, a regional-scale lateral transition between the Calcare di Base and the Lower Gypsum is envisaged.

It should be noted that the name "Lower Gypsum" is usually intended the selenite facies which is characteristic of the Cattolica Fm.; however, the most common gypsum facies found associated with the Calcare di Base is the laminated gypsum (balatino and gypsarenites – see topic 5).

Is the lateral transition from CdB and selenite, also retained in the later models of Garcia-Veigas et al. (1995) and Rouchy and Caruso (2006), clearly visible or otherwise well documented by field or susurface data? Decima and Wezel (1971) support such an interpretation quoting a oral communication by Bommarito (1965), without specifying the kind of data above which this statement was based.

What is the true meaning of such envisaged lateral transition? Did gypsum and carbonate form in the same basin (or subbasin) and were genetically linked (as suggested by Rouchy and Caruso, 2006) or they formed independently but more or less synchronously in different basins (or subbasins)?

Topic 2 – Where did the Lower Gypsum originally form?

Messinian successions in inner wedge-top and foreland ramp depozones (Calatafimi-Rocca d'Entella, Ciminna, Licodia Eubea) show a relatively simple stratigraphy with massive selenite resting above Tripoli and cut by an erosional surface sealed by late Messinian conglomerates or directly by Lower Pliocene Trubi. No typical Calcare di Base, Salt or Upper Gypsum are present in these zones.

Looking at the large-scale distribution of Lower Evaporites deposits in the Caltanissetta basin, it is quite clear that massive selenite deposits only occur at the western end of the basin, in the type area of Cattolica Eraclea (S. Angelo Muxaro, Montallegro, Raffadali, Siculiana). In this area the Calcare di Base is missing; massive selenites usually occur as disarticulated blocks showing irregular lower contacts above chaotic deposits of different ages (Serravallian to Tortonian); as a consequence, are they found in place or where tectonically vs gravitatively displaced after their formation?

Topic 3 – Facies, cyclicity and stacking pattern of Lower gypsum: new tools for Mediterranean-scale correlations

New field observations, carried out in the Lower Gypsum of Northern Apennines (Vena del Gesso), Spain (Sorbas) and Sicily, allowed to reinterpret deposit usually assigned to facies 5 in the classic model of Vai and Ricci Lucchi (1977).

The vertical stacking pattern, the facies assemblage and thickness of the gypsum cycles show remarkable similarities.

The first two cycles are thinner and consist of giant selenite crystals (up to more than 2 m-tall). The 3rd, 4th and 5th cycles, forming the thickest beds, consist of vertically grown massive selenite grading into banded selenite (F3 and F4 facies of Vai and Ricci Lucchi, 1977, respectively). The upper part of the section (from the 6th to the 15th bed) consists of thinner cycles showing a basal massive and banded selenite, followed by nodular and lenticular selenite (F5 of Vai and Ricci Lucchi, 1977).

This nodular and lenticular selenite was considered by Vai and Ricci Lucchi (1977) as a clastic deposit (gypsarenite) that was subaerially exposed and developed sabkha features, such as anhydrite nodules that were then rehydrated back to form gypsum. The detailed study of this facies shows no clastic and supratidal features, but reveals that component clusters of selenite crystals are a primary subaqueous product and grew laterally, grouped in branches projecting outward from a nucleation zone surrounded by a gypsiferous carbonate-marly matrix. We interpret this facies as an extreme evolution of subacqueous selenite supercone structures described in the Sorbas basin (Spain) by Dronkert (1985). In the case that only the branch terminations can be discerned and no obvious conical shape may be recognized, we proposed the use of the term "Òbranching selenite" to emphasize the aspect that this crystals grew in organized subacqueous structures.

We are able to demonstrate that this facies is present in all the Lower Gypsum successions of the Mediterranean, including Crete and Spain (Sorbas), and appears starting from the 6th cycle through most of the sections. This has important implications for the overall meaning of Lower Gypsum cyclicity; the first occurrence of this facies in the same stratigraphic level throughout the Mediterranean basin offers a powerful tool for basinwide correlations and hence for a better comprehension of the factors controlling the areal distribution of gypsum deposits and their cyclical development.

Topic 4 – Distinguishing between Lower and Upper Gypsum: facies vs geochemical approach

The recognition in the field of the Upper Gypsum is often difficult, due to the common chaotic setting of Messinian deposits in central Sicily. Based on our observations, apart from the geochemical data, that in some cases may be controversial, Upper Gypsum can be readily distinguished from Lower Gypsum by means of facies characteristics.

The general assumption that the selenitic successions of the Upper Gypsum are characterized by thick marl intercalations whereas Lower Gypsum has only thin or missing shale or carbonate layers seems to be generally correct, but can not be applied in all cases and may be misleading. In the Northern Apennines, for example, the Lower Gypsum of the Idice section (Bologna), which has shale intercalations up to 20 m-thick, would be misinterpreted as Upper Gypsum.

The selenitic successions of the Lower Gypsum are remarkably devoid of laminites (“balatino”) either as primary precipitates or clastic, whereas laminites are present in most of the Upper Gypsum cycles. The Lower Gypsum selenites may contain localized clastic facies (gypsarenites and gypsrudite) but we never observed continuous "balatino"-like laminites.

The Upper Gypsum does not contain branching selenite (nodular and lenticular selenite, F5 facies, of Vai and Ricci Lucchi, 1977) or supercones, although localized domes and cavoli structures may be present (as in Eraclea Minoa). On the contrary the branching selenite is the most characteristic facies of the upper part of the Lower Gypsum.

Topic 5 – Origin and stratigraphic position of gypsum turbidites and olistostromes

Moving eastward from the western end of the Caltanissetta basin, the selenite facies quickly disappear and is replaced by a unit made of laminated microcrystalline gypsum (balatino), gypsarenites and gypsrudites, commonly containing large-scale selenite blocks (Casteltermini), resting above Tripoli or Calcare di Base Fms. This mainly clastic unit dramatically thickens toward the north, i.e. toward the inner margin of the Caltanissetta basin, where huge chaotic masses of clays containing discontinuous lenses and slabs of both selenitic and clastic gypsum are present. These deposits were emplaced by a variety of mass flows, ranging from low-density turbidity currents, to debris flow and giant submarine slides, thus bearing many similarities with the Northern Apennines examples (Manzi et al., 2005) and pointing to large-scale slope failures triggered by the major intra-Messinian tectonic events. Similar deposits also characterize the Belice wedge-top basin.

Laminated and clastic facies are by far the most common gypsum deposit in the Caltanissetta basin; they are usually referred to as Gessi di Cattolica, and this caused some confusion. As already recognized by Ogniben (1957) and also observed by Pedley and Grasso (1993), more clear lateral relationships between Calcare di Base and laminated gypsum can be recognized. Their areal distribution is controlled by a tectonically-induced topography, with the Calcare di Base developing on structural culminations and laminated gypsum in intervening depressions. These stratigraphic relationships are clearly recognized in the southern and eastern portions of the Caltanissetta basin (C. Gaspa, Trabia). To this respect, the Capodarso-Pasquasia section is paradigmatic; formerly proposed by Selli (1960) as the Messinian stratotype, it contains a Lower Evaporitic unit only consisting of clastic, laminated gypsum resting above the Calcare di Base. Detailed correlations, carried out integrating outcrop, borehole and mine data (Roda, 1967), show that the gypsum unit gradually thins moving from Pasquasia to M. Capodarso; conversely, the Calcare di Base thins out in the opposite direction, almost disappearing in the Pasquasia section.

Gypsum turbidites are reported in the Decima and Wezel's model above the Cattolica gypsum-Calcare di Base and below the halite. This stratigraphic relationships is derived from borehole (S. Antonio 1 and 9) and outcrop data (Eraclea Minoa).

In the Northern Apennines it has been documented that gypsum turbidites and olistostromes postdate the phase of deposition of massive selenites and that they were emplaced following an important phase of tectonic deformation in deeper and/or more subsiding subbasins which did not experienced primary evaporite precipitation. Is this the case also for the Caltanissetta basin? In any case, what is the meaning and the true age of these deposits? Are they the first product of the strong deformation event separating the Lower Evaporites from the Upper Evaporites?

Topic 6 – The stratigraphic position of Sicilian salt

Decima and Wezel (1971) pointed out that the Sicilian salt had no lateral relationships with the Calcare di Base or the Gessi di Cattolica. Instead, based on borehole data, they stated that halite lays above the Gessi di Cattolica through an intervening unit made up of gypsum turbidites. The upper boundary of the salt unit is represented by an erosional surface associated with angular unconformity above which lie the Upper Evaporites.

Garcia-Veigas et al. (1995), based on the lack of evidence for the occurrence of the Gessi di Cattolica below the salt, suggested instead a lateral transition between gypsum (massive selenite) and salt and thus their overall synchronous character. Incidentally, we point out that in this revised model a vertical superposition of salt above gypsum is still implied, at least in proximal areas. In this model, the important observation of the occurrence of gypsum turbidites below the salt simply disappears; clastic sulphates are reported immediately above the angular discordance topping the whole lower evaporitic complex, i.e. above the salt.

Rouchy and Caruso (2006) substantially confirm the Garcia-Veigas et al. (1995) model, proposing a genetic model linking together in a single evaporitic cycle the Calcare di Base limestone, the massive selenites and the salt. According to their model, the salt would be a perfect equivalent of the gypsum and developed in a time interval falling between 6.08 and 5.5 Ma; potash salt and at least one local desiccation surface within salt (Realmonte; Lugli et al., 1999) developed during the two glacial peaks occurring in such time interval at around 5.7-5.8 Ma (isotope stages TG20 and TG22).

These stratigraphic models do not take into account the huge complex of clastic gypsum which largely characterize the Caltanissetta basin and that were long considered to postdate the Messinian. Setting apart the borehole data provided by Decima and Wezel (1971), in these models the large number of observations derived from salt mine data reported by Ogniben (1957), Selli (1960) and Mezzadri (1990) showing that salt bodies are usually encased within clastic, often chaotic gypsum unit (the gypsum olistostrome), is not considered. Is this important from both a stratigraphic and genetic point of view?

Moreover, if the salt is coeval and genetically linked with primary gypsum, what about the well developed precessional cyclicity which characterizes the Gessi di Cattolica, as well as all the other massive selenite bodies around the Mediterranean? Do we have any evidence within the salt of the regular, cyclic occurrence of more diluted phases recorded by euxinic shales in gypsum units? Conversely, what’s the record within gypsum of the potash salt deposition and of desiccation event within salt?

In other words, do we really have strong evidence to support the synchronous deposition of salt and massive gypsum? More recent field, borehole and mine data suggest instead that in many basins of the inner foredeep system salt was associated with clastic gypsum. Basins located in more outer position (i.e. Realmonte) salt is underlain by shales.

What’s the real age of salt deposition and how long lasted its deposition? Do we have any tool to establish the length of the salt phase?

Topic 7 – Marine vs continental nature of the upper cycle and its high-resolution chronostratigraphic framework

The upper Messinian cycle of Sicily consists of two lithostratigraphic units: the Pasquasia Gypsum below and the Arenazzolo above. The

Pasquasia Gypsum corresponds to the Upper Evaporites and is characterized by the rythmic alternation of gypsum bodies (balatino and selenites) and marls. The thickness of this unit is variable attaining its maximum in the southwestern margin of the Caltanissetta basin (200 m at Eraclea Minoa) and thinning progressively to the east and along the northern and southern flanks. The base of the unit is represented by an erosional surface truncating with angular discordance the underlying deposits of the Lower Evaporites. However such surface is visible only on structural culminations and has been traced downbasin through the integration of borehole and mine data.

The Arenazzolo is made up of siliciclastic sediments indicating the development of fluviodeltaic systems within shallow basins just below the basal Pliocene flooding. This non marine unit is characterized by the typical brackish to freshwater ostracod assemblages with paraTethyan affinity indicating an important episode of dilution at the end of the Messinian.

The underlying Pasquasia Gypsum suggest a cyclic fluctuation of water salinity with average values higher than in the Arenazzolo. However, paleontologic and geochemical proxies provide mixed and controversial indications about the environmental conditions during this phase.

As in other Mediterranean basin (Sorbas, Nijar, Apennine foredeep, Cyprus, Crete, Calabria, Piedmont, Tuscany), the uppermost Messinian deposits show a clear bipartition in two units characterized by a different precipitation regime recorded by a sharp vertical facies change indicating the activation of flood-dominated fluvio-deltaic systems. What's the meaning of such change? Is it synchronous throughout the Mediterranean? How can we correlate the Sicilian succession with the other Mediterranean basins?

DAY 1

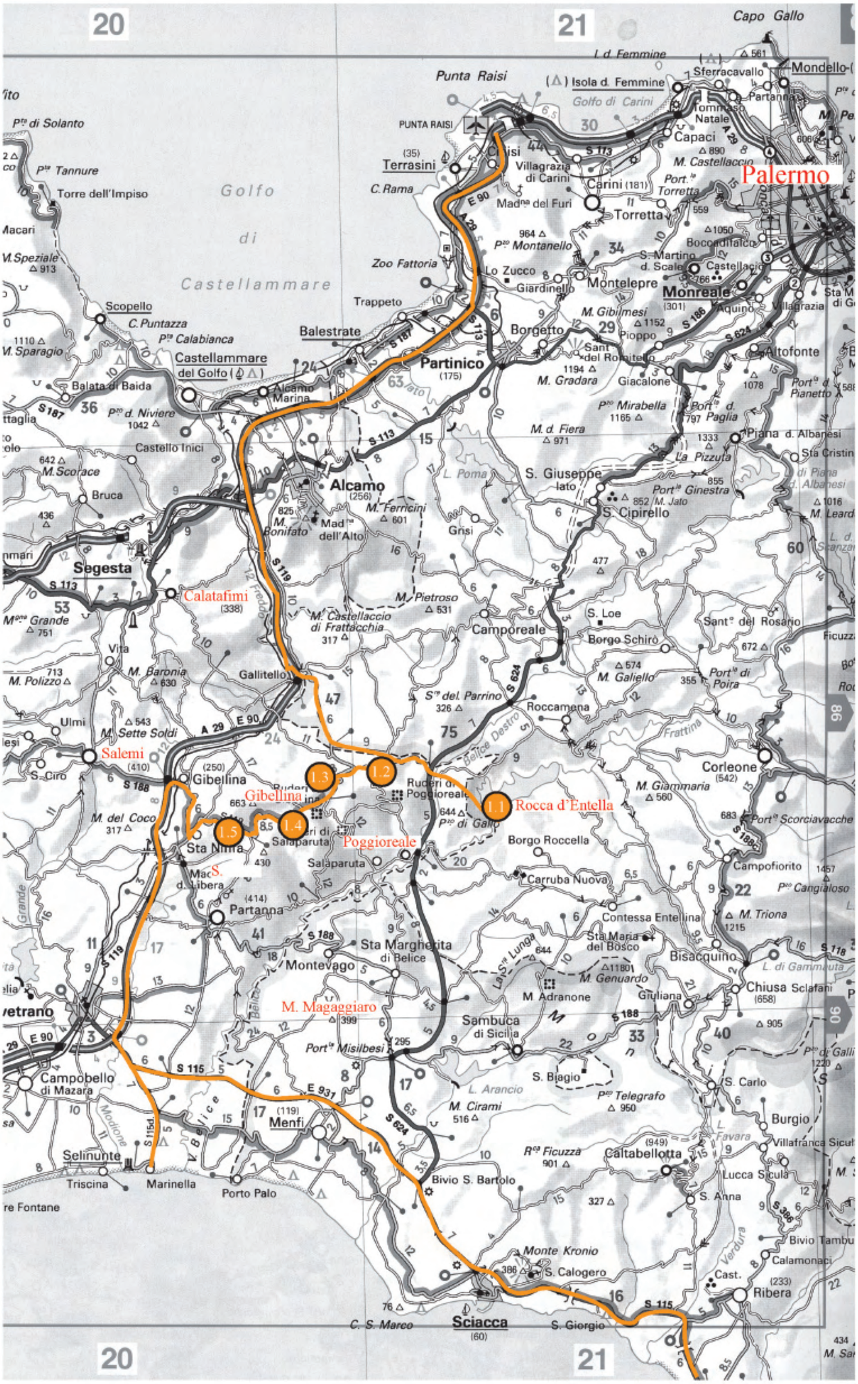

Fig. 8 – Day 1 stops.

Introduction to Day 1 – The Messinian succession of the Belice Basin (Western Sicily) –

Roveri M., Lugli S., Manzi V., Schreiber B.C., Vitale F.

The Belice basin is located in Western Sicily; it developed as a wedge-top basin since the Messinian above the Outer Carbonate thrust system of the Maghrebian-Sicilian belt (Vitale, 1990, Di Stefano and Vitale, 1993, Catalano 1997; Vitale 1995, 1996,1997a-b, Vitale and Sulli, 1997), and in particular above the M. Magaggiaro thrust sheet. This basin, roughly elongated in a E-W direction, is bounded to the north by the Poggioreale ridge and to the south by the M. Magaggiaro-M. Arancio antiforms (Fig. 9).

The Poggioreale ridge is a complex anticline structure which was mainly active during the Pliocene, controlling the facies distribution, geometry and thickness of Pliocene deposits and providing spectacular examples of syntectonic sedimentation (Vitale, 1997); however, the characteristics of the Messinian succession suggest that it started to grow much earlier, probably in the late Tortonian-early Messinian interval. The Plio-Quaternary sedimentary fill of the Belice basin has been studied in detail by Vitale (1990,1995, 1997a-b), while the Messinian succession is less known. The latter is characterized by the occurrence of both resedimented and primary gypsum facies resting above shallow to moderately deep-water mainly argillaceous deposits of the Terravecchia Fm. The occurrence of clastic gypsum, resedimented through gravity flows was pointed out by Schreiber (1973). Messinian deposits are in turn overlain by the Pliocene Trubi Fm.; they show abrupt facies changes and a high degree of disarticulation and deformation which do not affect the overlying Pliocene deposits that seem to close this phase of deformation. This led Vitale (1995) to suggest an important tectonic event during the Messinian, responsible for observed thin-skin deformation of the gypsum.

A re-examination of the Messinian Belice basin succession suggests however a somewhat different evolutionary scenario (Fig. 10).

Messinian deposits mainly crop out along the northern edge of the basin between S. Ninfa and Poggioreale. The succession can be subdivided in two main units; the lower unit consists of well-stratified gypsarenites topped by a gypsum breccia and assembled into a tabular body up to 50 m-thick extending from Costa Raia (see Fig. 10) on the east extending to S. Ninfa to the west. At Costa Raia this body pinches out rapidly toward the NE, while at Gibellina it onlaps a Lower Messinian patch reef (Fig. 11). This unit has a remarkable continuity and a low degree of deformation. It is made up of thin to thick-bedded graded beds of gypsarenites and gypsiltites with erosional bases, commonly showing load casts on bedding soles; planar as well as small-scale cross lamination is commonly observed. Thicker beds made of gypsrudites or gypsum breccia also occur in the upper part that thickens westward; in some cases also small to large scale gypsum olistoliths, both of primary and clastic origin, are found within the unit. These deposits can be interpreted as emplaced gravity flows of different volume and density and are very similar to the Apennines examples (Manzi et al., 2005).

This lower unit is overlain by a much thicker one (up to 200 m) characterized by the irregular occurrence of large-scale blocks of primary selenite, often still showing the original bedding, floating in a matrix made of highly deformed brownish shales containing disrupted

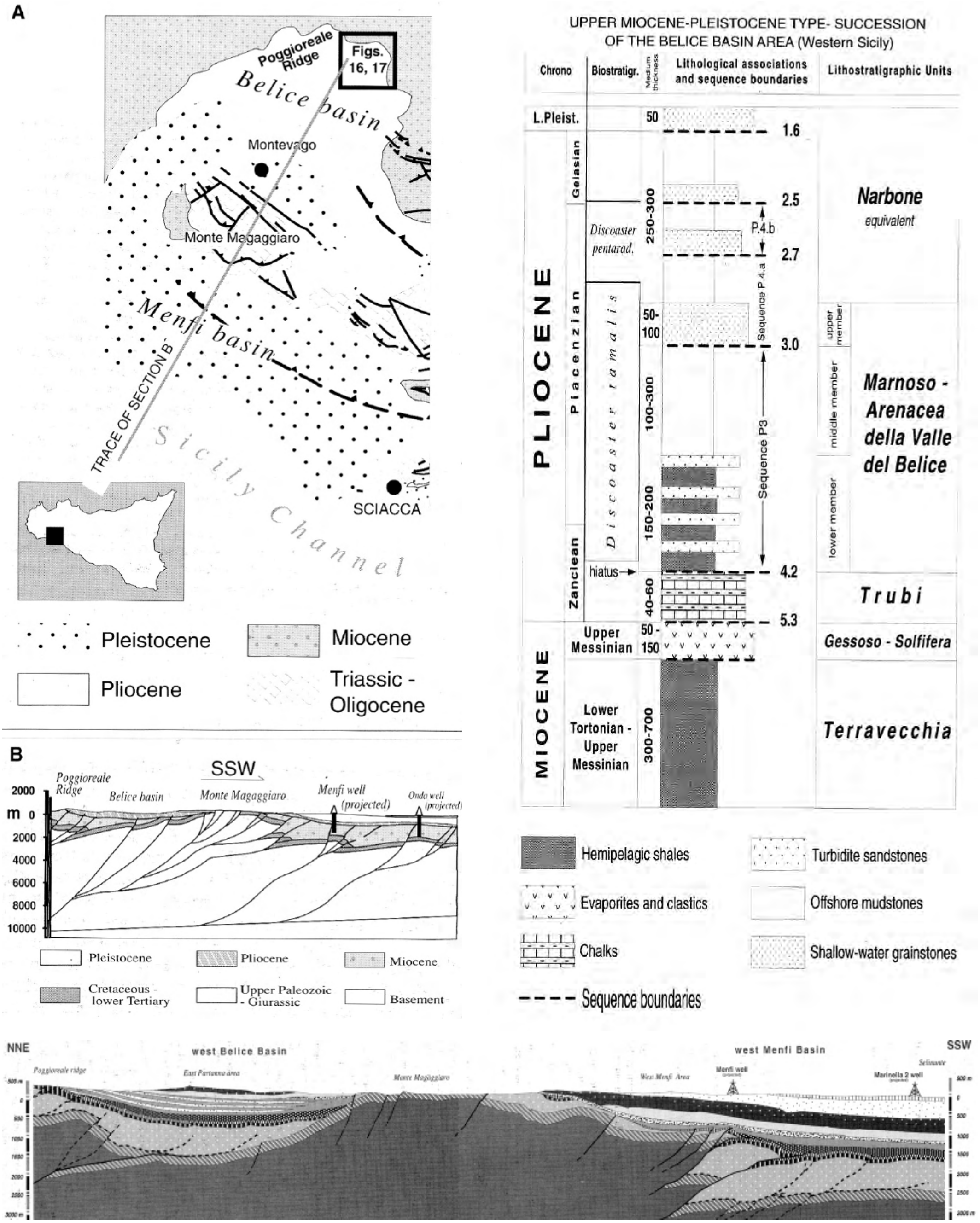

Fig. 9 – Simplified geological map, stratigraphic column and geological section of the Belice basin (from Vitale et al., 1997b).

and contorted gypsarenite beds. In some cases, gypsum turbidites fill the depressions between adjacent selenite blocks (see stop 1.3, Fig. 16). The upper unit is here interpreted as a chaotic complex emplaced by mass failures along a unstable slope. The close association with gypsum turbidites reinforces this interpretation and suggest a purely gravitational origin of the severe deformation affecting gypsum units. In the eastern area, close to Poggioreale, Vitale (1995, 1996) pointed out the occurrence of discontinuous lenses of Porites limestones as well as of continental deposits similar to the Arenazzolo Fm., directly overlain by Trubi (basal Pliocene), at the very top of the Messinian succession. As for the Porites limestone, we suggest here that they could have a early Messinian age and hence being in allochthonous position, like the underlying Lower Gypsum blocks. In this case the succession of the upper Messinian of the Belice basin would describe a sort of inverted stratigraphy, with the vertical superposition of progressively older terms; this recalls what happened in the Northern Apennines (Manzi et al., 2005) and could be interpreted as related to the progressive exhumation and dismantlement of a Tortonian-Messinian succession.

An alternative interpretation would consider the Porites limestone in place and equivalent of the Terminal Carbonate Complex (TCC) which characterizes the uppermost Messinian succession in the Betic basins and in northern Africa, except that here it is gypsified.

Fig. 10 shows a preliminary sketch of the stratigraphic setting of the Belice basin along a section roughly oriented NE-SW. It is interesting to note that gypsum turbidites pinch-out toward the base of a tectonically-active slope corresponding to the Poggioreale ridge, suggesting its possible activation since the Messinian. This tectonic structure infact separates the Belice basin, dominated by gravity-emplaced deposits, by a northern area characterized by the occurrence of autochthonous massive selenites having the same facies and stacking pattern features of the Lower Gypsum as seen in the Cattolica Eraclea area. They crop out extensively in the Calatafimi area and at Rocca d'Entella, i.e. to the north and to the east of the Poggioreale ridge. At Rocca d'Entella an almost complete succession of selenites occurs

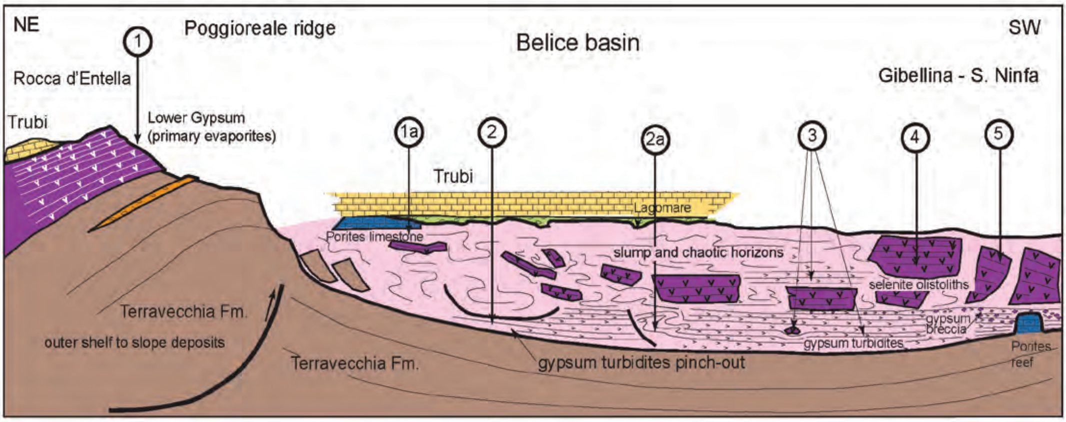

Fig. 10 – Sketch of stratigraphic relationships of Messinian deposits of the Belice basin. Circled numbers refer to Day 1 stops.

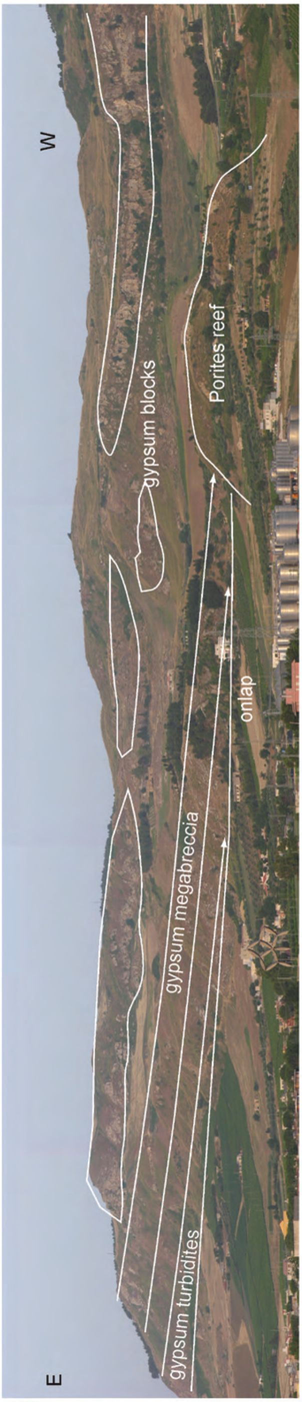

Fig. 11 – Gibellina Nuova, the onlap of gypsum mass flow and turbidites against a Lower Messinian Porites reef.

resting above the Terravecchia Fm. and cut at top by an erosional surface overlain directly by the Lower Pliocene Trubi Fm. In the area corresponding to the culmination of the Poggioreale structure, several Lower Messinian Porites reefs occur (Salemi, S. Ninfa), again suggesting the possible early development during Late Tortonian-Early Messinian of topographic highs related to growing tectonic structures.

The relationships between the Calatafimi-Rocca d'Entella basin to the north and the east and the Belice basin to the south, strongly resemble the situation of the Northern Apennines, where massive selenites formed in semi-closed basins bounded by thrust-related anticlines growing since the Late Tortonian and adjacent deeper basins received the products of the dismantlement of evaporitic basins following a intra-Messinian tectonic phase.

During this first day we will examine facies characteristics of the different evaporitic deposits of the Belice basin Messinian succession and their stratigraphic relationships, starting from Rocca d'Entella and ideally moving downslope toward S. Ninfa, according to the scheme of Fig. 10. The last stop will be devoted to the introduction of a new facies making up a significant part of the Lower Gypsum and to discuss its position and implications for the interpretation of precessional cyclicity.

Day 1 stops -

Stop 1-1 – Rocca d'Entella – primary, *in situ*, Lower Evaporites (facies, cyclicity, stacking pattern); general geologic-stratigraphic framework (Fig. 10); close and panoramic views.

Lugli S., Manzi V., Schreiber C., Roveri M., Vitale F.

The facies assemblage of the section is surprisingly similar to that of the Vena del Gesso Lower Evaporites in the Northern Apennines.

At least ten cycles can be observed separated by thin carbonate layers. We may observe most of the facies along the private road climbing up to the top of the plateau that cut through the evaporite beds.

The first two cycles are composed of very regular, large selenite crystals (up to 1 m tall; Fig. 12). Starting from the third cycle, the basal massive selenite facies is followed by banded selenite and starting from the 6th cycle the branching selenite appears on top of the banded facies.

The upper part of the section contains progressively more carbonate (calcilutite) and the upper part of the last visible cycle (probably the 10th

Fig. 12 - Rocca Entella basal giant selenite truncated by a dissolution surface and overlain by banded selenite.

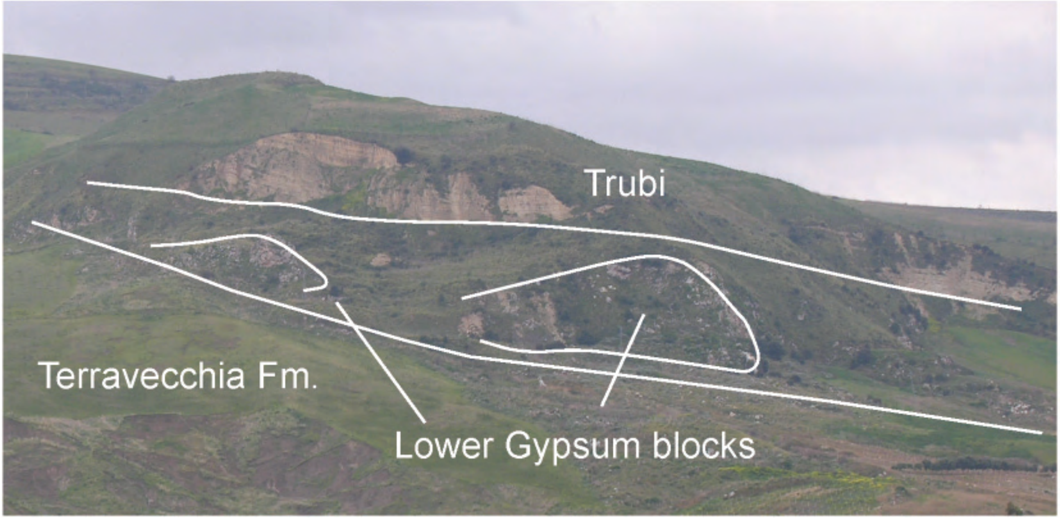

Fig. 13 – Belice river, near Garcia Lake. Chaotic gypsum overlain by Trubi Fm. pelagic deposits.

cycle) is composed of a massive carbonate bed at least 2 m-thick (Castello Arabo archeological site on top of the plateau).

Stop 1-1a - Belice River (south of Rocca d'Entella): close and panoramic views on disarticulated gypsum blocks sealed by Lower Pliocene Trubi Fm (Fig. 13) – examples of large-scale gravitative collapses on a tectonically active slope – the intra-Messinian tectonic phase

Roveri M., Lugli S., Manzi V., Schreiber C., Vitale F.

Stop 1-2 – Road Poggioreale-S.Ninfa – Costa Raia. Moving downslope along the intra-Messinian unconformity: eastward pinchout of gypsum turbidites.

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The panoramic view offers the opportunity to recognize the basic elements of the stratigraphic succession of the Belice basin, their large-scale geometrical characteristics and relationships. Gypsum turbidites represent the base of the entire succession and forms a distinct tabular body, virtually underformed, laterally persistent and well recognizable in the morphology.

Stop 1-2a – close-up view of gypsum turbidites; evidence of synsedimentary deformation: slump folds in gypsum turbidites (Rocca Tonda east – Fig. 14).

Lugli S., Manzi V., Schreiber C., Roveri M.

Gypsum turbidites are here involved in spectacular synsedimentary deformations, consisting in overturned slump folds testifying for the syntectonic nature of this unit. Gypsum turbidites are overlain by the chaotic complex containing large gypsum olistoliths.

Stop 1-3 (several stops along the road to s. Ninfa) – stratigraphy and sedimentology of the resedimented evaporites complex of the Belice basin (Fig. 15): basal gypsum turbidites (with small gypsum olistoliths) and debrites, upper chaotic unit with floating large-scale Lower Gypsum blocks (Fig. 16), gypsum turbidites

Fig. 14 – Rocca Tonda East section. Gypsum turbidites (below) affected by synsedimentary folding (slump) overlain by Lower Gypsum olistoliths (above).

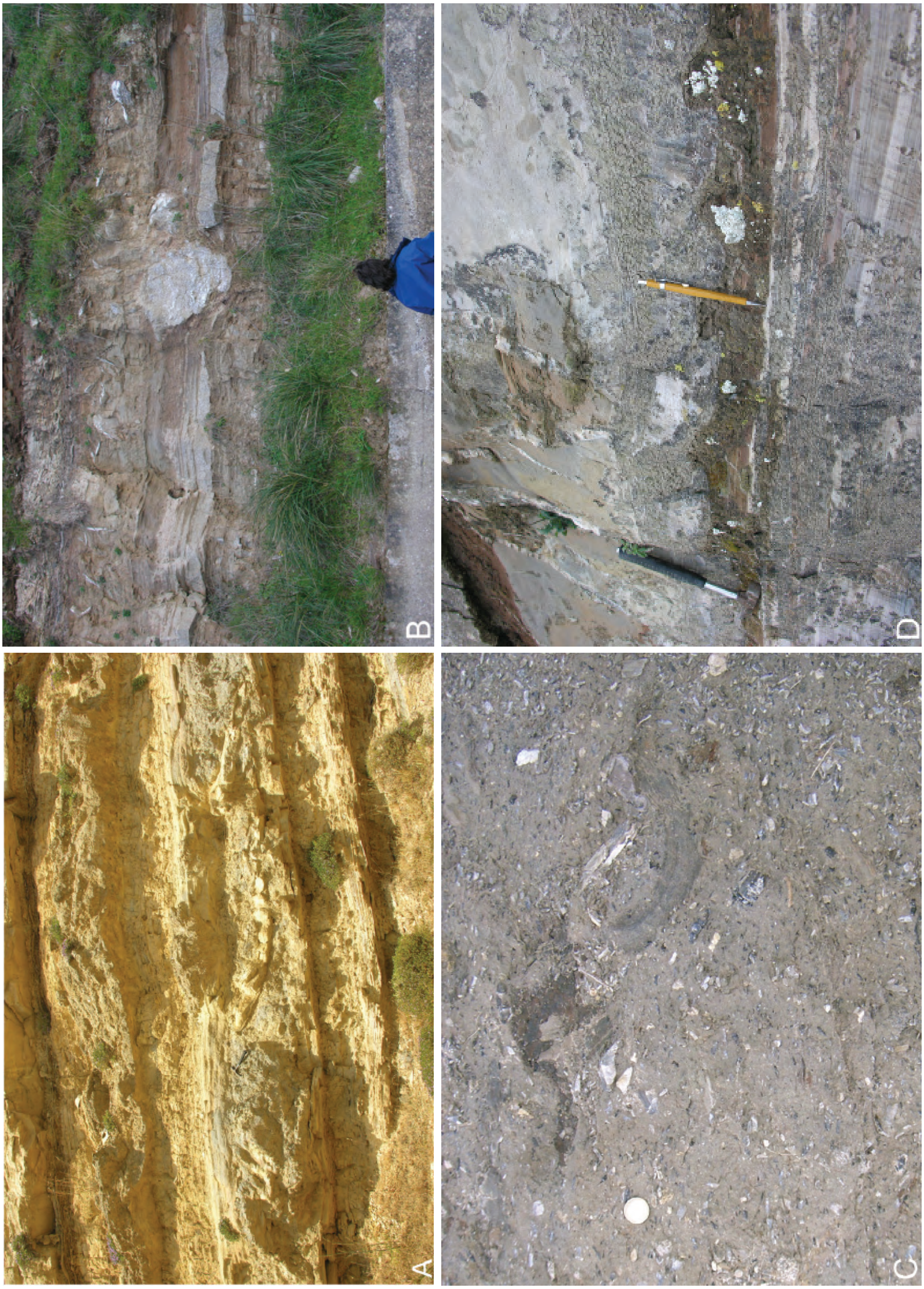


Fig. 15 – Stop 1-3. Details of gypsum turbidites and mass flows. Note slurry beds (A), small-scale gypsum olistoliths (B), gypsrudites (C) and load cast at the base of a graded gypsarenite layer (D).

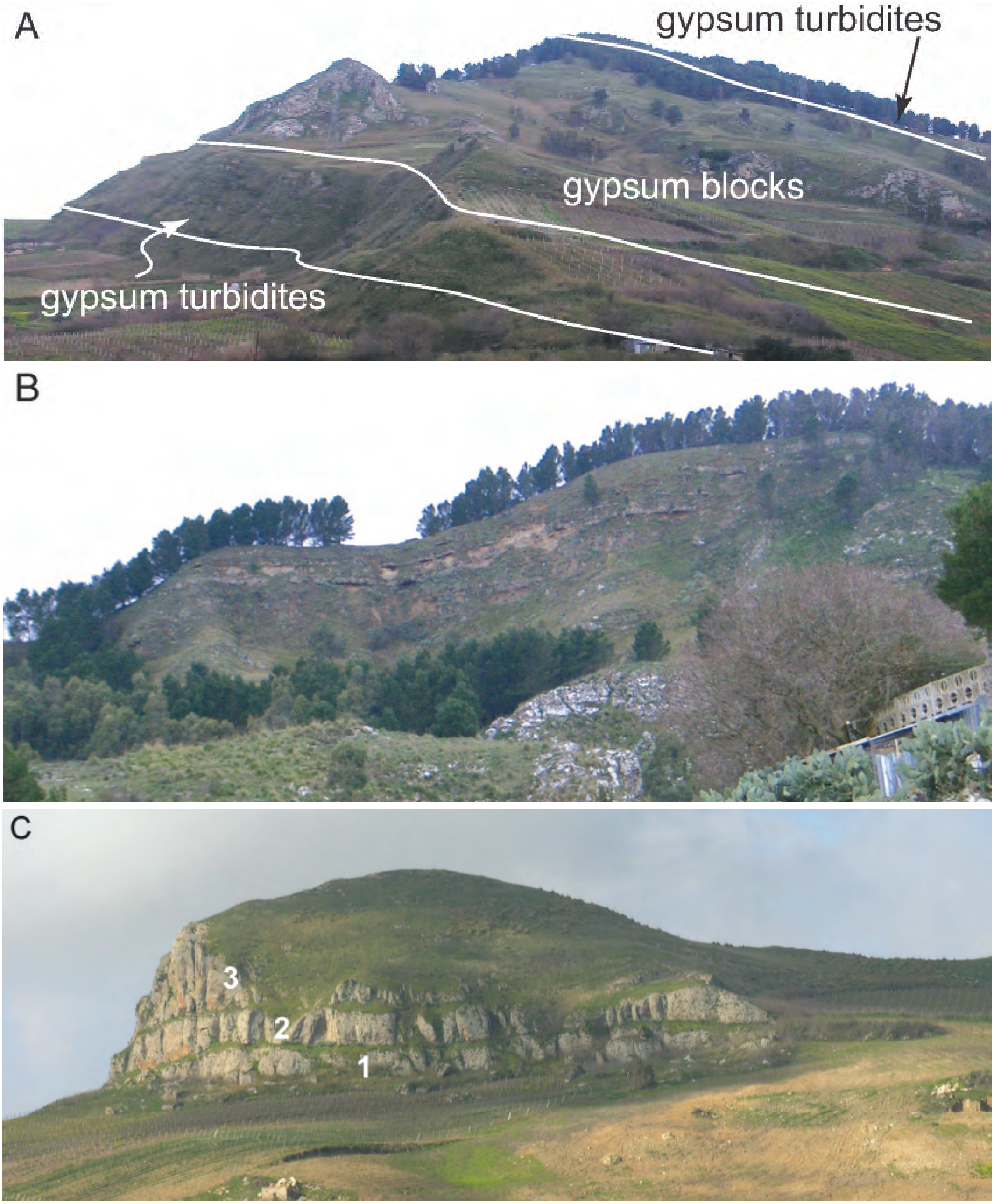


Fig. 16c – Rocca delle Penne. Large sized Lower Gypsum block floating within the upper chaotic unit with well recognizable basal (1st to 3rd) cycles; giant selenite crystals are present at the base. Fig. 16 a,b – Stops 1-3, 1-4. General view from Martorina with Lower Gypsum disarticulated blocks sandwiched between gypsum turbidites.

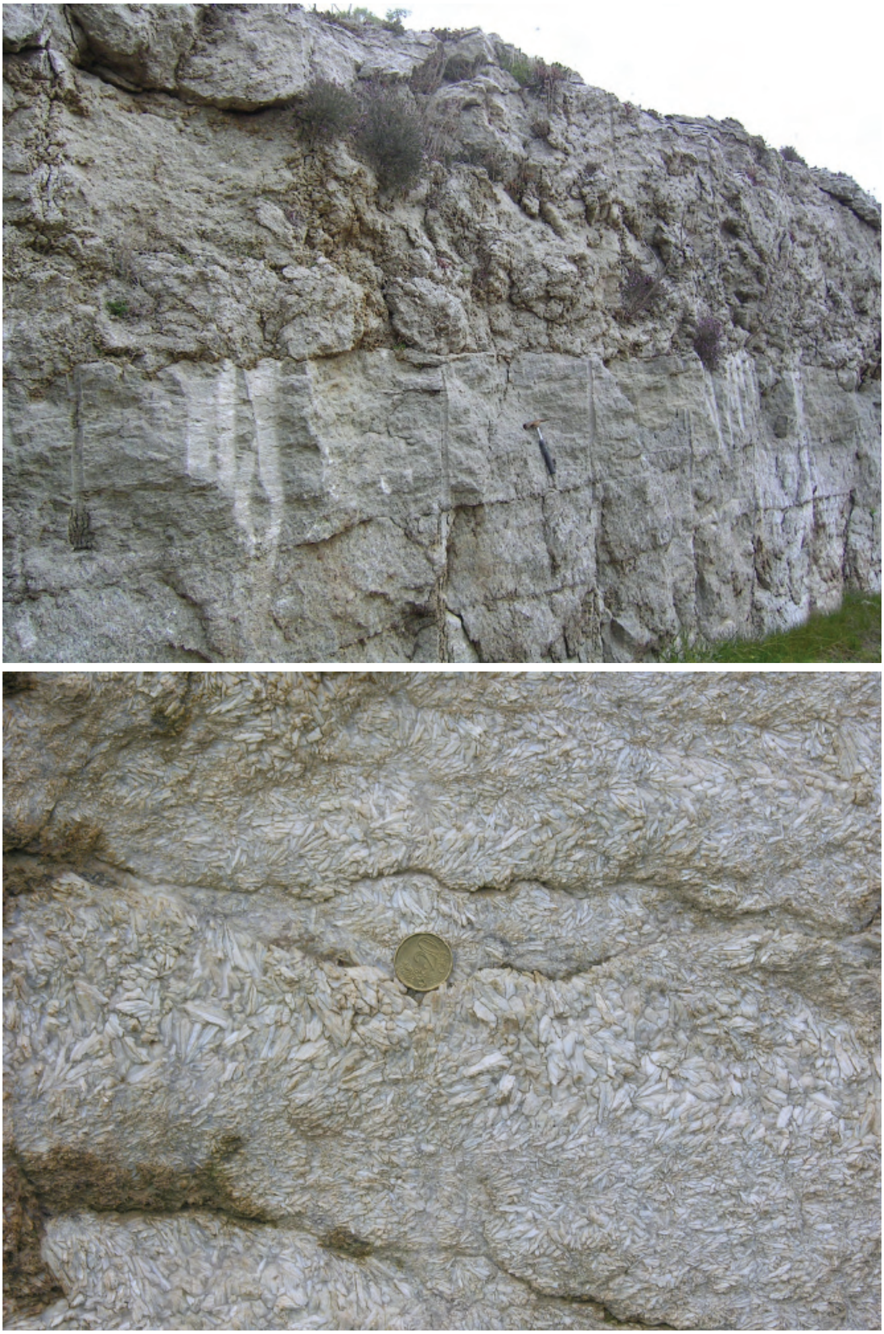


Fig. 17– S. Ninfa, road to Poggioreale, km. 40. Branching selenite facies in the Lower Evaporites.

and slumped marls (Rocca Tonda, Martorina, Rocca delle Penne).

Schreiber C., Lugli S., Manzi V., Roveri M.

Gypsum turbidites consist of thin to thick graded bipartite beds, usually showing a gypsarenite lower division sharply or more gradually overlain by a gypsum-siltite upper division and finally by dark shales. Bed bases are slightly erosional with possible groove casts; internal structures are represented by horizontal and small-scale cross lamination. These beds can be interpreted as deposited by low-density, fully turbulent gravity flows; they are associated with thicker and coarser-grained beds showing a basal gypsrudite division also containing angular to subrounded clasts of different lithologies. Such beds are the product of higher density gravity flows sustained by inertial mechanisms (grain collisions, fluid overpressure).

Stop 1-4 – Rocca delle Penne - upper chaotic unit with floating large-scale Lower Gypsum blocks (Fig. 16c).

Stop 1-5 – nearby S. Ninfa (km 40 of the S119) – “branching selenites”, a new primary facies: characteristics and palaeoenvironmental meaning – implications for the Lower Evaporites cyclicity (Fig. 17).

Lugli S., Manzi V., Schreiber C., Roveri M.

In a small quarry cut we can observe in detail the internal structure of the branching selenite (nodular and lenticular selenite of Vai and Ricci Lucchi, 1977). Clusters of selenite crystals grouped in branches project outward and downward from a nucleation zone that can not be seen in the outcrop. The branches terminate against a fine-grained gypsiferous matrix and against other branches projecting from different directions an belonging to other cone structures. In many cases the crystals are far smaller than in this outcrop and the internal structure of the branches are much more difficult to trace. We interpret this facies as an extreme evolution of subaqueous selenite supercone structures described in the Sorbas basin (Spain) by Dronkert (1985). In the case that only the branch terminations can be discerned and no obvious conical shape may be recognized, we proposed the use of the term "branching selenite" to emphasize the aspect that this crystals grew in organized subacqueous structures.

DAYS 2 and 3

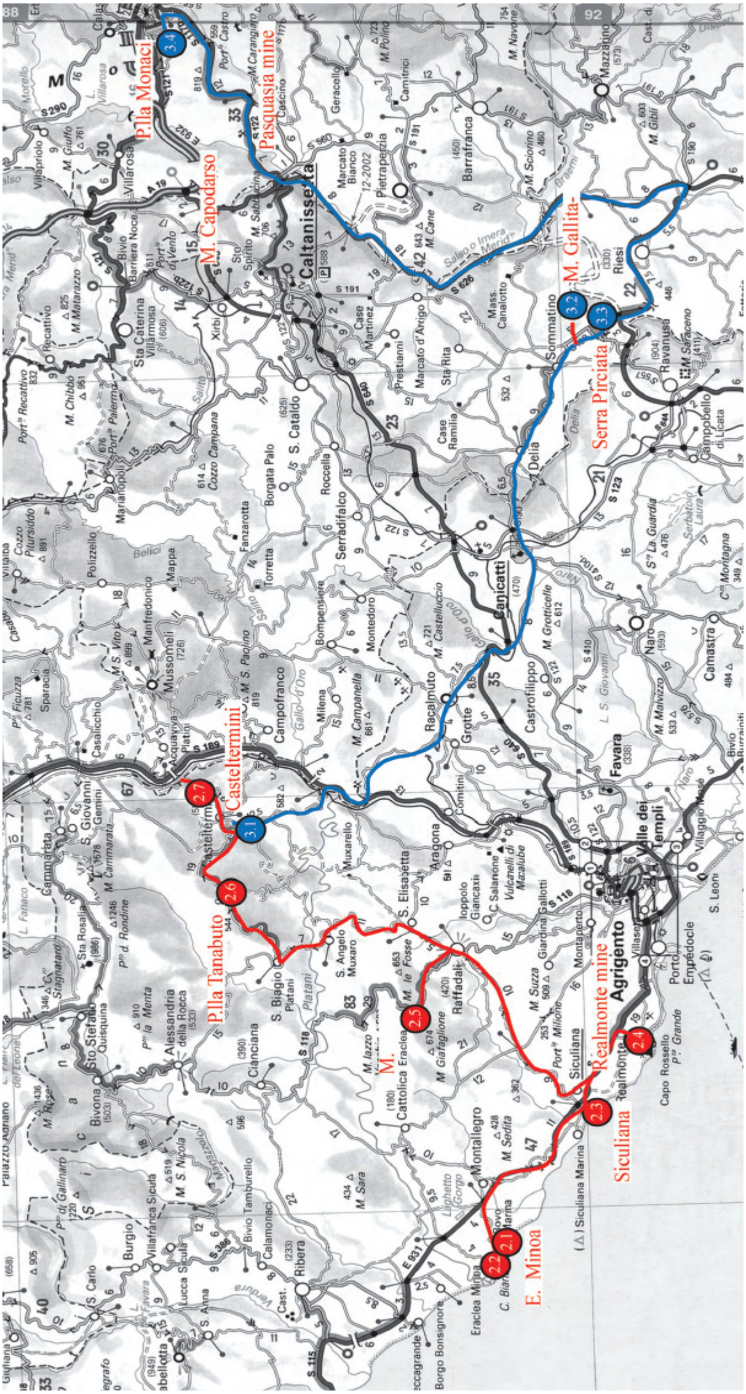


Fig. 18 – Days 2 and 3 stops

Introduction to Days 2 and 3 - The Caltanissetta Basin

A. Caruso, J.M. Rouchy

Among the basins uplifted at the periphery of the Mediterranean, the Sicilian basin is probably the one that provides the most complete sedimentary record of the Messinian Salinity Crisis. The close similarity of its sedimentary succession with that of the deep *offshore* Mediterranean basins led many authors to consider it as a reference for the interpretation of the evaporites present in the deepest Mediterranean basins which are essentially known from their seismic record, at least for the lower units i.e., the salt and the evaporite series recorded by the pre-salt reflectors. This correlation is strengthened by the results of earlier micropaleontological studies which demonstrated that the Sicilian basin was deep before and after the evaporite deposition (Benson, 1973; Cita, 1973; Sprovieri et al., 1996a and b; Sgarrella et al., 1997), although not as deep as the deepest central basins. Its water depth could have been greater than 1000 to 1300 meters. More than any other peripheral basins, the central Sicilian basin may thus provide crucial arguments to assess the viability of the different scenarios proposed to interpret the Messinian salinity crisis.

The major difference with the deep basins such as the Western Mediterranean basin lies within the importance of the tectonics that affected further this thrust-top basin through the whole period represented by the Messinian crisis continuing today.

According to Butler et al. (1995), the paleogeography of the basin changed continuously through the Messinian as it was composed of moving synclines at the front of the Maghrebian chain, but we assume the depth of the central trough remained deep during all this period. The deformation continued throughout the Pliocene and persisting today. The uplift of late Pliocene marine deposits at 900 meters of elevation at Enna or the thrust of the Messinian evaporites including the salt unit over the upper Pliocene deposits in the Realmonte-Punta Piccola area, are evidences of this intense tectonic deformation. In the central trough of the Caltanissetta basin where a thick salt unit is present, the halokinetic response of the salt associated to the different mechanical behaviour of the massive lower gypsum unit on one hand and of the sedimentary cycles of the upper evaporites and Pliocene marls on other hand, was responsible for very chaotic structures. The lower gypsum is thus fragmented into large masses of massive gypsum locally up to 200 m in thickness that are irregularly distributed and mixed with fragments of both upper evaporites and lower Pliocene Trubi deposits. The dissolution of the salt caused localized areas of collapse that aggravated the chaotic structure of the Messinian-Pliocene deposits in this area (Hsü et al, 1978; Rouchy, 1982; Rouchy and Caruso, 2006). There is however an alternative interpretation that considers the chaotic structure of the lower gypsum corresponds to large masses of gypsum resedimented from marginal basins into a foredeep (see Roveri et al., stop 2.).

Several sections have been selected to illustrate a complete sedimentary record of the salinity crisis (Fig. 1). The classical Eraclea Minoa section provides a continuous sedimentary succession including the lower gypsum unit, the upper gypsum and the transition from the upper gypsum to the early Pliocene. It permits detailed examination of the lower gypsum with the final erosional surface, the cyclic pattern of the upper evaporites, the transition from the late Messinian Lago-Mare to the early Zanclean marine deposits which occurred abruptly but without any significant erosional event. The access to the upper evaporites being difficult due to recent urbanisation, the section of Siculiana-Giallonardo has been selected to look in more detail the cycles of the upper evaporites. Two sections i.e.,

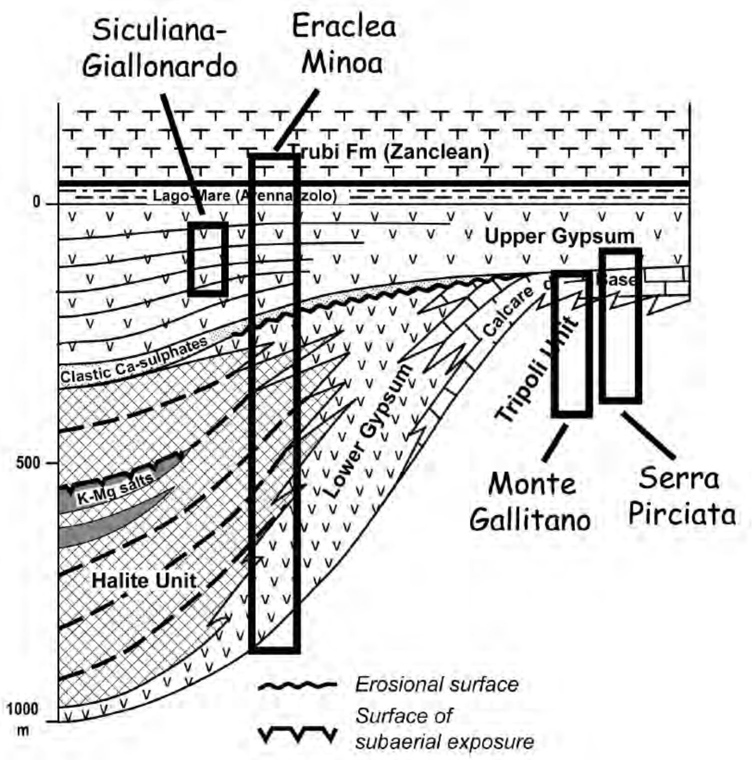


Fig. 19 – Schematic position of selected section within the interpretative cross-section through the central Sicilian basin (modified from Rouchy and Caruso, 2006).

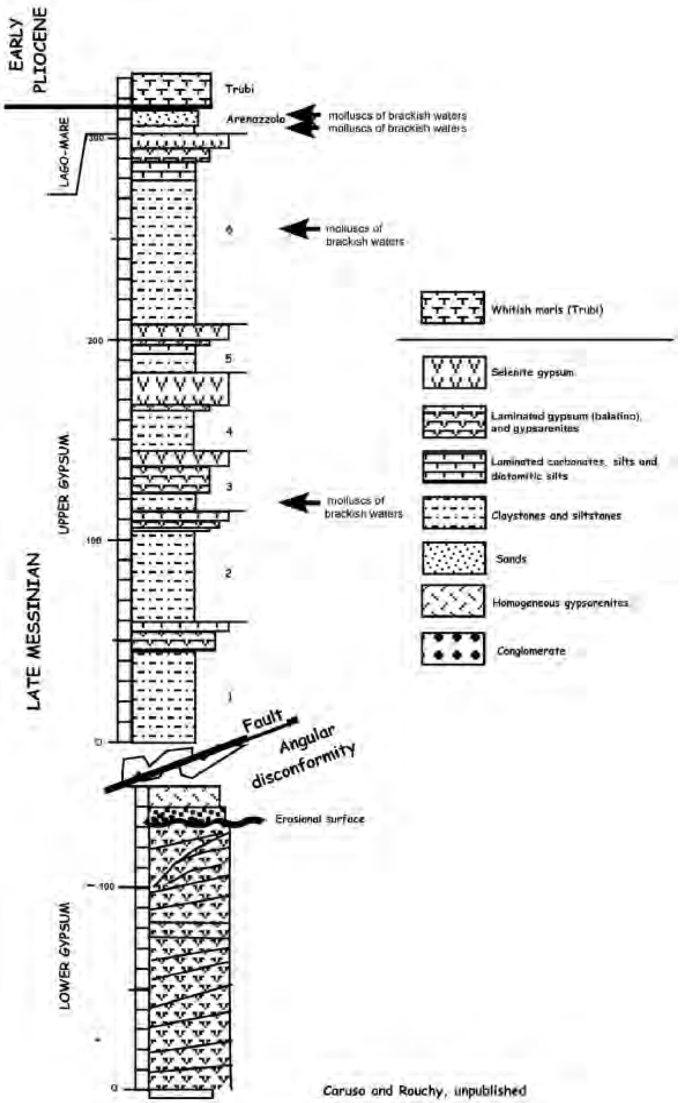
Serra Pirciata and Monte Gallitano are proposed to show the Calcare-di-Base and the transition from the Tripoli unit to the calcare di base. In these two sections like in several other sections (as Torrente Vaccarizzo and Monte Gibliscemi), the passage from the Tripoli to the calcare di base is transitional and does not displays any feature of large scale reworking.

Day 2 – the Messinian succession of the southwestern end of the Caltanissetta basin in its most typical outcrops; general geologic framework; stratigraphic problems and models

Stop 2-1 – The “Lower Evaporites” succession of Eraclea Minoa: gravity vs dissolution collapse, the meaning of uppermost clastic gypsum deposit; time and genetic relationships with salt deposits

Caruso A., Rouchy J.M.

The Eraclea Minoa section, located on the SW coast of Sicily 33 km SE of the city of Sciacca, is probably one of the most famous section for the study of the Messinian Salinity Crisis. It provides a complete sedimentary record from the onset of the Messinian salinity crisis up to the restoration of the normal marine conditions in the basal Zanclean and displays the classical succession of the Lower Gypsum, the Upper Gypsum and the Lago-Mare deposits. The section has been previously described in detail for lithology, stratigraphy, sedimentology, micropaleontology and geochemistry (Cita, 1973; Decima and Wezel, 1973; Decima and Sprovieri, 1973; Pierre, 1974; Brolsma, 1978; Mascle and Heiman, 1978; Schreiber et al., 1976; Longinelli, 1979; Rouchy, 1982; Hilgen and Langereis, 1993; Sgarrella et al., 1997; Bonaduce and Sgarrella, 1999; Pierre et al., 2006**;** among many other papers) (Fig. 20).



Caruso and Rouchy, unpublished

Fig. 20 – Stratigraphic column of the Eraclea Minoa section (Sicily)

The lower gypsum unit

In the central area of the Caltanissetta basin (Decima and Wezel, 1973; Rouchy, 1982), the Lower Gypsum is usually composed of a up to 300 m-thick pile of primary selenite gypsum, locally transformed into nodular gypsum after anhydrite and including layers of clastic gypsum. Good outcrops of these masses of selenite gypsum displaying a cyclical organisation may be observed around the town of Cattolica, on the beach of Siculiana Marina or along the road Casteltermini-Eraclea Minoa. The nodular facies are well exposed around the town of Montallegro.

In the Eraclea Minoa section, this unit lies upon pale gray to whitish marls that, like in most of this central area, can be dated as Serravallian to Tortonian (A. Caruso, unpublished data). This indicates an important stratigraphic hiatus at the base of the gypsum that could be related to a thrusted contact. The unit is composed, over about 150 meters, of beds of exclusively primary selenite gypsum which, in the upper half of the unit, exhibit a chaotic structure made by the accumulation of large fragments of disrupted gypsum layers (Fig. 21A, B). This structure may be interpreted as the result of collapse processes after dissolution of salt interbeds that occurred during a period of subaerial exposure at the end of the deposition of the Lower Evaporites (Hsü et al., 1978; Rouchy, 1982; Rouchy and Caruso, 2006).

Thick and massive salt units up to 400 m in thickness are present in subsurface (only 2 km to the north) as indicated by the two boreholes of Cattolica 5 and 6. A similar gypsum megabreccia probably formed by dissolution of salt lenses is also interbedded between the Lower and Upper Gypsum in the Polemi Basin, Cyprus, and on top of the gypsum unit in the Iraklion Basin, Crete.

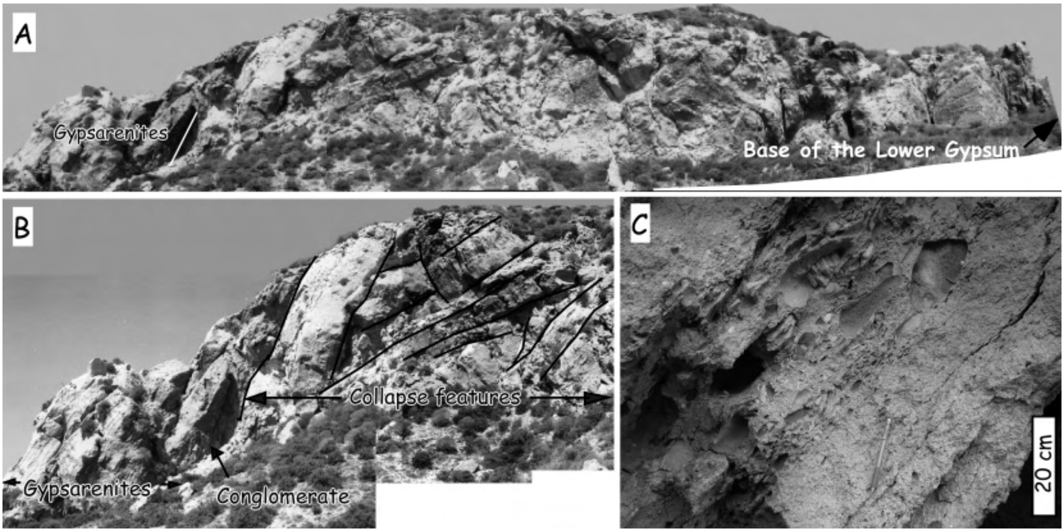


Fig. 21 – The Lower Gypsum Unit in the Eraclea Minoa section. A. View of the Lower Gypsum that appears as a chaotic accumulation of large fragments of disrupted gypsum layers which can be interpreted as the result of collpase after dissolution of salt interbeds. The upper part of the succession is made of gypsarenites (see photo B for details). B. Detail of the collapse features in the upper part of the unit. This interval is overlain by a sequence of normal graded clastic deposits that starts with a coarse conglomerate and grades upward into gypsarenites. C. Close-up of the conglomerates at the base of the gypsarenites that is predominantly composed of large rounded pebbles of diatomites from the pre-evaporitic Tripoli Fm. with minor amounts of other deposits.

The chaotic interval is unconformably overlain by a fining-upward sequence of clastics (Fig. 21B) starting by a coarse conglomerate that reworks the preevaporitic deposits, especially as cm to dm-sized fragments of diatomites from the Tripoli unit (Fig. 21C). Thus, a period of subaerial exposure occurred at the end of the deposition of the lower evaporites that caused a deep erosion and a reactivation of the drainage system. In agreement with Butler et al. (1995) and Krijgsman et al. (1999), we consider this unconformity as the trace of an important episode of subaerial exposure in the Sicilian basin and probably elsewhere around the Mediterranean. It coincides with the final filling of the central trough by the lower evaporites and the salt unit, leading to its desiccation.

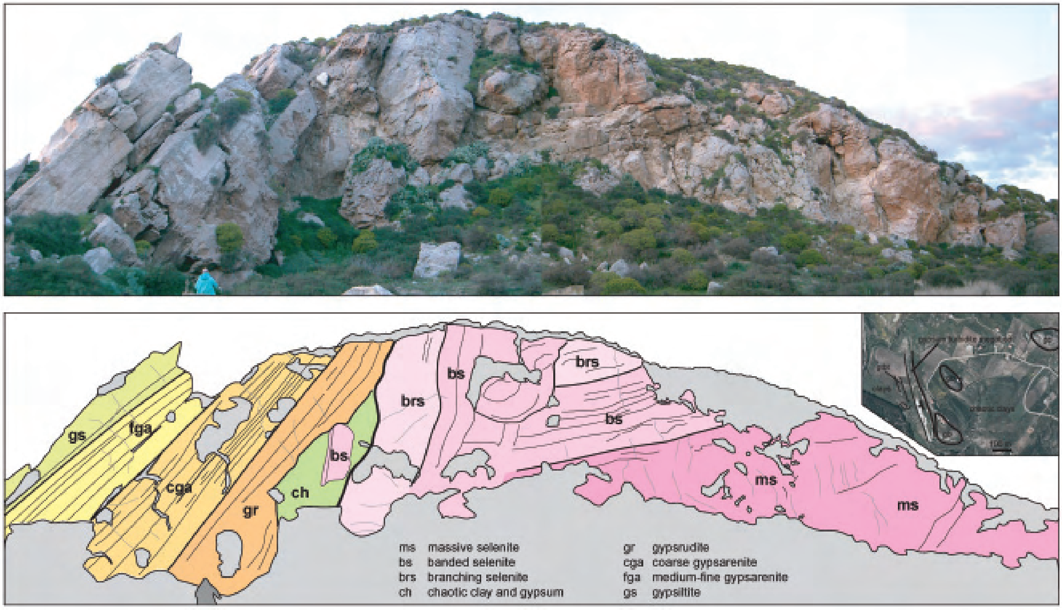


Fig. 22 – The deformed Lower Gypsum of the Eraclea Minoa section.

The Lower Gypsum deformations: an alternative interpretation

M. Roveri, V. Manzi, S. Lugli, F. Ricci Lucchi

An alternative interpretation of this outcrop is here proposed for discussion. The Lower Gypsum megabreccia could be the result of large-scale gravity collapses triggered by tectonic activity (Fig. 22). In this case, the graded gypsarenite unit on top of the megabreccia could be genetically related to the underlying deposit, representing the upper part of a bipartite flow consisting of a lower inertial division and an upper, fully turbulent one. The graded unit does not show any significant break indicating the superposition of multiple, discrete, depositional events; its general characteristics are compatible with deposition from a large volume, turbulent flow emplaced and ponded in a relatively small and confined basin. This deposit is similar to megaturbidites occurring in many tectonically active basins, usually associated to the collapse of carbonate platforms.

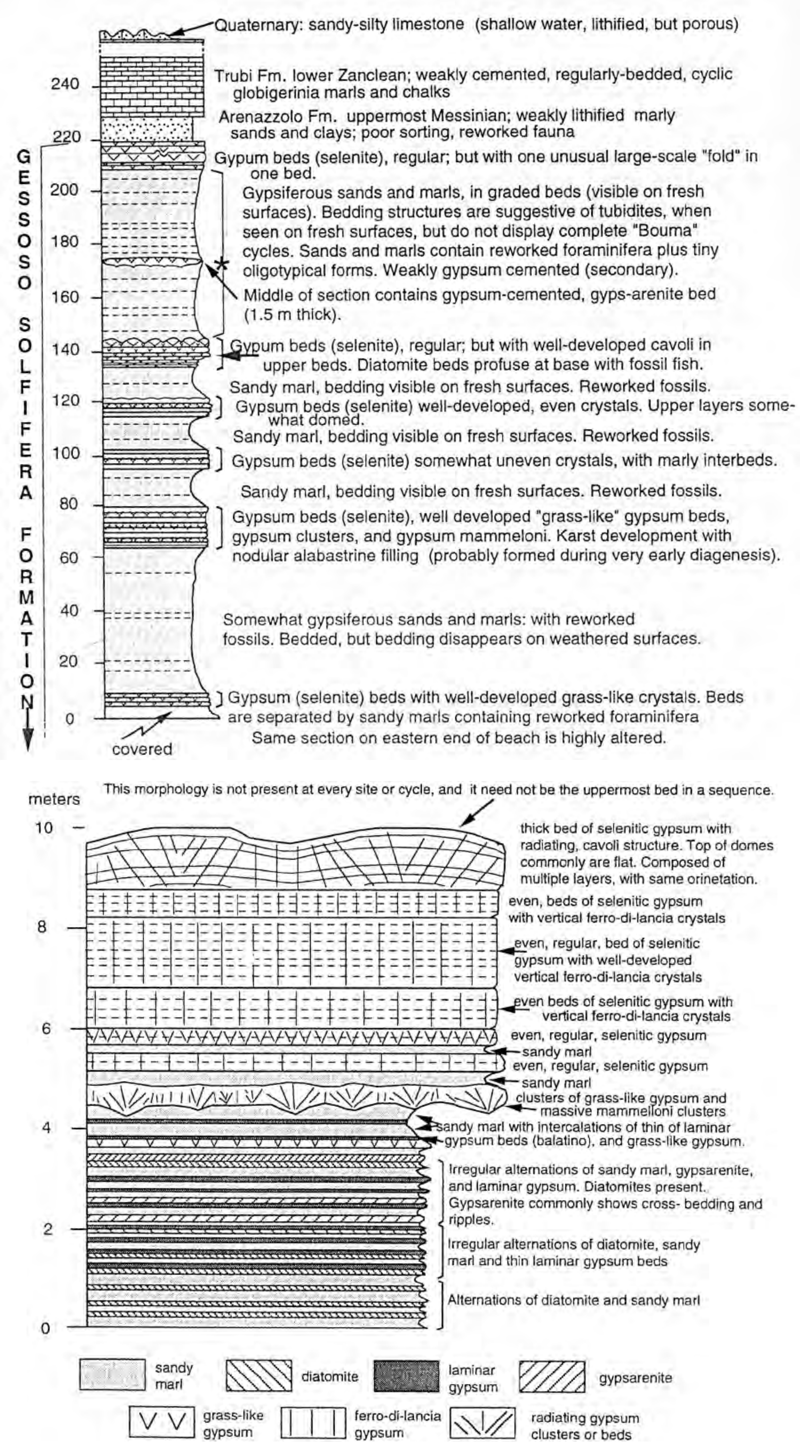


Fig. 23 – Stratigraphic column (above) of the Upper Gypsum at Eraclea Minoa; idealized cycle (below). From Schreiber, 1997.

Stop 2-2 – The Upper Evaporites-Arenazzolo-Trubi succession of Eraclea Minoa (Fig. 23); gypsum facies, palaeoenvironmental conditions at the end of the MSC, Late Messinian high-resolution stratigraphy

The Upper Gypsum Unit

Caruso A., Rouchy J.M.

As in a large part of the central area of the Caltanissetta basin, the contact between the Lower and Upper Gypsum units is marked by a sharp angular unconformity and, in the Eraclea Minoa section, by a fault underlain by highly deformed gypsum layers (Fig. 20). We think that this angular disconformity reflects mostly the contrasted mechanical behaviour of the sedimentary deposits which are marked by strong differences between the massive gypsum deposits of the lower unit and the clay-gypsum cycles of the upper unit, and also by halokinetic deformation of the thick salt unit (halite and potash deposits), during intra- and post-Messinian tectonic deformation, rather than a specific tectonic event (Rouchy and Caruso, 2006).

Unlike the lower unit that is composed of massive gypsum, the Upper Gypsum unit consists of six sedimentary cycles (Fig. 20; 24A, B, C). The intensely deformed gypsum deposits located along the faulted contact at the base of the unit could represent a seventh cycle. Each cycle starts with clays and marls interbedded with sands and thin layers of fine-grained carbonates. These later become thicker and more abundant in the upper part where they can be associated with few diatom-rich laminae. This interval is overlain by gypsum deposits composed of alternating layers of finely-laminated gypsum (balatino) and gypsarenites in the lower part and selenite gypsum in the upper part. Except for the layers of gypsarenites, all the gypsum formed by primary subaqueous deposition, either by precipitation of small crystals at the air-brine interface or within the brines for the balatino, or by development of gypsum crystals nucleated on the sedimentary bottom for the selenite. A typical sedimentary cycle is described below in the Siculiana section.

The great majority of the sediments interbebbed with the evaporites are barren or characterised, as in the Siculiana section, by reworked assemblages of foraminifers sometimes associated with ostracods. For Bonaduce and Sgarrella (1999), the assemblages of ostracodes and benthic foraminifers present in the Eraclea Minoa section are representative of brackish and moderately hypersaline environmental conditions. Diatoms assemblages present in several cycles as in the upper gypsum of the Porto Empedocle also indicate low salinity conditions (Rouchy, 1982). Poorly diversified assemblages of planktonic foraminifers of different ages however are present (Caruso, unpublished data), while monospecific assemblages of coccoliths (small Reticulofenestrids) in the finely-laminated gypsum and, as in the Siculiana section, are present within the selenite gypsum itself (Rouchy, 1976; 1982; Rouchy and Caruso, 2006). Small Reticulofenestrids indicate that influxes of marine waters persisted in restricted stressed conditions. The stable isotope composition of the gypsum from the upper evaporites also evidences the permanence of marine waters with a strong influence of meteoric waters (Pierre, 1973, 1982; Longinelli, 1979). Brackish molluscs typical of the Lago-Mare conditions (*Congeria sp.*, *Melanoides sp.*) are present in the middle part of the claystones of the cycle 3 and at the base of the cycle 5 (Fig. 24B, 25A).

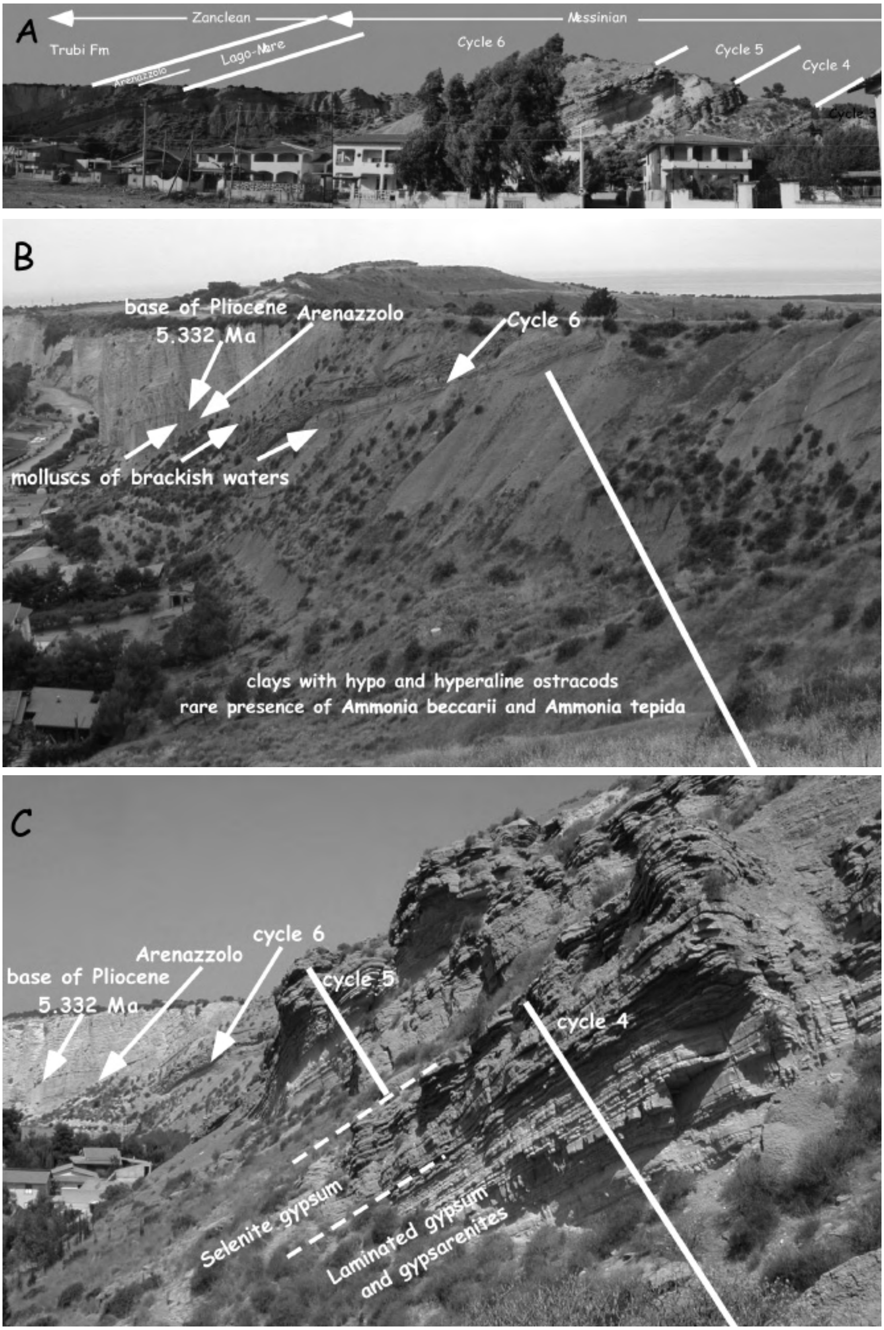


Fig. 24 – The Upper Gypsum Unit in the Eraclea Minoa section. A. View of the section showing the sedimentary cycles n° 3 to 6 and the transition to the late Messinian Lago-Mare and early Zanclean marine deposits (Trubi).B. View of the last sedimentary cycle (n° 6) characteried by a clay interval much more thicker than in the underlying cycles shown by the photo C. C. Detail of the cycles n° 4 and 5, showing their sedimentary organisation consisting in the succession of clays and carbonates, finely laminated gypsum (balatino) and gypsarenites which are capped by layers of primary selenite gypsum.

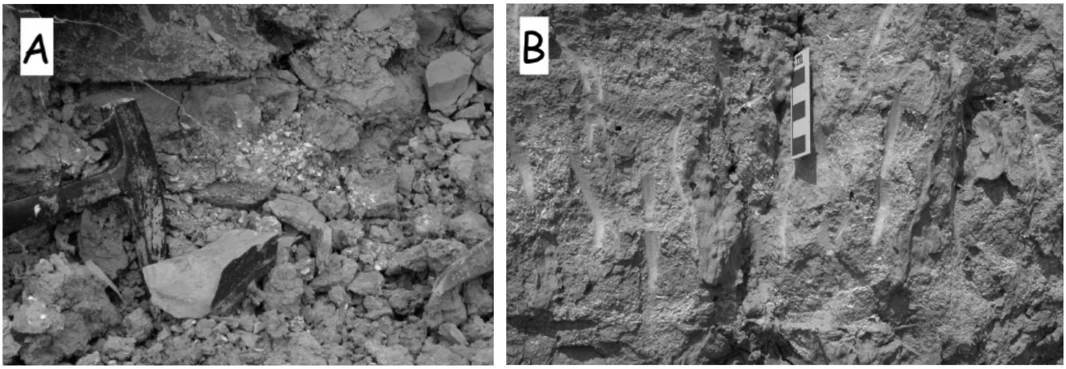


Fig. 25. Brackish molluscs in the Cycle 3 of the Upper Gypsum (A) and at the base of the Arenazzolo (B) of the Eraclea Minoa section.

The Lago-Mare and the restoration of the marine conditions

The sedimentary interval covering the transition from the gypsum to the basal marine Pliocene deposits has been previously described by Cita and Gartner (1973), Brolsma (1978), Cita et al. (1999), Van Couvering et al. (2000) and Pierre et al. (2006). Further description and data are given in the paper by Pierre et al. (2006).

Sedimentary description

Above the uppermost gypsum layer (N°6), the post-evaporitic late Messinian sedimentary interval consists of a 12 m-thick sequence of siltstones including some dm-thick layers of sandstones (Fig. 26A, D) overlain by about 3 m of sandy deposits, the so-called Arenazzolo unit. These sandy deposits display convolute structures related to fluidization processes (Fig. 26B). Abundant shells of brackish mollusks (the so-called Lago-Mare fauna) are disseminated over a thickness of 2 meters in the upper part of these siltstones and in the basal 30 cm of the sandy interval (Fig. 24B, 25B). In the westernmost part of the area, the uppermost gypsum and the overlying late Messinian sediments are involved in tectonic deformation which caused the stretching of the overlying siltstones and Arenazzolo sandstones that can locally resemble to a sedimentary discontinuity (Fig. 26C). There is no evidence in the section of a long period of subaerial exposure and erosion, all the features being explained only by sedimentary processes or tectonic deformation. The Arenazzolo grades upwards into grey claystones and siltstones over 60 cm below the sharp contact with the whitish Trubi marlstones and marly limestones. The uppermost 20 cm of the grey claystones and siltstones are characterised by intense burrowing (Fig. 26E).

The first beige-colored layer that marks the beginning of the precession-controlled cycles appears about 2 meters above the base of the Trubi marlstones (Hilgen and Langereis, 1988; 1993; Hilgen, 1991). The section was sampled every 30 cm in the Arenazzolo sands and underlying claystones, every 5 cm and even 2 cm around the MPB, and every 10 to 30 cm in the overlying Pliocene marlstones (102 samples).

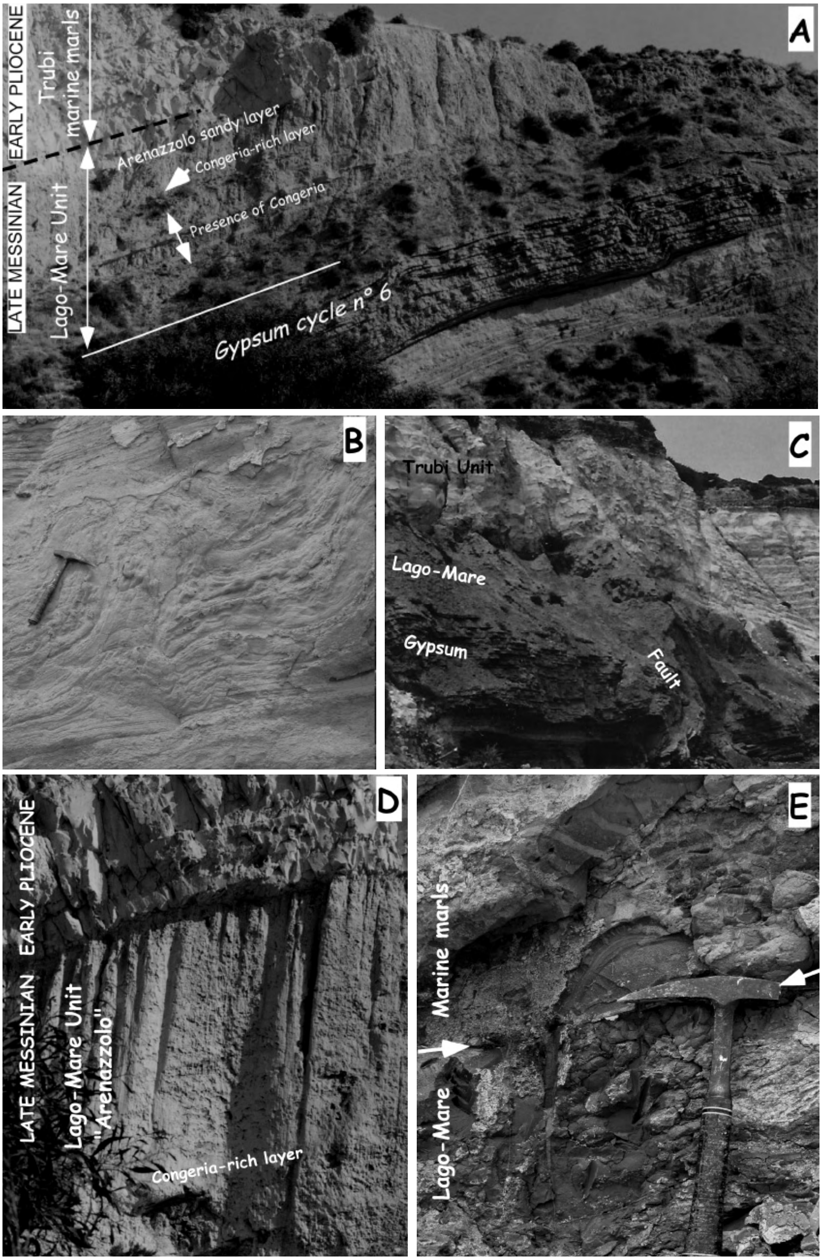


Fig. 26. The Messinian-Zanclean boundary in the Eraclea Minoa section. A. The uppermost gypsum layer (N° 6) is overlain by the Lago-Mare deposits composed of siltstones and sandstones (Arenazzolo) that are comformably and abruptly overlain by the marine oozes of the early Pliocene Trubi Fm. The typical Lago-Mare fauna (Congeria) are present at several levels, the major one being located in the lowermost part of the Arenazzolo sands. B. Convolute deformations in the upper part of the Arenazzolo sands. C. Local folding of the uppermost gypsum layer that led to the stretching of the late Messinian deposits. D. Detail of the Messinian-Zanclean transition. E. Close-up of the Messinian-Pliocene contact underlined by the white arrows that indicates an abrupt paleoenvironmental change without any trace of erosion. Although not clear on the photo, the contact is marked here by abundant burrows.

Mineralogy

The mineralogy displays a prominent change across the MPB marked by the rapid increase of the carbonate content from an average value of around 16 wt % in the late Messinian to values ranging from 65 to 77 wt% in the Trubi; this increase occurs progressively through a 35 cm-thick transitional interval (Fig. 7). The underlying deposits are characterized by low carbonate contents (15 to 30 wt %), while the quartz contents range from 3 to 18 wt % in the siltstones and increase up to a maximum of 30 wt% in the sandy Arenazzolo. The mollusc-rich layers are characterized by the presence of aragonite (up to 38 wt%). Dolomite is present in small amounts (< 6 wt%) and variations in its content mirror that of quartz, indicating its detrital origin. Remarkably, in the basal Trubi no abrupt mineralogical change was observed, but a decrease of terrigenous components and a progressive increase in carbonate content within a 35 cm-thick interval that corresponds to the appearance and subsequent changes of the assemblages of marine microfossils.

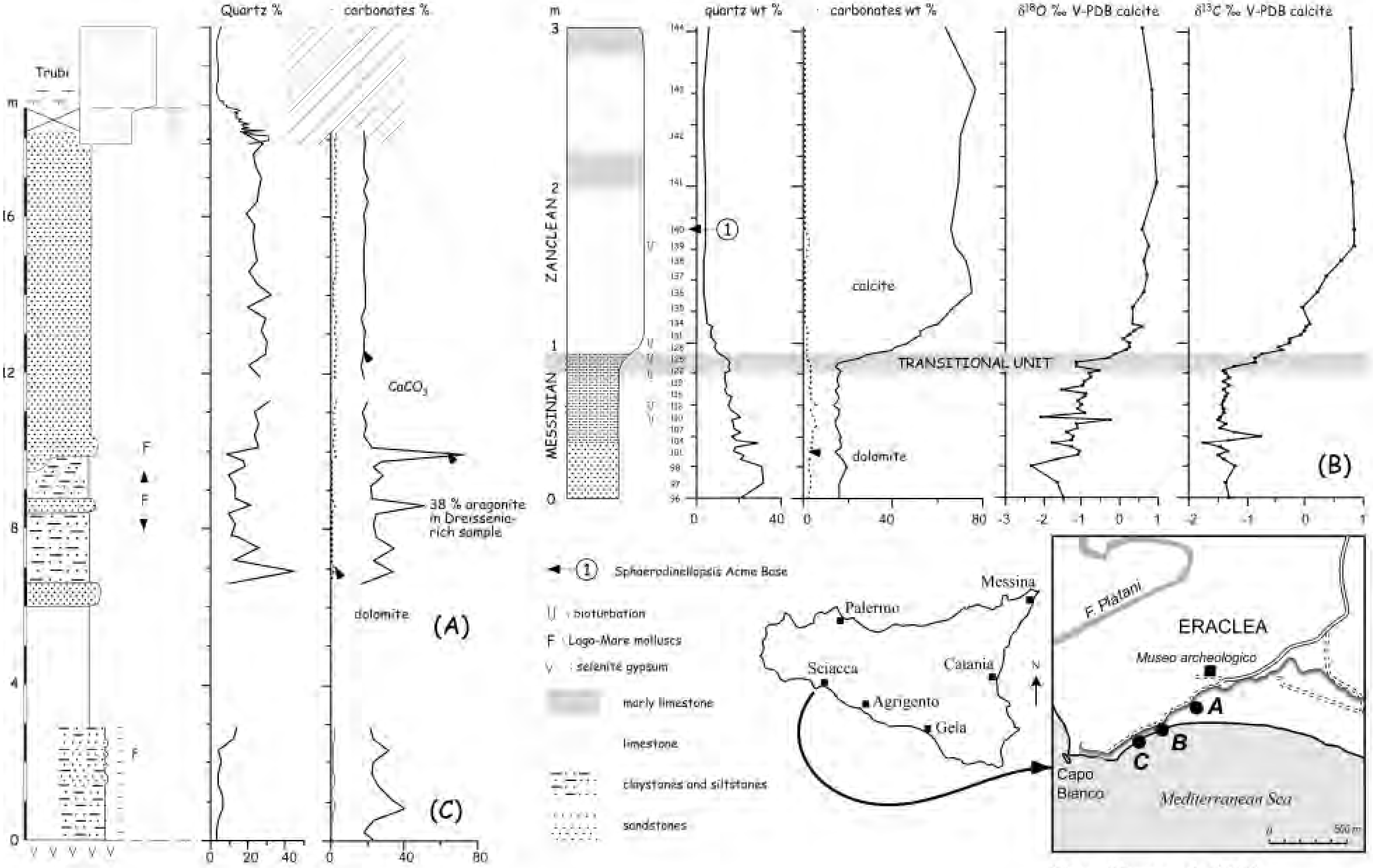
Biostratigraphy

Hilgen and Langereis (1993) proposed to place the Miocene/Pliocene boundary at the contact Arenazzolo/Trubi in the Eraclea Minoa section, obtaining an age of 5.33 Ma for the base of Pliocene (lithological cycle 1). This age has been re-calibrated by Lourens et al. (1996) at 5.332 Ma, which defines the MPB (Van Couvering et al., 2000).

The Arenazzolo/Trubi contact represents the return to normal marine conditions after the Messinian Salinity Crisis (Cita and Gartner, 1973; Ruggieri and Sprovieri, 1976). In particular, on the basis of brackish ostracods fauna, Ruggieri (1967) suggested that the Arenazzolo and the green clays occurring between the last two gypsum layers (Decima and Wezel, 1971) correspond to "Lago-Mare" phase of the late Messinian. Bonaduce and Sgarrella (1999) have described several species of ostracods of hypohaline and/or hyperhaline conditions with some specimens of *Ammonia tepida*. In the layers of the latest part of Messinian, planktonic foraminifers including *Globorotalia conomiozea*, *G. menardii*, and in some cases, *Paragloborotalia siakensis* are abundant as are many species of benthic foraminifers. *P. siakensis* and *G. conomiozea* disappeared from the Mediterranean area at 11.20 Ma (Hilgen et al., 2000; Caruso et al., 2002) and 6.50-6.51 Ma (Hilgen and Krijgsman, 1999; Sierro et al., 2001; Blanc-Valleron et al., 2002), respectively. Layers rich in reworked foraminifers originating from Serravallian-early Messinian sediments are intercalated with layers rich in brackish molluscs including *Dreissena sp.* and *Melanoides sp. (sensu* Di Geronimo et al*.,* 1991) and abundant brackish ostracods (Bonaduce and Sgarrella, 1999). We consider the origin of the foraminifers as due to reworking, the brackish or hyperhaline ostracods, however, are considered in place together with two benthic foraminifer species, as *Ammonia beccarii* and *A. tepida*. The position of the Transitional Unit (Iaccarino et al., 1999) and the base of MPl 1 are both indicated by the distribution of dextral and senistral forms of *N. acostaensis*.

Oxygen and carbon stable isotopes

The stable isotope compositions of calcite have been measured in the 49 samples collected through a 3 meters thick interval encompassing the MPB (from the uppermost meter of the Messinian siltstones and the two first meters of the Early Pliocene marlstones (Pierre et al., 2006) (Fig. 27). In the uppermost Messinian siltstones,



(From Pierre et al., 2006)

Figure 27. The Eraclea Minoa section (Caltanissetta Basin, Sicily). Synthetic lithological sequence, bioevents, mineralogical composition (wt% of quartz, total carbonate, calcite, dolomite), oxygen and carbon isotopic compositions of calcite (from Pierre et al., 2006).

the $\delta^{18}O$ values oscillate between −2.33‰ and –0.26‰ while the $\delta^{13}C$ values are more constant around −1.4‰; these rather low values cannot be related to marine conditions but to a brackish environment, which is in agreement with the presence of the Lago-Mare brackish fauna in these deposits. The oxygen and carbon isotopic compositions exhibit increasing values at the M/P passage. This trend coincides with that of the carbonate content and includes the topmost marly interval of the Arenazzolo unit and most of the Trubi cycle 1 of Hilgen and Langereis (1993). From the base to the top of this interval, the $\delta^{18}O$ values increase progressively from −1.15‰ to 0.61‰ and the $\delta^{13}C$ values increase also from –0.85‰ to ~0‰. This evolution describes the progressive establishment of marine conditions at the onset of Pliocene.

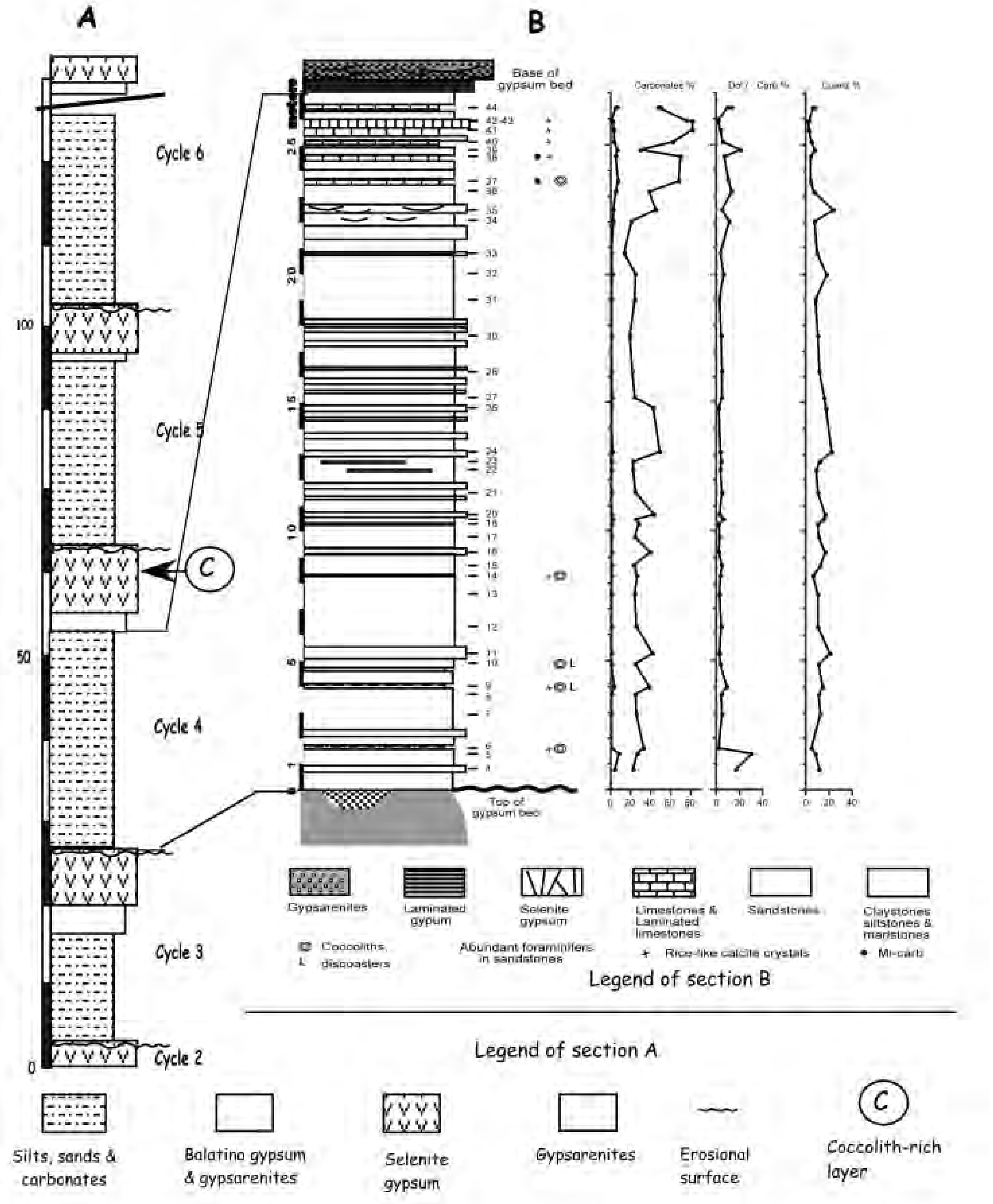
The overlying Early Pliocene sediments are characterized by positive and rather constant delta values ($0.57 < \delta^{18}O‰ < 0.96$; $0.36 < \delta^{13}C‰ < 0.86$), which are indicative of deposition in an open marine and stable environment.

Summary

According to the scenario proposed by Rouchy and Caruso (2006), in agreement with former models (Hsü et al., 1978), the Eraclea Minoa section can be considered as a model for the deposition of the Messinian evaporites in the deep Mediterranean basin. The chaotic character of the Lower Gypsum in the central trough where the Eraclea Minoa is located resulted mostly from an intense tectonic deformation overprinted by halokinetic deformation of the thick salt deposits. The base of the lower gypsum is probably affected by tectonic thrusting. The lower evaporites which comprise the Lower Gypsum unit and the Salt Unit which is present laterally in several boreholes deposited during the major phase of evaporative drawdown and ended by an important episode of desiccation-erosion. In the lower unit, the gypsum is exclusively made of primary selenite with no interbeds of resedimented gypsum. Gypsarenites are only present on top of the unit and postdate the phase of erosion–desiccation. The gypsum from this lower unit evaporites formed mostly in subaqueous conditions from residual brine bodies and ephemeral conditions prevailed during the deposition of the upper evaporites which are marked by a huge increase of the freshwater contribution that climaxed by the late Messinian dilution event, the so-called Lago-Mare, just before the abrupt restoration of the marine settings at the beginning of the Zanclean. As shown by Pierre et al. (2006) and former studies (Iaccarino et al., 1999a), the sedimentary, micropaleontological, and stable isotope record of the late Messinian environments and the restoration of the marine conditions at the beginning of the Zanclean in the Eraclea Minoa section are similar to those described in the other Mediterranean basins, either in deep or more marginal ones. Thus, the latest Messinian sediments are related to continental/brackish environments while the earliest Pliocene sediments were deposited in open marine settings. We have not observed any evidence of normal marine conditions in the late Messinian deposits and, as in many other deep basins, there are no significant episodes of subaerial erosion at the Miocene/Pliocene transition, neither at the base of the Arenazzolo nor at the Messinian/Zanclean boundary. In contrast, important erosional features have been reported in more marginal basins like in Crete (Delrieu et al., 1992) or in Morocco (Rouchy et al., 2003).

Stop 2-3 – Details of the Upper Evaporites in the Siculiana-Giallonardo section; gypsum facies, palaeoenvironmental conditions at the end of the MSC, Late Messinian high-resolution stratigraphy

A. Caruso, J.M. Rouchy



From Rouchy & Caruso, 2006; Rouchy, Caruso & Blanc-Valleron, unpublished

Fig. 28. Lithological column of the Siculiana-Giallonardo section (A) with a detail of the cycle 4 (B).

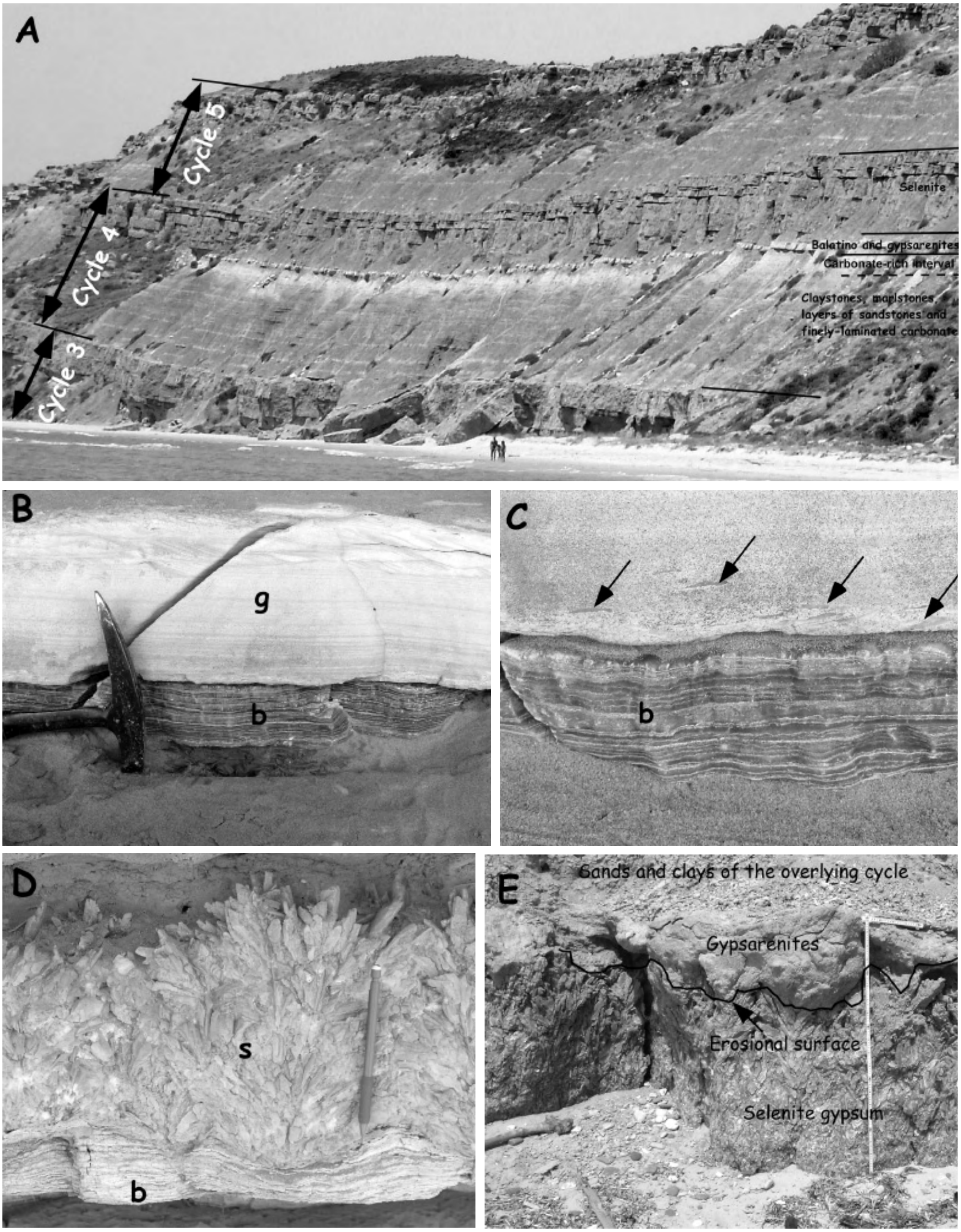


Fig. 29. Siculiana-Giallonardo section. A. View of the cycles 3, 4 and 5 with detail of the cycle 3. B. Small sedimentary sequence from the balatino-gypsarenite interval composed of siltstones (not visible on the photo), finely-laminated gypsum (balatino) (b) and gypsarenites (g). C. Chips (arrows) in the basal part of the gypsarenites in a sequence siltstone-balatino-gypsarenite of the cycle N°3 . D. Sequence composed of finely-laminated gypsum (balatino) (b) and selenite (s) at the base of a selenite interval of the cycle N° 3. E. Erosion on top of the cycle n° 2. The top of the selenite gypsum is truncated by an erosional surface filled by gypsarenites before the base of the siltstones of the overlying cycle. The thickness of the gypsarenites may vary from few cm to 50 cm.

The section is located immediately to the west of the Siculiana village along the Giallonardo beach. It displays four cycles of the upper gypsum similar to those from Eraclea Minoa, but the absence of any urbanization allows observing these cycles in great detail (Fig. 28, 29A). Unfortunately, the section does not provide the whole sedimentary succession as the first two cycles are not cropping out. The claystones of the sixth cycle are truncated by a fault and the contact between the Lago-Mare and the Trubi is strongly disturbed by tectonic deformations. Preliminary description of the section mostly focused on the description of the cycle 4 has been provided by Rouchy (1982) and Rouchy and Caruso (2006).

The composition of the cycles are similar to those from the Eraclea Minoa section. Their lower part is composed, over 13 to 26 meters, of siltstones with dm-thick interbeds of sandstones and thin interlayers of whitish finely-laminated carbonates whose number and thickness increase upward (Fig. 28A, B; 29A). These deposits are overlain by 1 to 3.5 meters of gypsum composed of dm-thick sequences of claystones-finely-laminated (balatino) gypsum and gypsarenites displaying flat pebbles, ripple cross-laminated and scouring features (Fig. 29C). They are in turn covered by a thickening upward succession of primary selenite gypsum beds whose thickness ranges from few decimeters to 2 meters. The lower part is made of sequences composed of clays-carbonates, finely laminated gypsum (balatino) and selenite (Fig. 29D). The total thickness of the primary selenite intervals varies from 6 to 9 m.

Only the cycle N° 4 has been examined in more detail (Fig. 28B, 29A). Most of the sediments are devoid of microfossils except for the sands which are usually rich in benthic and planktonic foraminifers which display a very large stratigraphic range indicating they are reworked (Fig. 30A). Calcareous nannoplankton is present within the marls, but it is difficult to know whether they are in situ or reworked (Fig. 30B). The finely laminated carbonates are mostly composed of subhedral crystals of calcite less than 10 μm in length displaying a lenticular habit (Fig. 30C, D). Similar crystals have also been described in in the ODP site 975 in the Balearic Basin by Marsaglia and Tribble (1999) and in lacustrine environments and are usually interpreted to result from inorganic precipitation in freshwaters (Kelts and Hsü, 1978). These calcite grains are associated with framboidal pyrite (Fig. 30D) and in the upper layers with assemblages of small and poorly diversified assemblages of coccoliths. A whitish fine-grained carbonate layers few cm in thickness, interbedded between two selenite layers in the cycle 4 is composed of monospecific assemblages of dwarfed coccoliths probably belonging to the genus *Reticulofenestra* (Fig. 30E) and similar to the assemblages described in the balatino gypsum from Montedoro and Eraclea Minoa (Rouchy, 1976) (Fig. 30F). In this cycle, we have not found diatomite layers like in the Eraclea Minoa and Porto Empedocle sections.

Unlike we can expect from the presence of the lenticular grains of calcite interpreted as precipitating from freshwaters, the isotope composition of the bulk calcite from the carbonate layers (C. Pierre, unpublished data) are not far from marine values (-1.69‰<δ^{18}O<1.17‰; -0.99‰<δ^{13}C<+3.65‰), but could be also related to hyposaline waters which have undergone significant evaporation.

These data indicate that during the periods of reflooding marked by the sedimentation of the fine-grained clastics and carbonate, influxes of marine water continued to enter the basin even if the freshwater contribution was predominating.

On top of each cycle, the selenite crystals are truncated by an erosional surface that is filled by

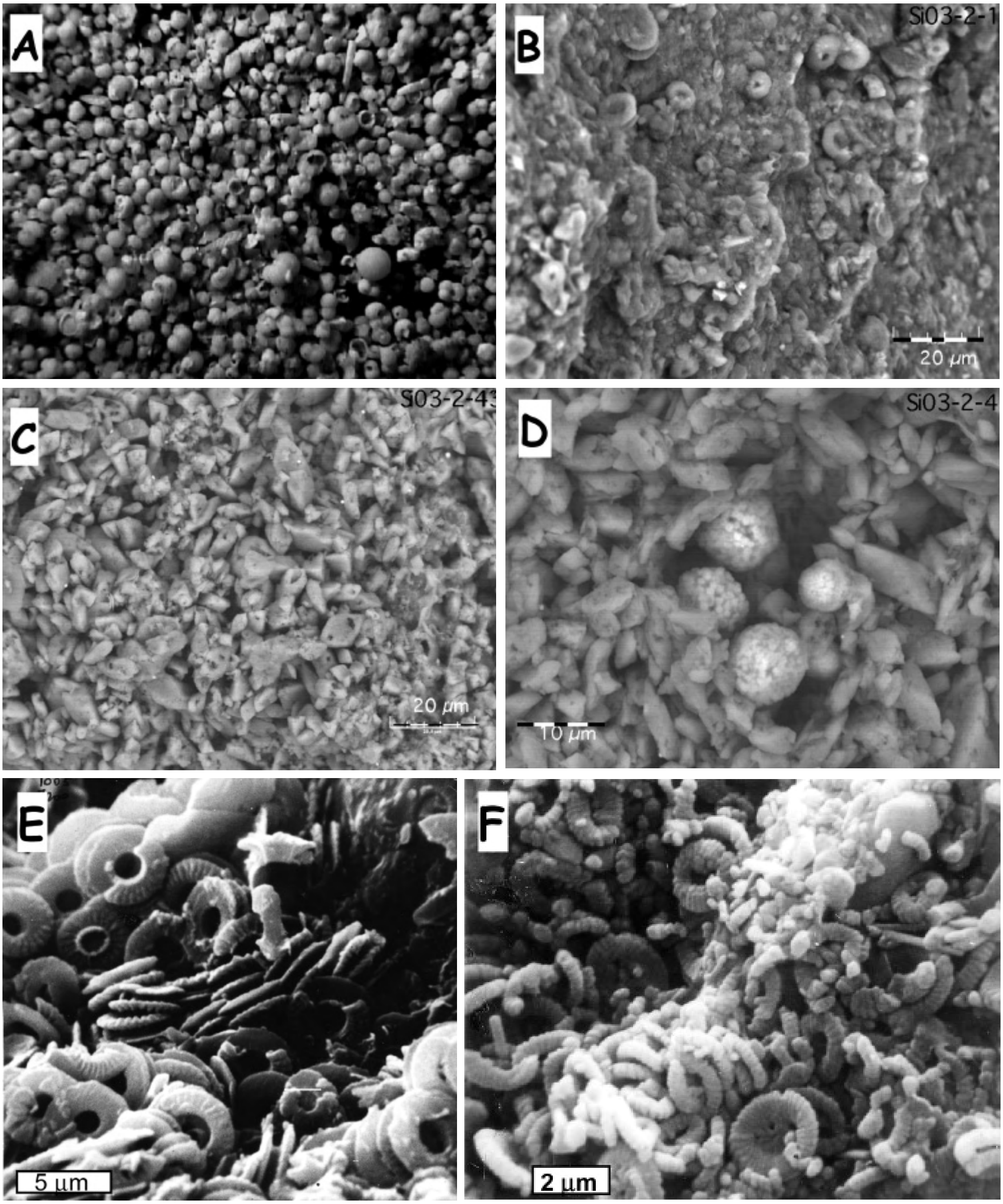


Fig. 30. Micropaleontological and mineralogical content of the silts, sands, marls and carbonates of the Upper Gypsum. A. Reworked benthic and planktonic foraminifers from foraminifer-rich sands intercalated within in the intra-gypsum deposits (Siculiana Giallonardo, Cycle N° 4). B. Disseminated calcareous nannoplankton within the marls (Siculiana Giallonardo, Cycle N° 4, SEM view). C. Subhedral to euhedral lenticular-shaped crystals of calcite within the finely laminated carbonate layers (Siculiana Giallonardo, Cycle N°4, SEM view). D. Framboids of iron oxides resulting from the oxidation of pyrite within the finely laminated carbonates (Siculiana Giallonardo, cycle N°4, SEM view). E. Monospecific assemblages of calcareous nannoplankton that form thin carbonate layers interbedded between selenite gypsum beds (Siculiana Giallonardo, Cycle N°4, location on Fig. 8A SEM view). F. Monospecific assemblages of calcareous nannoplankton from the thin carbonate laminae interlayered with the gypsum in the balatino gypsum (Montedoro section, SEM view).

gypsarenites, before the deposition of the first silty sediments of the overlying cycle (Fig. 29E). This suggests that the basin basin was lowered or dried out at the end of each period of evaporitic deposition Marsaglia and Tribble (1999).

Stop 2-4 - Visit to the Realmonte salt mine –

S. Lugli

Four main depositional units (from A to D) were recognized in the Realmonte mine (Agrigento), where the Messinian salt reaches a total thickness of 400-600 m (Decima and Wezel, 1971, 1973; Decima, 1978, Lugli et al., 1999; Fig. 31):

- Unit A: evenly laminated gray halite with white anhydrite nodules and laminae passing upward to gray massive halite beds; the unit is up to 50 m thick;
- Unit B: massive even layers of gray halite interbedded with light gray thin kainite laminae and with minor gray centimeter polyhalite spherulites and laminae and anhydrite laminae; the upper part of the unit contains at least six

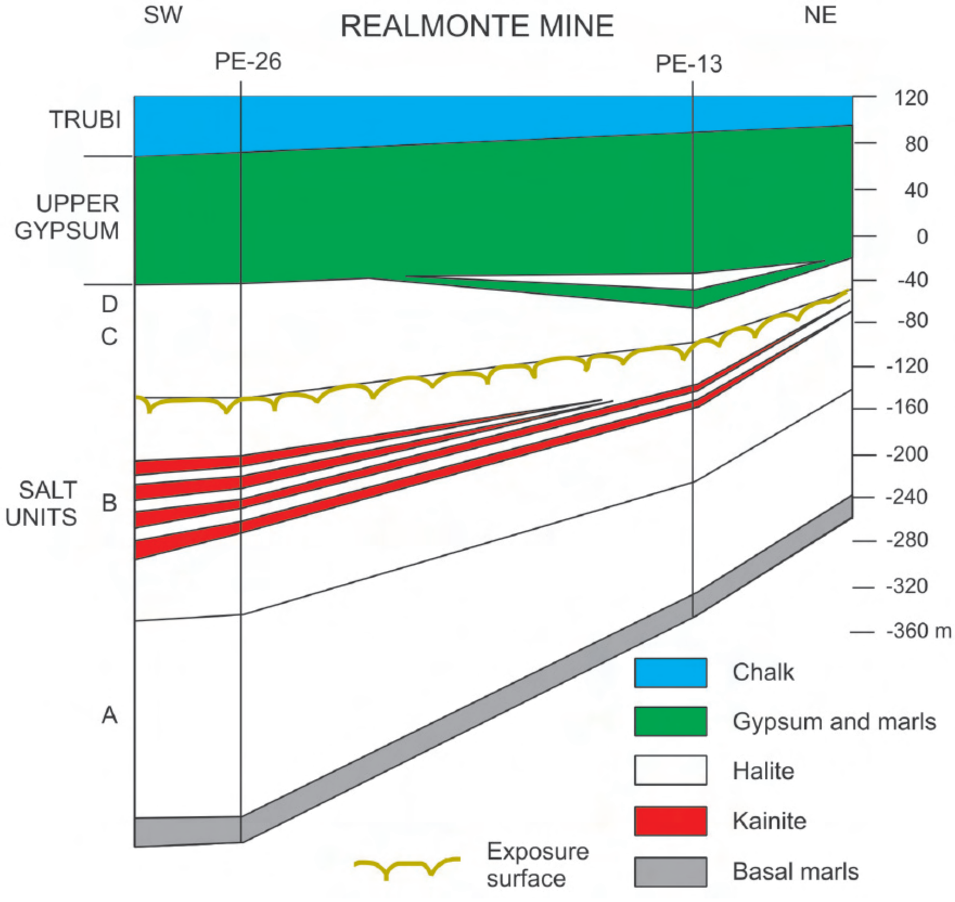


Fig. 31 – Stratigraphic diagram of the Realmonte mine (from Lugli, 1999).

light gray kainite layers up to 18 m-thick; total thickness is about 100 m;
- Unit C: white halite layers 10-20 cm thick sparated by irregular dark gray mud laminae and containing minor light gray polyhalite and anhydrite laminae; the total thickness is 70-80 m;
- Unit D: gray anhydritic mudstone (15-20 m thick) passing to an anhydrite laminite sequence followed by gray halite millimeter to centimeter layers intercalated with white anhydrite laminae; the total thickness is 60 m.

The planktonic foraminifers, nannoplankton, dinocysts and pollen grains contents of the intercalated mud layers suggest tropical to subtropical prevailing temperatures (Bertini et al., 1998). Sedimentologic and petrographic data from the Realmonte salt deposit (Lugli, 1997, Lugli et al., 1999) indicate that units A and B are composed of cumulates of well sorted halite plate crystals up to a few millimeters in size. Kainite layers embedded within unit B are composed of fine- to coarse-grained rocks (Garcia-Veigas et al., 1995) that also have a cumulitic origin. The salt layers show no evidence of bottom overgrowth, current structures, or dissolution and/or truncation surfaces. These characteristics indicate that evaporite precipitation took place in a stratified water body, a feature that suggests a significant water depth. Only the uppermost part of unit B shows a progressive appearance of large halite rafts together with localized dissolution pits filled by mud, characteristics that suggest a marked upward shallowing of the basin. Spectacular vertical fissures cut through the topmost part of unit B in many parts of the Realmonte mine at the boundary with unit C (Fig. 32).

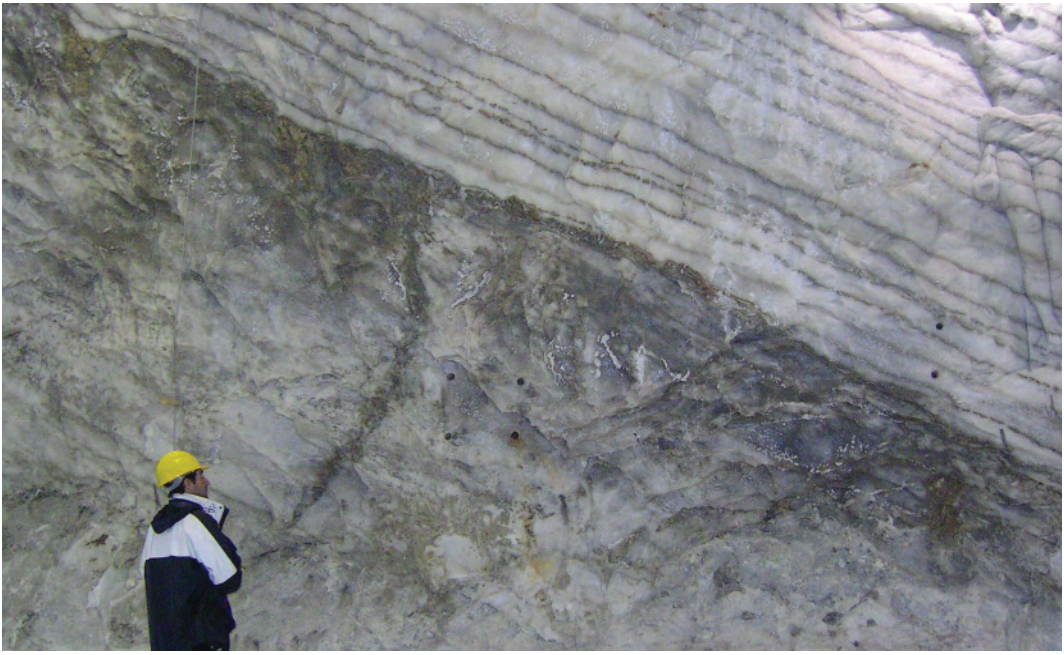


Fig. 32 – The desiccation surface separating the salt layers of unit B (below) and unit C (above) in the Chapel of the Realmonte mine (-28 m). A contraction crack cut trough the uppermost salt layers of unit B which are partially modified by dissolution pipes (A. Caruso for scale).

In the chapel and the underground garage area of the mine, at the -28 m depth, we may observe the vertical fissures that cut through the topmost part of unit B at the boundary with unit C. The fissures are spaced at intervals of up to 5 m apart and extend down for at least 6 m; maximum width is less than 5 cm. These fissures are commonly filled by red mud and in some zones an irregular green mud layer up to 0.5 m thick lies on top of the fissures sealing the B layer. In other zone of the mine the topmost salt beds of unit B affected by the fissures are commonly upturned, truncated and are onlapped by the flat-lying halite beds of unit C. The upturned layers are cut by closely spaced vertical pipes, a few centimeters across, filled by clear halite cement and red mud down to a depth of as much as 4 m below the fissured surface.

The overlying unit C is composed of cumulates of halite skeletal hoppers that show further vertical overgrowth (chevron) that occurred at the bottom of the basin after initial growth at the brine surface. The salt layers show dissolution pits filled by mud and irregular truncation of the upper crystal terminations, indicating precipitation from a nonstratified, relatively shallow water body. The paleotemperatures of the brine from which the halite crystals precipitated are highly variable from 22 to 32¡C (Lugli and Lowenstein 1997) and suggest a shallow hydrologically unstable body of water.

The C unit was deposited as a consequence of recycling (dissolution and reprecipitation) of previous halite by meteoric-continental waters (based on Br content; Decima 1978) or by seawater (based on the high sulfate concentration and significant potassium and magnesium content of fluid inclusions; Garcia-Veigas et al., 1995).

In summary: salt precipitation began in a relatively deep and stratified water body experiencing drawdown up to emersion of the salt layers. Thermal expansion and evaporative pumping of the groundwater induced the surficial halite layers to break into tepee structures, and exposure to rain caused the development of dissolution pipes. Annual insolation temperature changes caused the opening of deep vertical contraction polygons that collected detritus carried by the wind. Finally, seawater flooded the salt pan again, dissolving and truncating part of the previous halite, which was then redeposited under shallow-water conditions from a new, nonstratified water body.

Stop 2-5 – Road to Raffadali; the Lower Evaporites at M. Banco – M. Grotticelle section (Figs 33-34); primary evaporites facies and cyclicity; comparison with Rocca d'Entella; discussion on their actual stratigraphic position. –

S. Lugli, V. Manzi, B.C. Schreiber, M. Roveri

As stated in the general introduction to the Caltanissetta basin, the Lower Gypsum occur in this area as large disarticulated units or slabs, detached from their original substratum, but still preserving their internal sedimentary features (Figs 33-34). We will focus on one of the largest slab which shows a fairly complete succession, allowing to compare it with the Rocca d'Entella section.

Monte Banco represents one of the most spectacular outcrops of the Lower Evaporites in the entire Mediterranean. One particular interesting aspect of this outcrop is the striking similarity of vertical stacking pattern and facies assemblage with the Vena del Gesso Lower Evaporite section, which is located many hundreds of kilometers apart.

Here 10 evaporite cycles can be seen. The first two cycles are thinner and show the largest selenite crystals (up to about 15 cm-tall), althou-

Fig. 33 – Lower Gypsum at M. Banco section.

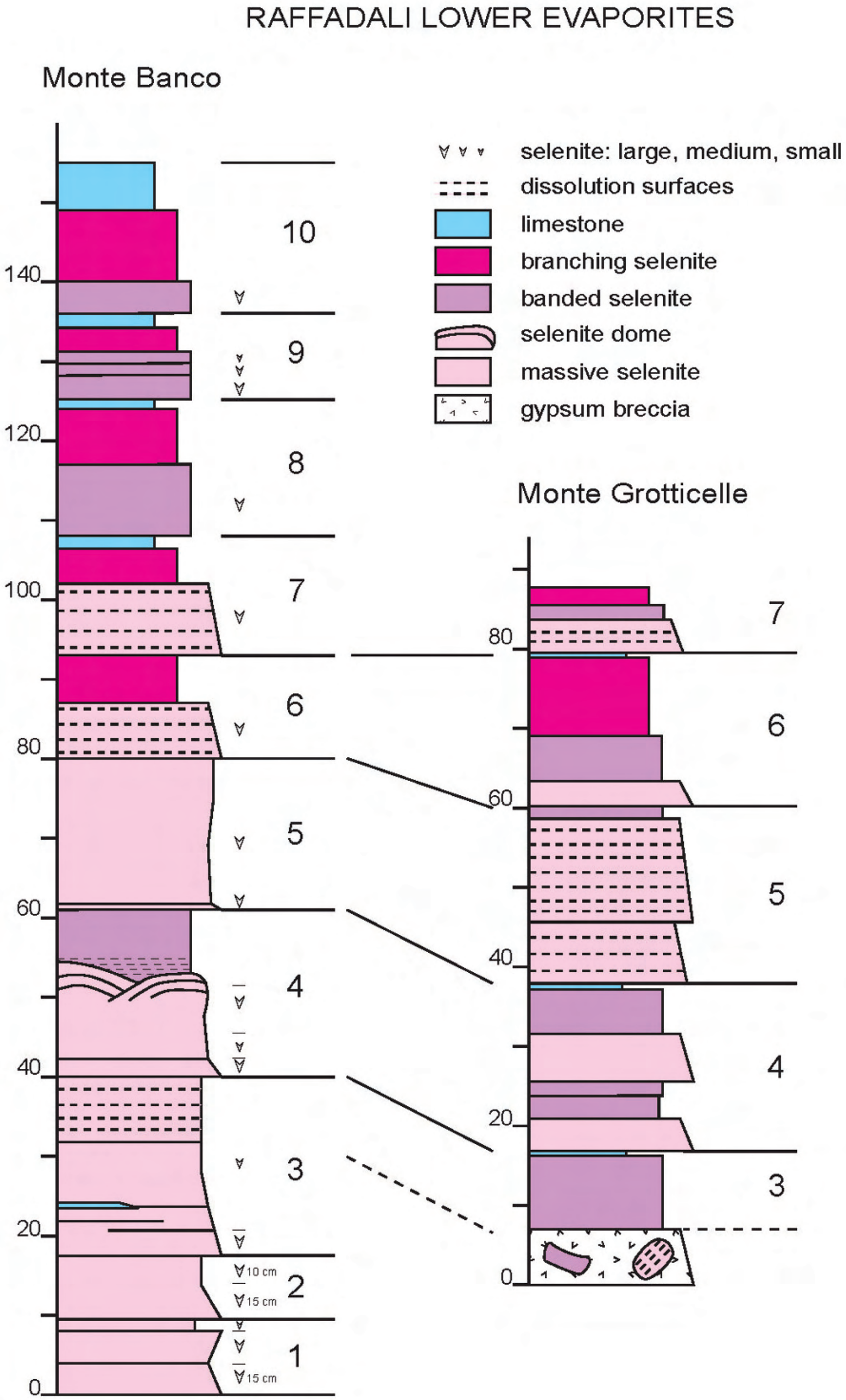


Fig. 34 – Correlation of Lower Gypsum deposits between M. Banco and M. Grotticelle sections.

gh not the usual large crystals seen in Rocca d'Entella and other outcrops in Sicily and Vena del Gesso (up to 2.5 m-tall).

The 3rd, and 5th cycles are made of thick beds (up to 25 m) of vertically grown massive selenite (F3 facies). The 4th begins with massive selenite grading into large domal structures followed by banded selenite. The upper part of the section (from the 8th to the 10th bed) consists of thinner beds (maximum thickness 15 m) with cycles showing a basal banded selenite, followed by branching selenite (F5). As in the case of the Vena del Gesso and Rocca d'Entella, the first appearance of the braching selenite is from the 6th cycle, demonstrating that this facies represent a powerful tool for stratigraphic correlations.

On the contrary of the Vena del Gesso, no shale layers but massive carbonate separates the gypsum cycles. The lower part is virtually devoid o carbonate, but intercalations appear starting from the 7th cycle and progressively become thicker upsection, up to the 6 m-thick layer which is capping the 10th cycle. Rocca d'Entella section also show a significant carbonate increase upsection.

The nearby section of M. Grotticelle, located about one kilometer from M. Banco, offers a comparison to study the lateral facies variations.

The selenite breccia at the base of the section appears to be related to the emplacement of the giant block, with loss of the lowermost two cycles and part of the third.

Massive selenite and massive selenite crossed by closely spaced dissolution surfaces appear to be lateral equivalent to each other and both are in turn lateral equivalent of the banded selenite as well. The M. Grotticelle section shows more dissolution surfaces in the massive selenite and a larger proportion of banded selenite, revealing a stronger influence of undersaturated solutions on the gypsum growth, which in turn suggest a slightly more marginal setting than for the M. Banco section.

Strontium isotope ratios of M. Grotticelle suggest oscillating conditions from solution dominated by continental input to solution dominated by seawater, as seen in the Vena del Gesso (Lugli et al., in press).

Transfer to Casteltermini via S. Biagio Platani – The road crosses the type area of the Cattolica Fm.; mountain-size slab of Lower Gypsum are scattered over a wide area with different bed attitudes and degree of disruption and deformation. After S. Angelo Muxaro, where an almost complete section of the Lower Gypsum crops out below the village, the road enters the northern sector of the central Sicilian basin.

Introduction to the Messinian stratigraphy of the northern flank of the Caltanissetta basin

M. Roveri, V. Manzi, S. Lugli, B.C. Schreiber, F. Ricci Lucchi

Casteltermini lies within the northern and innermost belt of the Caltanissetta basin, which is delimited by south-verging thrusts connected to the M. Sicani thrust front. This belt is elongated parallel to the thrust front; the Messinian succession crops out in a array of parallel, tight folds with vertical or overturned flanks clearly recognizable in the landscape for the alignment of laterally continuous Calcare di Base hogbacks (Fig. 35). The Calcare di Base overlies the Tripoli Fm. which in turn lays above lower to upper Miocene argillaceous deposits of the Terravecchia Fm.

This inner belt can be followed toward east where its northern boundary is given by the Madonie and Nebrodi thrust fronts. While in the western sector the basin fill is mainly represented

Fig. 35 – Looking west from Casteltermini. The Calcare di Base hogbacks north of Casteltermini. M. Cammarata Mesozoic carbonates in the background.

Fig. 36 – The Calcare di Base at Casteltermini. Note the close association of brecciated limestone with laminated gypsarenites (stop 2.7).

by a thick pile of chaotic, gypsum-bearing clays and marls, the eastern one is characterized by a higher content of terrigenous sediments (Corvillo and Nicosia basins) suggesting the activation during the Messinian of an articulated drainage pattern along the growing Sicilian-Maghrebian thrust belt.

The Calcare di Base is usually brecciated and shows frequently large-scale deformations and erosional surfaces; laminated gypsum intercalations are common features that mainly occur in the upper part of graded beds with a basal limestone breccia division (Fig. 36).

Immediately south of Casteltermini, in a large asymmetric syncline with an overturned northern flank, a thick succession of clastic gypsum overlies the Calcare di Base. This succession mainly consists of well stratified graded gypsarenite and gypsrudite beds, showing erosional bases, clay chips, horizontal to cross-laminated divisions; very thick debris flow with poligenetic clasts floating in a fine-grained gypsum matrix are also common, as well as slumped horizons. The most striking feature is the occurrence of large selenite olistoliths which are clearly encased within the turbiditic succession (Fig. 37), very similarly to what is seen in the Belice basin.

The gypsum turbidites are overlain by the Upper Gypsum, here consisting of 6 cyclically stacked marls and gypsum tabular bodies (both balatino and selenite).

In the subsurface of the Casteltermini syncline both salt and sulphur has been found and exploited in the past. The stratigraphic position of salt will be the object of discussion.

According to time availability, possible stops along the road (Portella Tanabuco – **stop 2.6**) for a general view of chaotic gypsum complex and close view of its basal part with gypsum laminites, gypsarenites, marls and brecciated limestone bodies (road Casteltermini-Acquaviva - **stop 2.7**).

Day 3

Stop 3-1 (a, b) – Casteltermini, close and panoramic view of the clastic gypsum succession of the inner margin of the Caltanissetta basin: gypsum turbidites and debrites, intraformational slumps, large-scale Lower Gypsum olistoliths (Fig. 37a); genetic and stratigraphic relationships with salt deposits; the Upper Evaporites and Trubi Fm.: general overview and considerations.

S. Lugli, V. Manzi, M. Roveri, B.C. Schreiber

Stop 3-2 – Monte Gallitano section

A. Caruso, J.M. Rouchy

Monte Gallitano section (Fig. 38) outcrops near Sommatino village along a south eastern slope 4.5 km north of Trabia-Tallarita mine. The lithological succession comprises 27.5 m of Tripoli Fm grading upward into 13 m of autobrecciated limestones and laminated gypsum (balatino) alternating with marls or diatomites. The uppermost part of the section is characterized by more than 15 m of massive selenitic gypsum. Thus, the Monte Gallitano section displays a continuous transition from the Tripoli to the gypsum through limestone layers which correspond to the Calcare di Base.

As previously described in other coeval sections (Caruso, 1999; Hilgen and Krijgsman, 1999; Blanc-Valleron et al., 2002), the Tripoli Fm is represented by the classic cyclicity determined by the succession of lithological triplet made of reddish marly laminites, diatomites and grey marls with sparse intercalation of calcareous beds (Fig. 39, 40). The section is involved in a large NW-SE oriented folded structure with a faulted and thrusted flank which is responsible for the disappearance of the lower part of the Tripoli Unit that overlies the Licata Fm through a tectonic contact.

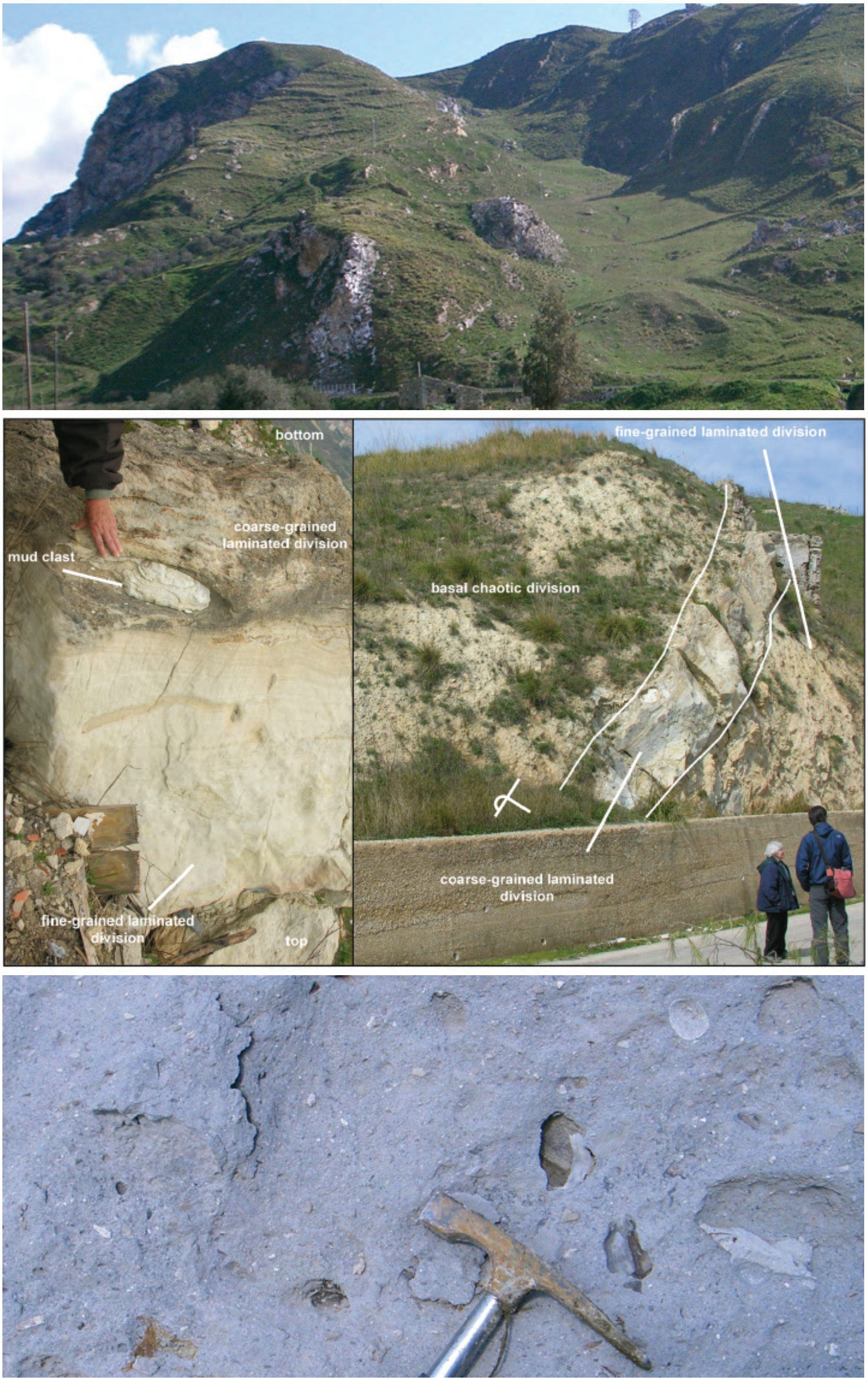


Fig. 37 – Casteltermini section; a) Lower Gypsum blocks within gypsum turbidites; b) close-up of a gypsum turbiditic bed; c) close up of a gypsum debris flow.

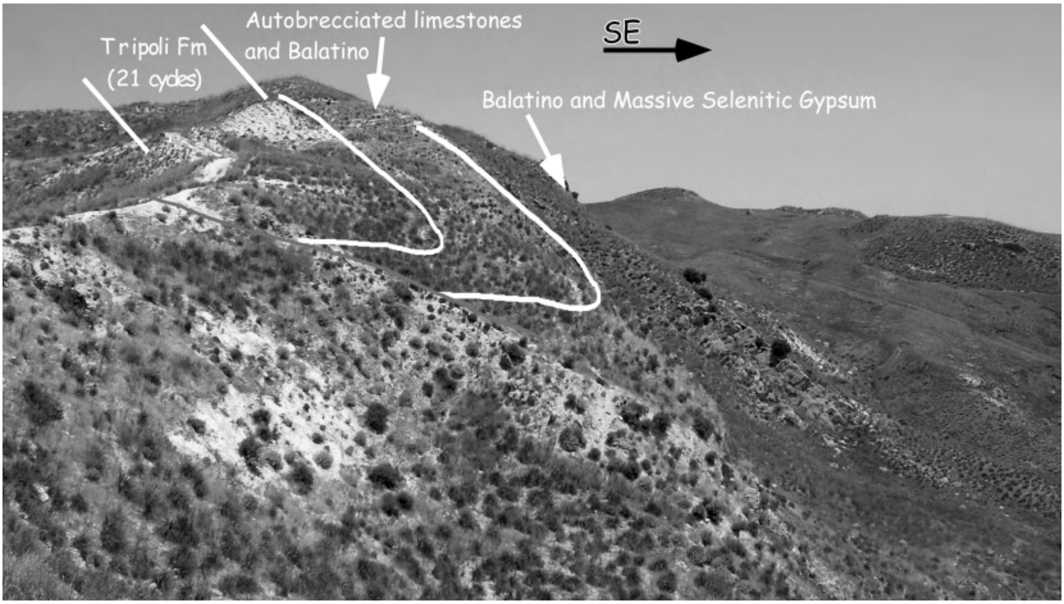


Fig. 38 General view of the Monte Gallitano section; the section is involved in a large NW-SE oriented folded structure with a faulted and thrusted flank which is responsible for the disappearance of the lower part of the Tripoli Unit that overlies the Licata Fm through a tectonic contact.

Lithostratigraphy and cyclicity

Due to the above described tectonic disturbance, only the upper part of the Tripoli Fm which consists of 21 cycles is exposed (Fig. 38, 39). The thickness of the individual diatomite layers is thicker than those described in other sections from the southern part of Caltanissetta Basin, especially the Falconara section. In agreement with Hilgen and Krijgsman (1999), the lithological cycles were numbered considering the reddish marly laminites as the base of each cycle and the grey marls as the top. In few cycles (e.g. cycles 24, 33, 34, 38, 41, 42, 43), the calcareous layers 10-15 cm in thickness which are intercalated between the grey marls and the reddish marly laminites, are considered as the top of the cycle (Fig. 39, 40). According to Hilgen and Krijgsman (1999), reddish laminites correspond to the insolation maxima/precessium minima and thus they were deposited during warm humid conditions.

These layers were correlated cycle by cycle with the reference section of Falconara using lithological cyclicities and planktonic foraminifera bio-events. Calcareous interbeds become more abundant in the upper part of the section (27 m) with layers of autobrecciated limestones displaying pseudomorphs of halite and gypsum crystals.

Biostratigraphy

The sediments of the lower 24 meters of the section are characterized by rich and well diversified assemblages of planktonic foraminifera. A drastic reduction of the assemblages occurs between 24.5 m and 30 m where planktonic

Fig. 39 A. Particular view of Tripoli Fm of Monte Gallitano section, cycles 24 to 34 are referred to the lithological cyclicity of Tripoli Fm outcropping at Falconara (reference section). Number 9 indicates *T. multioba* FCO, while number 10 corresponds to the coiling change of N. acostaensis from senestral to dextral; a carbonate bed occurs in cycle 34. B. Cycles from 33 to 39 of Monte Gallitano section, the hammer indicates the carbonate bed of cycle 34 described in photo A. On the right of the photo particular of cycle 36 and 37; cycle 36 is composed by a couplet (precessionaly controlled) of white diatomites (wd) and grey marls (gm); cycle 37 is composed by the classical triplet of Tripoli Fm (precessionaly controlled) gm, rd (reddish laminites), wd. C. View of cycles 37 to 43 of Tripoli Fm outcropping at Monte Gallitano section. Asterisk indicates the level in which planktic foraminifera disappear, in cycle 42 a laminated contorted limestones is present; in cycle 43 an autobrecciated limestone with pseudomorphs of halite and gypsum appears. Cycle 43 corresponds to the first evaporitic conditions at Monte Gallitano, this layer has been correlated to the cycle 43 of Falconara (Fig. 40) with an astronomical age of 6.11Ma.

foraminifera are pratically absent. In the whole section, benthic foraminifera are rare or absent except for some layers characterized by an olygotypic association typical of low oxygen conditions represented by *Bulimina aculeata*, *B. echinata*, *Uvigerina* spp. and *Bolivina* spp.. Benthic foraminifera are generally present in grey marls and, rarely, in diatomites.

From a biostratigraphic point of view, *Globorotalia conomiozea* is present from the base of the section up to the middle part of the third diatomitic layer 4 m higher, while the absence of *Globorotalia nicolae* through the whole section indicates that the lowermost 14 cycles of the Falconara section are not present at Monte Gallitano. The disappearence of *G.conomiozea* is correlated with the *G. conomiozea* Last Occurrence (LO) that in the Falconara-Gibliscemi composite section occurs in the cycle 24 with an astronomical age of 6.51 Ma (Hilgen and Krijgsman, 1999; Blanc-Valleron et al., 2002). The First Common Occurrence (FCO) of *Turborotalia multiloba* is recognized in a marl layer, five cycles above the *G.conomiozea* LO, in good agreement with the Falconara section where this bioevent was identified in the marls of the cycle 29 with an astronomical age of 6.415 Ma (Hilgen and Krijgsman, 1999; Blanc-Valleron et al., 2002). In the Monte Gallitano section as in Falconara, the coiling change of *Neogloboquadrina acostaensis* from dextral to senestral, occurs in the diatomites of the cycle 32, 3 cycles after the *T. multiloba* FCO, with an astronomical age of 6.34 Ma (Fig. 12A, 13). These bioevents permitted to correlate the sedimentary succession exposed at Monte Gallitano with the cycles 22 to 43 of Falconara. Three additional cycles which are laterally present in the uppermost part of the Tripoli Fm, can be correlated with he cycles 45-49 of Falconara. They are composed of grey marls-diatomites-carbonates and balatino gypsum. The diatomite layers contain an oligotypic assemblage of diatoms and radiolarians, with no foraminifers.

Characteristics of the Calcare di Base deposits

The autobrecciated limestones are similar to those that will be described in the Serrata Pirciata section. They are characterized by the presence of abundant pseudomorphs of halite crystals and some ghosts of gypsum. In the three additional cycles of the uppermost part of the section, the finely laminated gypsum (balatino) is locally irregularly replaced by carbonates and contains large nodules of microcrystalline elemental sulfur (Fig. 41) which indicates that processes of bacterial sulfate reduction were active. Laterally, sulphur-rich deposits were exploited in the Trabia-Tallarita mine.

Stop 3-3 –Serra Pirciata section: facies characteristics, stratigraphic position and meaning of the Calcare di Base limestones; the onset of the MSC: chronology and palaeoenvironmental changes in different depositional settings.

A. Caruso, J.M. Rouchy

The Serra Pirciata section (Fig. 42 A, B) outcrops near the old sulphur mine of Tallarita, about 5 km from the Riesi town, along the road from Riesi to Sommatino, about 4 kilometers south of the Monte Gallitano section. Previous descriptions were published by Pedley and Grasso (1993), Butler et al. (1995; 1999), McClelland et al. (1996), and Sprovieri et al. (1996b) while a complete biostratigraphical, mineralogical and geochemical study was published by Caruso (1999) and Bellanca et al. (2001).

The section is a hogback structure that outcrops along a monoclinal structure belonging

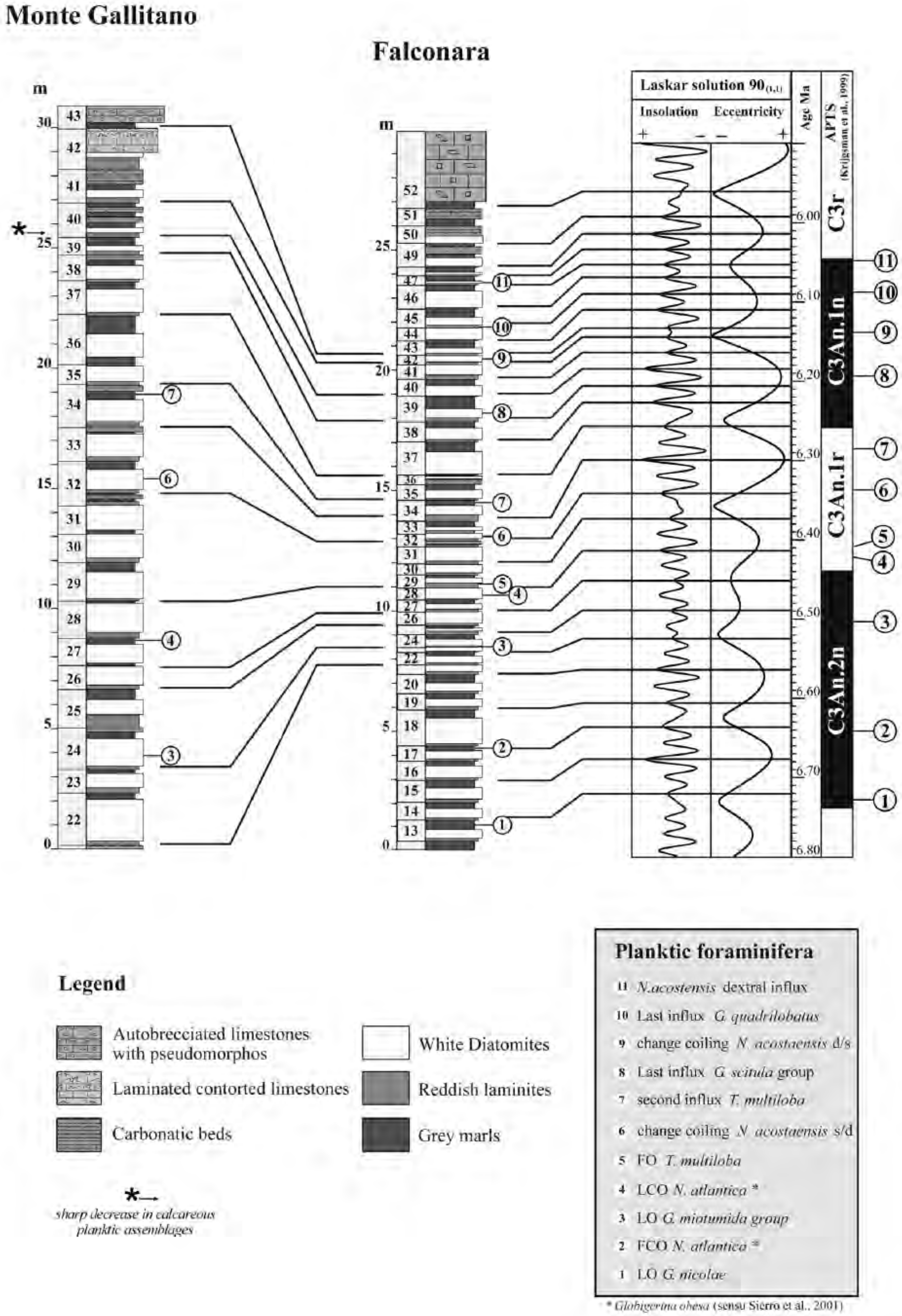


Fig. 40. Lithological column of Monte Gallitano section. At Monte Gallitano *T. multiloba* FCO and the coiling change of *N. acostaensis* are present. These two biovents have permitted to correlate the studied section to the Falconara reference section (Krijgsman et al., 2001; Blanc-Valleron et al., 2001). Each lithological cycle is composed by the classic tryplet of Tripoli Fm. Asterisk indicates the level in which planktic foraminifera disappear.

Fig. 41. View of autobrecciated limestone rich of psuedomorphs of halite and gypsum alternated to laminated gypsum (balatino) locally replaced by carbonates with large nodules of microcrystalline elemental sulfur.

to a large faulted fold tied to the strong tectonic activity of the area (Fig. 42A). The sedimentary succession 38 meters in thickness is composed by only 4 meters of marl-laminites (sapropels) of Licata Formation and over around 19 meters by a succession of 25 diatomite-bearing sedimentary cycles typical of the Tripoli Fm (Fig. 43) which grades upward into 15 m of grey marls alternating with autobrecciated limestones related to "Calcare di Base" unit. The Tripoli Fm overlies the Globigerina Marls of the Licata Fm (middle Tortonian-lower Messinian) through a faulted contact (Fig. 42A).

The lowermost part 2.80 thick meters of the Tripoli Fm consist of 7 cycles made by the classical triplet composed of reddish marly laminites, white diatomites and grey marls. As described before for Monte Gallitano section and according to Hilgen and Krijgsman (1999), the laminites were deposited during insolation maxima/precession minima. Because of a fault, the interval from 2.80m to 4.50m (Fig. 43) was not sampled. From 4.50 m to 13 m, 15 lithological cycles are present composed of grey marl-diatomite couplets with no reddish laminites. At 13.20 m a first carbonate bed, containing few pseudomorphs of halite and

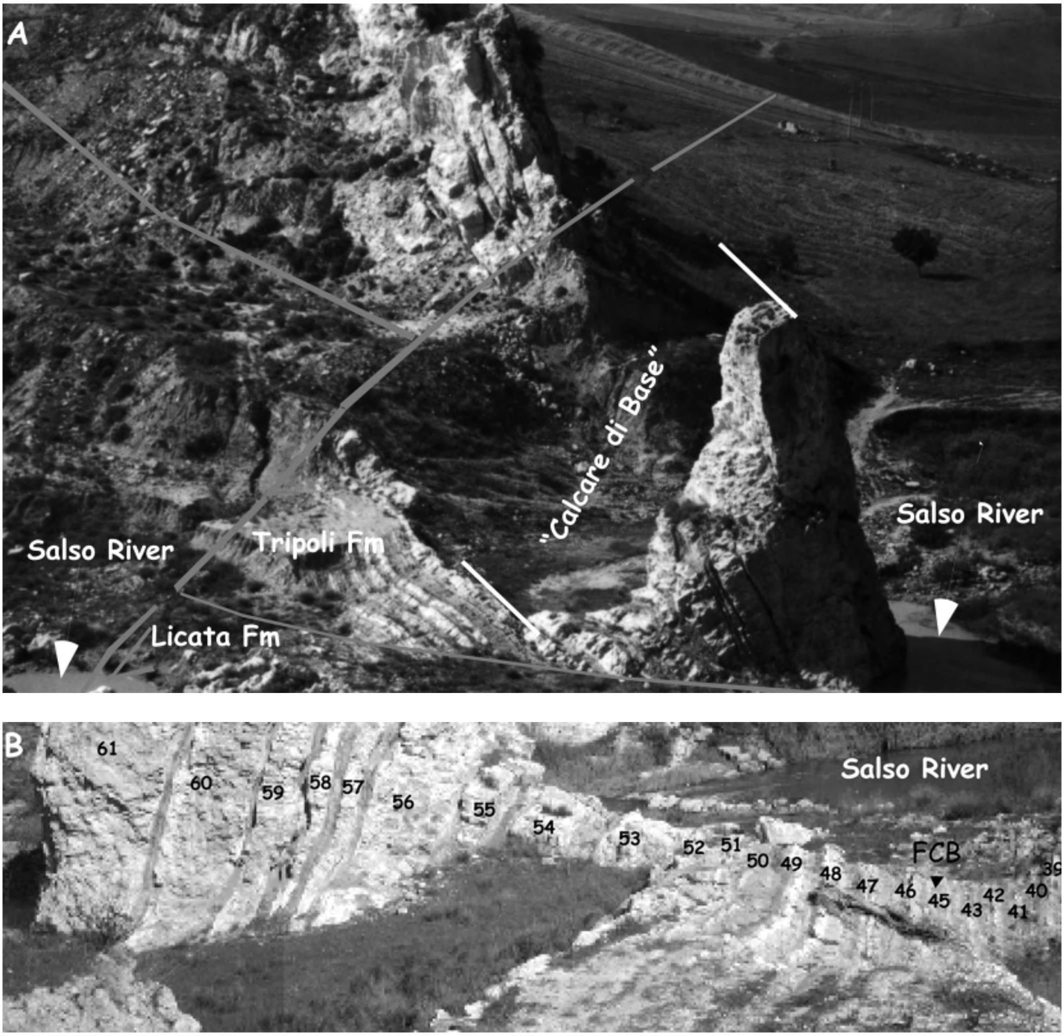


Fig. 42. A. View of Serra Pirciata section, Tripoli Fm overlies Licata Fm through a faulted contact. Only 4 meters of Licata Fm are present in the section. B. Lithological cyclicity of Tripoli Fm controlled by precessional forcing (cycles 39-51), that grades upward into 15 m of grey marls alternating with autobrecciated limestones related to “Calcare di Base” unit (cycles 52-61).

gypsum, appears intercalated with diatomite and grey marls. This layer has previously been interpreted by Pedley and Grasso (1993) as a marker of incipient evaporitic conditions in the Caltanissetta Basin and referred as First Carbonate Bed (FCB) (Fig. 42B, 43).

Between 13 and 19 m, the succession becomes enriched in layers of laminated dolomitic carbonates interbedded with clays and diatomitic marls forming a gradual passage towards the Calcare di Base Fm. The cyclic sedimentary pattern is still clearly marked in this interval although the thickness of the white diatomites increases significantly. Thus, this cyclicity permits an accurate correlation with the Falconara section.

The uppermost 12 meters of the section, from 19 to 31 metres, correspond to the true Calcare di Base (Fig. 42B) composed of a thickening upward succession of 19 carbonate beds alternating with clay and marl layers, which are described below in more detail.

Biostratigraphy and cyclostratigraphy

The calcareous nannoplankton and planktonic foraminifers are relatively abundant and diversified in the first local 7 cycles only where they display the same lithology-controlled variations as in the Falconara section (Hilgen and Krijgsman, 1999; Blanc-Valleron et al., 2002) while benthic foraminifera are rare or absent throughout the section. In the diatomite layers, the association of foraminifers is dominated by high percentages of *N. acostaensis and G. bulloides*, which are considered to be indicative of nutrient-rich waters (Lourens et al., 1992). The diatom association is generally dominated by *Thalassionema nitzschioides* and *Asterolampra acutiloba.* Planktonic foraminifera disappear at 7 m from the base in the local cycle 9 while an association rich only of diatomites and radiolarians persist until to 19.50 m. According to Sprovieri et al. (1996b) and Caruso (1999), the presence of *Globorotalia conomiozea*, *Globorotalia miotumida* together with *Reticulofenestra rotaria* in the 4 meters of Licata Fm and in the lowermost part of Tripoli Fm section (0-2.80 m, see Fig. 43) indicates that this interval belongs to the *Globorotalia conomiozea* biozone lower Messinian in age. Besides the contemporaneous absence of *Globorotalia nicolae* and *Amaurolithus amplificus* in Tripoli Fm indicates that the lowermost 14 cycles of Falconara section are not present here. In particular at Falconara-Gibliscemi composite section *G.nicolae* and *G.conomiozea* group LOs occur respectively in cycle 13 and 24 at 6.72 and 6.50 Ma (Hilgen and Krijgsman, 1999; Blanc-Valleron et al., 2002). At Serra Pirciata, *G. conomiozea* disappears in the local cycle 5 that we correlate to cycles 24 of Falconara. In addition the coiling change of *Neogloboquadrina acostaensis* from senestral to dextral has been recognised at Serra Pirciata at 5.70 m in the local cycle 7, after a covered-disturbed interval. This important event occur in the diatomites of cycle 32 of Falconara section (Hilgen and Krijgsman, 1999; Blanc-Valleron et al., 2002), thus this bioevent permits to correlate the local lithological cycle 7 with lithological cycle 32 of Falconara. The interval from 4.5 m up to the top of the section is characterized by a good lithological cyclicity that permits the progressive numbering of all cycles as compared with the Falconara reference section (Fig. 42B, 43). Thus, in the Serra Pirciata section cycles 21 to 25 and 31 to 52 of Tripoli Fm are present. Salso River (Fig. 43) in which abundant benthic and planktic foraminifera, lower Pliocene in age, have been found. In particular two stratigraphical markers of lower Pliocene as *Globorotalia margaritae* and *Globorotalia puncticul*ata are also recognized clearly re-sedimentated into the laminae of the lower Messinian diatomites.

Mineralogical and geochemical data

This section describing the mineralogy and stable isotope composition of the carbonates is from a paper published by Bellanca et al. in 2001. The carbonate fraction constitutes up to 40 % of the bulk sediment and is predominantly composed of calcite related to the biogenic fraction, various types of carbonate debris with size up to 100 µm and small amounts of micrite. The dolomite content is generally less than 10 % (Fig. 44).

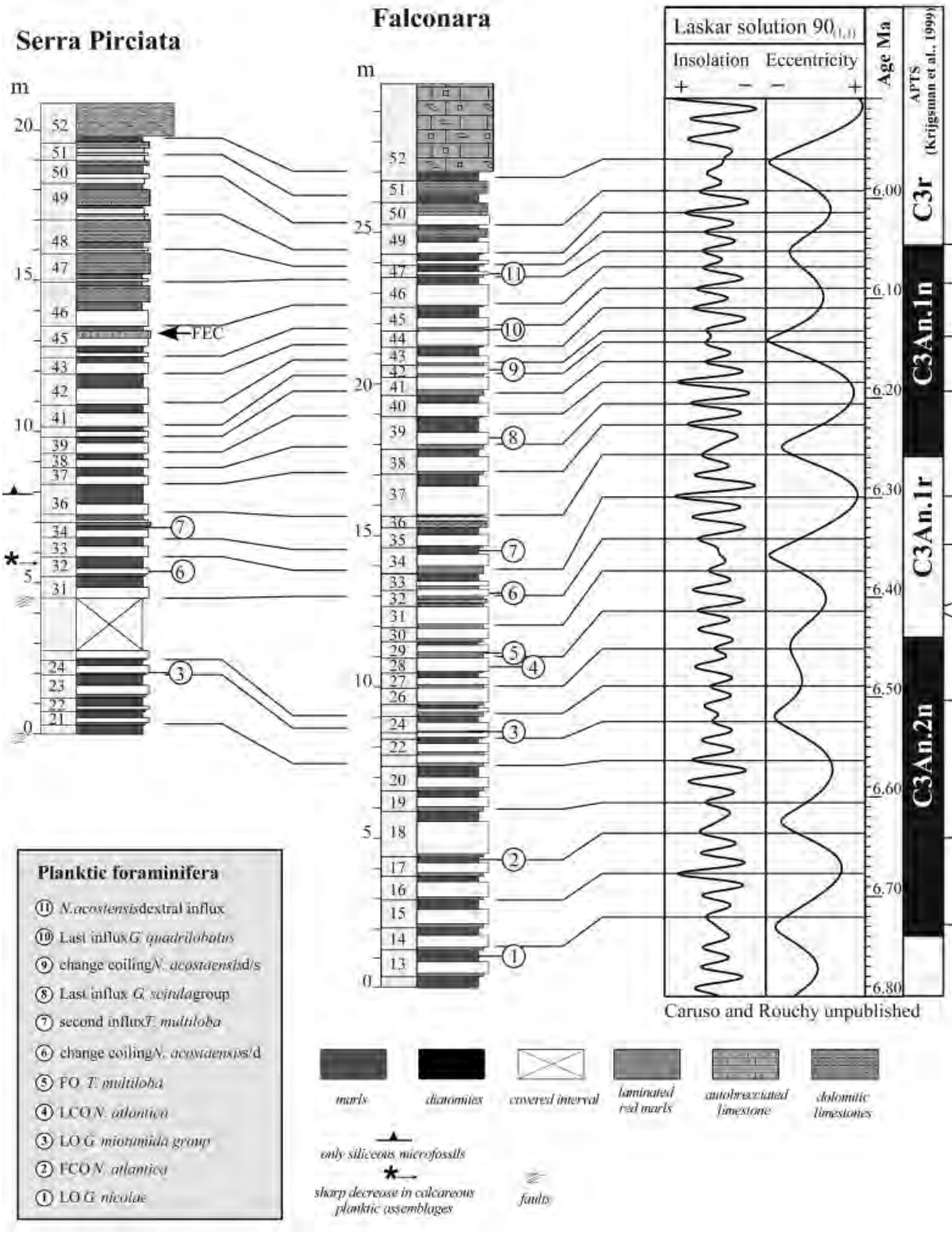
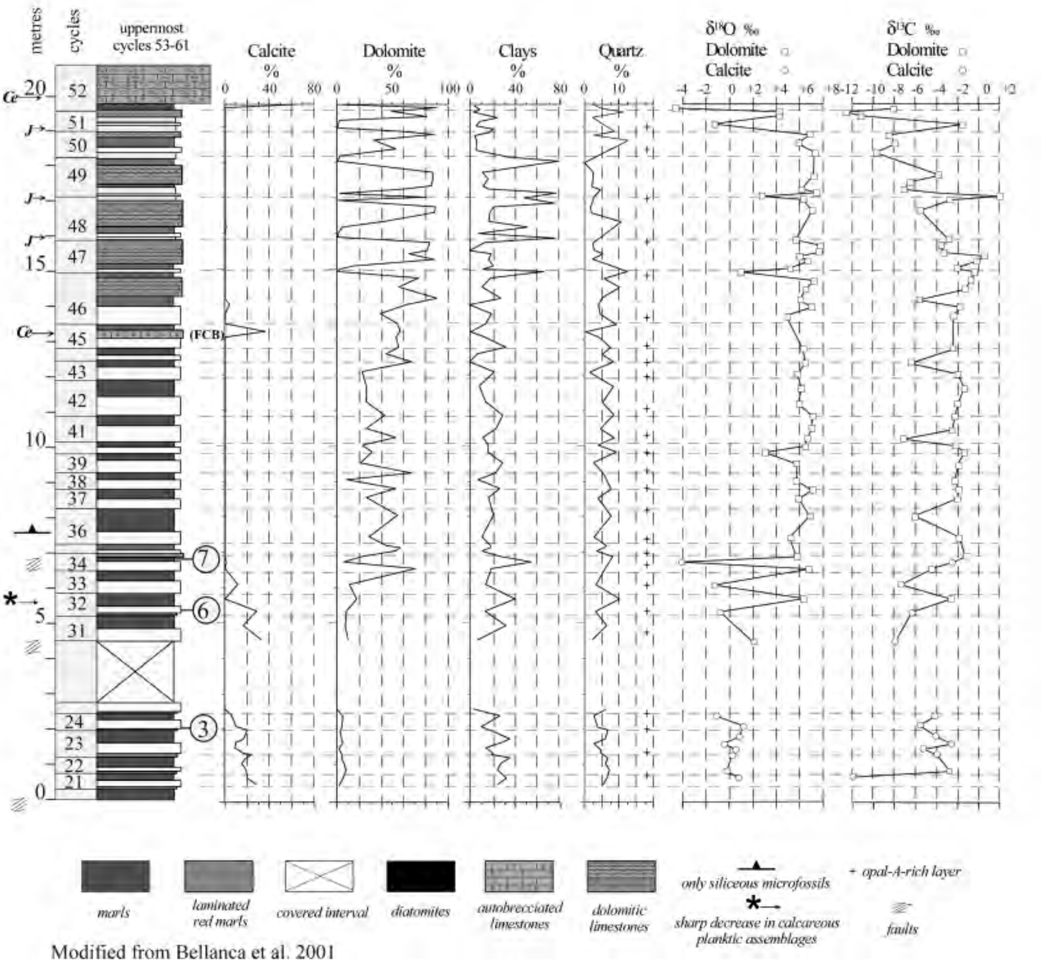


Fig. 43. Lithological log and bioevents of Serra Pirciata section correlated to Falconara reference section (Krijgsman et al., 2001; Blanc-Valleron et al., 2001). The lower part of the section is composed by the classical triplet of reddish laminites (sapropel), white diatomites and grey marls. The middle part of the section is characterised by couplets of white diatomites and grey marls, reddish laminites are not present. In cycle 45 a First Evaporitic Carbonate (FEC) is present. Between 13 and 19 m, the succession becomes enriched in layers of laminated dolomitic carbonates interbedded with clays and diatomitic marls forming a gradual passage towards the Calcare di Base Fm.



Modified from Bellanca et al. 2001

Fig. 44. The Serra Pirciata section (Caltanissetta Basin, Sicily). Synthetic lithological sequence, micropaleontological, mineralogical composition (wt% of quartz, total carbonate, calcite, dolomite), oxygen and carbon isotopic compositions of calcite (modified from Bellanca et al., 2001). Ce (Celestine), J (jarosite). Hyperhaline conditions started in the upper part of cycle 34. The First Evaporitic Carbonate (FEC o FCB) appears in cycle 45 with an astronomical age of 6.08 Ma.

The stable isotope composition of the calcite (Fig. 17) is characterized by δ18O values comprised between -1.3 and 2.1‰, which reflect marine conditions affected to slight fluctuations of salinity and/or temperature. Except for two values as low as -7.7 and -12.0‰, the negative δ13C values fluctuate around -4‰. Whole-rock isotopic data should be used with caution in descriving a primary environmental signal because significant geochemical changes may occur in response to post-depositional diagenetic alterations (see discussion in Sass et al., 1991; Marshall, 1992; Spicer and Corfield, 1992; Shackleton et al., 1993). For the Tripoli sections, petrographic data (thin section and SEM observations) supported by a lack of correlation between $\delta^{18}O$ and $\delta^{13}C$ rule out alterations by meteoric waters and intense recrystallization during burial and suggest that cementation in these deposits occurred during early diagenesis, mainly by locally derived carbonate. In this context, some quite negative $\delta^{13}C$ values, between -4 and -12‰, in the lower part of the Serra Pirciata section could indicate a more severe influence of early diagenetic reactions involving organic carbon and probably related to stagnant bottom conditions, which is consistent with the lack of benthic foraminifers.

A fall in both the abundance and diversity of the calcareous planktonic assemblages occurs in the cycle 33 followed by the definitive disappearance of the foraminifers in the cycle 36. The overlying deposits are barren except for some diatomitic layers which contain marine diatoms with an assemblage generally oligotypic and dominated by *Thalassiothrix longissima* and *Actynocyclus curvatulus* (Fig. 43, 44, 45A).

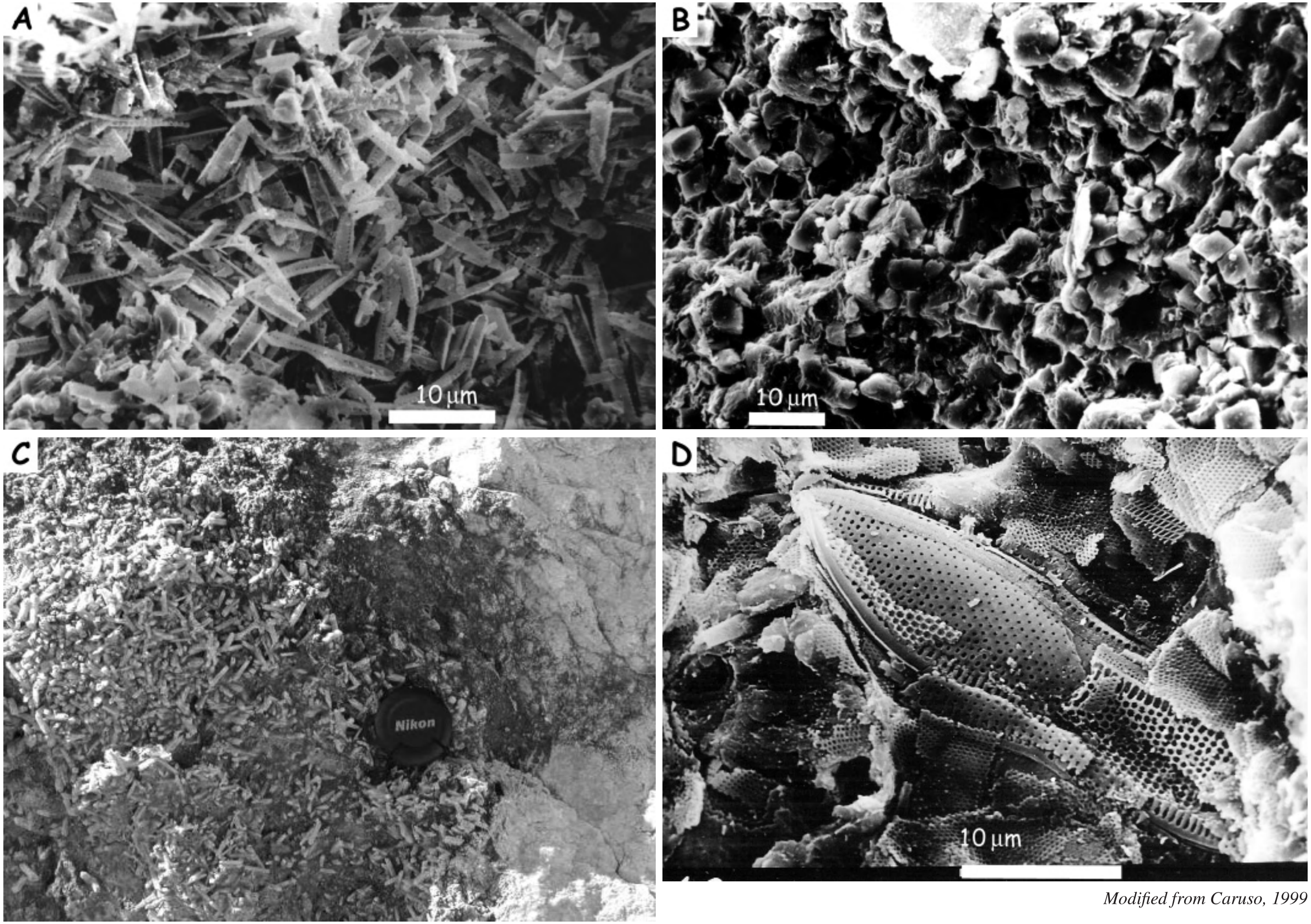
This biological event suggests a rapid deterioration of the environmental conditions marked also by an abrupt change in mineralogy of the carbonate fraction which is characterized by the disappearance of calcite, whereas the dolomite becomes the exclusive component, reaching up to 90 % of the bulk sediment in the marl layers. Under the SEM, the dolomite appears as euhedral to subhedral crystals with average size of 5 μm (Fig. 45B).

The base of cycle 45 contains significant proportions of celestite while jarosite is common in the interval comprised between cycles 48 and 52. The jarosite formation implies i) a source of H2S linked with sulphate bacterial reduction and ii) a redox boundary promoting oxidation of the sulphide.

The stable isotope composition of the dolomite exhibits high δ18O values that are close to 6‰, or heavier, with the exception of a few lower values (Fig. 44). Most data indicate that the dolomite precipitated from highly evaporated solutions, whereas the sudden decreases of $\delta^{18}O$ are interpreted as evidence for short dilution events. Between cycles 34 and 47, the $\delta^{13}C$ values of the dolomite fluctuate mostly around -2.5‰ with some more negative values down to - 7.3‰, and then decrease progressively down to -12.4‰ through the transitional interval with the overlying Calcare di Base. This pattern indicates substantially increased availability of ^{13}C-depleted biogenic CO_2 derived from processes involving microbial oxidation of organic matter or, at least for extremely negative $\delta^{13}C$ values, microbial sulphate reduction. In the two last cycles at the transition with the Calcare di Base (51-52), the $\delta^{18}O$ values cover a wider range of variation (from 7.1 to -4.7‰) suggesting that salinity fluctuated rapidly between highly evaporated and diluted conditions. Such a scenario of a basin subjected to poorly oxygenated to anoxic conditions associated to intense evaporation and periodically refreshed by considerable influxes of continental waters accounts for the occurrence of jarosite-bearing blackish argillites in the upper part of the section and just in proximity of beds marked by a sudden decrease of $\delta^{18}O$ concomitant with increase of $\delta^{13}C$.

Characteristics of the Calcare di base deposits

The thickness of the carbonate beds ranges from few decimeters to 6 meters for the uppermost bed (Fig. 42B). These carbonates are very rich in pseudomorphs of halite and accessorily gypsum crystals (Fig. 46) and in celestite (Fig. 45C) which appears usually distributed along fractures and diaclases. The base of the "Calcare di Base" has been defined by a first carbonate layer rich in celestite. In addition to the halite



Modified from Caruso, 1999

Fig. 45. Scanning electron microscope (SEM) images. A. Oligotypic assemblage of diatoms composed of Thalassiotrix longissima (Serra Pirciata section, cycle 50. B. Euhedral to subeuhedral crystals of early diagenetic dolomite in marls (Serra Pirciata section, cycle 47) modified from Caruso (1999). C. Particular of carbonate bed (cycle 52) rich of celestite crystals.

and gypsum ghosts, the uppermost carbonate layer exhibits a nodular structure with rounded, ovoid to contorted nodules several cm to one dm in size which could be interpreted as due to either reworking of unconsolidated carbonates or carbonate replacement of nodular gypsum or anhydrite. This second interpretation fits the sedimentary features better and the sedimentary context of the unit. These carbonates are very representative of most of the Calcare di Base deposits from the other Sicilian sections that are commonly composed of peloidal limestones deformed and brecciated by the early diagenetic interstitial growth of halite and gypsum crystals, like for instance in Contrada Gaspa (Fig. 46B) or Grotte (Fig. 46C). The deformation of the sediment induced by crystal growth and further dissolution of the halite and its replacement by calcite was responsible for the intense disturbance of the primary structures of the sediment and its brecciation as illustrated by the Fig 46 B. In other sections, like those of Torrente Vaccarizzo, Contrada Gaspa, Monte Gallitano, Gibliscemi, some gypsum layers are still preserved within the Calcare di Base. In the Serra Pirciata section, all the carbonate beds consist of primary peloidal carbonates, with no intercalation of secondary carbonates due to sulfate replacement by processes of bacterial sulfate reduction ("sulfifera limestones") which are abundant in many other places in relation sulphur ore deposits. But, these diagenetic carbonates are present laterally as the section is located close to the old sulphur mine of Tallarita. Their absence in the Serra Pirciata section located only few hundred of meters from the mine is probably due to the fact that the upper part of the Calcare di base is missing as the result of the faulting that truncated the section hindering the transitional interval with the gypsum. These diagenetic carbonates are present at Monte Gallitano where the laminated gypsum is partly replaced by secondary carbonates with formation of elemental sulphur nodules (Fig. 41). These two sections clearly show that the Calcare di Base corresponds to either primary or diagenetic carbonates and are involved in the sedimentary cyclicity forced by the astronomical precession.

The Calcare di Base from Sicily has been subject to many studies for sedimentology and stable isotope geochemistry of the carbonates: Pierre (1974), McKenzie (1985), Decima et al. (1988), Bellanca et al. (2001), among other works. More recently, the results of an integrated sedimentological and stable isotope composition of these carbonates from different sections from Sicily and Calabria, including Serra Pirciata, have been presented during the Parma Colloquium (2006) by Pierre et al. This study revealed a great variability of the mineralogical and stable isotope composition of the carbonates and great differences from a section to another. At Serra Pirciata, 75 samples have been studied from cycles 52 to 61. They are predominantly composed of a few layers calcite containing aragonite, dolomite and sparse traces of strontianite. The stable isotope composition of the calcite is characterized by $\delta^{18}O$ values comprised between – 3.80 and 2.15‰ and $\delta^{13}C$ values comprised between -16.89 and - 0.44‰. These $\delta^{18}O$ values indicate a significant dilution by continental waters while the presence of very abundant pseudomorphs of halite argues for hypersaline conditions. This indicates that the depositional environment underwent to rapid and large fluctuations probably under climate control, dilution that occurred during wetter periods caused the dissolution of the halite previously precipitated during dryer periods and its replacement by carbonates. The low values of $\delta^{13}C$ suggests that processes of bacterial sulfate reduction occurred episodically. The Serra Pirciata carbonates differ from those Torrente Vaccarizzo section (Si-

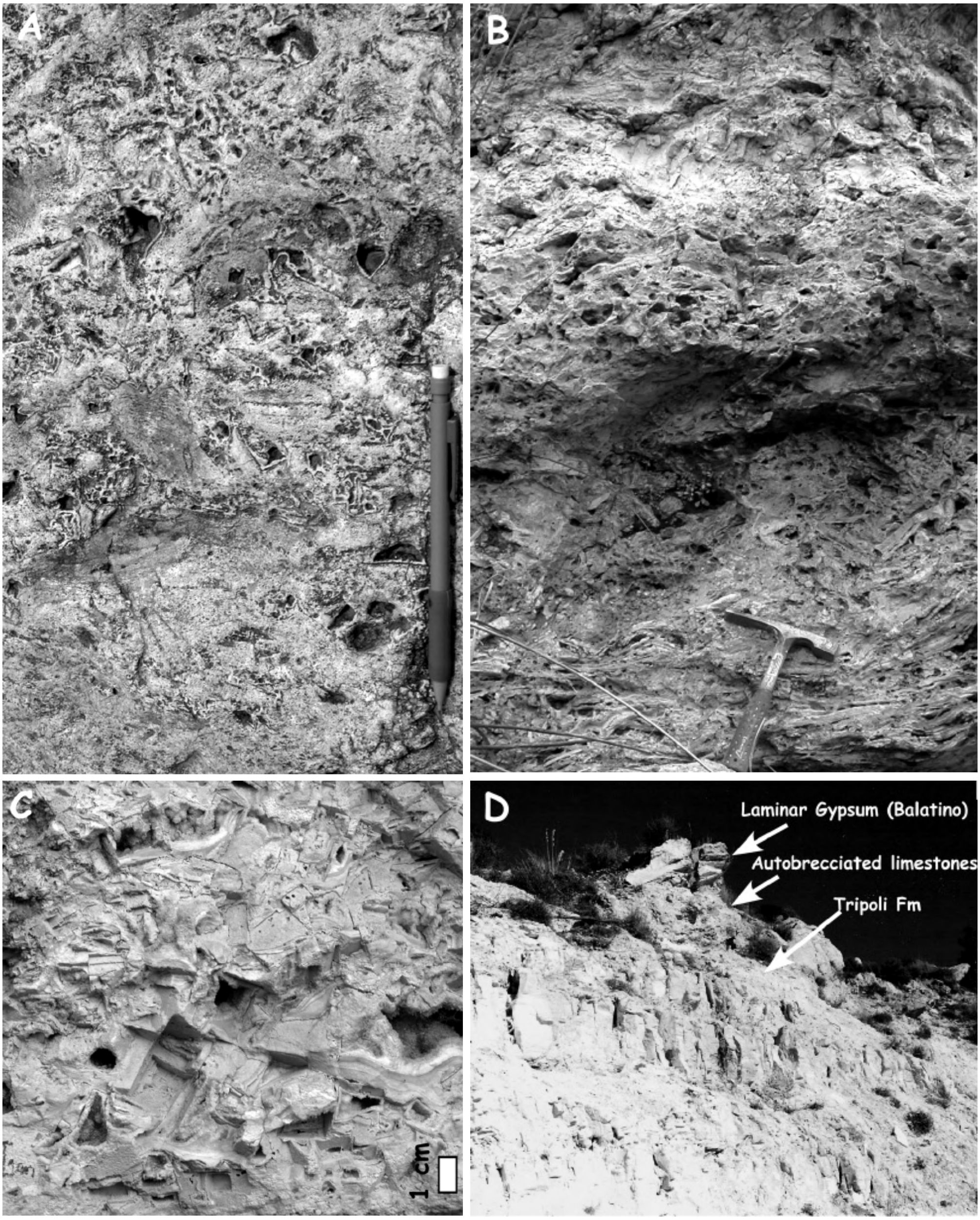


Fig. 46. Illustration of some sedimentary features of the Calcare di Base from different sicilian sections. A. Carbonate layer showing very abundant carbonate pseudomorphs of halite crystals. Serra Pirciata section. B. Autobrecciated carbonate displaying abundant ghosts of halite crystals as carbonate pseudomorphs or voids resulting of their dissolution. The lower part of the photo shows a deformation and a brecciation of the carbonate matrix around the halite crystals, indicating thus the brecciation was caused by the early diagenetic interstitial growth of the halite crystals. Contrada Gaspa section. C. Carbonate bed with very abundant carbonate pseudomorphs of halite crystals which indicates the bed was mostly composed of halite before carbonate replacement. Grotte section. D. Laminar Gypsum (balatino) intercalated to autobrecciated carbonates with pseudomorphs of halite and gypsum crystals in the upper part of Gibliscemi section.

cily) where aragonite and dolomite are abundant and very positive $\delta^{18}O$ values indicate more stable hypsersaline conditions. They are also completely different from the diagenetic carbonates associated to the sulphur ore deposits from Monte Muculufa, Contrada Gaspa and Capodarso which are characterized by very negative $\delta^{13}C$ values related to processes of bacterial sulfate reduction and oxidation of methane.

Summary

The multidisciplinary approach (bio-cyclostratigraphical, sedimentological, mineralogical and geochemical) has permitted us to demonstrate (Caruso, 1999; Rouchy and Caruso, 2006) that in the Serra Pirciata section the hyperaline conditions started before than Falconara-Gibliscemi composite section in the upper part of cycle 34, here a drastic reduction of calcareous microfossils and changes of both the carbonates mineralogy and the stable isotope composition of the bulk carbonates has been recognized (Fig. 43, 44), which is related to a significant increase of salinity. Thus the astronomical calibration of lithological cycles has permitted to obtain an astronomical age of 6.29 Ma for the increase of Salinity and an astronomical age of 6.08 Ma for the First Evaporitic Carbonate (FEC) that occurs in cycle 45. Finally the onset of Calcare di Base unit start in cycle 52 (Celestite layer) as recognized by Hilgen and Krijgsman, 1999 at Falconara.

Stop 3-4 – Portella Monaci, Enna - The “Lower Evaporites” of the Pasquasia Ridge. General geologic framework, facies and stratigraphy of the Messinian succession in the type area of the Upper Evaporites (Pasquasia gypsum).

M. Roveri, V. Manzi, S. Lugli, B.C. Schreiber,
R. Gennari, S. Iaccarino

The field trip ends in the nearby of Enna, where the Messinian succession crops out in the so called M. Capodarso-Pasquasia ridge (Fig. 47), a topographic relief elongated in a NE-SW direction and representing the southern flank of the Marcasita anticline (Butler and Grasso, 1995). This succession has a historical relevance, as it was indicated by Selli (1960) as the Messinian stratotype. The Calcare di Base crops out at M. Capodarso where it lies unconformably (Suc et al., 1995) above the Tripoli Fm.

The latter unit is progressively eroded below the Calcare di Base, as also suggested by biostratigraphic studies (D’Onofrio, 1964); outcrop and borehole observations (Roda, 1967; Fig. 48) show that moving to the S and to the NE, the CdB rapidly disappears, while the overlying Lower Gypsum thickens considerably. These geometrical relationships and rapid thickness changes are clearly tectonically controlled suggesting important synsedimentary Messinian growth of the Marcasita anticline. This offers the opportunity to discuss the regional-scale meaning of the Tripoli-Calcare di Base transition.

Here, the Lower Gypsum forms a laterally persistent body consisting of laminated gypsum (balatino) and graded gypsarenites resting directly above the Tripoli Fm.

According to Selli (1960) and Roda (1967) the huge salt body exploited in the Pasquasia mine (Fig. 49) and occurring in the footwall syncline south of the Marcasita anticline, is a lateral equivalent of the Lower Gypsum, and more precisely of a shale intercalation in its lower part.

The Lower Gypsum is conformably overlain in outcrop by the upper cycle marls and evaporites, here represented by a relatively thin unit

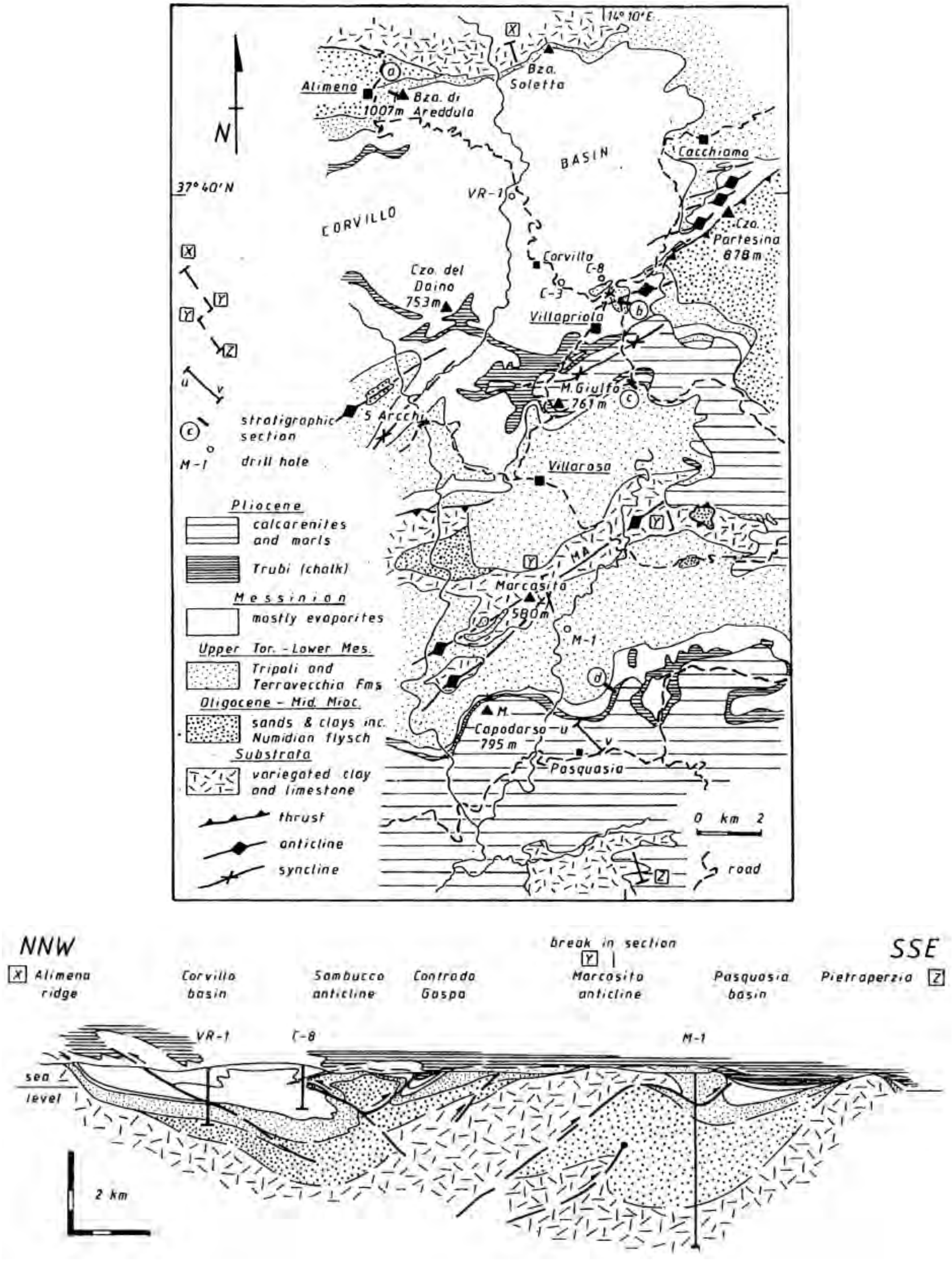


Fig. 47 – Simplified geologic map and cross-section of the Caltanissetta area with the ubication of the M. Capodarso-Pasquasia section (from Butler et al., 1995).

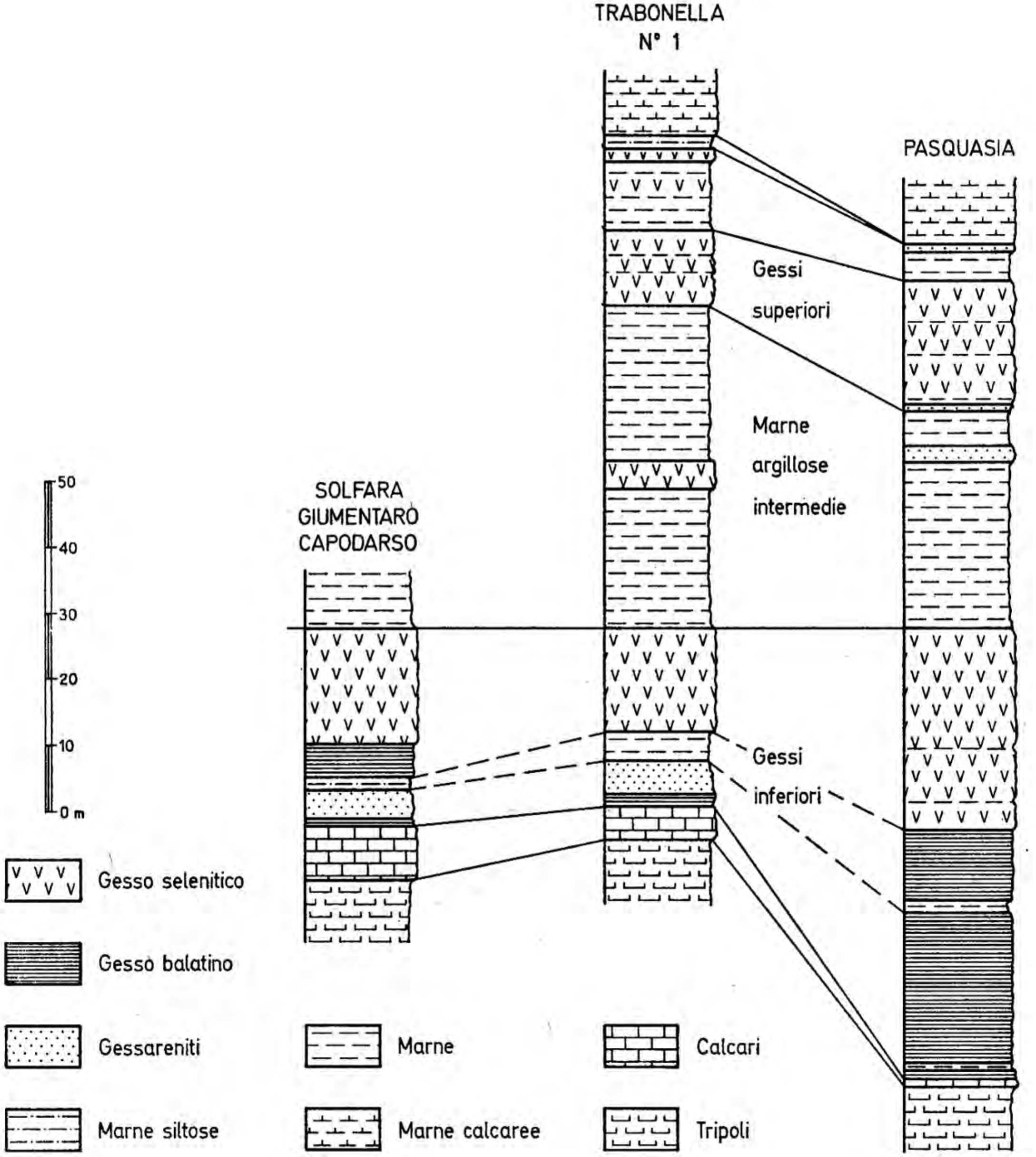


Fig. 48 – Correlation of outcropping and borehole Messinian successions in the Capodarso-Pasquasia area showing the strong lateral thickness changes of both Calcare di Base and Lower Gypsum (modified from Roda, 1967). Actually, no primary selenites are found in the Lower Gypsum unit.

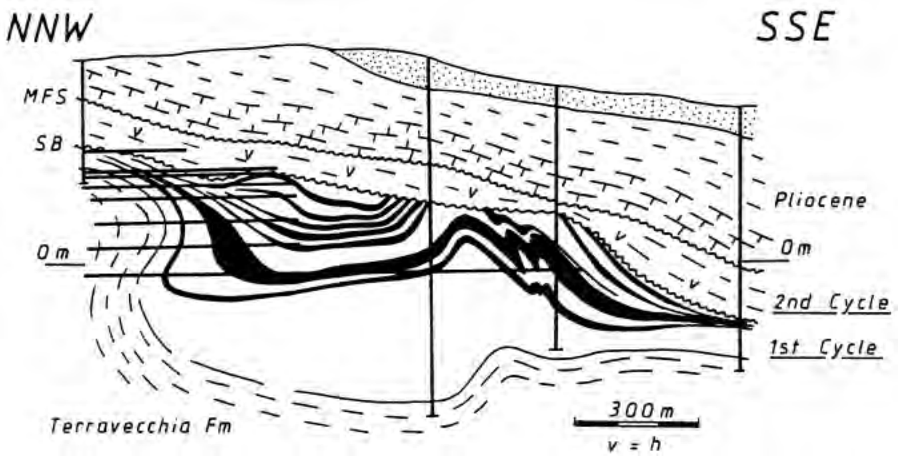


Fig. 49 – Geologic cross-section through the Pasquasia Mine (modified from Butler et al., 1995).

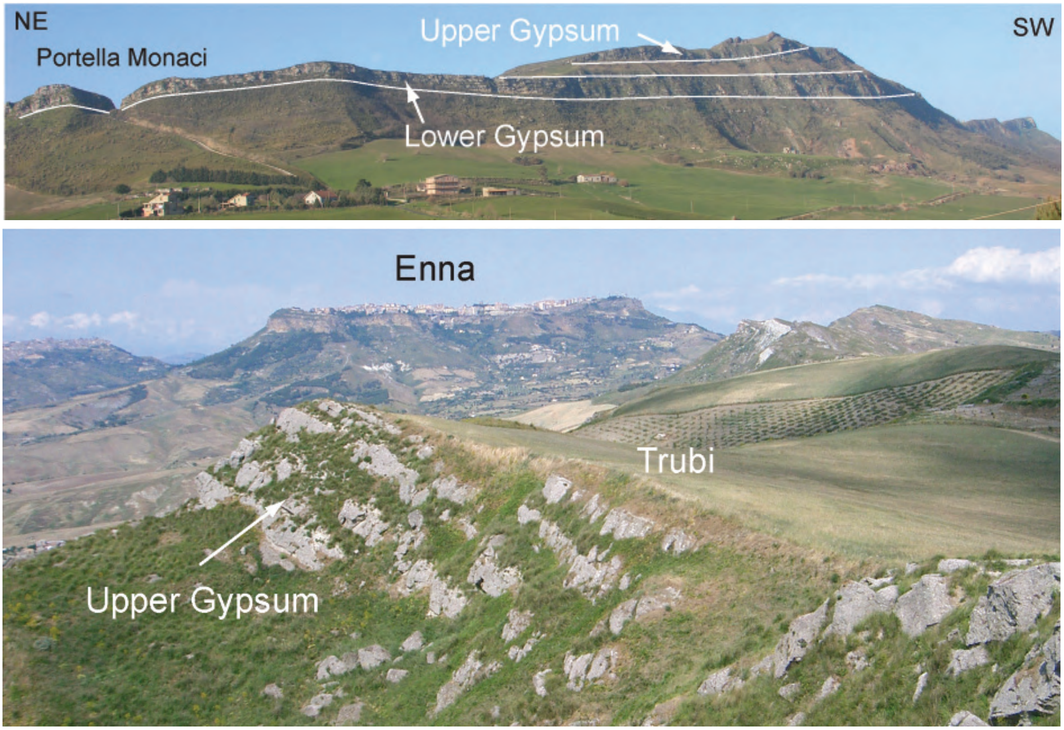


Fig. 50 – above, the Pasquasia ridge looking south from Enna; "Lower Evaporites" gypsum turbidites at the base; Upper Evaporites on top separated by a marly horizon; Portella Monaci to the left; below, detail of the Upper Evaporites on the western termination of the Pasquasia ridge with Enna in the background.

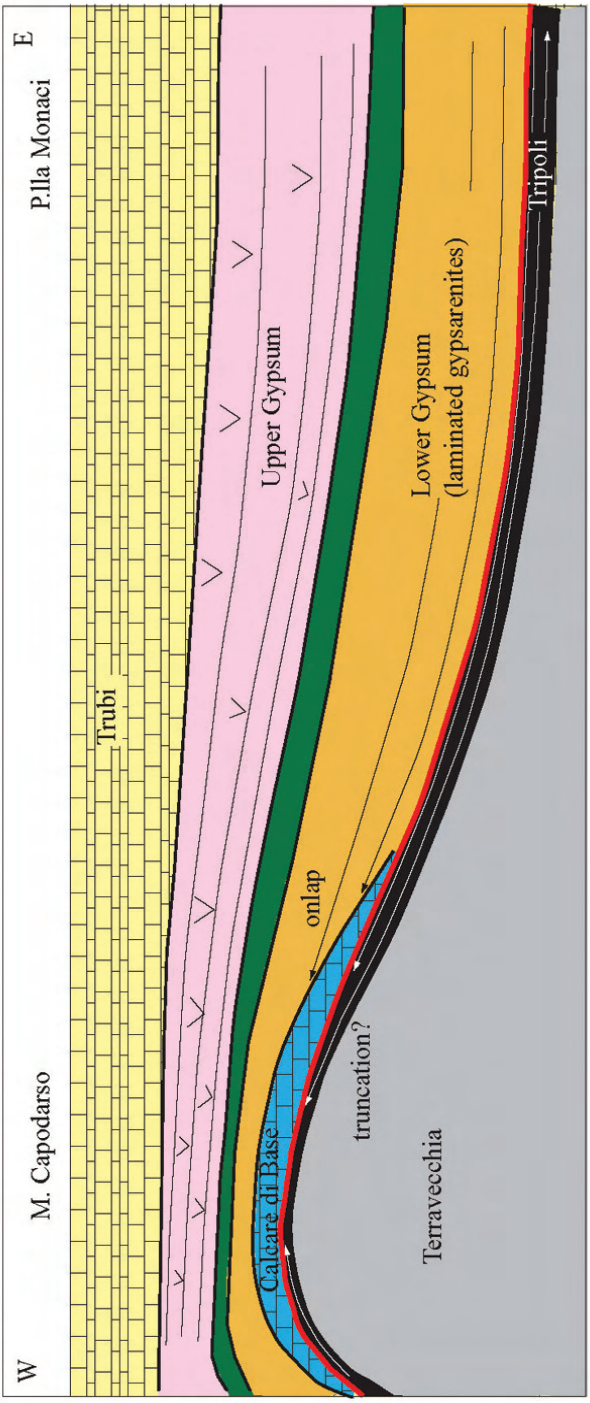


Fig. 51 – Schematic cross-correlation between M. Capodarso and P.lla Monaci, showing the inferred geometric relationships between Tripoli, Lower Gypsum and Calcare di Base.

made of 6 highly altered selenite gypsum cycles almost lacking the interbedded shales. The Messinian succession is topped by a very thin and discontinuous sandstone horizon (Arenazzolo Fm.) overlain by Lower Pliocene Trubi.

A good outcrop showing the transition between the upper part of the Tripoli and the Lower Gypsum can be observed at Portella Monaci, at the northeasternmost end of the Pasquasia ridge (Fig. 50). A preliminary study of the uppermost Tripoli at Portella Monaci section, showed a thick barren interval just below the Lower Gypsum, here mainly of clastic origin. Its correlation with the Capodarso section (Fig. 51) as well as the general meaning of local Lower Gypsum with respect to the Cattolica area will be discussed.

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