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Corresponding Author: Dr. Vinicio Manzi, Ph.D.

Corresponding Author's Institution: University of Parma

First Author: Vinicio Manzi, Ph.D.

Order of Authors: Vinicio Manzi, Ph.D.; Stefano Lugli, Prof.; Marco Roveri, Prof.; B.Charlotte Schreiber, Prof.; Rocco Gennari, Ph. D.

Abstract: Three different types of carbonate deposits are included within the "Calcare di Base", commonly envisaged to record the Messinian salinity crisis onset: type 1 consists of sulphur-bearing limestones, representing the biogenic product of bacterial sulphate reduction after original gypsum; type 2 comprises dm-thick laminated dolomitic limestones interbedded with diatomites, sapropels and marls found at the top the Tripoli Formation; type 3, the most common variety, consists of m-thick brecciated limestones interbedded with shales and clastic gypsum.
Type 3 shows sedimentary features suggesting a clastic origin and deposition from high- to low-density gravity flows; thus, these deposits can be regarded as an end-member of a large variety of evaporite-bearing gravity flow deposits, with a dominant carbonate component.
The genetic and stratigraphic characterization of these carbonates has strong implications for a better comprehension of Messinian events; the three types of Calcare di Base seem to have formed during different stages of the Messinian salinity crisis (MSC). Type 2 formed in the first stage (5.96-5.60 Ma), and is the only type that can be regarded as the Lower Gypsum time-equivalent. Type 3 was deposited in the second stage (5.60-5.55 Ma) and its base is associated with a regional-scale hiatus and erosion (Messinian erosional surface). Type 1 formed even later, likely in post-Messinian time, through diagenetic processes affecting resedimented gypsum deposited during the second stage of the MSC.
It follows that not all the Calcare di Base deposits record the onset of the Messinian salinity crisis, as commonly thought. Thus, a detailed facies characterization of these carbonate deposits is fundamental for both stratigraphic reconstructions and a better comprehension of Messinian events.

Suggested Reviewers: Macej Babel
m.babel@uw.edu.pl
Expert in evaporites

Federico Orti
orti@geo.ub.es
Expert in evaporite and Messinian rocks

Jean-Jacques Cornee
jean-jacques.cornee@gm.univ-montp2.fr
expert in carbonate sedimentology

Franco Ricci Lucchi
frarilu@libero.it
Expert in sedimentology and Messinian rocks

Wout Krijgsman
krijgsma@geo.uu.nl
Expert in Messinian stratigraphy

Wolfgang Schlager
wolfgang.schlager@falw.vu.nl

Opposed Reviewers: Jean-Marie Rouchy
Rouchy@mnhn.fr

Martin Pedley

Response to Reviewers: Ref.: Ms. No. B30262
The Messinian "Calcare di Base" (Sicily, Italy) revisited.
The Geological Society of America Bulletin

ADDRESS TO THE REVIEWERS AND EDITOR COMMENTS

ADDRESS TO EDITOR COMMENTS
Following the Editor suggestion the following changes has been made to the manuscript:
- the length of the manuscript has been considerably reduced (both text and figures).
- the overlap with previous publications has been eliminated
- a complete re-read and overall improving of the text has been carried out paying particular attention to the abstract, introduction, discussion and conclusions sections

ADDRESS TO REVIEWER #1 COMMENTS
Minor changes and integrations suggested by this reviewer have been made to the manuscript.
As for point 6, the reviewer suggests to discuss the possible correlation of CdB with the deep Med succession and particularly with the thick clastic unit underlying the Lower Evaporites that he proposed to be related to the Messinian erosional phase started at around 5.6 Ma. To this respect we observe that:
1) the idea of the possibly resedimented nature of the deep Mediterranean Lower Evaporites was first suggested by Roveri et al. (2001) and subsequently substantiated by Manzi et al. (2005), Roveri et al. (2008), based on the Northern Apennines and Sicily outcropping successions; these papers have not been cited in Bache et al. (2009);
2) the possible stratigraphic relationships between outcrop (particularly the Sicilian succession) and offshore Messinian deposits has been fully discussed in CIESM (2008) and Roveri et al. (2008). So it

would more interesting instead to know from the reviewer if and how their deep Mediterranean deposits fit the scenario suggested in these works;
3) we cannot provide our opinion and discuss the possible relationships between CdB (or, better, our RLG unit) and the deep clastic unit underlying the evaporitic suite described by Bache et al. (2009) as in their paper no unequivocal data are provided about their actual age. Other Authors (Lofi and Bernè, 2008) actually contend this interpretation and we believe that the available data are not sufficient at the moment to solve this problem.

ADDRESS TO REVIEWER #2 COMMENTS
All the changes and integration suggested by the reviewer have been bring to the manuscript. Moreover we address here to specific comments

A) the authors cannot write "subaerial and subaqueous unconformity." and refer to Clauzon et al. (1982) and Lofi et al. (2005); for the latters, the Messinian erosional surface is strictly "subaerial". It appears important to distinguish between Clauzon et al.'s and Lofi et al.'s view of the Messinian erosional surface and that of the authors of this manuscript. Bache et al. (2009) -EPSL, 286, 139-157- should be added as reference after Lofi et al. (2005).
According to Lofi et al., 2005 "It is difficult to estimate how far the MES extends basinward because the surface progressively becomes conformable with the underlying strata". As a consequence, a fully subaerial origin is not envisaged by these Authors all the basin wide.
Reference to Bache et al. (2009) has been added.

B) just to recall that Suc et al. (1995) -here cited- have described at Capodarso thin couplets of limestone immediately overlying the Tripoli Formation, the clayey beds being rich in pollen of halophytes. They could belong to CdB type 2.
The paper cited by the Reviewer does not actually provide a detailed description of the carbonates on top of the Tripoli Fm. allowing their attribution to CdB type 2. According to our field investigations the CdB of this section lay on the Messinian Erosional Surface (MES) and includes mostly brecciated carbonate (CdB type 3), locally diagenetic carbonate after gypsum is also present (type1).
The manuscript (both text and figures) has been improved to better explain the stratigraphy of this section.

C) Gautier et al. (1994) -C.R.Acad.Sci.Paris, 318, 1103-1109- were the first to date the beginning of the Messinian Salinity Crisis 100 kyrs after the C3An.1n - C3r reversal. The fact that Krijgsman et al. (1999) did not refer in Nature to this pioneer work is not a good example to follow!
The reviewer is right! It was our fault. Reference to Gautier et al. (1994) has been added.

D) see comment "B".
See answer to comment B

E) Reference to Gautier et al. (1994) is again missing: is it implied within the comment "magnetostratigraphic data are actually scarce and not fully reliable" despite the clear homogeneity of measurements?
Reference to Gautier et al. (1994) has been added. Actually the term "reliable" was not correct; we better explain in the new version of the manuscript that the problem was essentially related to the absence of astronomically calibrated data.

F) it is assumed that the erosional surface displayed in the manuscript is the Messinian erosional surface. This aspect needs some discussion as it was recently proposed with serious arguments that this Sicilian truncation could have resulted from tectonic activity (El Euch - El Koundi et al., 2009, Terra Nova, 21, 41-48). Validation of the Messinian erosional surface depends on its continuous evidence

from land to the deep desiccated basin. This point directly relates to the status of the Sicilian basin implicitly accepted in the manuscript as a representative of a deep Mediterranean central basin uplifted during the Pliocene and Pleistocene. Recently, the succession of events which occurred during the peak of the Messinian Salinity Crisis has been clarified by Bache et al. (2009) for the deep Gulf of Lions, the status of which is unquestionable: erosion preceded deposition of the low sea-level detritic cone itself preceding deposition of evaporites. Such a succession is considered by Manzi et al. for the Sicilian basin as illustrated on Figure 25. In the marginal part of the Gulf of Lions and onland, only the Messinian erosional surface is observable directly overlain by prograding Zanclean sediments (Lofi et al., 2005; Clauzon, 1982). In Sicily, several data indicate that coastal environments existed just before the onset of the Messinian Salinity Crisis, such as coastal pollen evidences at Capodarso (Suc et al., 2005) and in situ coral reefs at Cacchiamo (and other places) (Grasso & Pedley, 1988); these layers, representative of coastal environments, are overlain by Calcare di Base type 3. How to solve the contradiction in which coastal places could rapidly belong to a deep basin without involving a yo-yo tectonical evolution of Sicily? The possibility of a tectonic origin of the so-called "Messinian erosional surface" in Sicily between the Lower and Upper Evaporites should be at least discussed, as far as another assumption has been recently proposed for the Messinian erosional surface in Sicily below the Arenazzolo deposits (Popescu et al., 2009 - attached).
G) I believe that "shallow-water" environments (see point F) can be reliably taken into account for the Sicilian basin without a "considerable sea-level fall" at the onset of the Messinian Salinity Crisis if the basin was a marginal one, evaporites (including halite) being deposited during some rise in sea-level as suggested by full marine clay intercalations within halite at Realmonte and Racalmuto mines (Bertini et al., 1998 - Micropaleontology, 44, 4, 413-433).
H) Points F and G show that the debate on the status (marginal or deep) of Sicily cannot be discarded in this manuscript, as it was developed in the CIESM (2008) "Consensus paper". In my opinion, the dogmatic view of the Sicilian basin cannot be considered "a priori" without an actual discussion of the results with respect to this very important debate.
POINTS F, G, H
The points arisen by the reviewer has been debated in detail in our previous papers (Roveri et al., 2008; Manzi et al, 2009) and do not represent the main target of this manuscript that deals with the characterization of the different types of the Calcare di Base and their sedimentological and stratigraphic significance to support the MSC age model published in previous papers. The full treatment of these arguments would considerably increase the length of the manuscript and the overlap with already published work; we don't think it is necessary as the interested readers can easily refer to the cited papers.
In our view the controversy around the geodynamic setting of the Sicilian basin (peripheral vs. deep) is not fully motivated; the Sicilian basin is a foredeep system showing both shallow and deep depocenters which underwent differential subsidence during the Messinian and particularly between 5.6 and 5.4 Ma. The deep Sicilian depocenters were for sure somewhat shallower than the Mediterranean basins floored by oceanic crust, but this does not necessary means that their Messinian stratigraphy has to be considered different. We believe, as many other do, that the Messinian succession of Sicily is time equivalent of the deep Mediterranean one and in our papers as well as in the CIESM (2008) consensus report the inferred correlations are suggested. We have provided in a number of papers all the field data above which our interpretation has been based. So we firmly reject the qualification of "dogmatic". Our view of Sicily is not "dogmatic": it is simply our view and we'd rather prefer to discuss on the data and the interpretations.
As far as we know, the only dogma in all the Messinian debate is the idea of the desiccation of the deep basins, or anyway the 1500 m of envisaged sea-level fall. Of course we are aware that on this specific point there are different views but again we think that this argument is not fundamental for the aims of this specific manuscript.
Only a brief comment to the Arenazzolo problem: the reviewer cites the paper by El Euch - El Koundi et al. (2009) to support the idea of a MES associated with the base of the Arenazzolo; actually the observations at the base of such interpretation are provided by Popescu et al, (2009) and consist in the

highly variable thickness of the Lagomare deposits comprised between the Arenazzolo and the uppermost Upper Gypsum cycle that could be explained only by the presence of a unconformity. Our recent paper (Manzi et al., 2009) clearly shows through detailed basinwide correlations of Upper Gypsum cycles that no significant erosional surfaces cut this unit at its top and that thickness change of terrigenous intervals within gypsum cycles are controlled by the morphostructural setting and distance from sediment entry points. This is why we infer that the true MES in Sicily corresponds to the erosional surface separating PLG from the RLG+Halite units. As explained in the cited papers, we believe that the MES has a strong tectonic component in many geodynamic and depositional settings of the Mediterranean; as a consequence, differentiating between a exclusively drawdown-related erosional surface (the true MES according to Suc's view) and other, more local, tectonically-related unconformities is in our view misleading. According to our interpretation, the MES is a polygenetic surface better developed at basin margins and corresponding downbasin to a complex unit recording the MSC acme between 5.6 and 5.55 Ma.
As for this specific point, we suggested the possible occurrence of deep marine (turbiditic) deposits in the deep Med basins (i.e. the Lower Evaporites seismic unit) overlying the MES and its correlative conformity well before the paper by Bache et al. (2009) (see Roveri et al., 2001; Roveri et al. (2003), Manzi et al. (2005), Roveri et al. (2008)).

Finally, let us observe that while the reviewer warmly recommends to consider (and cite) the papers by El Kuch-El Koundi (2009) and Popescu et al. (2009), in such works our previous papers on this subject have not been cited (Roveri et al., 2008; Manzi et al., 2009).
Instead being quoted as "dogmatic", it would have been more interesting to know the reviewer's comments to the arguments that we provided in these papers to support our interpretation of Messinian Sicily stratigraphic and geologic evolution.

ADDRESS TO REVIEWER #3 COMMENTS

This is a manuscript that I think I have seen before in similar form. It appears that hardly any of the previous comments were taken into account, reiterating my main criticisms of the MS. These are:
(i) The progression from description to discussion. Following a lengthy
description of localities especially in Sicily (pp. 6-21), the authors discuss the Calcare di Base in general (pp. 22-31). It is not clear to me how these sections are linked.
(ii) There is a good deal of overlap between this MS and previous articles. The text builds on and in some cases repeats parts of other publications (including figures) in which these authors have recently been involved (e.g., Lugli et al., 2008; Roveri et al., 2008a,b).
The authors should thoroughly revise the MS, and probably considerably shorten it. They should ensure that the sections link together clearly, and they should avoid repetition of previously published work. The authors appear to be 'shingling' some of their results in a series of overlapping papers. But this MS also reminds me how convoluted the discussions of the Messinian Salinity Crisis have become. It seems to me that the authors themselves find it hard to see the wood for the trees, and - based on the present MS - even specialist readers would find to difficult to work out how they reach some of their conclusions.
Comments of Reviewer #3 are quite generic and not specifically addressed to specific points; as they are completely opposed to the comments of the other reviewers, it seems that they are related to a personal disagreement with our recent publications rather to this manuscript.
Anyway, this new version of the ms has been improved as much as possible in order to meet also the comments of Reviewer #3.

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Cover Letter

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The Messinian "Calcare di Base" (Sicily, Italy) revisited

Vinicio Manzi[1-4*], Stefano Lugli[2], Marco Roveri[1-4], B. Charlotte Schreiber[3], Rocco Gennari[1-4]

[1] Dipartimento di Scienze della Terra, Università degli Studi di Parma, Via G.P. Usberti, 157/A, 43100 Parma, Italy

[2] Dipartimento di Scienze della Terra, Università degli Studi di Modena e Reggio Emilia, Piazza S. Eufemia 19, 41100 Modena, Italy.

[3] Department of Earth and Space Sciences, University of Washington, P.O. Box 351310, Seattle WA 98195, USA

[4] ALP, Alpine Laboratory of Paleomagnetism, Peveragno, Italy

* Corresponding author's e-mail: vinicio.manzi@unipr.it

ABSTRACT

Three different types of carbonate deposits are included within the "Calcare di Base", commonly envisaged to record the Messinian salinity crisis onset: type 1 consists of sulphur-bearing limestones, representing the biogenic product of bacterial sulphate reduction after original gypsum; type 2 comprises dm-thick laminated dolomitic limestones interbedded with diatomites, sapropels and marls found at the top the Tripoli Formation; type 3, the most common variety, consists of m-thick brecciated limestones interbedded with shales and clastic gypsum.

Type 3 shows sedimentary features suggesting a clastic origin and deposition from high- to low-density gravity flows; thus, these deposits can be regarded as an end-member of a large variety of evaporite-bearing gravity flow deposits, with a dominant carbonate component.

The genetic and stratigraphic characterization of these carbonates has strong implications for a better comprehension of Messinian events; the three types of Calcare di Base seem to have formed during different stages of the Messinian salinity crisis (MSC). Type 2 formed in the first stage (5.96-5.60 Ma), and is the only type that can be regarded as the Lower Gypsum time-equivalent. Type 3 was deposited in the second stage (5.60-5.55 Ma) and its base is associated with a regional-scale hiatus and erosion (Messinian erosional surface). Type 1 formed even later, likely in post-Messinian time, through diagenetic processes affecting resedimented gypsum deposited during the second stage of the MSC.
It follows that not all the Calcare di Base deposits record the onset of the Messinian salinity crisis, as commonly thought. Thus, a detailed facies characterization of these carbonate deposits is fundamental for both stratigraphic reconstructions and a better comprehension of Messinian events.

INTRODUCTION

The “Calcare di Base” (CdB) is a composite lithostratigraphic unit made up of carbonate, marls and locally gypsum formed during the Messinian salinity crisis (MSC) mainly in Sicily and Calabria, where these deposits crop out extensively forming tabular bodies up to 60 m thick (Decima et al., 1988). Similar carbonate deposits, with much smaller volumes, are also present in the Messinian successions of the Northern Apennines and Tertiary Piedmont Basin (TPB; Sturani, 1976; Vai and Ricci Lucchi, 1977; Vai, 1988).
The carbonate fraction, variously calcite or aragonite (Decima et al., 1988), is usually a micritic limestone of evaporative and/or bacterial origin (Guido et al., 2007), which most commonly occurs as a brecciated deposit and is usually associated with sulphur mineralizations.
The term “Calcare di Base” (= “*basal limestone*”), first used by Ogniben (1957) for the Messinian succession of Sicily, is related to the basal position occupied by limestone in a

depositional suite expected by evaporating seawater (Usiglio, 1849). Accordingly, the CdB has been commonly considered to be the first product of the Messinian evaporitic suite and its base a reliable proxy for the onset of the MSC.

This caused some confusion, as the term “Calcare di Base” has been used through the time in a simplistic way to indicate all the carbonate-bearing units of Messinian age underlying gypsum or other evaporite rocks.

In the Northern Apennines Vena del Gesso basin (VdG) the pre-MSC unit shows, like in the other Mediterranean basins, cyclically stacked marl-sapropel couplets, recording precession-controlled dry-wet climatic oscillations (Krijgsman et al., 1999). In the uppermost six cycles marls are replaced by limestone, forming a carbonate-bearing unit usually referred to as CdB (Vai, 1988). A similar cyclicity characterizes the overlying Lower Gypsum unit, but with gypsum replacing limestone (Krijgsman et al., 1999). The lowermost gypsum cycles (1 to 3, Fig. 1) commonly show at their base a thin stromatolitic limestone (facies F2 of the VdG ideal evaporitic cycle of Vai and Ricci Lucchi, 1977), passing upward and laterally to massive selenite. In the Moncucco quarry (TPB) Sturani (1976) observed at the base of a gypsum cycle a similar limestone showing features interpreted as diagnostic of subaerial exposure (desiccation cracks).

Thus, a genetic link between marls, carbonates and gypsum has been envisaged, as they all formed during precession-driven dry peaks in a Mediterranean water body undergoing a gradual increase of water saturation related to its progressive isolation from the ocean. This apparently supports the Usiglio’s model, thus suggesting that the usage of the term CdB could be appropriate, at least for the thin limestones at the base of individual Lower Gypsum cycles.

Nevertheless, all these limestones are not evaporitic in origin, as already recognized by Vai and Ricci Lucchi (1977), Sturani (1976) and Vai (1988).

Moreover, these deposits are considerably different with respect to the CdB of Sicily. In fact, the “classic” MSC geological models (Decima and Wezel, 1971), consider the CdB of the Caltanissetta basin (Sicily), usually found above the lower Messinian Tripoli Formation (Fig. 1; Hilgen and Krijgsman, 1999), as an evaporitic and/or microbial deposit (Decima and Wezel, 1971; Decima et al., 1988; Guido et al., 2007) passing laterally to primary selenite of the Lower Gypsum unit (Gessi di Cattolica; Selli, 1960; Primary Lower Gypsum - PLG, Roveri et al., 2008a,b).

In other terms, the Sicilian CdB is not considered to lie *below* the Messinian evaporitic unit but *within* it, thus more similar to the thin limestone beds occurring at the base of individual PLG cycles of the VdG and TBP (Fig. 1). It follows that the base of CdB in Sicily is assumed to mark the MSC onset; the different age of the deposits underlying the CdB obtained from different Sicilian sections has been interpreted as a proof of a diachronous MSC onset (Fig. 1; Rouchy and Caruso, 2006; Butler et al., 1995).

More recently CdB and primary selenite were also considered a lateral equivalent of halite (Fig. 1; Garcia-Veigas et al., 1995; Rouchy and Caruso, 2006) and, due to the local presence of halite and gypsum moulds, the brecciated CdB deposits have been interpreted as the product of *in situ* collapse due to the dissolution of intervening halite or gypsum beds (autobreccia; Pedley and Grasso, 1993; Rouchy and Caruso, 2006). Unfortunately, such lateral relationships between CdB, PLG and halite have never been proved.

The revision of the Messinian stratigraphic and geologic evolution of Sicily foreland basin (Roveri et al., 2008b) suggested a completely new picture of the temporal and spatial distribution of CdB, framed into the two-step/three stage MSC scenario put forward by CIESM (2008) and derived from the two-step model of Clauzon et al. (1996).

The actual significance of Sicily as a possible outcrop analog of the deepest Mediterranean basins has long been debated; different interpretations still persist concerning its shallow vs deep-water nature and the stratigraphic position of the MES (see El Euch - El Koundi et al., 2009 and references therein). Our point of view has been fully illustrated in Roveri et al. (2008b), CIESM (2008) and Manzi et al. (2009), to which the interested readers are addressed for a more comprehensive discussion. The main aim of this study is to substantiate such a conceptual framework proposed in a synthetic and preliminary way by Roveri et al. (2008b). Here we focus on the more comprehensive description of the field criteria which are the basis of the new CdB classification proposed in Roveri et al. (2008b) and discuss their genetic meaning and stratigraphic position, as well as their implications for the MSC.

Based on facies and basin analysis here we describe three main types of limestone deposits commonly included in the CdB: (1) sulphur-bearing limestones deriving from post-depositional bacterial sulphate reduction (Dessau et al., 1959); (2) interbedded dolostones, sapropels and diatomites usually found at the top or above the Tripoli Fm.; (3) micritic limestones of evaporative and/or bacterial origin occurring as resedimented deposits, commonly brecciated, forming m-thick beds associated with clastic gypsum.

Particularly we deal with CdB type 3, because it represents the most common type. Based on sedimentological and petrographical observations we re-interpret the rocks of this type as clastic deposits that are not suitable for the definition of the MSC onset. Actually only type 2 CdB recorded the MSC onset and first stage (5.96-5.6 Ma; CIESM, 2008; Roveri et al, 2008a, b), while type 3 formed during the very short second stage (5.6-5.55 Ma); type 1 is a diagenetic product, likely formed in post-Messinian times, after original gypsum, mainly of clastic origin, belonging to Reworked Lower Gypsum (RLG) unit and deposited during MSC stage 2.

MSC stages 1 and 2 deposits are separated by the Messinian erosional surface (MES), a partially (Lofi et al., 2005) to fully (Clauzon et al., 1982) subaerial unconformity cutting the Mediterranean shelves and slopes and commonly related to a phase of fluvial rejuvenation accompanying the Mediterranean drawdown during MSC peak (Ryan, 1978; Bache et al., 2009). As not all CdB types mark the MSC onset and two of them (*i.e.* 1 and 3) could belong to MSC stage 2, their correct recognition in the field represents a fundamental key not only for regional-scale geological reconstruction, but also to better understand the time and spatial hydrological changes associated with the different MSC stages.

THE CALCARE DI BASE IN SICILY

The recent re-examination of the Messinian successions of Sicily (Roveri et al., 2006; 2008b) resulted in a more articulated stratigraphic framework than the classic Decima and Wezel's (1971) model and its subsequent modifications (Garcia-Veigas et al., 1995; Butler et al., 1995; Rouchy and Caruso, 2006). Messinian deposits accumulated in three main depozones of the Apenninic-Maghrebian foredeep system (Fig. 2A), showing a different stratigraphy (Fig. 2B); from North to South, *i.e.* from inner to outer sectors of the foredeep system, they are: 1) the wedge-top (Calatafimi, Ciminna, Belice basins), 2) the main foredeep (Caltanissetta basin) and 3) the Hyblean-Pelagian foreland ramp. It is worth noting that the classic stratigraphic models for the Messinian of Sicily were actually based only on the Caltanissetta basin, thus missing some crucial information from the other sectors. In fact, PLG deposits, formed during the first MSC stage (Roveri et al., 2006; 2008a,b), are present in their original stratigraphic position only in innermost wedge-top and foreland ramp depozones, where they overlay shelfal siliciclastic and/or carbonate deposits and are always unconformably overlain by uppermost Messinian or Lower Pliocene deposits.

The main foredeep shows a complex morphostructural framework with several depocenters separated by intrabasinal highs related to the Messinian synsedimentary growth of thrust-related anticlines (Pedley and Grasso, 1993). The Lower Gypsum unit here comprises mainly clastic, resedimented gypsum also including huge slabs and blocks of collapsed PLG deposits (RLG); large halite and K-Mg salt lenses (several kainite/carnallite horizons are included in the main halite body) up to 700/1000 m-thick are found encased within this unit in the main depocenters.

Significantly, *in situ* PLG deposits are missing in this depozone. The Upper Gypsum (UG; Gessi di Pasquasia; Selli, 1960)) unit, overliying the RLG unit along an irregular stratigraphic contact, possibly complicated by the dissolution of underlying halite bodies (Manzi et al., 2009), consists of cyclically stacked primary gypsum and marl beds capped by the siliciclastic Arenazzolo Fm., in turn sharply overlain by the Pliocene marine Trubi Fm.

CdB deposits are absent in wedge-top and foreland ramp depozones; in other words, CdB is never found clearly associated with *in situ* Lower Gypsum evaporites recording the MSC onset in the marginal, more elevated settings of the Sicilian basin. On the contrary, CdB is commonly observed within the main foredeep; type 1 and 3 CdB deposits occur on top and along the flanks of intrabasinal highs while in intervening depressions resedimented gypsum deposits occur; type 2 CdB is usually sandwiched between the Tripoli Formation and type 1 or 3 CdB units or lies directly below resedimented gypsum in the depocenters.

Here we present a brief summary of the main CdB-bearing sections from the different depozones of the Sicilian foredeep system.

Inner foredeep

Cozzo Prangi section, western Petralia basin (CP)

The Petralia basin (Fig. 2, 3) offers well-exposed examples of gypsum and carbonate-bearing gravity flow deposits and is a fundamental site to assess the relationships between the different deposits included within the RLG unit.

The Cozzo Prangi section (Fig. 4A, B) is located west of Petralia Sottana (Fig. 3) and consists of clastic evaporites, mainly represented by m-thick composite graded layers (Fig. 4C) usually formed by three divisions: a basal gypsrudite, also including Mesozoic carbonate cobbles (Grasso and Pedley, 1988), an intermediate gypsiltite and an upper shale or fine-grained limestone (Fig. 4D). These layers, showing erosional bases, normal gradation, clay chip alignments and parallel cross-lamination, can be interpreted as the product of hybrid high-density gravity flows deposited in moderately deep-water settings. The section is about 60 m-thick and is characterized by a progressive upward increase of the carbonate component (Fig. 4B) terminating in an “up to 30 m-thick unfossiliferous lime mudstones” interpreted as a lacustrine deposit (“Terminal complex”; Grasso and Pedley (1988). Actually, these limestone beds may be interpreted as the uppermost, fine-grained divisions of hybrid gravity flow deposits, thus representing a variety of CdB type 3.

Balza Bovolito section, eastern Petralia basin (BB)

This section, located south of the Petralia Salt Mine (Fig. 2, 3), from which it is separated by a back-thrust (Butler et al., 1995), shows a 50 m-thick succession of clastic evaporites, lying above the pre-MSC Terravecchia Formation (Fig. 5A) and comprising a lower gypsum-bearing unit and an upper carbonate-rich one (Fig. 5B). The lower unit consists of m-thick composite layers with a basal gypsrudite division overlain by m-thick gypsiltite and shale intervals (Fig. 5C). The basal gypsrudite contains broken crystals of massive selenite (Fig. 6A), rounded siliciclastic pebbles (Fig. 6B) and angular limestone clasts (Fig. 6C). In the thinner beds the gypsrudite is commonly overlain by gypsarenite and by a dm-thick division of laminar gypsarenite and gypsiltite (Fig. 6D). The base of the upper unit is marked by the first carbonate breccia bed (Fig. 5B); the gypsum clastic component decreases progressively toward the top and the uppermost bed shows the typical brecciated aspect of type 3 CdB (Fig. 6C). Carbonate breccia forms m-thick layers separated by dm-thick shale horizons representing the fine-grained tails of the flows.

In the NW portion of the Balza Bovolito cliff the deposits of the lower unit were partially involved in a submarine slide (Fig. 5 and Fig. 6E). We interpret bed amalgamation and sudden lateral terminations toward the NW of the upper carbonate unit (Fig. 4) as related to the subaqueous topography created by the slide accumulation.

Moving SSW from Balza Bovolito toward the quarry close to Casa Cerami (Fig. 3) the basal clastic evaporites onlap against the anticline bordering the southern margin of the Petralia basin and only the upper carbonate breccia crops out in that direction.

Balza Soletta - Alimena, Corvillo basin (BS)

A thin belt of brecciated limestones (CdB type 3), extending about 10 km eastward from Alimena, crops out along the inner (northern) flank of the Corvillo syncline (Fig. 2). A thick halite body extensively exploited in the past for its thick potash intercalations is preserved in the syncline core. At Balza Soletta the CdB sharply overlies dark, organic-rich euxinic shales, also included as cobbles and boulders in its basal portion, resting in turn upon fine-grained terrigenous deposits of the Terravecchia Fm. The CdB is associated with clastic gypsum and is unconformably overlain by a thick clastic unit comprising cyclically-stacked fluvio-deltaic, gypsum-bearing conglomerates and sandstones and shelfal marls, usually interpreted as proximal deposits of the Upper Evaporites unit. The angular discordance between the CdB and the uppermost Messinian clastic deposit is considered among the best evidences of the tectonic activity associated with the development of the MES and it clearly separates the two main Sicilian evaporitic cycles (Fig. 1). Based on such evidence the halite and the CdB have been usually ascribed to the first evaporitic cycle of Sicily and hence considered a lateral equivalent of the (primary) Lower Gypsum deposits (Decima and Wezel, 1971; Butler et al., 1995; Rouchy and Caruso, 2006).

Contrada Gaspa – Sambuco anticline, Corvillo basin (CG)

This section is located in the southern Corvillo basin (Fig. 2) along the road between Cacchiamo and Contrada Gaspa. Here a composite carbonate unit characterized by an irregular thickness and overall thinning toward the south, *i.e.* downslope, can be observed on the southern limb of the Sambuco anticline. It is made up of a few m-thick composite beds with erosional bases and pinch-out geometries; they commonly consist of a thicker basal limestone breccia division (CdB type 3), an intermediate gyparenite or gypsiltite division and a upper shale one. These deposits may be regarded as the product of hybrid high-density gravity flows and their irregular geometries can be related to slope instability caused by the syndepositional growth of the Sambuco anticlne. At Contrada Gaspa these carbonates are unconformably overlain by the uppermost Upper Gypsum bed, in turn capped by the Pliocene Trubi Fm. (Manzi et al., 2009).

Casteltermini (CT)

Located south of the M. Cammarata, representing the Monti Sicani thrust front (Fig. 2), this area shows several aligned belts of CdB limestone corresponding to the flanks and culminations of parallel, SW-NE trending anticlines. CdB is here mainly represented by composite beds with a lower dm- to m-thick carbonate breccia division overlain by a dm-thick parallel or cross-laminated gypsarenites and gypsiltites and by dm-thick shale. These deposits, ascribed to CdB type 3, are locally involved in slope failure processes, as witnessed by slump structures. In the intervening synclines, thick RLG deposits are present, including huge floating blocks of the PLG unit (Passo Funnuto). At the base, these deposits likely interfinger with sulphur-bearing limestones (CdB type 1), extensively exploited in the past (Cozzo Disi sulphur mine; Dessau et al., 1959).

Sutera (S)

A few kilometres east of Casteltermini, the village of Sutera (Fig. 7A) is built just below a mountain-sized block of PLG floating over a chaotic shaly unit including blocks consisting of m-thick graded beds of gypsrudite and gypsarenite, sulphiferous carbonate (Fig. 7B) and dolostone. Along the road to Campofranco the sulphiferous carbonate (CdB type 1), is associated with thin gypsarenite-beds and a slumped horizon including slabs of Tripoli diatomites (Fig. 7C). To the northwest of Sutera a large slab including diatomite and dolostone layers crops out (Fig. 7A, D). The isotopic values of the dolomite show very positive values for $\delta^{18}O$ (average value = +10.80; Olivieri et al., 2010) suggesting deposition under strongly evaporative conditions. Based on their lithological characteristics, these deposits could be included in CdB type 2.

Main foredeep

Marianopoli (M)

The CdB unit crops out along the main road to S. Cataldo together with the underlying Tripoli Fm. Cyclostratigraphic studies have been carried out on this section (Fig. 2) by Bellanca et al. (2001) and Caruso (1999) to date the MSC onset. The section comprises at the base about 10 m of Tripoli Fm. with microfossil assemblages related to the terminal pre-MSC unit. It follows an alternation of diatomites, marls and laminated dolostones for about 8 m. characterized by a basal dolomitic portion showing strong positive $\delta^{18}O$ values (6-8‰; Bellanca et al., 2001). The uppermost unit consists of m-thick, barren carbonate breccia graded beds (CdB type 3) showing low lateral persistency, pinch out terminations and an upward increase of bed amalgamation highlighted by clay-chip alignments (Fig. 8). Thin gypsarenite beds cap the carbonate unit, whereas no primary sulphates have been recognized.

Torrente Vaccarizzo (TV)

At the base of the section the Tripoli Fm. is characterized by marls alternating with, from the base to the top, indurated silty marls, marly limestones, diatomaceous silty marls and laminated dolostones. According to previous studies (Bellanca et al., 2001; Caruso, 1999), microfossil assemblages of the lower part can be ascribed to the pre-MSC stage. The sharp decrease of calcareous planktic microfossils prevents the identification of the uppermost pre-MSC bioevents (Sierro et al., 2001), so that a definitive age cannot be determined. Above a slump horizon dolomitic beds (CdB type 2) are present, characterized by strongly positive $\delta^{18}O$ values (Bellanca and Neri, 1986). The overlying evaporite unit begins with a laminated gypsarenite bed followed by 10 meters of m-thick carbonate breccia beds (CdB type 3) containing abundant clay-chips and rip-up clasts of the underlying diatomites, here characterized by soft sediment-deformation and slumps.

Capodarso – Giumentara sulphur mine (C)

Since the work of Selli (1960), the Capodarso section (Fig. 09) has been considered, together with the adjacent Pasquasia section, one of the key reference sections for the Messinian. Here the MSC onset was first dated at around 5.7 Ma by the pionieer biomagnetostratigraphic study of Gautier et al. (1994); this event was later astronomically calibrated at 5.96 Ma (Hilgen and Krijgsman, 1999). The studies of this section were mainly focused on the diatomites of the Tripoli Fm. (D'Onofrio, 1964; Suc et al., 1995), while the overlying Lower Evaporites deposits have been generically described as evaporitic limestones. Actually, these consist of a 2 m thick basal carbonate breccia bed containing abundant clay-chips, nodular alabastrine gypsum and native sulphur, overlain by a few meters of gypsarenites alternating with carbonate breccia. This unit has been extensively exploited for native sulphur (Giumentara mine). The limestone is a not primary deposit but has a clear diagenetic origin (CdB type 1) and is overlain by a clastic gypsum unit. Moving up-hill, a brecciated carbonate (CdB type 3) is found at the base of the RLG unit (Fig. 9).

Pasquasia (P)

The Pasquasia section, correlated with Capodarso through the basal sulphiferous carbonate layers (Selli, 1960), shows from the base: i) a lower clastic gypsum unit, with a basal sulphur-bearing carbonate, ii) a primary cumulate gypsum unit; iii) an upper clastic gypsum; iv) a thin shale horizon; and v) 6 beds of massive selenite belonging to the UG capped by the lower Pliocene Trubi Fm.

As for the Capodarso section, the sulphur-bearing carbonates can be ascribed to CdB type 1. The shale unit underlying the Lower Evaporites has been continuously cored. Preliminary results (Gennari et al., 2009) highlight a 20 m-thick, organic-rich unit barren of fossils and included in a reversed magnetzone, sharply overlain by gypsiferous sandstones in turn capped by type 1 CdB cropping out at the coring site.

S. Elisabetta (SE)

Southeast of Santa Elisabetta village (Fig. 2) a continuous succession recording the MSC onset is preserved at the base of a large tilted block of PLG (Fig. 10). This section is located in the southwestern end of the Caltanissetta basin, the classic type area for PLG (Cattolica Eraclea Fm.). Actually, these deposits form large disarticulated blocks and slabs detached from their base and floating in a chaotic muddy matrix also made up of gypsum clastites. This section is unique as here PLG deposits preserved their basal stratigraphic contact with the underlying unit consisting of a 4 m-thick succession of beige marls including dm-thick massive limestone beds crops out below the first selenite bed. Marine microfossil assemblages occurring in the basal part of the section are mainly composed of benthonic foraminifers. Thus, lower Messinian planktonic markers are lacking; benthonics are dominated by *Bolivina* spp., co-occurring with *Bulimina echinata*, *B. aculeata* and subordinate inner shelf taxa. Biostratigraphic evidences and facies distribution and stacking pattern of the overlying PLG (Lugli et al., 2008), led us to the recognition of the seven lowermost PLG beds. It follows that this carbonate-bearing unit can be ascribed to the pre-MSC stage, similar to that observed in the Northern Apennines Vena del Gesso basin; consequently it should not be included in the CdB.

Favara quarry (FV)

The Favara quarry is a representative section for the whole area between Racalmuto and Canicattì (Fig. 2) where the brecciated carbonates belonging to CdB type 3 are widespread. Commonly they form m-thick carbonate breccia beds separated by thin shale veneers. These deposits likely developed on the flank of an intrabasinal high hosting a carbonate factory. Today no primary carbonate has been recognized *in situ*, although the low degree of evolution of the clastic deposits may suggest that the source area should have been located very near.

Outer foredeep and foreland ramp

Montagna Grande-Pietraperzia

This area (Fig. 2) is characterized by a narrow, elongate antiformal structure (15 km long), characterized by the presence of amalgamated beds of brecciated limestones (CdB type 3); boulders included in this unit (Castle of Pietraperzia) suggest a close proximity of the original carbonate source. The stratigraphic relationships between the CdB and the other Messinian units can be observed at Montagna Grande where an impressive onlap of the Upper Gypsum unit against the CdB is preserved (Manzi et al., 2009).

Monte Gibliscemi (G)

Monte Gibliscemi is one of the key sections for the pre-MSC Tripoli Fm. (Fig. 2; Hilgen and Krijgsman, 1999); at the top of this formation 4 carbonate beds, about 2 m-thick each, can be observed. The lowermost bed is almost entirely made up of carbonate breccia (CdB type 3) containing gypsum and halite moulds; the other beds also include a chaotic division at their base (slurry bed) or large-sized rip-up mud clasts (Fig. 11) and clay chips derived from the erosion of the underlying unit. In the upper part of these beds normal gradation, parallel and cross-laminations are present. The CdB unit is overlain by a gypsum cumulate horizon, in turn capped by the UG (Manzi et al., 2009).

Serra Pirciata (SP)

The Serra Pirciata section (Grasso and Pedley, 1988; Butler et al., 1999; Bellanca et al., 2001) is located along the Salso riverbed, close to the road between Riesi and Ravanusa (Fig. 2). This section is characterized by a well-developed lithological cyclicity (Fig. 12); from the base 15 distinct marl and diatomite couplets can be recognized (total thickness 15 m) overlain by 5 marl-diatomite dolostone triplets (CdB type 2, total thickness 5-6 m), in turn capped by 10 limestone breccia (CdB type 3) beds separated by reddish marls (Fig. 12). This carbonate breccia is conformably overlain by a cumulate gypsum horizon and by the

UG (Manzi et al., 2009).
The diatomite succession at the base of the Serra Pirciata section has been object of biomagnetostratigraphic studies (Butler et al., 1999; Bellanca et al., 2001) that unfortunately do not provide unequivocal results. The reconstructed polarity zones do not match the number of precessional cycles recognized in the section (Butler et al., 1999; Figure 4 and text description) and thus are not appropriate for cyclostratigraphic purposes. The suggested age model (Bellanca et al., 2001) is questionable as: i) the main bioevents have been recognized only in the lower part of the section (*N. atlantica* FCO) that is bounded at its base by a fault and by a covered interval of unknown duration at the top; ii) the bioevents recognized above the covered interval are not unequivocally defined as both the sx-dx coiling change of *Neogloboquadrina acostaensis* and the second influx of *T. multiloba* are not supported by quantitative analysis and are based on a low number of samples. More interestingly, according to Bellanca et al. (2001), from the cycle 34 onward the section is characterized by a strong reduction in both the abundance and diversity of the calcareous planktonic assemblages and by the definitive disappearance of foraminifers from cycle 37 upward. This interval coincides with the base of type 2 CdB unit (Fig. 12) and is characterized by a change of carbonate composition, with a strong increase of the dolomite content, and by a sudden increase of the $\delta^{18}O$ values suggesting a marked increase in evaporative conditions (average $\delta^{18}O = +6\%$).

Falconara (F)

The Falconara section (Fig. 2, 13; Gautier et al., 1994; Hilgen and Krijgsman, 1999) is characterized by the occurrence of laminated dolostones at the top of the Tripoli Fm., here ascribed to CdB type 2. This interval, which is characterized by the disappearance of the foraminifera and calcareous nannoplankton (Blanc-Valleron et a., 2002), is affected by slump deformations and shear planes, and cut on top by a carbonate breccia (CdB type 3).

Licodia Eubea (LE)

This section is located in a structural depression of the Hyblean foreland ramp (Fig. 2). Here an almost complete succession of PLG crops out. Based of facies and stacking pattern distribution up to 13 gypsum cycles, starting from PLG cycle 1 can be recognized. Below the PLG a shale unit is present with interbedded calcarenite beds in its upper portion; preliminary biostratigraphic analysis on a few samples denote the occurrence of lower Messinian foraminifer assemblages. These deposits were previously described as CdB deposits (Grasso et al., 1982); similarly to what envisaged for the Santa Elisabetta section, this carbonate unit is here ascribed to the pre-MSC stage.

THE CALCARE DI BASE OUTSIDE SICILY

Basilicoi, Crotone basin, Calabria (B)

A limestone breccia, also including fragments of gypsum, has been described in the Crotone basin (Fig. 14 and 15 A) at the base of the local Lower Evaporite unit and ascribed to the CdB for its similarities with the Sicilian Messinian succession (Roda, 1964). This breccia consists of a sequence of up to 100 m of gypsum-bearing gravity flow deposits *l.s.*, mainly debris flow and high- to low-density turbidites with slides and slumps in the upper part, ascribed to the RLG unit (Roveri et al., 2008a). The basal carbonate unit actually consists of m-thick carbonate-gypsum breccia (Fig. 15 B and C; CdB type 3) and gypsrudite beds characterized by a fining-upward trend and an overall upward increase of the clastic gypsum content. This unit is floored by a sharp erosional surface charcterized by onlap terminations (Fig. 15 A) against the lower Messinian clayey (Ponda Fm.) and “Tripoli-like” deposits (Duermejer et al., 1998; Gennari et al., 2009). The latter consist of 16 couplets of dm-thick diatomite and sapropel layers (total thickness 12 m) that, according to recent studies (Gennari et al., 2009), only yield siliceous microfossils (prevalently diatoms) and fall into a reversal polarity zone. Thus, according to what observed in the Northern Apennines (Fanantello section; Manzi et al., 2007) this unit could be considered a PLG time-equivalent deposited in deep-water, anoxic settings. The RLG unit in turn is overlain by a hybrid, *i.e.* gypsum, carbonate and terrigenous, clastic unit encasing halite lenses; thus the section frames the Halite deposits in the RLG unit, as proposed for the Sicilian foredeep (Roveri et al., 2008a,b).

Cropalati, Rossano basin (CR)

The Cropalati section crops out about 35 km to the NNE of Basilicoi, in the Rossano basin (Fig. 14); CdB here consists of two massive limestone beds with a highly variable thickness truncated by a carbonate breccia bed (CdB type 3). Based on detailed observation on the microfacies and organic matter content, these deposits are interpreted as microbialites formed in a marine depositional setting influenced by freshwater (Guido et al., 2007). We interpret these sediments as originating from gravity flows redepositing unconsolidated (the lower ones) or early-consolidated (the overlying breccia) limestones; accordingly they are interpreted as subfacies of CdB type 3. This is not in contradiction with the microbialitic interpretation suggested by (Guido et al., 2007), but simply implies that the original carbonate underwent early erosion and resedimentation. As in the Basilicoi section, a cyclical alternation of diatomite and sapropels is present below the limestone unit. Up to 12 diatomite/sapropel couplets have been recognized in the uppermost portion; two levels at the base and at the top of this interval yield very rare *T. multiloba* and Neogloboquadrinids, interpreted as reworked. Palaeomagnetic samples from below and within the CdB unit show a reversal polarity (Gennari et al., 2009).

Northern Apennines and Tertiary Piedmont Basin

In the Northern Apennines the limestone-marl couplets occurring at the top of the pre-evaporitic successions and the thin stromatolitic limestones at the base of the lowermost PLG cycles have been usually grouped within the local CdB unit (Fig. 1) together with sulphur-bearing massive limestones (“cagnino” facies, see Vai, 1988) which are commonly found at the base of the RLG unit in the Romagna-Marche area (Manzi et al., 2005).

In the TPB, besides the pre-evaporitic limestones and the stromatolitic limestone found at the base of individual gypsum cycles (Sturani, 1976), a barren unit consisting of up to four limestone-marl couplets has been recently recognized in the Alba sub-basin (Dela Pierre et al., 2009). This unit is younger than 5.96 Ma (Lozar et al., 2009) and is overlain by PLG deposits. The sedimentologic characteristics of PLG deposits permit to correlate the lowermost local gypsum cycle with the fifth one at the Mediterranean-scale, thus suggesting that the underlying barren limestone-marl unit may be a lateral equivalent of the four lowermost gypsum cycles (Gennari et al., 2009). Based on these considerations, this unit can be included within the CdB type 2. A similar situation has been recently pointed out also in the Northern Apennines; in the Val Marecchia area (Romagna Apennines), PLG deposits here locally lack the basal gypsum cycles (the first 2 in the Legnagnone section; Gennari et al., 2009), there replaced by barren marl-limestone couplets which show the typical features of CdB type 2.

SEDIMENTOLOGICAL CHARACTERIZATION OF THE CALCARE DI BASE

Based on facies and stratigraphic analysis carried out in the above described sections, a comprehensive summary of the characteristics of the three CdB types (Fig. 16) is provided in this section.

Type 1 CdB

The CdB type 1 commonly consists of massive or brecciated m-thick carbonate beds, containing abundant clay-chips, nodular alabastrine gypsum and native sulphur. The sulphur derives from the bacterial sulphate reduction (BSR) of clastic gypsum in presence of hydrocarbons derived from the underlying organic-rich diatomites and sapropels. For this reason type 1 CdB is commonly present at the base of resedimented gypsum units and is mostly present on top and upper flanks of anticlines, forming a typical hydrocarbon trap. Because the sulphur formed after the original gypsum became anhydrite, it is not an early alteration feature. Depending on the intensity of the diagenetic processes a large variety of deposits can be found, ranging between two end-members: clastic sulphates with sulphur nodules and the sulphur-rich massive carbonates, commonly characterized by a brecciated texture. Thus, type 1 CdB may pass laterally to type 3 CdB and to clastic gypsum. In Sicily, the best examples of this CdB facies are in the Pasquasia and Capodarso sections, but scattered outcrops can be recognized all over the Caltanissetta basin in association with clastic evaporites. In the Apennines the best examples are in the Sapigno and Giaggiolo-Cella synclines (Roveri et al., 1998; Manzi et al., 2005).

Type 2 CdB

This CdB type is represented by dm-thick laminated dolomitic limestones interbedded with diatomites, sapropels and marls. These deposits develop gradually above the Tripoli Fm., from which they can be distinguished also for their barren nature, and are sharply overlain by clastic gypsum or by CdB limestones of types 1 and 3. These deposits are common in the more external portion of the Caltanissetta foredeep and on structural highs, whereas in the inner portion they are deeply eroded by the MES. This facies is commonly present where the terrigenous input is particularly low and the diatomites are well developed.
The most developed successions of this CdB type are in the Serra Pirciata and Falconara sections. In the Northern Apennines (Legnagnone) and TBP (Pollenzo) CdB type 2 deposits underlie the PLG unit, thus offering the possibility to establish their genetic relationships with the massive selenite deposits.

Type 3 CdB

This type is the most common variety of CdB and mainly consists of m-thick brecciated limestone beds separated by thin shale or gypsarenite horizons.
Due to the presence of halite and gypsum moulds and the association of CdB with halite in the Dittaino borehole reported by Ogniben (1963), the typical brecciated texture of type 3

deposits has been usually related to 1) dissolution of the intercalated halite from the original aragonitic mud by undersaturated marine or meteoric waters or 2) to *in situ* collapse of partially lithified aragonitic mud exposed to undersaturated waters (Decima et al., 1988). This concept was later developed in a broader sense with the term *autobreccia* (Pedley and Grasso, 1993; Rouchy and Caruso, 2006) which implies the doline collapse of lime mudstones during exposure to meteoric waters by dissolution of the displacive evaporite minerals formed during desiccation in a sabkha setting. Our observations reveal that most type 3 CdB beds actually show a wide range of sedimentary features like bed gradation, erosional bases, load structures and incorporated clay chips. None of these features, overlooked in the past, can result from karstic collapses and/or autobrecciation. Instead they suggest a clastic origin and moderate distance transport through high- to low-density gravity flows (Fig. 17). The widespread presence of displacive halite casts or moulds in marine sediments without the formation of evaporite layers has been reported in a variety of sediments including, other than carbonate, mudstone and arenite (Muñoz et al., 1992; Demicco and Hardie, 1994).

Clastic and laminated gypsum is commonly associated with type 3 CdB, in isolated beds, or, more classically, as portion of a single graded bed (*e.g.* gypsarenite on top of carbonate breccia or massive limestone topping gypsrudite beds). These gypsum-carbonate compositional changes within single graded beds are common features in the Caltanissetta basin. Based on the reconstructed lateral facies changes within the RLG unit, deposition from mixed gravity flows, *i.e.* with a bimodal grain population (Fig. 17), is here proposed. This CdB type is commonly observed on top of the main anticlines, especially around Favara; but the most significant sections for establishing the relationships with the other MSC units are those of Petralia (Balza Bovolito), Contrada Gaspa and Casteltermini and surrounding areas. Brecciated limestones with abundant gypsum clasts are also commonly present at the base of RLG unit in Calabria (Crotone basin) whereas in the Northern

Apennines this facies is only locally found.

GEOCHEMICAL CONSIDERATIONS

The CdB shows a wide range of stable isotope values; a modified version of the original $\delta^{18}O$-$\delta^{13}C$ diagram published by Decima et al. (1988) is reported in Fig. 18. Here the samples are grouped according to the proposed classification. These data mainly derive from CdB type 3, and to a lesser extent from CdB type 1. Consequently we have integrated the original data with those measured on CdB type 2 reported in more recent papers (Bellanca et al., 2001; Blanc-Valleron et al., 2002). This new plot shows that the differentiation of the three CdB types is well reflected by their stable isotope signature.

Type 1 CdB shows dispersal pattern elongated along the vertical axis. This cluster comprises highly ($\delta^{13}C_C$ = -19.53 to -26.50 ‰) to extremely ($\delta^{13}C_D$ = -32.51 to -49.07 ‰) ^{13}C-depleted samples, that can be related to diagenetic transformations. Significantly these samples are taken from sulphurous carbonates (s-marked samples in Fig. 18) or derive from sites characterized by the widespread presence of native sulphur within the CdB (Capodarso, Ciavolotta) that have been extensively exploited. Moreover, at Capodarso, the carbonates are associated with clastic (now alabastrine) gypsum, thus suggesting that at least part of these carbonates could have been derived from bacterial sulphate reduction (BSR) of original clastic gypsum deposits.

^{13}C strongly depleted samples ($\delta^{13}C$<-25 ‰) received a significant contribution of carbonate ions as by-product of methanogenic processes (Decima et al., 1988). Although methanogenic carbonates are common in the Miocene of the Apennines, neither seeping/venting features or the classical fossil assemblages associated with these deposits have been found in the CdB unit.

Type 2 CdB is poorly represented also because it is the less common type. The average values of the dolomite-rich layer interbedded at the top of the Tripoli Fm. in the Serra

Pirciata (Bellanca et al., 2001) and Falconara (Blanc-Valleron et al., 2002) sections plot separately from the main cluster. The plot shows relatively homogeneous $\delta^{13}C$ values ($\delta^{13}C$ = +2 to -2 ‰) while oxygen isotope is characterized by high positive values ($\delta^{18}O$ > 6 ‰); thus suggesting deposition under strongly evaporative conditions.

Type 3 CdB provides the larger part of the dataset that plots into two sub groups. The first one, showing slightly positive and negative values of stable isotopes ($\delta^{13}C$ = +1.33 to -4.31 ‰; $\delta^{18}O$ = +4.52 to -2.90 ‰), includes samples derived from the inner foredeep. $\delta^{18}O$ values obtained for these samples suggest an origin from a mostly open marine water body characterized by minor contribution of diluted water undergoing strong evaporative conditions. The second subgroup, comprising samples derived from the outer foredeep, is characterized by more negative values for both isotopes ($\delta^{13}C$ = +2.50 to -4.80 ‰; $\delta^{18}O$ = +2.82 to -14.31 ‰) that could probably related to moderate diagenetic processes. This change in the $\delta^{18}O$ from north to south could be related to the existence of stronger evaporative conditions in the northern part of the Caltanissetta basin related to the physiography of the basin.

The dataset shows an overall dispersal pattern in $\delta^{13}C$ confirming the idea recently pointed out by Roveri et al. (2008b) that carbonates with diverse origins have been historically included within the CdB. Nevertheless, the geochemical characterization of CdB deposits needs to be improved by new isotopic analysis carried out on single rock components defined through detailed petrological and sedimentological observations.

Preliminary measures of Sr isotopes from Favara, Sambucco and Torrente Vaccarizzo performed on CdB type 3 provide values ranging from 0.708920 to 0.709000 (obtained from 4 samples). These values are in the range of the Lower Evaporites and Halite and suggest that the deposition of CdB type 3 occurred when the Mediterranean was connected to the global Ocean (Flecker and Ellam, 2006; Lugli et al., 2007 and references therein).

STRATIGRAPHIC MEANING OF CDB TYPES

The reputed cyclicity of the CdB has been related to precession, similarly to the other Messinian pre-evaporitic and evaporitic units; as a consequence this unit has been usually considered in cyclostratigraphic studies (Hilgen and Krijgsman, 1999; Bellanca et al., 2001; Rouchy and Caruso, 2006) for dating the MSC onset, assuming that the beginning of the evaporite phase corresponds to its base.

However, our observations indicate that the Tripoli Fm. is conformably overlain by a shale unit showing as well a cyclic alternation of diatomites, marls and laminated dolostones (type 2 CdB) barren of fossils, showing strong positive values of the $\delta^{18}O$ isotopic ratio and usually falling within an inverse polarity magnetozone. The available magnetostratigraphic data (Gautier et al., 1994; McClelland et al., 1996; Butler et al., 1995) are actually scarce and not astronomically calibrated; however, based on these works and on our data from the Pasquasia core and the Calabrian sections, the three CdB types appear to fall within a reverse magnetic interval. According to McClelland et al. (1996), in some cases the CdB would apparently fall within a normal interval (e.g. Palma di Montechiaro section); actually, samples with normal polarity come from the underlying unit, thus in this case the upward extension of the magnetic zone to include the CdB is not justified.

Type 2 CdB deposits are more or less deeply cut at their top by a clastic complex including carbonate breccia (CdB type 3), sulphiferous limestones (CdB type 1) and clastic gypsum.

The age of the CdB base has been usually defined based on the age of underlying deposits, assuming the conformable character of this lithostratigraphic boundary. In the Falconara section, prudently, Hilgen and Krijgsman (1999) limited their cyclostratigraphic reconstruction at the base of type 2 CdB, dating this transition at around 5.96 Ma (Roveri et al., 2008a,b); thus, according to Manzi et al. (2007) and Roveri et al. (2008a,b), type 2 CdB can be regarded as the deep-water time-equivalent of the PLG deposits.

Other authors (Bellanca et al., 2001; Rouchy and Caruso, 2006) interpreted type 3 CdB as precession-related deposits as well; the variable number of carbonate beds recognizable in different sections has been taken as support for the diachronous onset of the MSC (Fig. 1), already suggested by Butler et al. (1995).

Furthermore, in some cases clastic gypsum deposits underlie CdB type 3, thus ruling out the possibility that it can be considered a depositional precursor of primary gypsum. We suggest that the astronomical calibration of type 3 CdB lithological cyclicity is not correct. Moreover, the base of type 3 CdB is commonly unconformable and, based on the tight genetic relationships with gypsum clastic deposits, its deposition must postdate the PLG (Manzi et al., 2007). As a consequence, the diachronous nature of the base of the CdB suggested by several authors, based on the age of the deposits occurring below CdB types 3 and 1 could be more simply related to the intrinsically erosional character of this surface at a regional scale (Fig. 19). According to observations in the Apennines (Manzi et al., 2007) we argue that carbonate units including CdB type 2 could represent the basinal time-equivalent of PLG deposits, whereas the overlying CdB types 1 and 3 lie on a regional-scale erosional surface corresponding to the MES (Fig. 19).

MAIN IMPLICATIONS FOR BASIN ANALYSIS

The recognition of the three CdB types has strong implications in the reconstruction of the depositional history of the Sicilian foredeep during the MSC, concerning the distribution of the clastic evaporitic deposits (Fig. 20) and the possibility to trace regional-scale time lines for correlating the MSC onset.

Clastic evaporites distribution

CdB type 3 brecciated carbonates and laminar gypsum can be regarded as end-members of a broad spectrum of gravity-driven deposits (Fig 21) where the final products of the resedimentation process are related to the following factors: 1) nature of the sediments in the parent flow; 2) nature of the sediment incorporated downslope; 3) downcurrent flow transformations. The latter factors are mainly related to the morpho-structural setting of the basin and they influence the flows exclusively after their start moving downslope; they are typical of gravity flow and are not discussed here. The first factor is strictly related to the environmental conditions and to the peculiar depositional settings developed during the MSC. Three main lithological components are involved in the resedimentation process: carbonate, sulphate, siliciclastic.

The **carbonate** component is represented by fine-grained carbonate, both calcite and aragonite usually consisting of irregular, pelletal, or clotted micrite to microsparite with variable amounts of celestite and strontianite (Decima et al., 1988); the clotted aragonite peloidal micrite fabric has been interpreted as bacterially-induced mineralization (Guido et al., 2007); most aragonite then was transformed into calcite with the release of significant amounts of Sr into the system and the subsequent crystallization of secondary celestine (with sulphate present) and strontianite (Decima et al., 1988).

The **sulphate** component can be supplied through: i) recycling of older evaporitic units (PLG) or ii) by primary cumulate deposits. In the first case the processes of erosion, dismantling and resedimentation of the PLG selenite provide different sulphate deposits based on the available facies of primary evaporitic deposits (Manzi et al., 2005). In the second case the sulphate component may derive from coeval gypsum cumulates deposited in structurally and topographically more elevated positions within the Caltanissetta basin (intrabasinal highs) or interbedded within the main Halite unit (Roveri et al., 2008b; Manzi et al., 2009).

The **siliciclastic** supply is mainly derived from the erosion of the older Tripoli and Terravecchia formations, thus the terrigenous component is largely fine-grained; only minor input of older rocks has been identified (*e.g.* Eocene carbonates, Oligo-Miocene Sicilid units including the Numidian Flysch quartzarenite, the Argille scagliose and the Argille Varicolori).

Type 3 CdB commonly forms m-thick carbonate breccia beds separated by thin shale veneers, and represents the fine-grained tails of gravity flows (see Cozzo Prangi and Balza Bovolito sections). These beds are vertically stacked to form coarsening and thickening upward sequences (Fig. 22) that resemble a progradational pattern recording the progressive lateral growth and/or uplift and dismantling of shallow-water carbonate source-areas.

The CdB is commonly present close to the main intrabasinal highs of the Caltanissetta basin and passes downslope into clastic gypsum deposits (Fig. 19, 22). Locally CdB beds show deformation structures related to submarine slides. In the inner portion of the basin (the Casteltermini, Marianopoli, Mussomeli alignment) CdB type 3 reaches its maximum thickness, suggesting that the main source areas were relatively close.

CdB type 3 can be regarded as a syntectonic deposit formed above growing structural highs, which were progressively dismantled due to the ongoing uplift (Pedley and Grasso, 1993). Primary carbonate sources could have been almost completely dismantled and accumulated as brecciated deposits in adjacent ramps and slopes, associated with the main intrabasinal highs. The deeper portions of the basin are characterized by the deposition of mixed carbonate-gypsum clastic evaporite beds probably derived from more efficient gravity flows.

CONCLUSIONS

The facies analysis carried out in the Caltanissetta basin, led us to group the calcareous facies recognized in the studied CdB sections, into three main types (Fig. 16, 19) separated in space and time and formed during different MSC stages (Fig. 23): (1) sulphur-bearing limestone, (2) dolostone and (3) brecciated micritic limestone.

Type 1 carbonate formed as the diagenetic product of bacterial sulphate reduction (BSR) of original clastic gypsum in presence of hydrocarbons.

Primary limestone deposits consisting of laminated dolomitic limestone (type 2) have been found interbedded with diatomite, sapropel and marl in the uppermost Tripoli Formation. These deposits formed during the first stage of the MSC and represent a deeper-water counterpart of the PLG.

A revisitation of the classical CdB sections together with observations on new sections reveals that beside its primary origin, either evaporitic and/or microbial, the CdB largely consists of resedimented deposits sharing a typical brecciated structure (type 3) and intimately associated with clastic gypsum deposits. The concept of an autobrecciated origin (Grasso and Pedley, 1988; Rouchy and Caruso, 2006) for these deposits does not explain the widespread presence of sedimentary features suggesting a clastic origin and moderate distance transport through high- to low-density gravity flows. As recently pointed out (Roveri et al., 2008a,b) LE in the Caltanissetta basin consist exclusively of RLG deposits representing the product of erosion and resedimentation of PLG, occurred between 5.61 and 5.55 Ma, and including both chaotic and stratified clastic evaporites. Thick brecciated carbonate beds of CdB type 3 and clastic gypsum deposits. and can be regarded as the product of mixed gravity flows resedimenting microbialitic or evaporitic limestone previously eroded from their original depositional environment. The wedge-top basins, closer to the original areas of deposition of the PLG, receive larger amounts of gypsum clastics, whereas the main foredeep and more specifically the intrabasinal highs and the outer ramp are mainly characterized by carbonate breccia deposits.

The CdB most commonly overlies Tripoli laminites but, locally, it can be found above clastic gypsum deposits, thus implying that its deposition, at least in some areas, postdates the clastic evaporites. Moreover, CdB is never associated with the Lower Evaporites massive selenite but is more commonly capped by the UG;) locally showing clear onlap terminations against it. CdB types 1 and 3 are here considered syntectonic deposits formed above growing structural highs, which were progressively dismantled due to the ongoing uplift.

This study documents a much more complex origin and palaeoenvironmental meaning than commonly thought of Messinian carbonate deposits referred to as CdB. Their subdivision in several types with different modalities of formation and ages may help to solve some apparent contradictions still present in the MSC literature.

As previously discussed, CdB deposits have been always considered as the first product of the MSC. and the sharp base and “shallow-water” characteristic of these deposits has been related to a considerable sea-level fall at the MSC onset. This is contradicted by the recognition of the moderately deep-water nature (up to 150-200 m) of PLG (Lugli et al., 2008), whose base does not necessarily imply any significant sea-level fall at the MSC onset; moreover, the different ages of underlying deposits led to envisage a slightly to strongly diachronous onset (Rouchy and Caruso, 2006; Butler et al., 1995).

These contradictions can be easily explained by considering that the CdB involved in such a discussion often belongs to types 3 and 1 which, according to this interpretation, actually formed in the second stage of the MSC and whose base corresponds to the MES. Thus, they formed during the MSC peak and not at its onset; their base can be consequently associated with a variable amplitude hiatus and much caution should be used in considering them for cyclostratigraphic purposes due to their clastic nature; together with resedimented gypsum and halite lenses form the RLG unit, which spans a very short time interval between 5.6 and 5.55 Ma characterized by a strong reduction of Mediterranean-Atlantic connections, tectonic activity and sea-level fall related to glacial stages Tg 12 and TG 14.

In the future an effort for a better characterization of CdB type 2, which is the only type recording the onset and first stage of the MSC, is needed in order to define in more detail its palaeoenvironmental meaning.

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FIGURE CAPTIONS

FIG. 1 Idealized logs of the Messinian successions of the Northern Apennines and of Sicily, showing the stratigraphic distribution of “Calcare di Base” (CdB) deposits according to Decima and Wezel (1971) and Rouchy and Caruso (2006). Note the inferred lateral transitions between Lower Gypsum, Calcare di Base and Halite. MSC, Messinian salinity crisis; MES, Messinian erosional surface; M/P, Miocene-Pliocene.

FIG. 2 (A) Schematic geological map of Sicily with the distribution of the Lower Evaporites (modified after Roveri et al., 2006) and the location of the sections described in the text: **BB**, Balza Bovolito; **BS**, Balza Soletta - Alimena; **C**, Capodarso - Giumentara sulphur minemine; **CG**, Contrada Gaspa - Sambuco anticline; **CP**, Cozzo Prangi; **CT**, Casteltermini; **F**, Falconara; **FV**, Favara quarry; **G**, Monte Gibliscemi; **LE**, Licodia Eubea; **M**, Marianopoli; **MG**, Montagna Grande - Pietraperzia; **P**, Pasquasia; **S**, Sutera; **SE**, Santa Elisabetta; **SP**, Serra Pirciata; **TV**, Torrente Vaccarizzo. (B) Schematic geological cross-section across the Sicilian Basin flattened at the base of the Pliocene showing the upper Messinian deposits (above the Tripoli Formation) (from Roveri et al., 2006). **PLG**, Primary Lower Gypsum; **RLG**, Resedimented Lower Gypsum; **H**, Halite unit; **UG**, Upper Gypsum.

FIG. 3 Simplified geological map of the Petralia basin (modified after Grasso and Pedley, 1988) with the location of the Cozzo Prangi (**CP**) and Balza Bovolito (**BB**) sections. The dashed rectangles indicate the frame of their panoramic view. **RLG**, Resedimented Lower Gypsum.

FIG. 4 Cozzo Prangi section (see location in fig. 2) panoramic view (A) and synthetic sedimentologic log (B). Stars indicate the most prominent beds used as reference in the log. Note the overall fining upward of the section corresponding to a marked increase of the carbonate component (“Terminal complex” of Grasso and Pedley, 1988). C) close view of a gypsum breccia bed. D) close view of the hybrid gypsum/carbonate turbiditic beds from the upper portion of the section.

FIG. 5 Balza Bovolito panoramic view (A), synthetic sedimentologic log (B) and line drawing (C). Stars indicate the most prominent beds used as marker in the log. Similarly to the Cozzo Prangi section, an overall fining upward of the section is accompanied with a marked increase of the carbonate component. The chaotic body involving the lower gypsum-bearing unit at the left is unconformably overlain by carbonate breccia.

FIG. 6 Close view of the clastic evaporites of the Balza Bovolito section. (A) twinned selenite crystal of the Primary Lower Gypsum included in a gypsrudite bed. Close views of the lowermost gyprudite bed, including terrigenous rounded pebbles (B) and carbonate blocks (C). Facies transition within a single graded gypsum bearing-turbidite bed (D); gr, gypsrudite; ga, gypsarenite; gs, gypsiltite. Particular of the chaotic body of Fig. 4 separating the lower gypsum-bearing unit from the overlying carbonate one (E); gr, gypsrudite; ga, gypsarenite; s, shale; lms, limestone; cb, carbonate breccia (CdB type 3).

FIG. 7 The Sutera section. (A) panoramic view (from NW) of the Sutera section showing a mountain-sized block of Primary Lower Gypsum (PLG) floating on a chaotic shale unit including large-size slabs of CdB type 1 and 2. (B) Fresh cut of the chaotic shale unit including sulphiferous limestone (CdB type 1 in C), gypsarenites, diatomites and dolostones (CdB type 2). (D) Slump deformation of the diatomites and dolostones (CdB type 2) slab showed in A, picture taken from SE.

FIG. 8 Marianopoli section. The m-thick carbonate breccia (CdB type 3) layers becoming amalgamated toward the top of the section as highlighted by clay chips aligments.

FIG. 9 Panoramic view of the Monte Capodarso – Giumentara sulphur mine section.

FIG. 10 Panoramic view of the Santa Elisabetta section. (A) pre-MSC shale unit with interbedded limestone beds cropping out of at the base of the verticalized PLG block (B).

FIG. 11 Close view of the CdB type 3 at Monte Gibliscemi. Note the large-size rip-up clast and the chaotic aspect of the base of the carbonate bed, the third from the base.

FIG. 12 Serra Pirciata section. (A) schematic sedimentologic log (modified after Grasso et al., 1982; Bellanca et al., 2001), (B) panoramic view of the CdB type 3 beds, (C) close view of the base of the CdB type 3 unit, (D) close view of the CdB type 2 deposits. See section description for more detailed information. PLG, Primary Lower Gypsum; RLG, Resedimented Lower Gypsum.

FIG. 13 Falconara section. Schematic sedimentologic log of the uppermost portion of the Tripoli Fm where diatomite are interbedded with CdB type 2 layers, cut on top by the CdB type 3 deposits. MSC onset after Hilgen and Krijgsman (1999).

FIG. 14 Schematic geological map of northern Calabria including the Rossano and Crotone basins showing the location of the Basilicoi (B) and Cropalati (CP) sections described in the text.

FIG. 15 A) Panoramic view of the Basilicoi section (Crotone basin) showing the onlap of the clastic evaporite unit (RLG), including both brecciated carbonate (CdB type 3) and gypsum, against the uppermost barren part of the Tripoli formation. B) close view of a clastic evaporite composite megabed. It consists of a lower hybrid breccia and an intermediate graded hybrid arenite division abruptly capped by a gypsum siltite and shale division. C) close-view of the hybrid clastic evaporite facies.

FIG. 16 Schematic reconstruction of the Sicilian foredeep during the MSC showing the distribution of the three CdB types. PLG, Primary Lower Gypsum; RLG, Resedimented Lower Gypsum. The sections described in the text are located based on their structural position within the main foredeep.

FIG. 17 Overview of the most typical Sicilian hybrid deposits recognized in the clastic evaporite unit (RLG). (A) limestone breccia with clay chips; Torrente Vaccarizzo. (B)

Hybrid fine-grained composite turbiditic bed with erosional base and overall gradation formed by three sedimentological divisions, separated by by-pass surfaces, respectively consisting from the base of graded massive coarse calcarenite, gypsum-carbonate plane to cross-bedded fine arenite and laminate gypsiltite; Casteltermini. (C) Hybrid coarse-grained composite bed; Balza Bovolito, Petralia basin. A lower coarse-grained division of carbonate-gypsum breccia with erosional base and local chaotic features is abruptly capped, through a by-pass surface, by plane laminated gypsarenites and shales. The latter are locally eroded by the basal limestone breccia division of the overlying bed. (D) Hybrid coarse-grained composite bed; S. Anna, NE of Sciacca. It consists of a lower hybrid breccia and by a cross-bedded to plane laminated coarse arenite division separated by a bypass surface. (E) Hybrid composite bed; block included in the chaotic shale unit on which rest the PLG block of Sutera. It consists of three divisions separated by bypass surfaces; from the base: a thick crudely laminated gypsrudite with limestone chips, a hybrid arenite with plane to cross-laminate and climbing ripples and, on top, a thin shale horizon.

FIG. 18 Stable isotope characterization of the three CdB types (modified from Decima et al., 1988). It is worth noting the presence of four main clusters. Type 1 CdB is characterized by strongly negative $\delta^{13}C$ values, suggesting bacterial sulphate reduction (BSR) and methanogenetic processes. Type 2 CdB, here are plotted the mean values obtained from the sections of Serra Pirciata (Bellanca et al., 2001) and Falconara (Blanc-Valleron et al., 2002), shows clearly positive $\delta^{18}O$ values, suggesting deposition under strong evaporative conditions. Type 3 is characterized by a main cluster, represented by the samples collected in the inner portion of the Sicilian Foredeep, showing $\delta^{18}O$ values suggesting deposition from a fresh to open marine water body. Whereas a second less numerous cluster of CdB type 3 sample collected in the external foredeep is characterized by more negative $\delta^{13}C$ values that could be related to uncomplete processes of BSR.

FIG. 19 Stratigraphic distribution of CdB types and their relationships with the other Messinian units according to the new classification scheme proposed in this study. Compare with the scheme of figure 1. The figure shows the idealized logs of shallow to deep-water successions of the Northern Apennines, Tertiary Piedmont Basin, Sicily and Calabria. Note that, according to our reconstructions, the largest volume of CdB deposits (i.e. types 1 and 3) of Sicily lays above the Messinian erosional surface (MES), thus largely postdating the MSC onset which is marked by the base of type 2 CdB. PLG, Primary Lower Gypsum; RLG, Resedimented Lower Gypsum; UG, Upper Gypsum; MSC, Messinian salinity crisis; MES, Messinian erosional surface; M/P, Miocene-Pliocene.

FIG. 20 Map of the Caltanissetta basin showing the distribution of the evaporitic facies during the MSC second stage, between 5.60 and 5.55 Ma. **BB**, Balza Bovolito; **BS**, Balza Soletta - Alimena; **C**, Capodarso - Giumentara sulphur minemine; **CG**, Contrada Gaspa - Sambuco anticline; **CP**, Cozzo Prangi; **CT**, Casteltermini; **F**, Falconara; **FV**, Favara quarry; **G**, Monte Gibliscemi; **LE**, Licodia Eubea; **M**, Marianopoli; **MG**, Montagna Grande - Pietraperzia; **P**, Pasquasia; **S**, Sutera; **SE**, Santa Elisabetta; **SP**, Serra Pirciata; **TV**, Torrente Vaccarizzo.

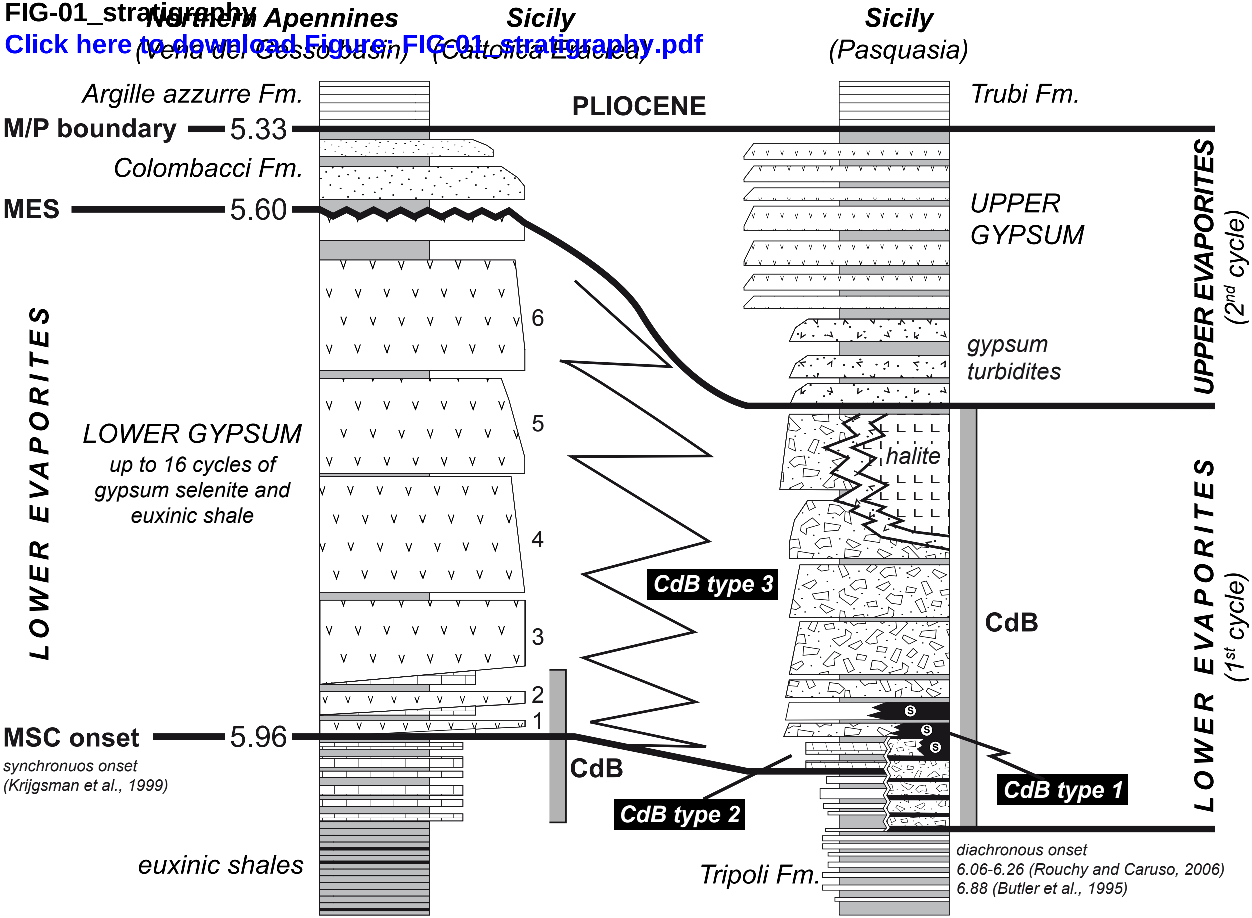
FIG. 21 Genetic relationships between the different hybrid clastic evaporite deposits; gypsum, carbonate and shale are the main components of the flow. The flow efficiency is favoured by the presence of unconsolidated shaly or carbonate sediments and by the relative abundance of gypsum clastic with respect to the carbonate of the consolidated portion. Lithified carbonate rocks mainly provide carbonate breccia.

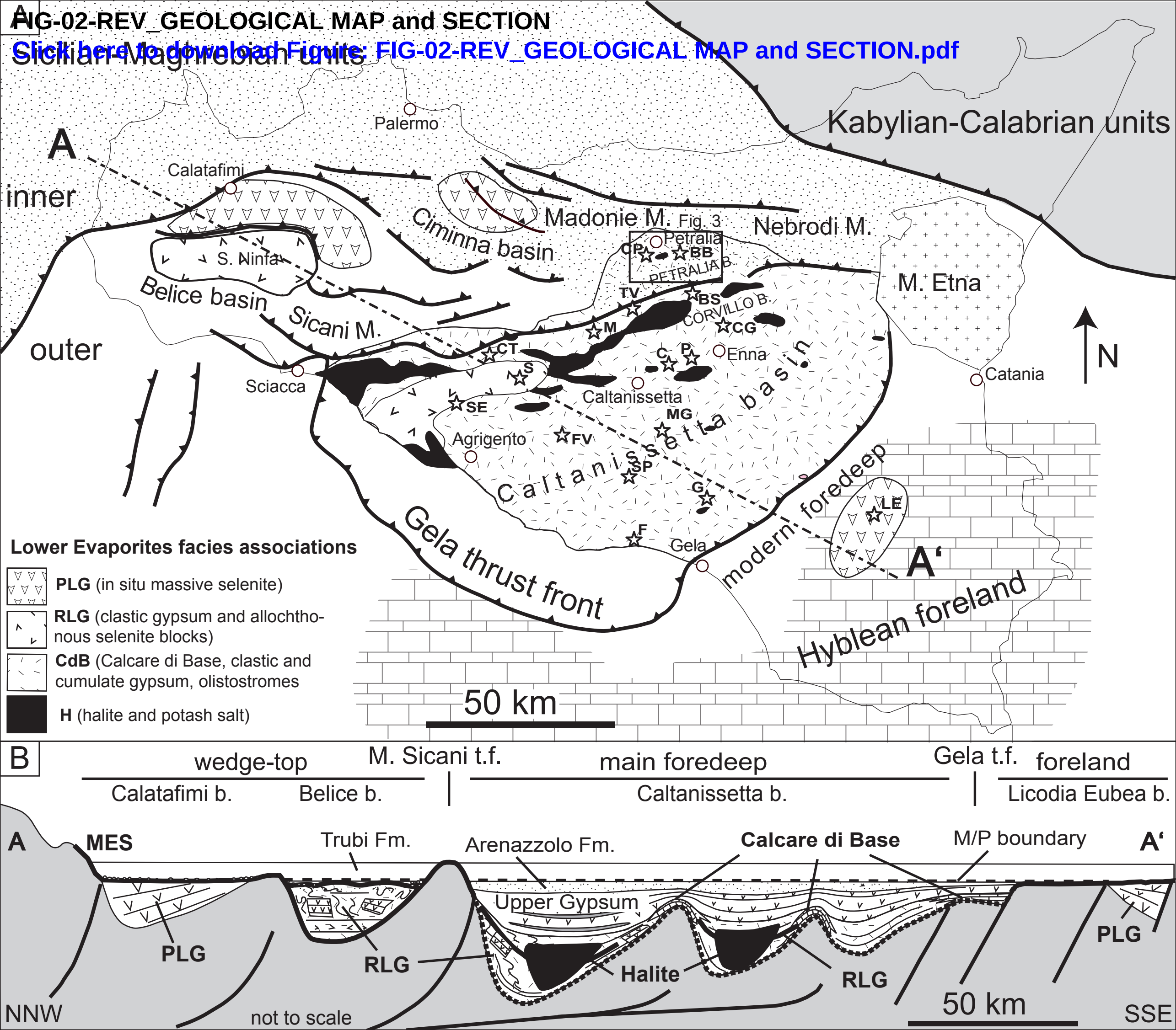
FIG. 22 Panoramic view of type 3 CdB at Alimena, northern flank of the Corvillo basins. Note the typical thickening upward stacking pattern.

FIG. 23 The new MSC scenario of CIESM (2008) modified to include the stratigraphic positions of the three CdB types.

FIG-01_stratigraphy

Click here to download Figure: FIG-01_stratigraphy.pdf




A
Sicilian-Maghrebian units
Kabylian-Calabrian units
Palermo
A
Calatafimi
inner
Ciminna basin
Madonie M.
Fig. 3
Petralia
Nebrodi M.
CP
BB
PETRALIA B.
S. Ninfa
Belice basin
Sicani M.
M. Etna
TV
BS
CORVILLO B.
M
CG
outer
CT
C
P
Enna
N
Sciacca
S
Catania
Caltanissetta
SE
MG
Agrigento
FV
Caltanissetta basin
SP
G
LE
modern foredeep
F
Gela thrust front
Gela
A'
Hyblean foreland
Lower Evaporites facies associations
PLG (in situ massive selenite)
RLG (clastic gypsum and allochthonous selenite blocks)
CdB (Calcare di Base, clastic and cumulate gypsum, olistostromes
H (halite and potash salt)
50 km
B
wedge-top
M. Sicani t.f.
main foredeep
Gela t.f.
foreland
Calatafimi b.
Belice b.
Caltanissetta b.
Licodia Eubea b.
A
MES
Trubi Fm.
Arenazzolo Fm.
Calcare di Base
M/P boundary
A'
Upper Gypsum
PLG
RLG
Halite
RLG
PLG
50 km
NNW
not to scale
SSE

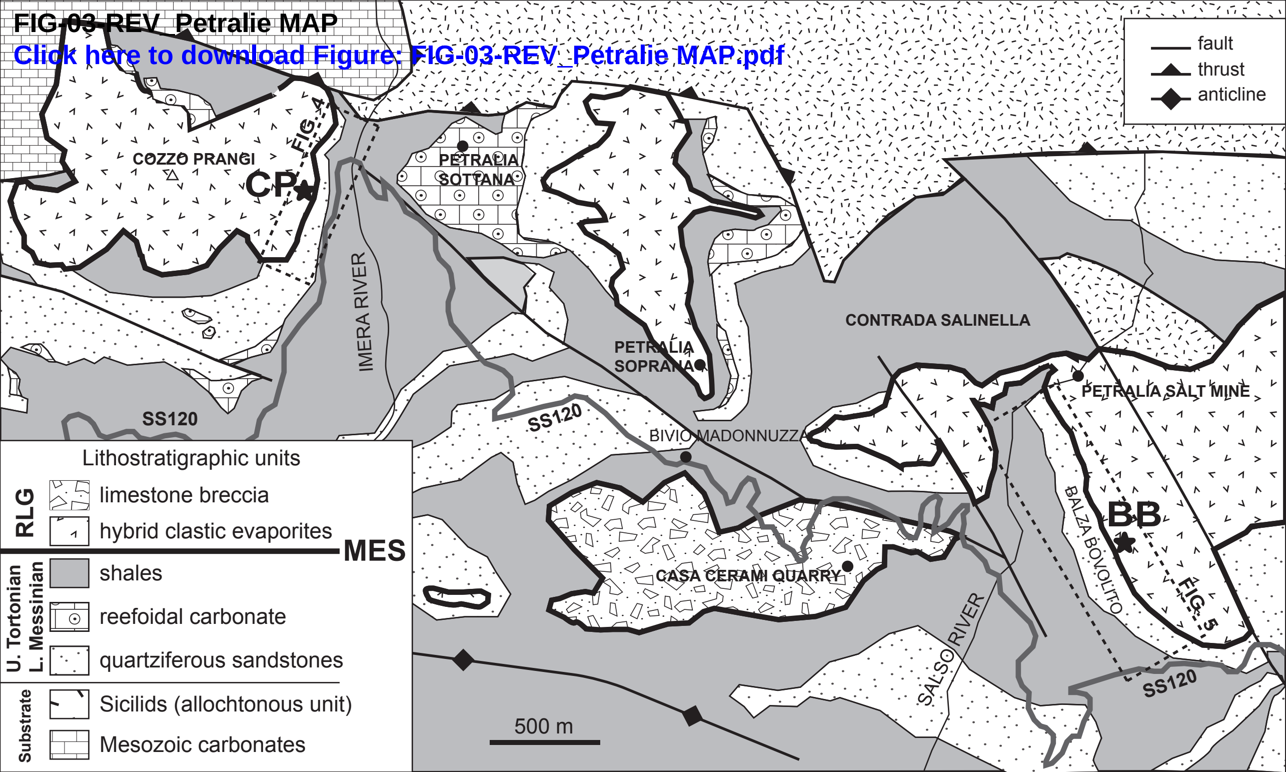

fault
thrust
anticline
COZZO PRANGI
CP
FIG. 4
PETRALIA SOTTANA
IMERA RIVER
PETRALIA SOPRANA
CONTRADA SALINELLA
PETRALIA SALT MINE
SS120
SS120
BIVIO MADONNUZZA
BALZA BOVOLITO
BB
FIG. 5
CASA CERAMI QUARRY
SALSO RIVER
SS120
500 m
Lithostratigraphic units
RLG
limestone breccia
hybrid clastic evaporites
MES
U. Tortonian L. Messinian
shales
reefoidal carbonate
quartziferous sandstones
Substrate
Sicilids (allochtonous unit)
Mesozoic carbonates

FIG-04 Cozzo prangi
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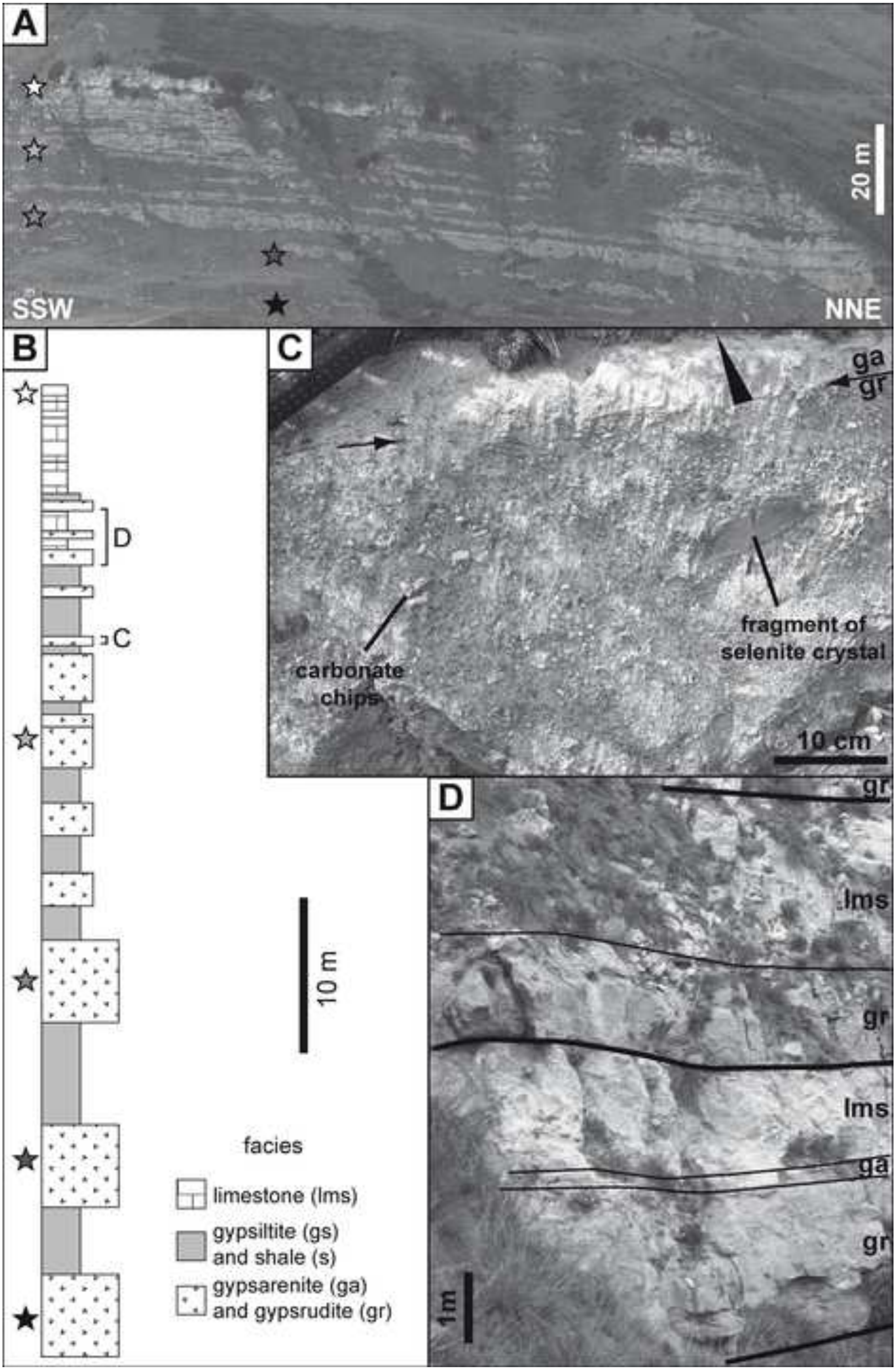

FIG-05_BALZA BOVOLITO
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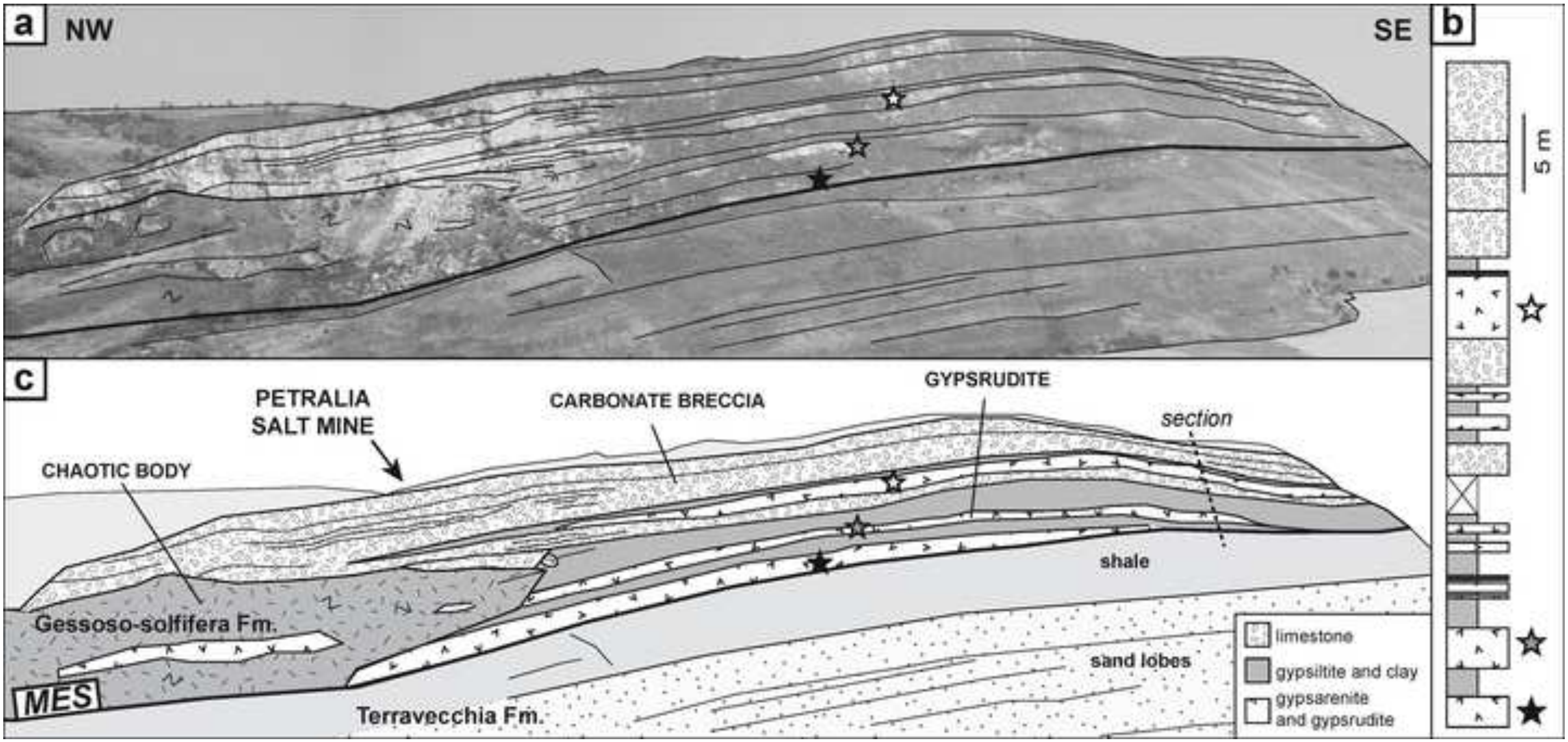

FIG-06_BALZA BOVOLITO-FACIES
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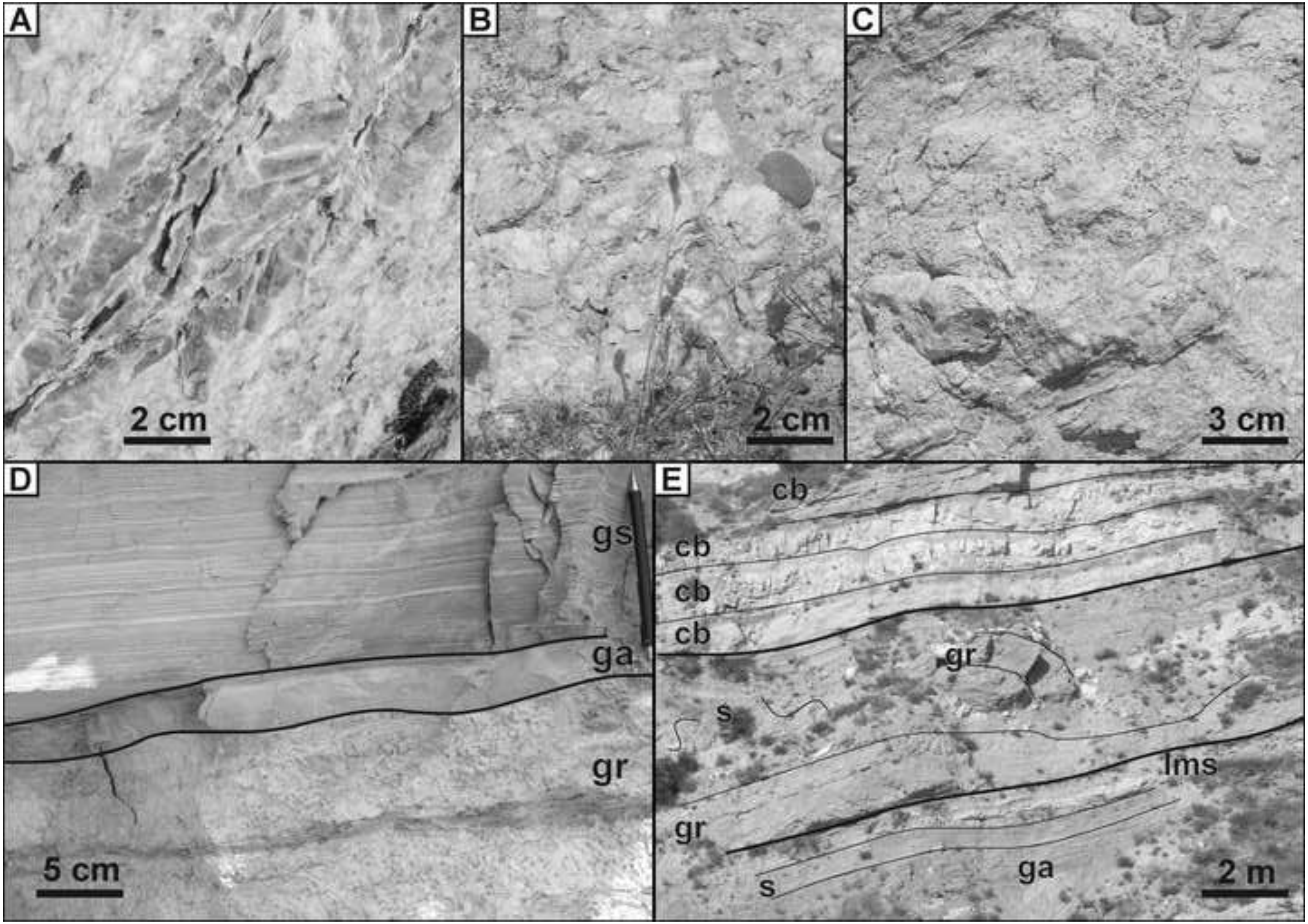

FIG-07-REV_Sutera
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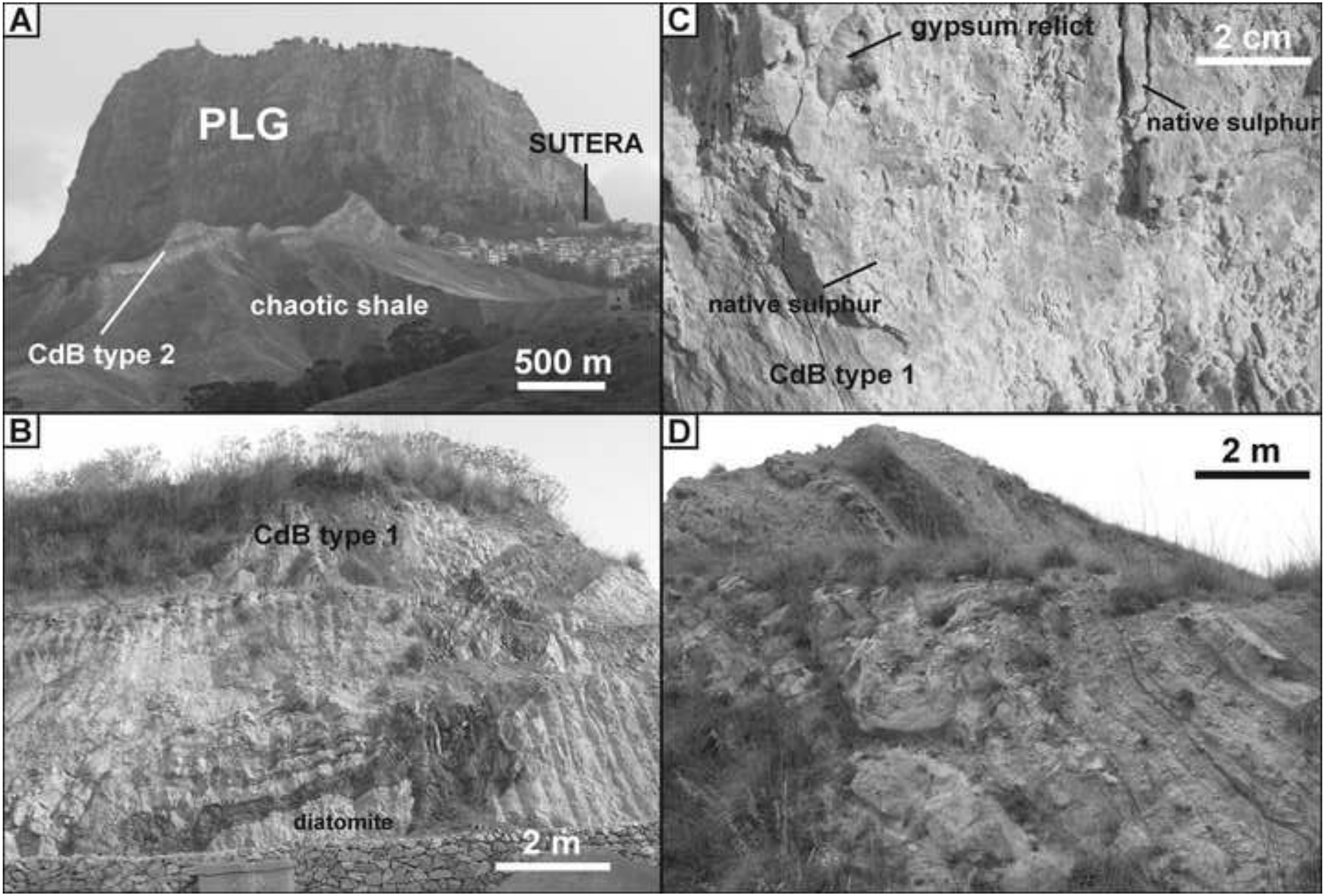

FIG-08-REV_marianopoli
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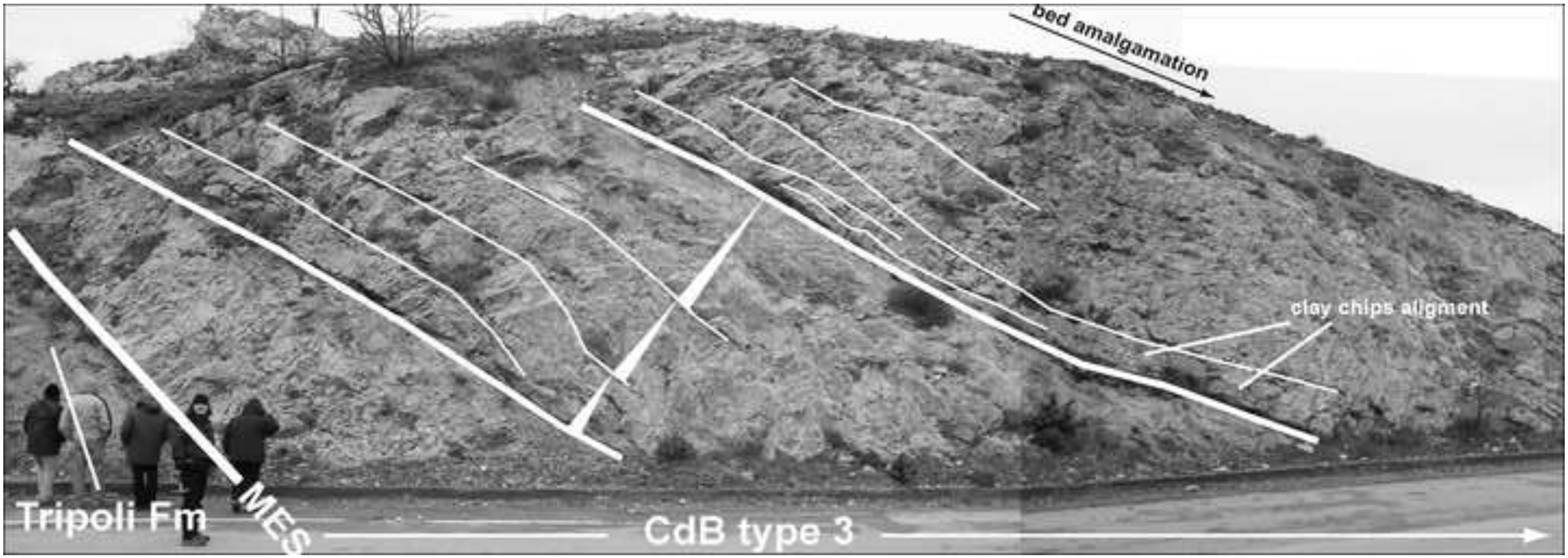

FIG-09-REV_Monte Capodarso
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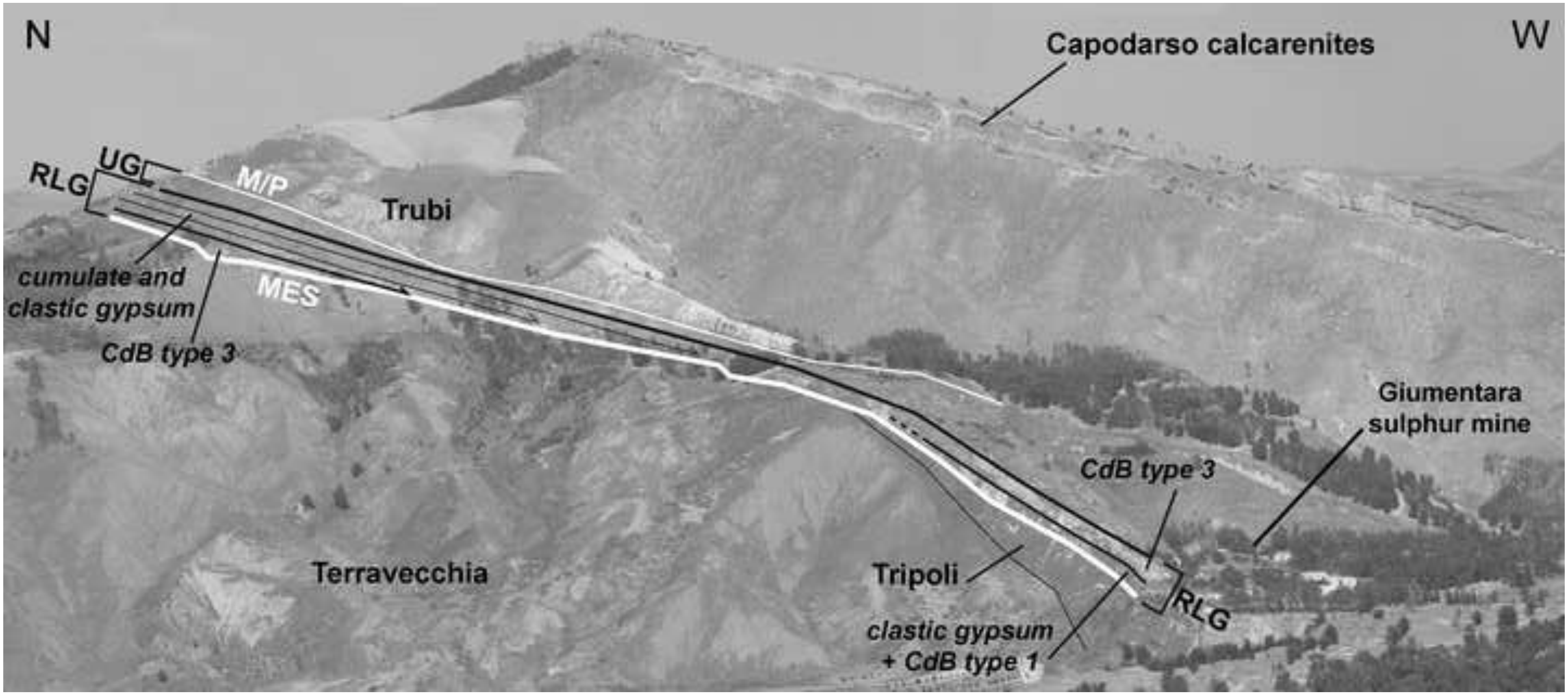

FIG-10-REV_Santa Elisabetta
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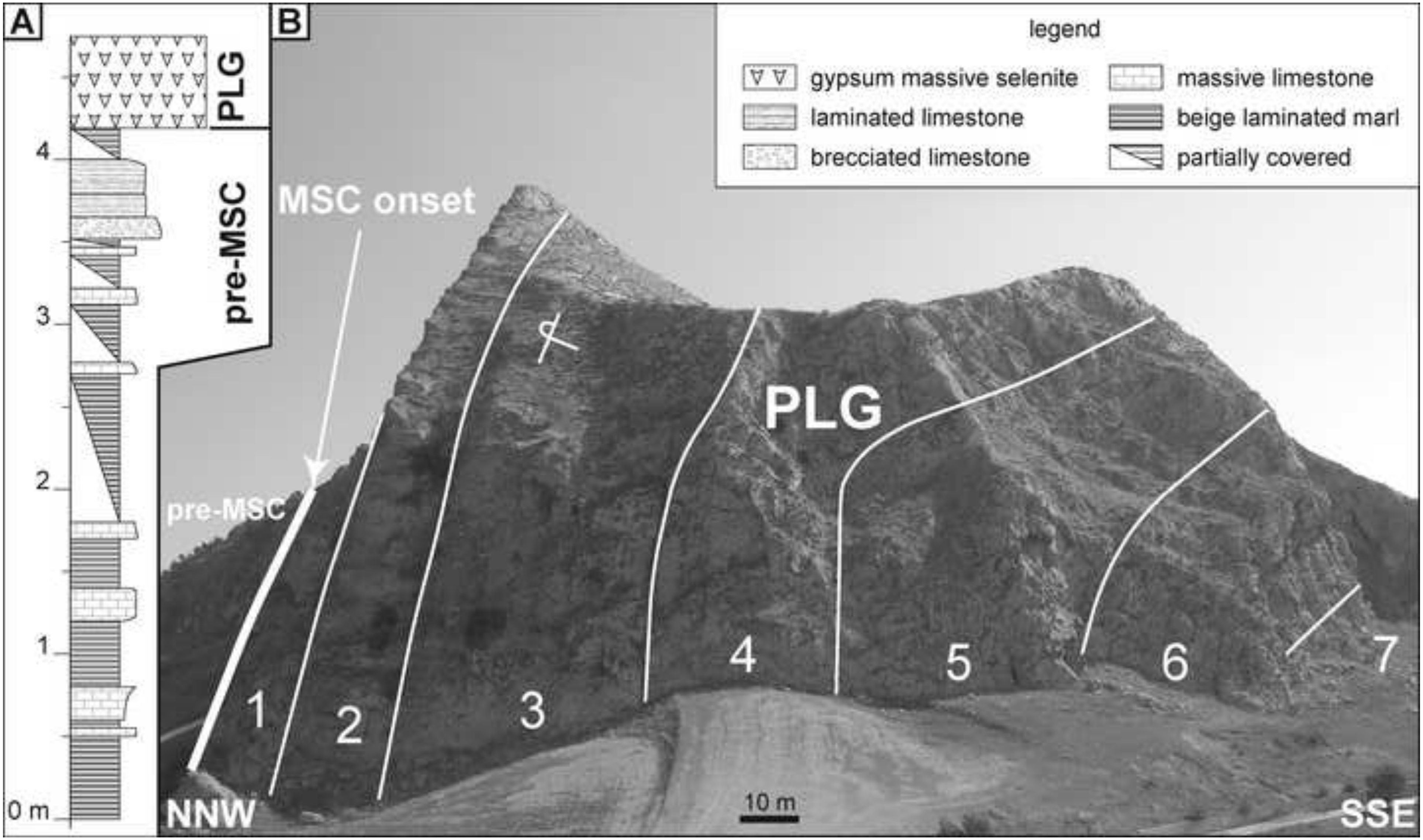

FIG-11-REV_Monte Gibliscemi
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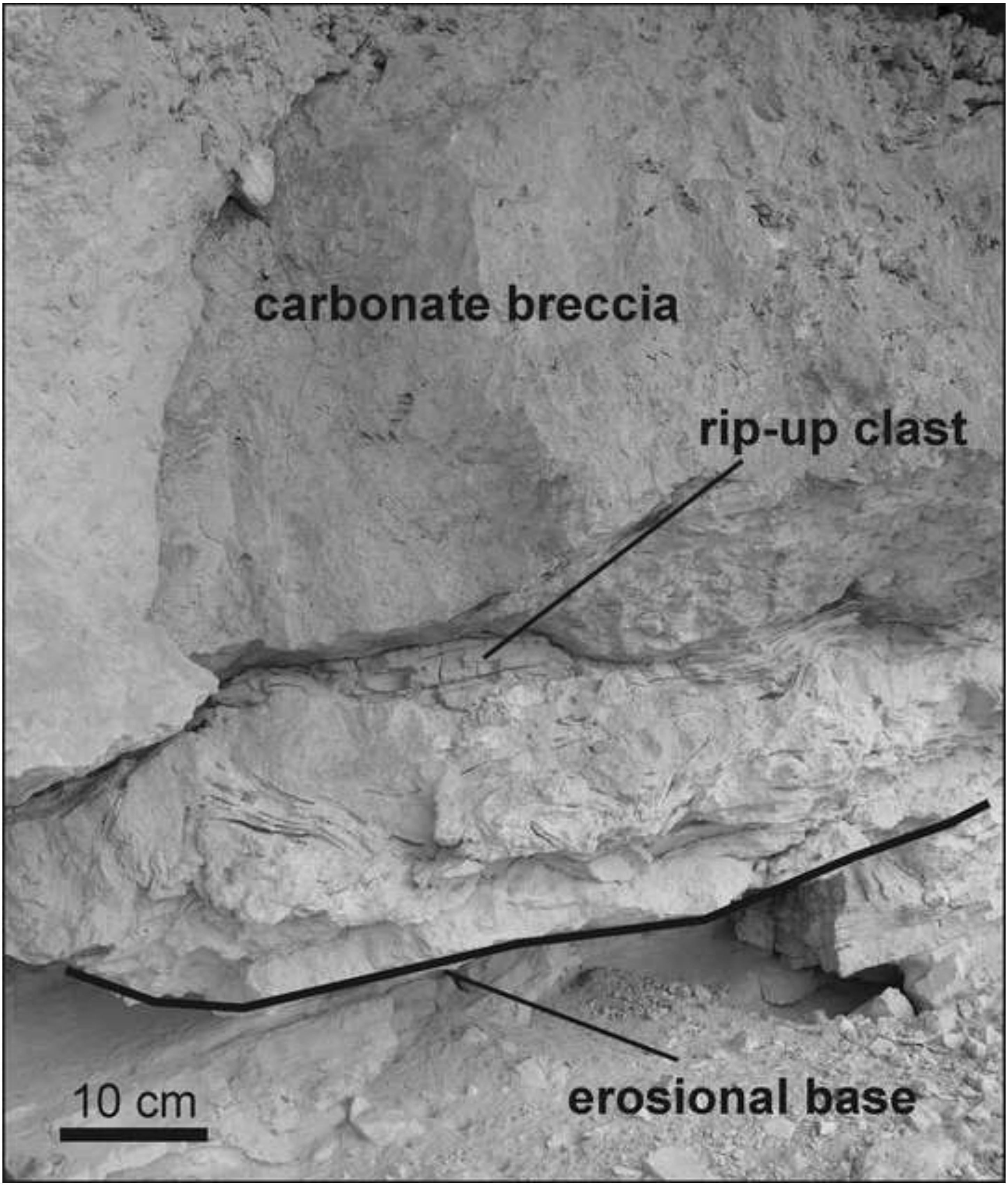

FIG-12-REV_serra-pirciata

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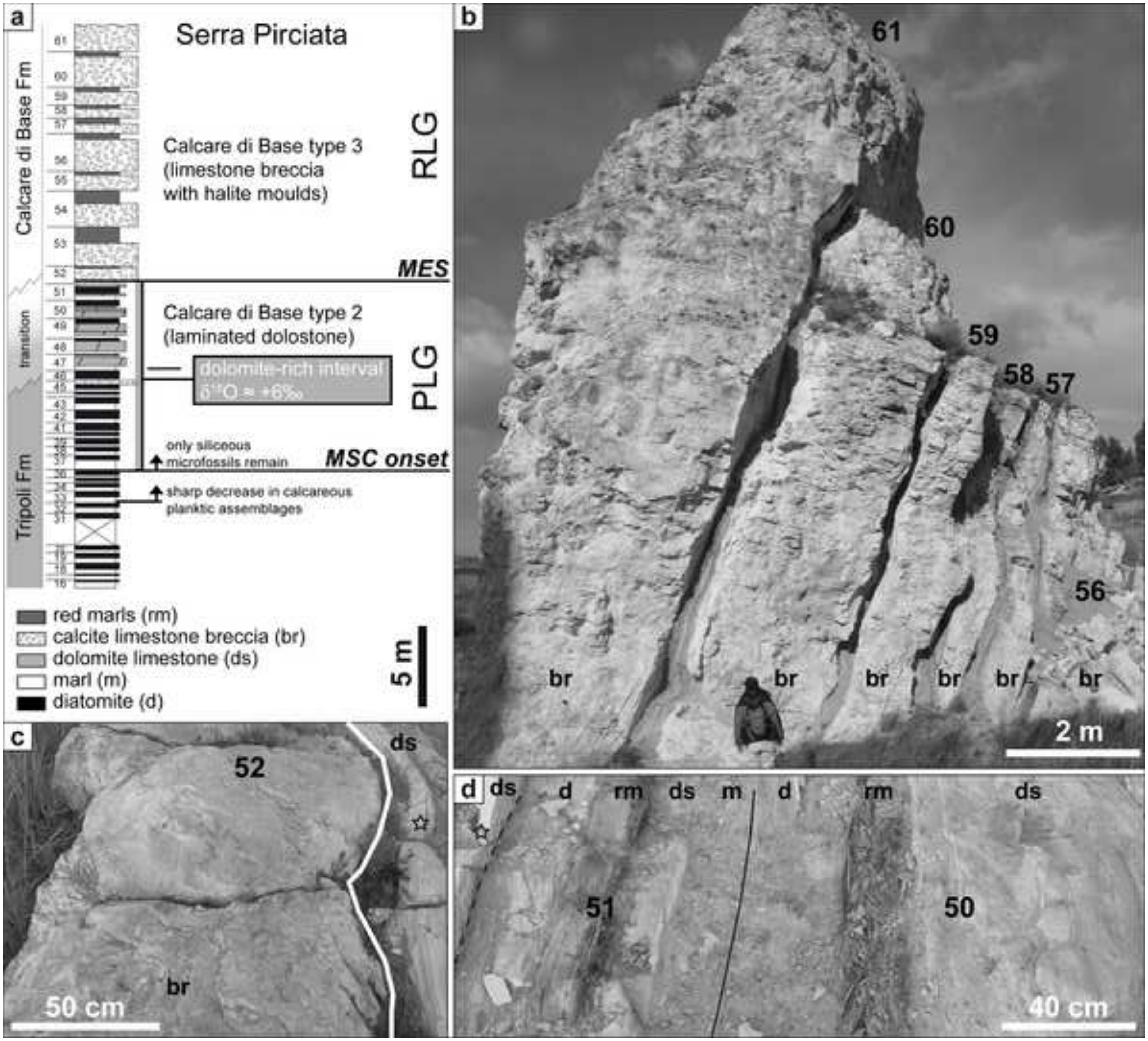

FIG-13-REV_Falconara
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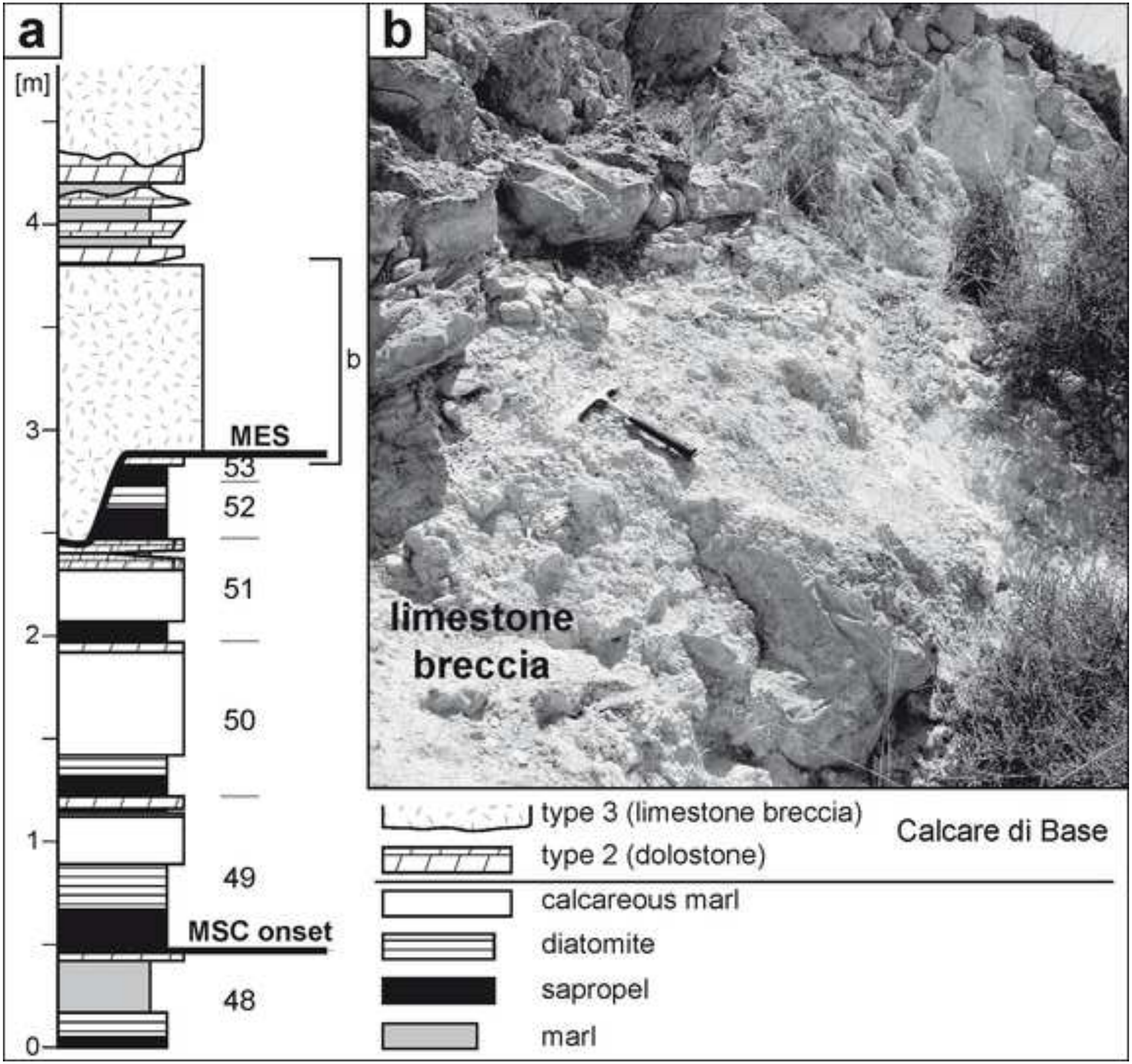

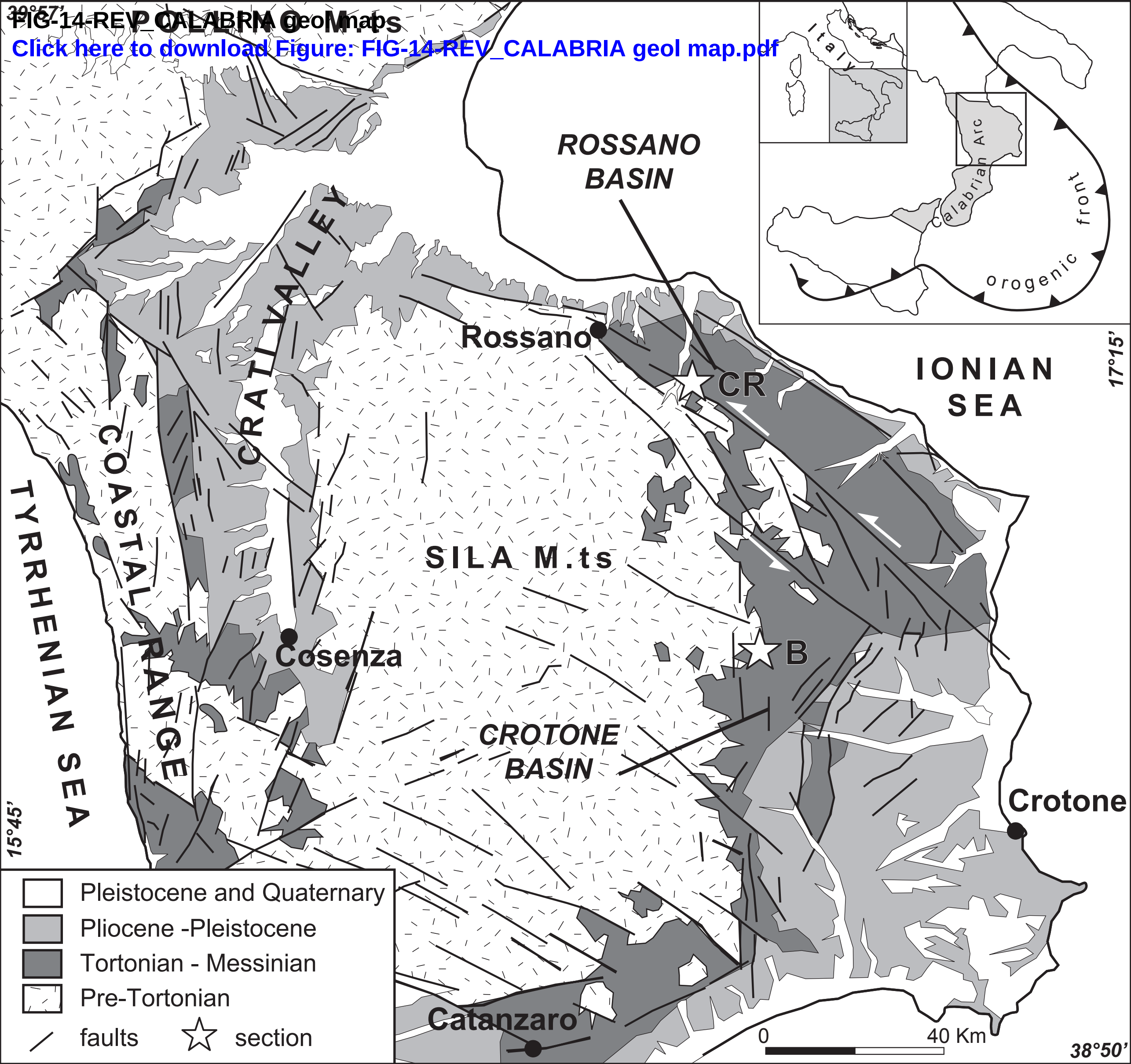
39°57'
ROSSANO
BASIN
Italy
Calabrian Arc
orogenic front
Rossano
CR
IONIAN
SEA
17°15'
CRATI VALLEY
COASTAL RANGE
TYRRHENIAN SEA
SILA M.ts
Cosenza
B
CROTONE
BASIN
Crotone
15°45'
Catanzaro
0
40 Km
38°50'
Pleistocene and Quaternary
Pliocene -Pleistocene
Tortonian - Messinian
Pre-Tortonian
faults
section

FIG-15-REV_calabrian-CdB-facies
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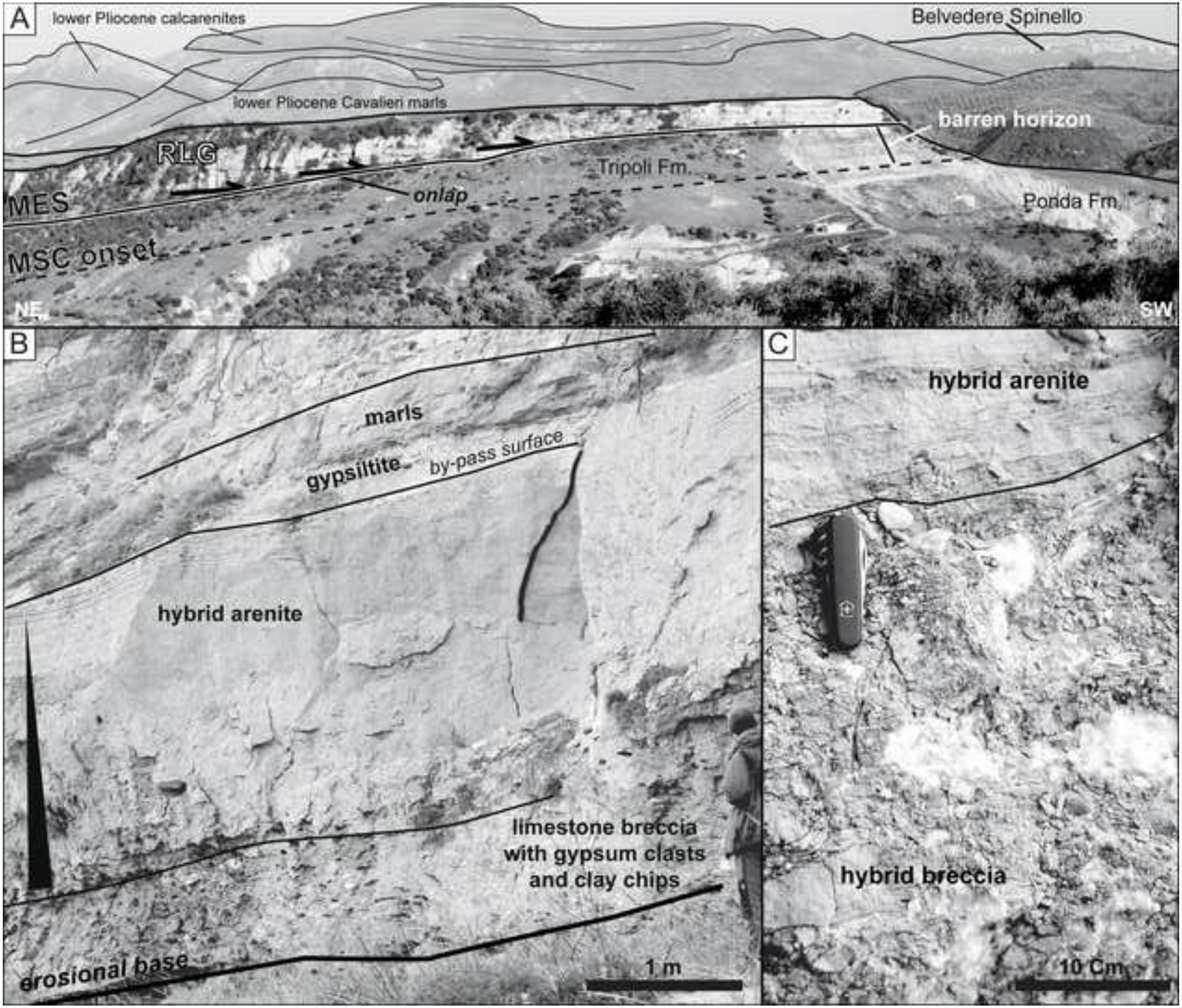

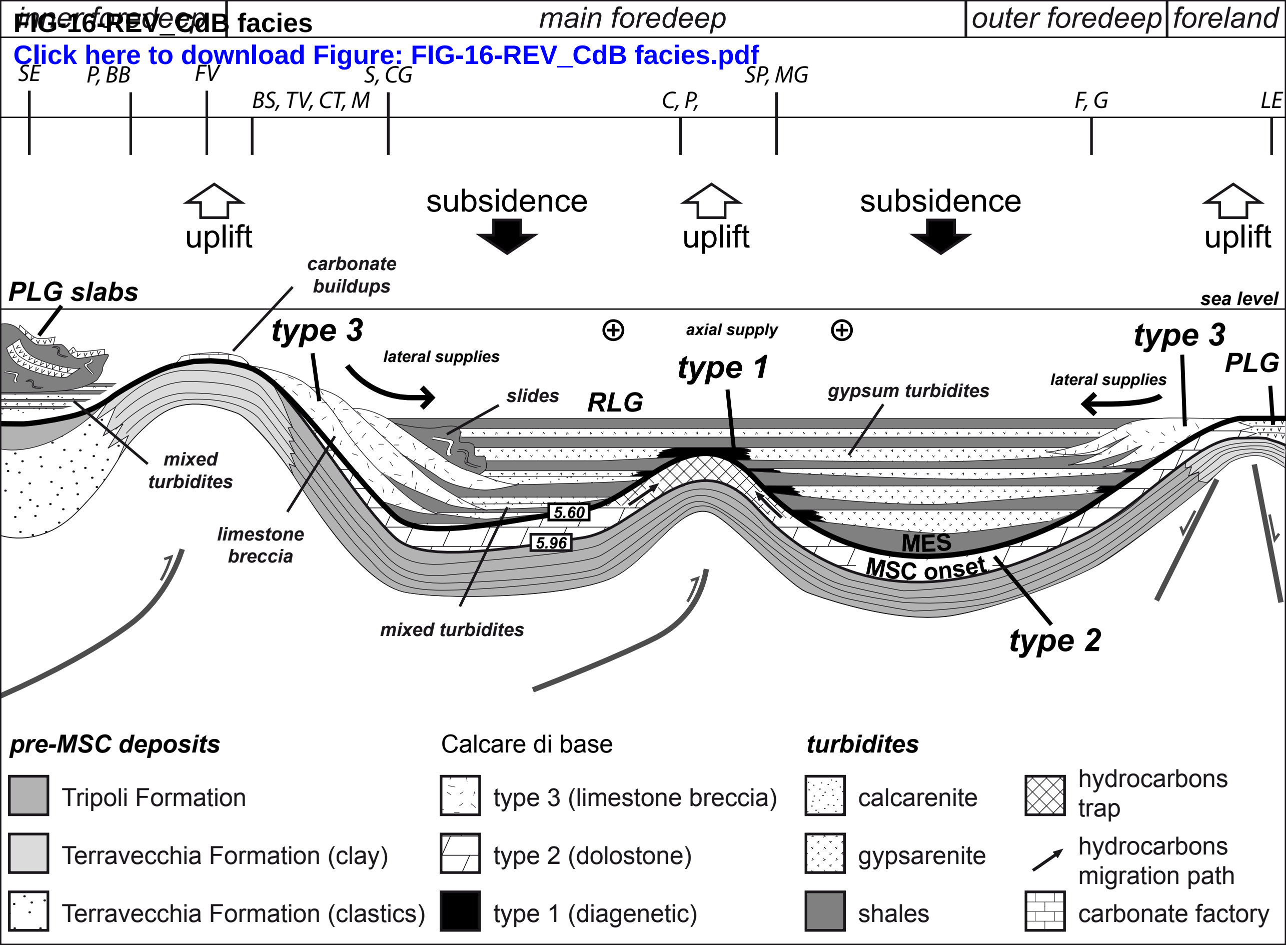
inner foredeep
main foredeep
outer foredeep
foreland
SE
P, BB
FV
BS, TV, CT, M
S, CG
C, P,
SP, MG
F, G
LE
uplift
subsidence
uplift
subsidence
uplift
carbonate buildups
PLG slabs
sea level
type 3
axial supply
type 3
lateral supplies
type 1
PLG
slides
RLG
gypsum turbidites
lateral supplies
mixed turbidites
limestone breccia
5.60
5.96
MES
MSC onset
mixed turbidites
type 2
pre-MSC deposits
Tripoli Formation
Terravecchia Formation (clay)
Terravecchia Formation (clastics)
Calcare di base
type 3 (limestone breccia)
type 2 (dolostone)
type 1 (diagenetic)
turbidites
calcarenite
gypsarenite
shales
hydrocarbons trap
hydrocarbons migration path
carbonate factory

FIG-17_REV_mixed facies
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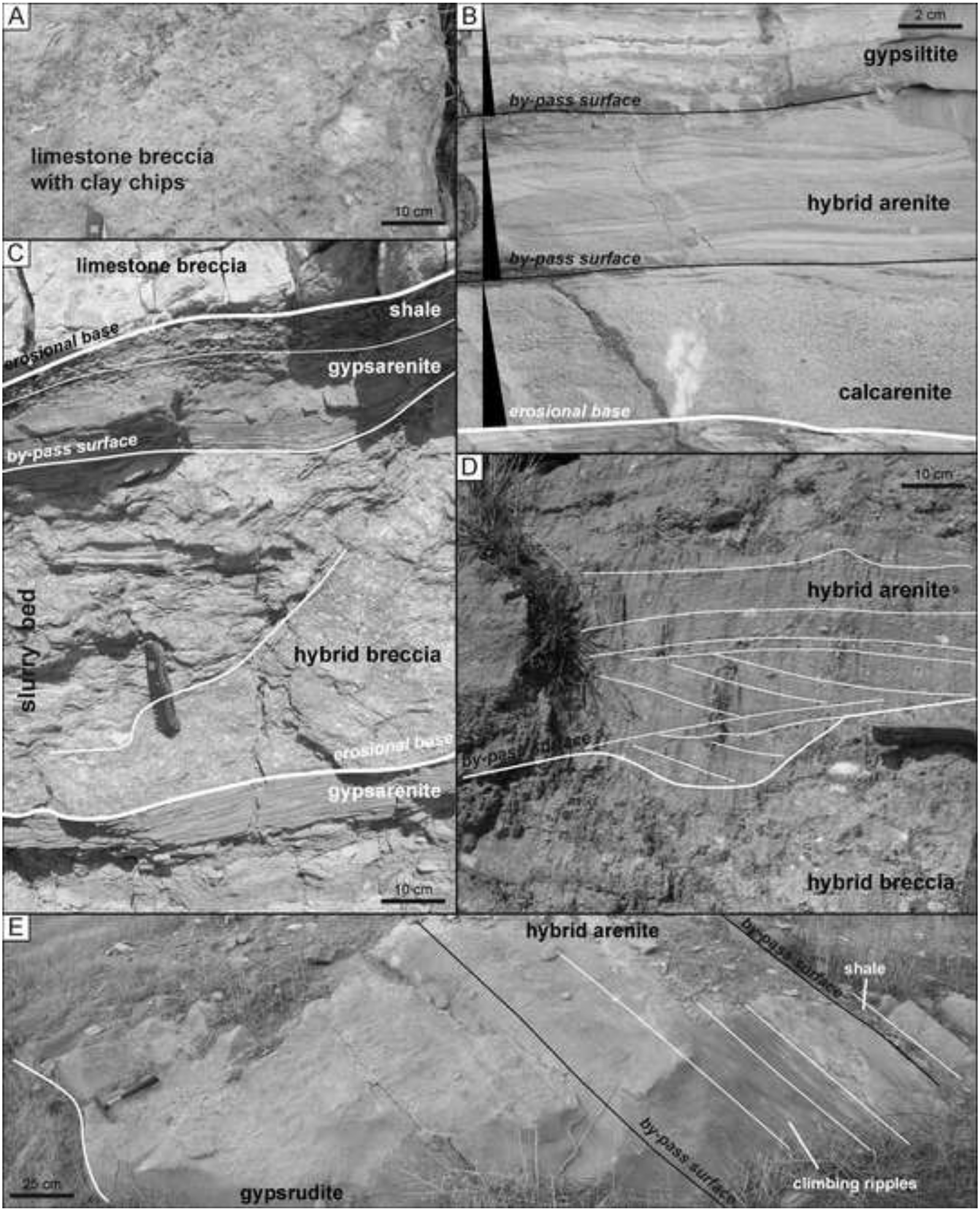

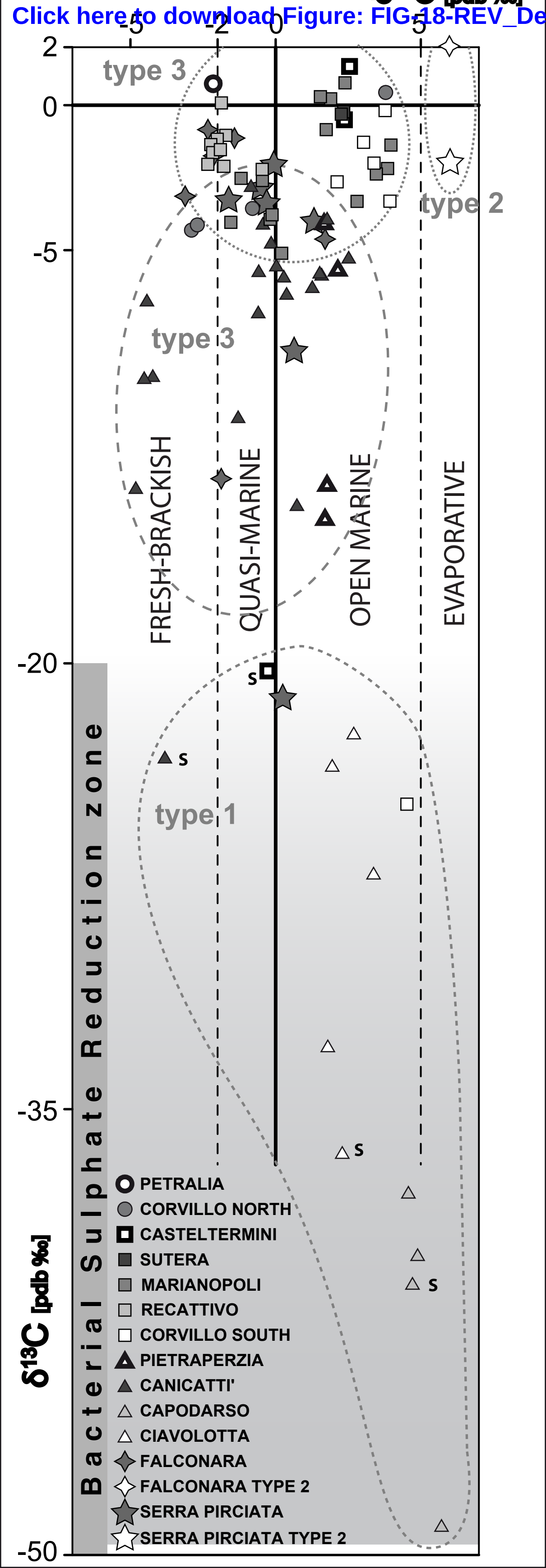
δ18O [pdb ‰]
-5
-2
0
5
2
0
-5
-20
-35
-50
δ13C [pdb ‰]
type 3
type 3
type 2
type 1
FRESH-BRACKISH
QUASI-MARINE
OPEN MARINE
EVAPORATIVE
Bacterial Sulphate Reduction zone
S
S
S
S
PETRALIA
CORVILLO NORTH
CASTELTERMINI
SUTERA
MARIANOPOLI
RECATTIVO
CORVILLO SOUTH
PIETRAPERZIA
CANICATTI'
CAPODARSO
CIAVOLOTTA
FALCONARA
FALCONARA TYPE 2
SERRA PIRCIATA
SERRA PIRCIATA TYPE 2

FIG-19-REV_revised stratigraphy

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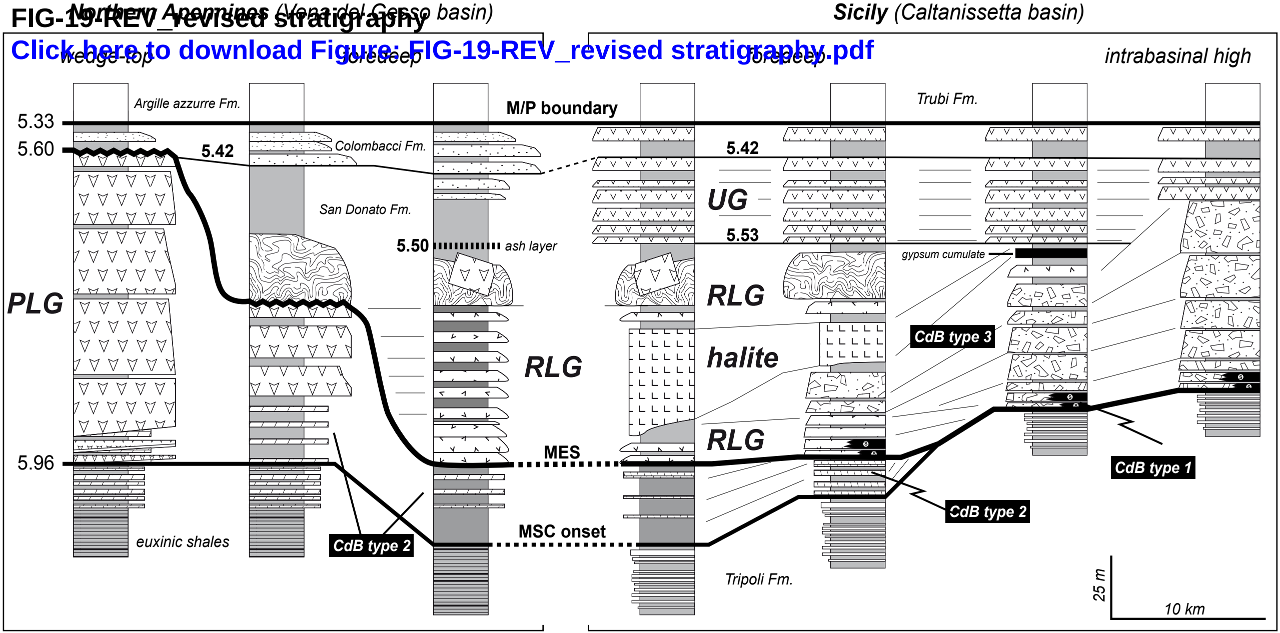

FIG-20-REV_CdB distribution
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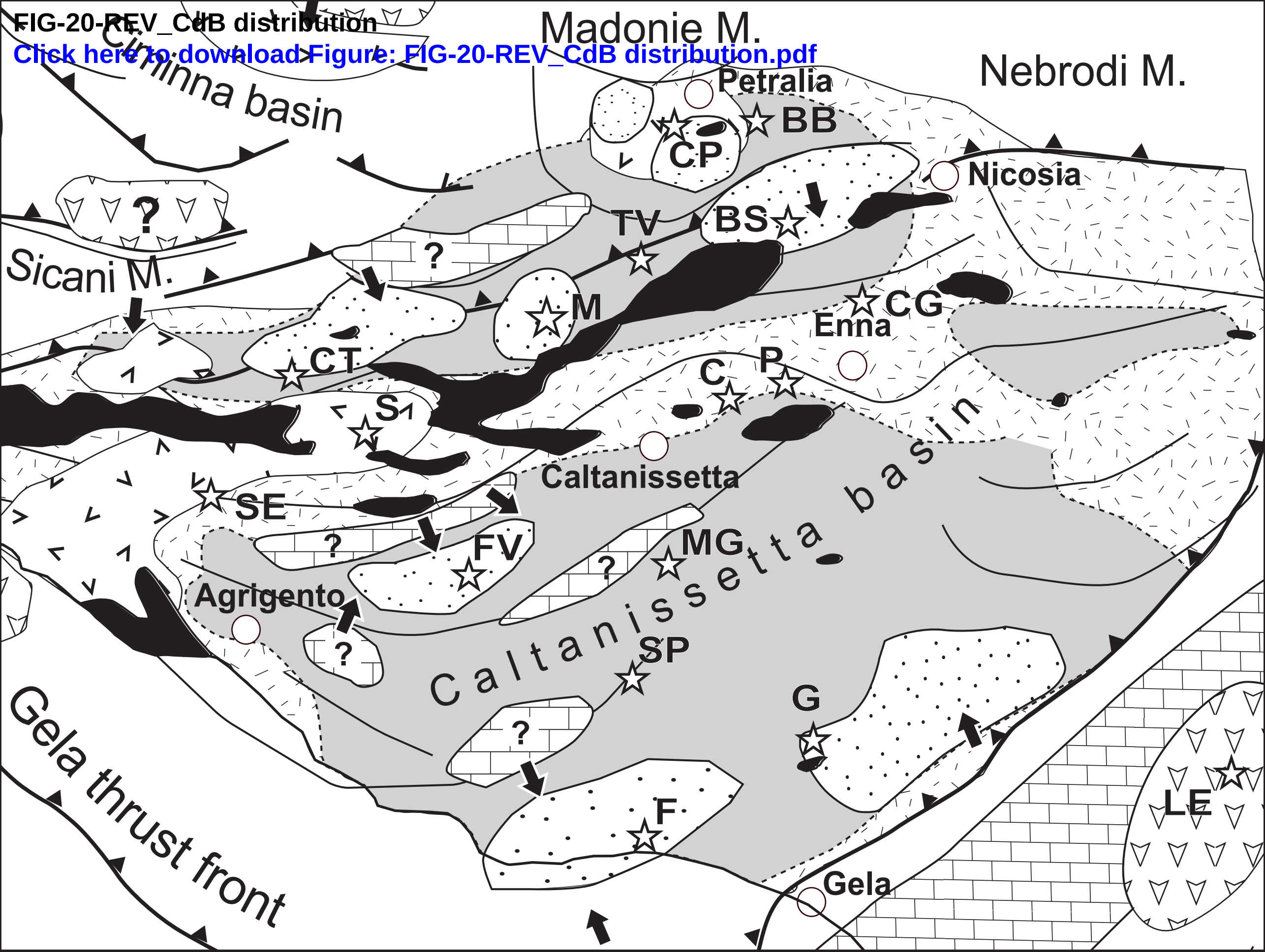

Lower Evaporites facies associations

- In situ massive selenites
- Clastic gypsum and allochthonous selenite blocks
- Clastic and laminated gypsum (balatino), olistostromes
- Halite and potash salt

Lower Evaporites facies associations

- presumed main carbonate factories
- main clastic carbonate depocentrres (mostly CdB type 3)
- Calcare di Base main outcropping area
- entry points

FIG-21-REV_hybrid gravity flows
Click here to download Figure: FIG-21-REV_hybrid gravity flows.pdf

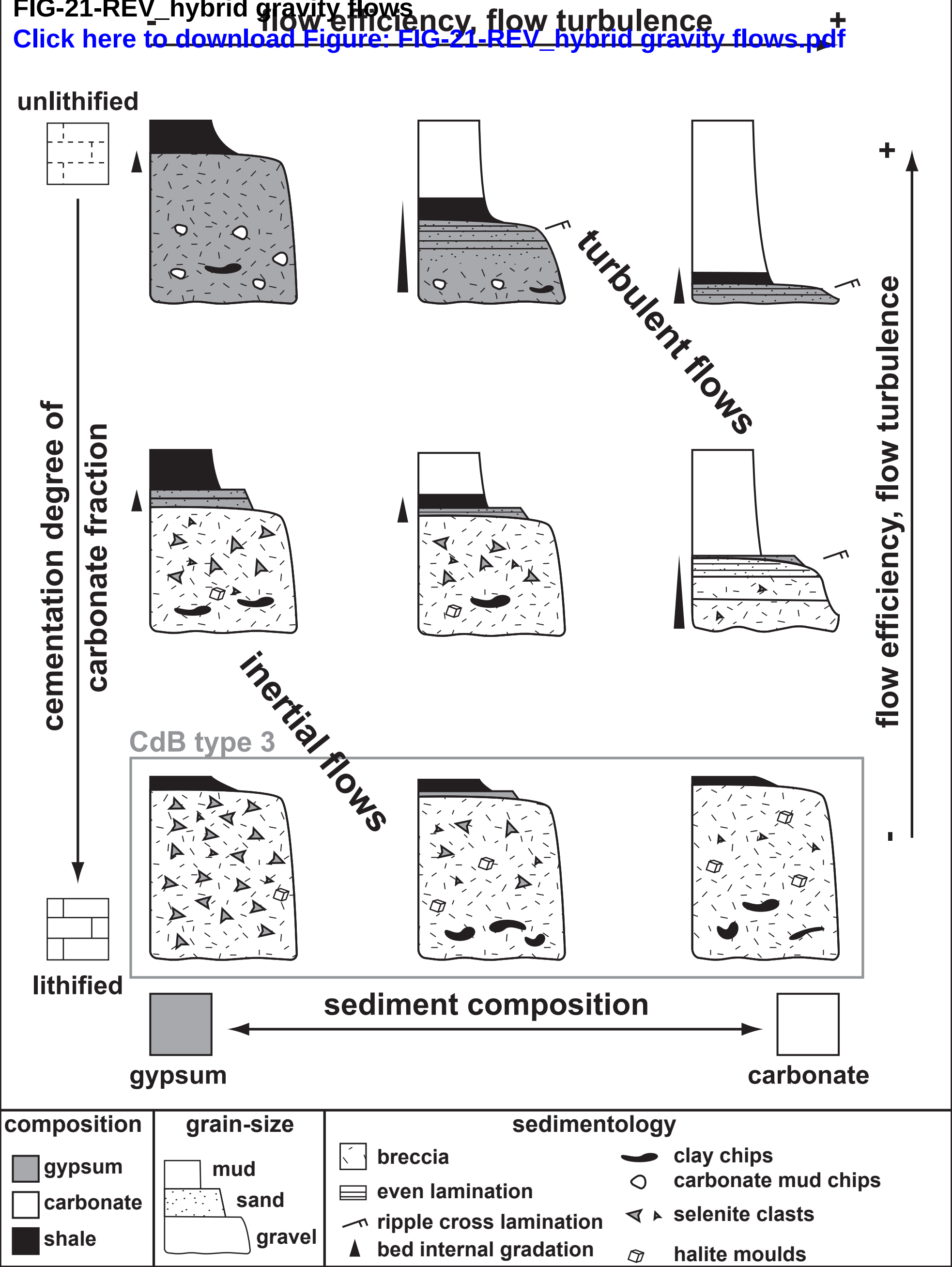

FIG-22-REV_STACKING PATTERN

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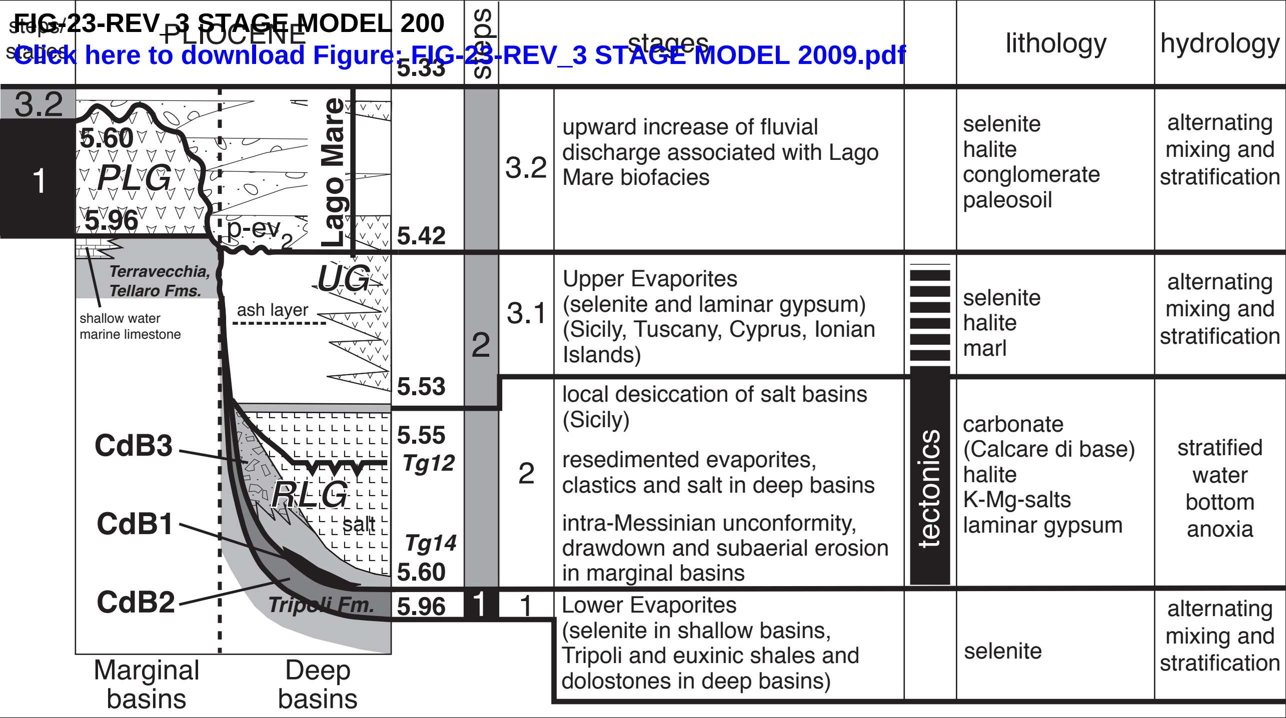
steps/stages
PLIOCENE
5.33
steps
stages
lithology
hydrology
3.2
1
5.60
PLG
5.96
p-ev2
Lago Mare
5.42
3.2
upward increase of fluvial discharge associated with Lago Mare biofacies
selenite
halite
conglomerate
paleosoil
alternating mixing and stratification
Terravecchia, Tellaro Fms.
shallow water marine limestone
UG
ash layer
5.53
2
3.1
Upper Evaporites (selenite and laminar gypsum) (Sicily, Tuscany, Cyprus, Ionian Islands)
selenite
halite
marl
alternating mixing and stratification
CdB3
CdB1
CdB2
RLG
salt
5.55
Tg12
Tg14
5.60
2
local desiccation of salt basins (Sicily)
resedimented evaporites, clastics and salt in deep basins
intra-Messinian unconformity, drawdown and subaerial erosion in marginal basins
tectonics
carbonate (Calcare di base)
halite
K-Mg-salts
laminar gypsum
stratified water bottom anoxia
Tripoli Fm.
5.96
1
1
Lower Evaporites (selenite in shallow basins, Tripoli and euxinic shales and dolostones in deep basins)
selenite
alternating mixing and stratification
Marginal basins
Deep basins