[PS]Carbonate Platform-Basin Transition in SW Sicily: Implications for the Petroleum Exploration in the Maghrebian Fold and Thrust Belt*

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Search and Discovery Article #30110 (2010)
Posted March 3, 2010

*Adapted from poster presentation at AAPG Convention, Denver, Colorado, June 7-10, 2009

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Abstract

The interplay between paleotectonic structures and the accretion of orogenic wedges is of crucial importance in evaluating the petroleum potential in fold and thrust belts (FTB). A Triassic/Jurassic carbonate platform to basin transition, nearly orthogonal to the thrust propagation, has been recently revealed by the carbonate facies analysis in the Apenninic-Maghrebian FTB from SW Sicily.

The shelf edge records the evolution from an Upper Triassic Dachstein-type reef to a Bahamian-type sandy margin during Early Jurassic times, as a consequence of the T/J biotic crisis. Large slope-aprons in adjacent deep-water successions consist of reef-derived carbonate breccias and oolitic-skeletal turbidites. Middle Jurassic pelagic sediments seal the carbonate system.

A complex Meso-Cenozoic sedimentary dynamics of the shelf margin has been traced on the basis of several outcrop sections. Multiple erosional or stepped discontinuity surfaces, swarms of neptunian dykes associated with volcanics, and megabreccias account for Jurassic transtensional activity and Late Cretaceous basin inversion along the shelf edge. During the Neogene, oblique thrusting along the paleomargin, coupled to right-lateral transpression and clockwise rotations, resulted in a complex stack imbricate. The imbrication of thin tectonic slices of Permian deep-water sediments could suggest that the Triassic paleomargin is a Late Paleozoic inherited structure. The orientation of this paleomargin is nearly parallel to the NW-SE margin of the Streppenosa Basin in the Hyblean region and to the Malta Escarpment. The collected stratigraphic dataset, associated with previous structural interpretations, allows us to suggest that the reconstructed shelf to deep-water transition in SW Sicily (Sciacca area) can be considered as a deformed segment of the rifted southern passive margin of the Permo-Triassic Ionian Tethys.

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Università degli studi di Palermo
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Presidenza del Consiglio dei Ministri
Ministero dell'Istruzione, dell'Università e della Ricerca

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AAPG Annual Convention & Exhibition

Theme IV: Carbonate Sedimentology and Sequence Analysis for Exploration and Improved Reservoir Prediction

ANNUAL CONVENTION AND EXHIBITION
7–10 JUNE 2009 • DENVER COLORADO

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The interplay between paleotectonic structures and the accretion of orogenic wedges is of crucial importance in evaluating the petroleum potential in fold and thrust belts (FTB).

Regarding the Sicilian thrust and fold belt (STFB), several authors have highlighted how the strong thickness differences between thick shelf carbonates and thin deep-water successions could have triggered oblique thrusting, lateral escapes and rotations during the tectonic stacking (e.g. SPERANZA et alii, 2000; Nigro & Renda, 2002, among others).

A Triassic/Jurassic carbonate platform to basin transition, nearly orthogonal to the thrust propagation, has been recently revealed by the carbonate facies analysis along the SFTB in SW Sicily. It is indicated as the Sciacca Paleomargin.

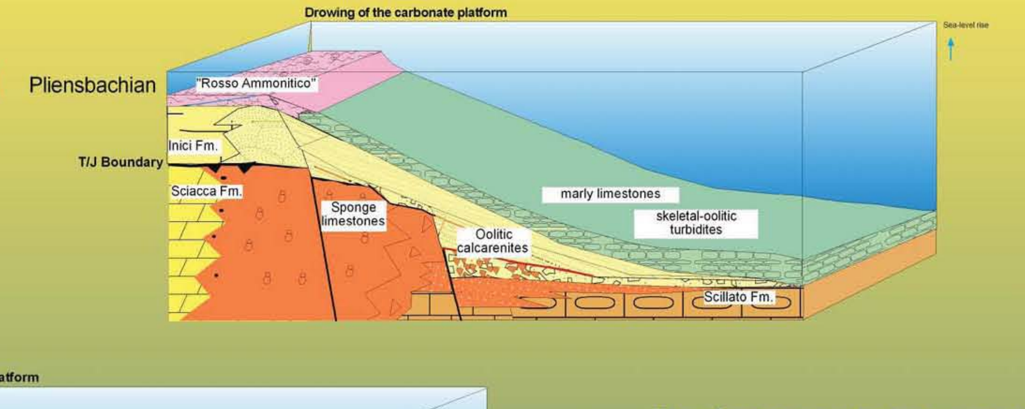
The shelf edge records the evolution from an Upper Triassic Dachstein-type reef to a Bahamian-type sandy margin during Early Jurassic times, as consequence of the T/J biotic crysis. Large slope-aprons in adjacent deep-water successions consist of reef-derived carbonate breccias and by oolitic-skeletal turbidites. Middle Jurassic pelagic sediments seal the carbonate system.

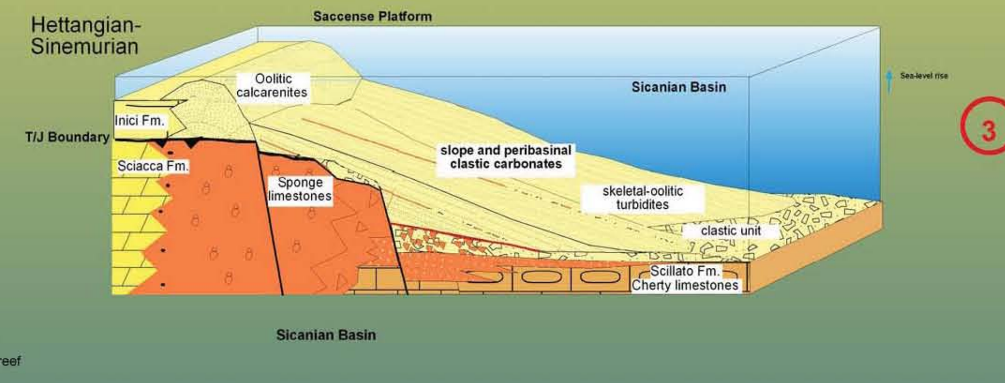
A complex Meso-Cenozoic sedimentary dynamics of the shelf margin has been traced on the base of several outcrop sections. Multiple erosional or stepped discontinuity surfaces, swarms of neptunian dykes associated with volcanics and megabreccias account for a Jurassic transtensional activity and a Late Cretaceous basin inversion along the shelf edge. During the Neogene, oblique thrusting along the paleomargin, coupled to right-lateral transpression and clockwise rotations, resulted in a complex stack imbricate. The imbrication of thin tectonic slices of Permian deep-water sediments could suggest that the Triassic paleomargin is an inherited structure since the Late Paleozoic.

The present-day orientation of the Scaicca Paleomargin fits a major NW-SE trending right-lateral shear zone postulated by several authors on the base of seismic data (i.e. the Segesta fault, Casero & Roure, 1994; see the map of Sicilian plays of Casero, 2004 to the left). It is nearly parallel to the the NW–SE margin of the Streppenosa basin in the Hyblean region and to the Malta Escarpment.

SEDIMENTARY EVOLUTION OF THE SCIACCA PALEOMARGIN AROUND THE TRIASSIC/JURASSIC BOUNDARY

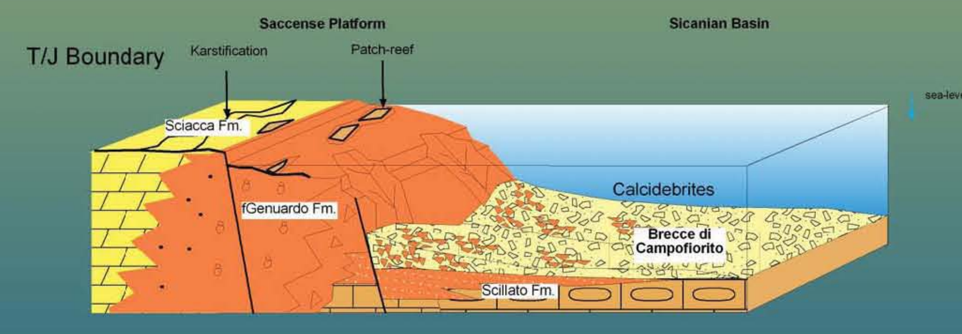
(4) During Pliensbachian times the demise of the Inici carbonate platform is recorded, followed by the Rosso Ammonitico condensed successions in the structural highs and by cherty calcilutites (Calcari di Santa Maria del Bosco, equivalent to the Modica Fm.) in deeper water settings.

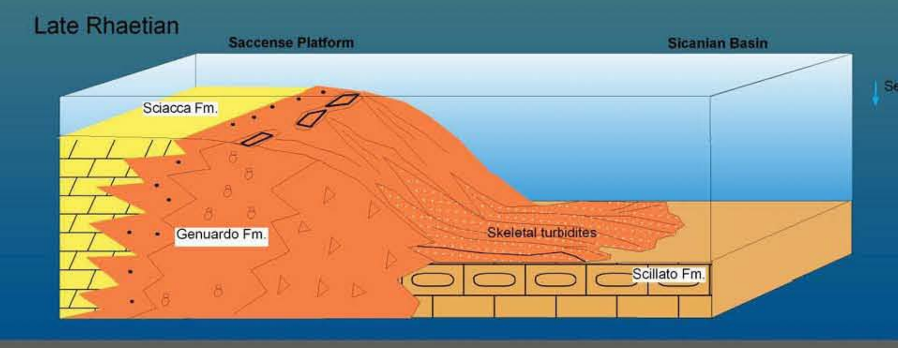




(3) The fast aggradation– progradation of the Early Jurassic carbonate platform indicates the recovery of a very healthy carbonate factory coupled to a sea-level rise during Hettangian times. As a result, an intense shedding of carbonate sands in the adjacent slope and peribasinal areas was produced. The observed sedimentary dynamics from the Sciacca platform–basin transition indicates that the extensional tectonics has played a minor role in the carbonate platform evolution around the TJB when compared with the sea-level fluctuations and the biotic crisis.

(2) Around the Rhaetian–Hettangian boundary, a widespread clastic wedge resulting from the cannibalization of the UT reefs was formed downslope. The selective source of clastics (reef limestones) suggests, as trigger mechanisms, collapses in the outer margin induced by decreasing hydrostatic pressure during sea-level fall (HILBRECHT, 1989) as well as an intense wave erosion of the early cemented reef flank during the lowstand stage (GRAMMER *et alii*, 1993). However the Monte Genuardo angular unconformity points to an interplay of the extensional tectonics producing platform margin retreats and possible collapse at this time. The observed switching in the distal slope settings of the intrabasinal carbonate supply from scarce biodetritus with reef-derived foraminifers to abundant oolitic and skeletal grains can be used as a proxy of the TJB.





(1) During Late Triassic the Sciacca paleomargin is bordered by an extensive Dachstein-type reef complex The latest evolutionary stages of this reef, besides the global biotic crisis, seems to have been controlled by a Late Rhaetian sea-level fall. This is supported by a widespread erosional truncation on top of the UT platform strata associated in some areas with karstic dissolution features (the Cozzo Gelso section at Pizzo Telegrafo). Lowering of the sea-level is also supported by a forced shedding of reef-derived biodetritus in the adjacent slope–basinal area, favoured probably by the shifting of the active bioconstruction to the outer margin/upper slope.

Conclusions

The collected stratigraphic dataset, coupled with previous structural interpretations, allows us to suggest that the reconstructed shelf to deep-water transition in SW Sicily (Sciacca area) can correspond to a segment of the rifted southern passive margin of the Permo-Triassic Ionian Tethys.

During Tertiary times the Sciacca margin has played as major right-lateral shear zone during the Maghrebian mountain building.

This first order structure revealed by the sedimentological data has to be taken in account for the petroleum potential evaluation along the Maghrebian fold and thrust belt.

It could imply a reduced extension of the Saccense-Hyblean units underthrusted below the basinal allocthons (Imerese and Sicanian units) in central and eastern Sicily.

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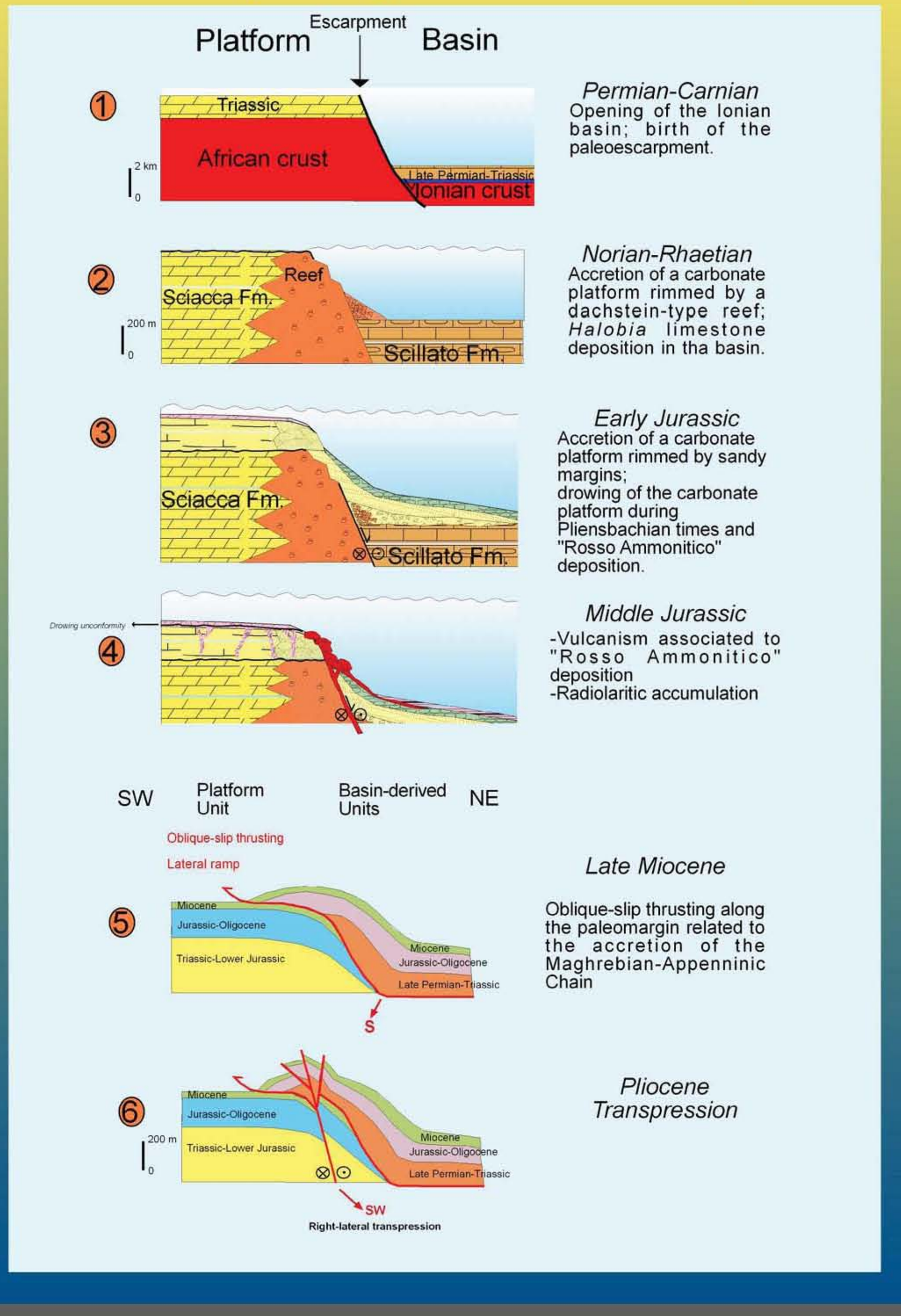
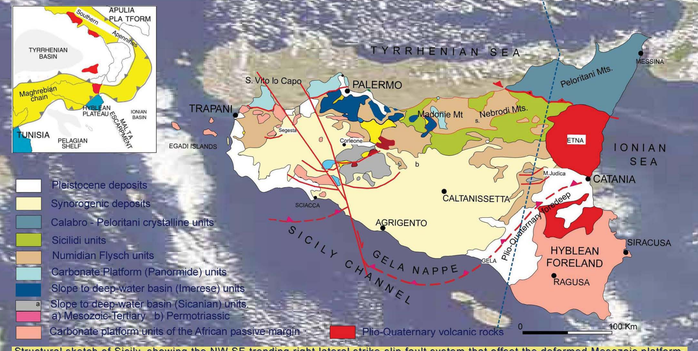
Cartoon summarizing the tectono-sedimentary evolution of the Triassic paleomargin from southwestern Sicily



Geological Setting



Structural sketch of Sicily, showing the NW-SE trending right lateral strike-slip fault system that offset the deformed Mesozoic platform-basin transition in the Sciacca-Monti Sicani area. Its prosecution in the Sicily channel is based on Casero & Roure (1994).

Sicily is a segment of the Neogene Apenninic-Maghrebian fold and thrust belt. To the north it is bounded by the Tyrrhenian Basin, an extensional area subjected to crustal thinning since Tortonian times (Malinverno & Ryan, 1986; Rehault *et al.*, 1987). Southward the Sicilian chain is bounded by the Plio-Pleistocene foredeep, a narrow furrow from Gela to Catania, and by a less deformed African foreland represented by the Sicily Channel and the Hyblean plateau (Grasso & Reuther, 1988). To the East the Hyblean Plateau is transitional to the Ionian basin through the Malta Escarpment.

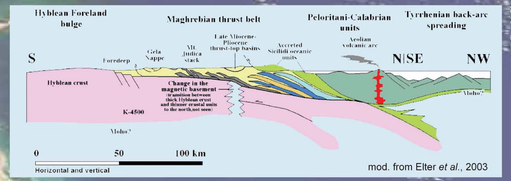
The Sicilian fold and thrust belt can be differentiated in turn in: i) an European Kabilo-Calabride element, that crops out in the Peloritani Mountains, ii) a Sicilide element of Alpine Tethyan affinity, well exposed in the Nebrodi Mountains, and iii) an E-W trending Maghrebian element. The latter consists of Meso-Cenozoic thrust imbricates that are well exposed in western Sicily and in central-northern Sicily (Madonie Mountains) while in central-southern Sicily they are covered by a large allocthonous complex of mostly Miocene and Pliocene sediments known as the Gela Nappe (Argnani, 1987; Grasso *et al.*, 1991).

The Meso-Cenozoic thrust imbricates forming the Maghrebian element were deposited in extensional, mostly carbonate, sedimentary basins located along the African continental margin during Late Paleozoic and Mesozoic times (Di Stefano, 1988; Catalano *et al.*, 1991).

During Late Oligocene the area experienced the tectonic inversion of these basins from extensional to compressive (Catalano & D'Argenio, 1982). These processes resulted in the development of new basins associated to a change of the sedimentary regime from carbonate to siliciclastics (e.g. Numidian Basin).

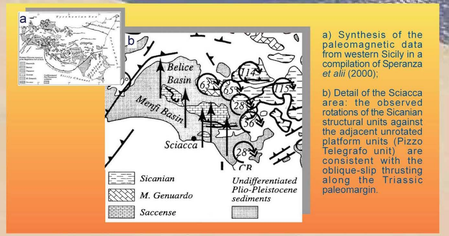
On the basis of their Triassic to Eocene stratigraphic architecture, the thrust sheets that belong to the Sicilian Maghrebids are classically differentiated into groups that correspond to former paleogeographic zones (Catalano & D'Argenio, 1982). The Trapanese and Saccense structural units are characterized by thick Triassic and Lower Jurassic carbonate platform strata, followed by pelagites and deeper water sediments. A similar stratigraphic architecture can be found in the subsurface of the Hyblean foreland (Patacca *et al.*, 1979, Antonelli *et al.*, 1991). The Panormide units (Ogniben, 1960) consist of Triassic to Eocene carbonate platform sediments separated by major unconformities, discontinuous levels of Jurassic pelagites and/or bauxites. The Imerese and Sicanian units consist of Triassic to Oligocene deep-water marls and cherty limestones with repeated intercalations of platform-derived clastic-carbonates and of Jurassic radiolarites and pillow lavas (Catalano & D'Argenio, 1982, Di Stefano *et al.*, 1996).

Several authors have pointed out that the collisional processes were controlled by pre-existing differences in physiography and crustal thickness among the paleogeographic sectors involved in the orogenic accretion (Speranza *et al.*, 2000; Nigro & Renda, 2002; Di Stefano *et al.*, 2008).



mod. from Elter *et al.*, 2003

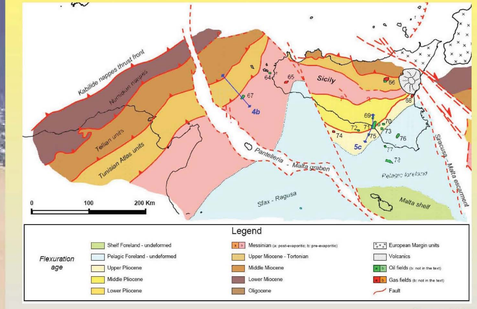
N-S CRUSTAL SECTION ACROSS THE EASTERN SECTOR OF THE SICILIAN FOLD AND THRUST BELT
(for location see the map above)



a) Synthesis of the paleomagnetic data from western Sicily in a compilation of Speranza *et alii* (2000);

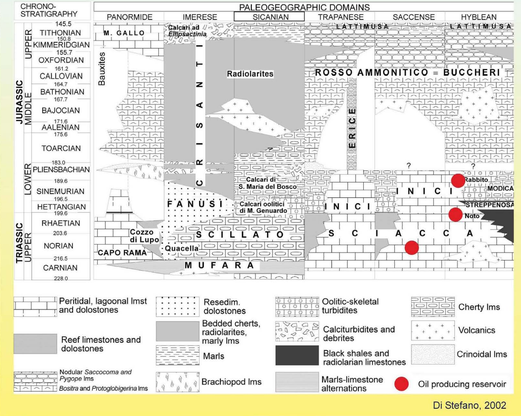
b) Detail of the Sciacca area: the observed rotations of the Sicanian structural units against the adjacent unrotated platform units (Pizzo Telegrafo unit) are consistent with the oblique-slip thrusting along the Triassic paleomargin.

STRUCTURAL MAP OF SICILY SHOWING MAJOR NW-SE TRENDING SHEAR ZONES

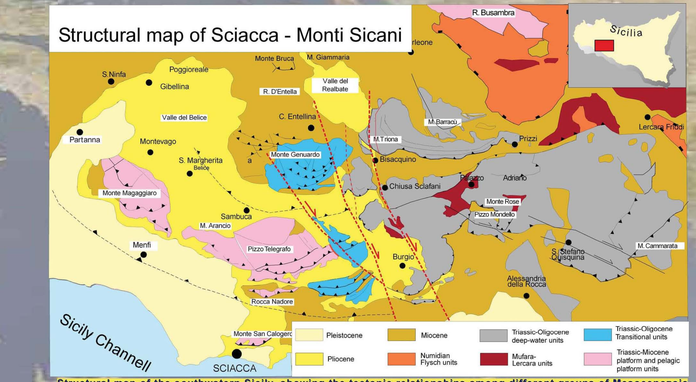


Casero, 2004

STRATIGRAPHIC CHART OF THE MESOZOIC MAGHREBIAN UNITS FROM THE SICILIAN FOLD AND THRUST BELT



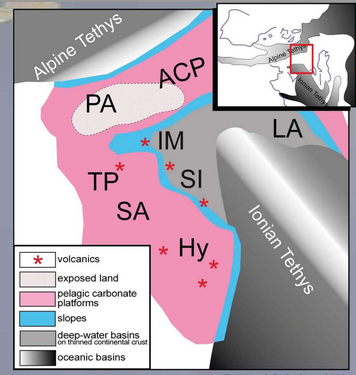
Di Stefano, 2002



Structural map of the southwstern Sicily, showing the tectonic relationships among different groups of Mesocenozoic thrust sheets: in pink the thick carbonate platform units (Saccense units), in cyan the transitional units, in grey the basin-derived units (Sicanian Units).

MESOZOIC PALEOGEOGRAPHY OF THE CENTRAL MEDITERRANEAN AREA

Owing to the complex tectono-stratigraphic mosaic of the area. The paleogeographic reconstruction of the Central Mediterranean during Late Paleozoic and Mesozoic times is still debated. Main questions arise about the timing of the individuation and opening of the Ionian Tethys and the presence of a continental connection between Africa and Adria (Ziegler, 1988; Dercourt *et al.*, 1993; Stampfli & Borel, 2002; Rosenbaum *et al.*, 2004; Finetti, 2005; among others). A tentative reconstruction of the different paleogeographic zones during Jurassic times is given in the figure to right. In this reconstruction (Turco *et al.*, 2007, Zarcone & Di Stefano, 2008) the Panormide Platform is considered as a crustal element isolated by the opening of the Alpine Tethys and connecting Africa to Adria, via the Apennine Platform. The Trapanese, Saccense and Hyblean carbonate platforms are considered to be part of the rifted continental margin of Africa, already individuated during Permian and Triassic times, while the Imerese and Sicanian basins (and the northernmost Lagonegro Basin), represent the western termination, on a thinned continental crust, of the Ionian Tethys.

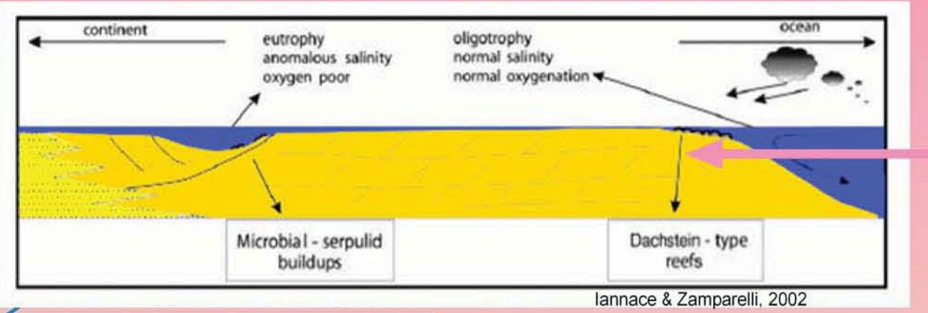


Zarcone & Di Stefano, 2008

ACP = Apennine Carbonate Platform;
PA= Panormide Carbonate Platform;
TP= Trapanese Carbonate Platform;
SA= Saccense Carbonate Platform;
Hy= Hyblean Carbonate Platform;
LA= Lagonegro Basin;
IM= Imerese Basin;
SI= Sicanian Basin.

TRIASSIC/JURASSIC CARBONATE FACIES ARCHITECTURE

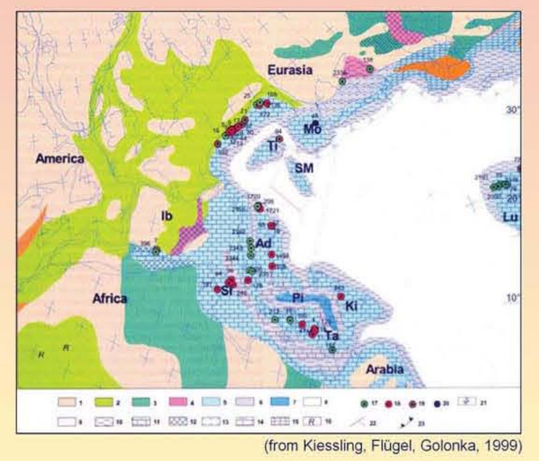
The Upper Triassic Dachstein-type reefs are basic markers of carbonate platform margins facing open and high-energy deep-water basins



Iannace & Zamparelli, 2002

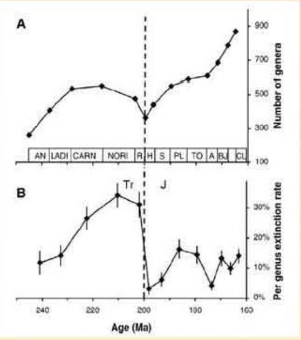
Microbial-serpulid buildups are typical from the margins of intraplatform basins

Distribution of the Upper Triassic reefs along the Tethyan margins



(from Kiessling, Flügel, Golonka, 1999)

The end-Triassic biotic crisis caused the demise of the Upper Triassic reef complexes



Standing diversity based on boundary crossing genera (A) and per genus extinction rate (B) of all marine animals from the Middle Triassic (Anisian) to the Middle Jurassic (Callovian), based on an analysis of Sepkoski's (2002) compendium. **From Kiessling *et al*., 2007.**

Pizzo Telegrafo (Saccense platform unit): A transition from the thick peritidal successions of the Gela formation to Upper Triassic reef limestones (Dachstein-type) has been observed in the easternmost sector of this structural unit. Biota in the reef limestones are highly diversified. Sphictozoan sponges, inozoans and chaetetids are common framebuilders, associated with microbial crusts. Cavities are filled up with a fine peloidal packstone or grainstone with abundant reef-dwelling foraminifers. Lagoonal and marginal facies of the Inici Fm. follow upwards separated by a dscontinuity surface that is recorded at a regional scale in Sicily. Karstic dissolution cavities filled-up by red silt, along the discontinuity, point to the emersion of the platform around the T/J boundary.

a) Reef margin boundstones of Upper Triassic age onlapped by Lower Jurassic oolitic-skeletal grainstones.

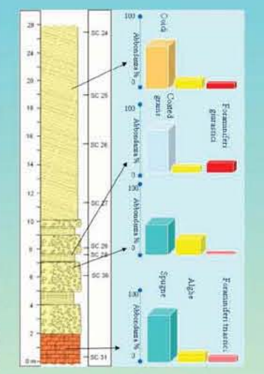
b) Karstic dissolution cavities, filled-up by red silt, overprint a sharp discontinuity surface on top of the uppermost Triassic platform strata (*Triasina* facies).

c) *Celyphia submarginata* encrusting *a* chaetetid.

d) Common texture of the sponge boundstone: Inozoan and Sphinctozoan sponges, enveloped by microbial crusts. A peloidal grainstone with reef-dwelling foraminifers occur as filling of the interbiolithitic cavities.

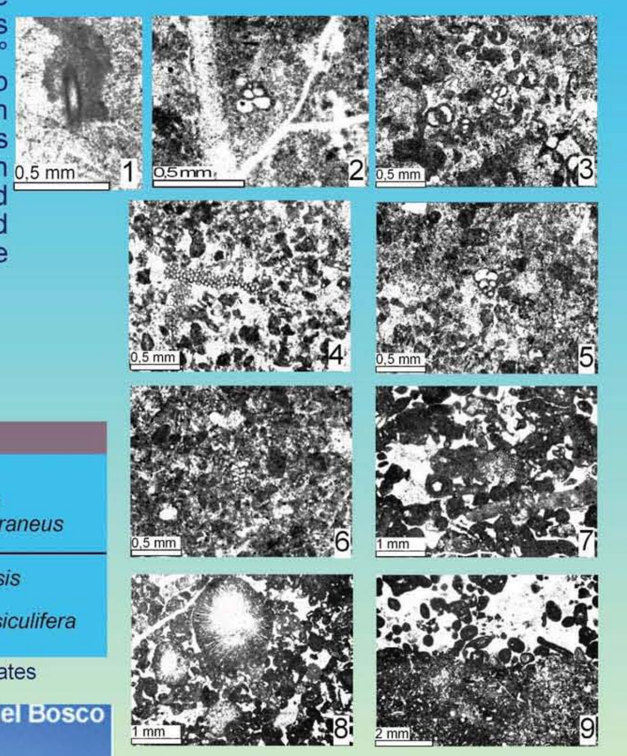
e) *Colospongia catenulata* (1) and *Cheilosporites tirolensis* (2).

Platform/basin transitional units (Monte Genuardo): along the succession it is possible to observe UT platform limestones that are upwardly truncated by an angular unconformity of about 10° with a karstic overprint. This is covered in turn through a downlap surface by Lower Jurassic oolitic-skeletal turbidites interbedded with radiolarian marls. The angular unconformity at Monte Genuardo points to an end- Triassic transtensional tectonics that caused uplift, erosion and the subsequent drowning of sectors of the platform margins around the TJB. This is in good agreement with the extensional stress field connected to the fragmentation of Pangea and the opening of the Alpine Tethys.



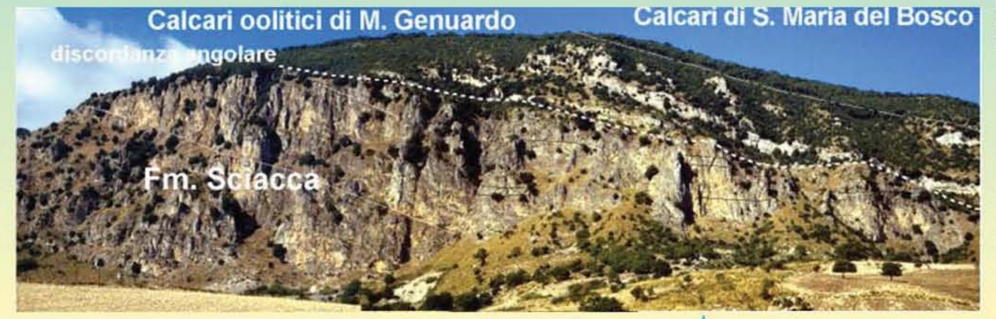
Chrono	Biozones
Lower-Mid Sinemurian	*Siphovalvulina colomi* *Textulariopis sinemurensis* *Palaeodasycladus mediterraneus*
Hettangian	*Siphovalvulina gibraltarensis* *Aeolisaccus dunningtoni* *Thaumatoporella parvovesiculifera*

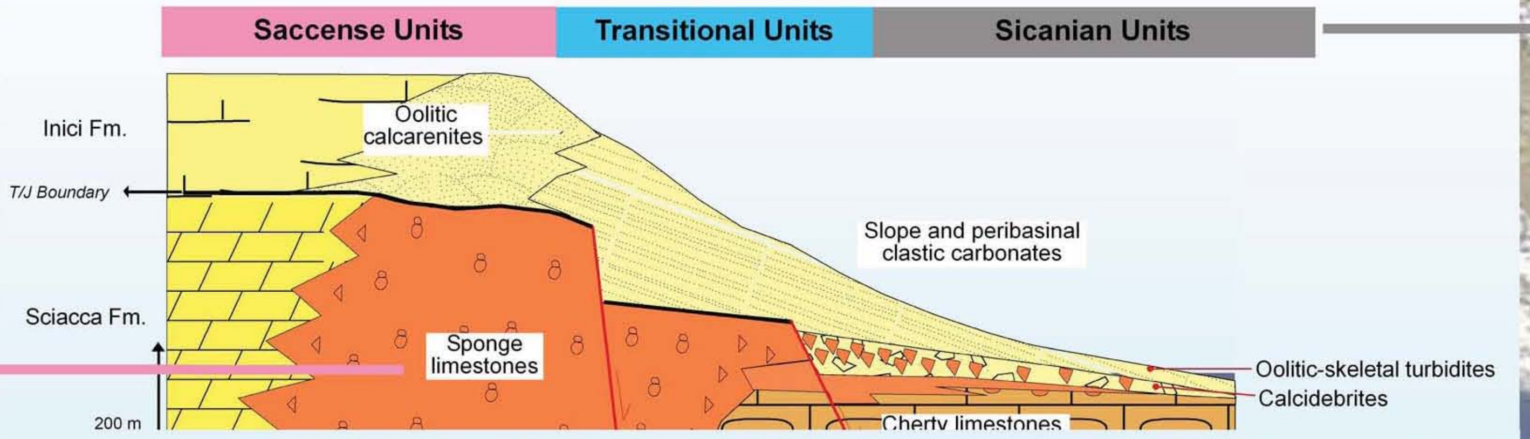
Lower Jurassic biozonation of shallow-water carbonates



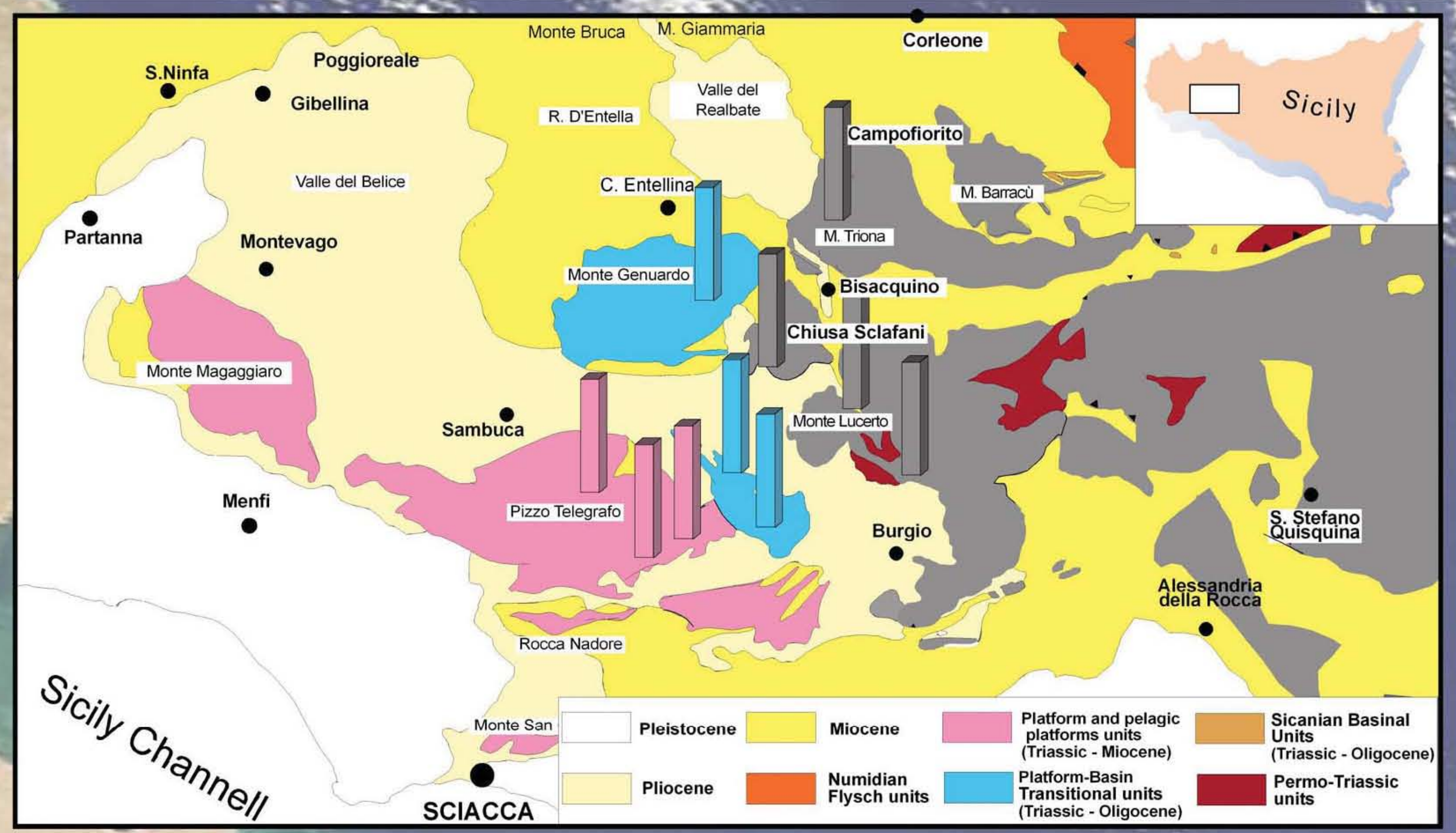
Microfacies in the Lower Jurassic oolitic-bioclastic limestones from Monte Genuardo

1. *Aeolisaccus dunningtoni*
2. *Siphovalvulina gibraltarensis*
3. Skeletal-grainstone with *coated grains* and benthic foraminifers.
4. *Thaumatoporella parvovesiculifera*
5. *Siphovalvulina gibraltarensis*
6. *Textulariopsis* sp.
7. Skeletal-oolitic grainstone with algae (*Cayeuxia*-type)
8. Oolitic grainstone bearing *Palaeodasycladus mediterraneus*
9. Oolitic grainstone and radiolarian wackestone.



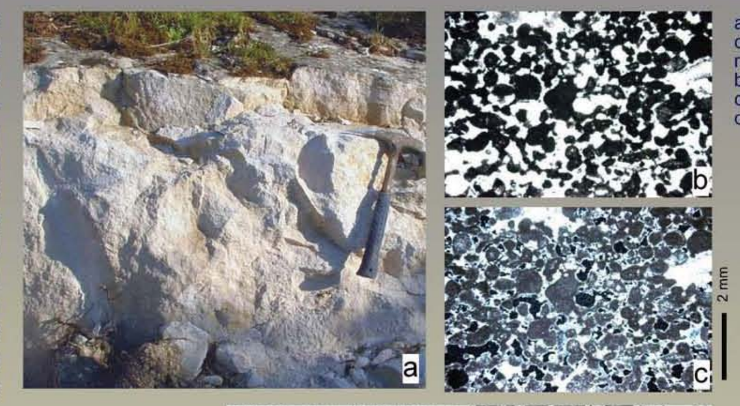


Restored stratigraphic scheme of the Upper Triassic-Lower Jurassic sediments, across the Sciacca-Monti Sicani platform-basin transition.

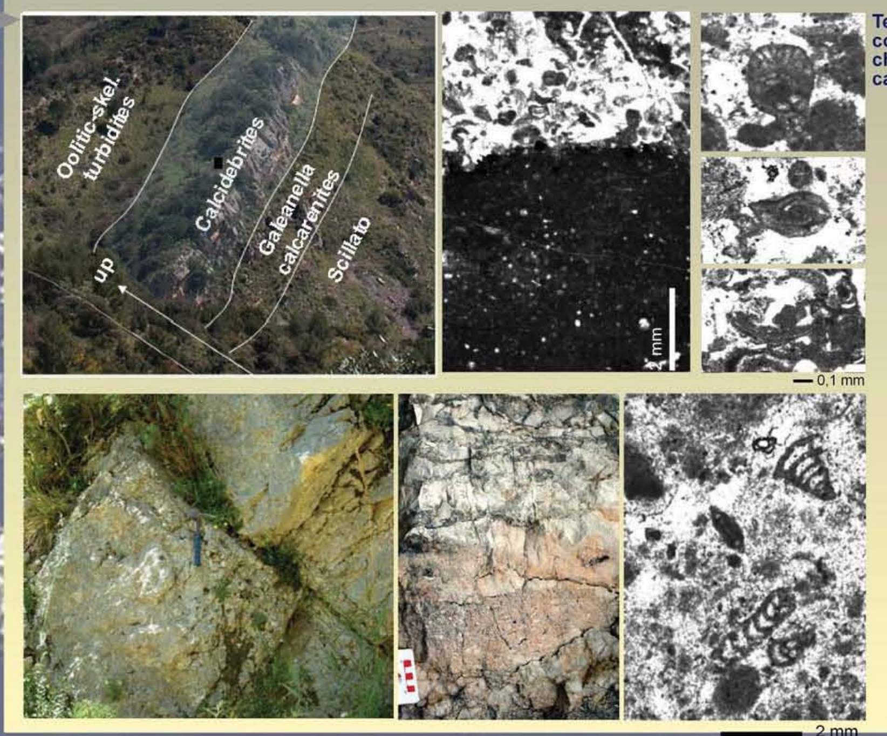


Three main types of structural units came into contact in the study area along a NW–SE trending belt): 1) platform-derived structural units (known as Saccense or Sciacca units). Their T/J successions consist of up to 3000 m thick Norian–Rhaetian peritidal dolostones overlain by Lower Jurassic peritidal and oolitic limestones (Inici Fm.); 2) transitional structural units (e.g. Monte Genuardo unit). They are characterized by Triassic peritidal dolostones laterally transitional to reef limestones and dolostones followed by Lower Jurassic oolitic-skeletal turbidites; 3) deep-water structural units (Sicanian units). Their T/J stratigraphy consists of cherty limestones, followed by calcareous turbidites and debrites, and by Lower Jurassic oolitic turbidites.

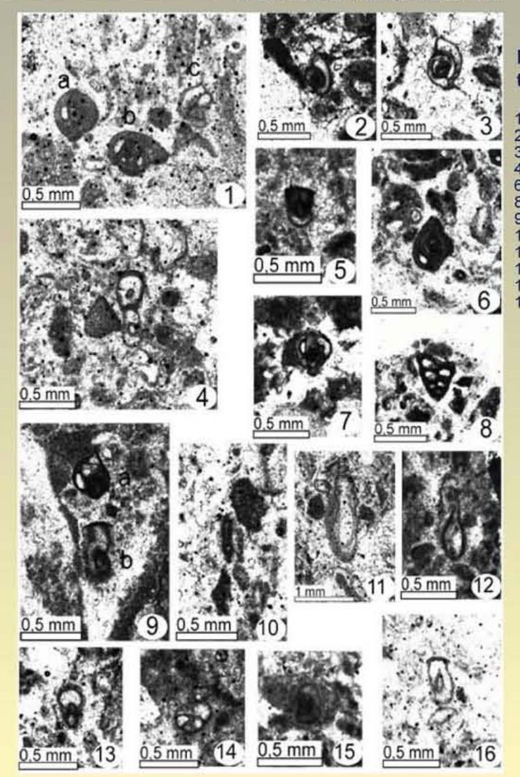
Monte Lucerto and Campofiorito (Sicanian basinal units): three different lithostratigraphic units on top of the cherty limestones can be differentiated along the Sicanian succession: the first one is a package of thin-bedded packstone–grainstone with abundant reef-derived biodetritus, such as sponge fragments and reef-dwelling foraminifers, alternating with radiolarian wackestones. The second one is a coarse calcidebrite with large angular reef-derived extraclasts well comparable to those found at Pizzo Telegrafo and Monte Genuardo. The matrix between elements consists of reef-derived biodetritus with foraminifers, pointing to a still-active bioconstruction of the reef during the resedimentation processes as well as a Rhaetian age of these sediments. The third unit follows with a sharp contact and consists of oolitic-bioclastic turbidites with Thaumatoporella parvovesiculifera, valvulinids and rare *Aeolisaccus* sp. that indicate a Hettangian age.



a) Early Jurassic slope aprons. They consist of oolitic-skeletal turbidites, locally intercalated to thin levels of radiolarian wackestone.
b) Oolitic-skeletal grainstone with "*Tubyphites*" *obscurus* and other microproblematic organisms.
c) High interparticle porosity in the oolitic-skeletal grainstones.



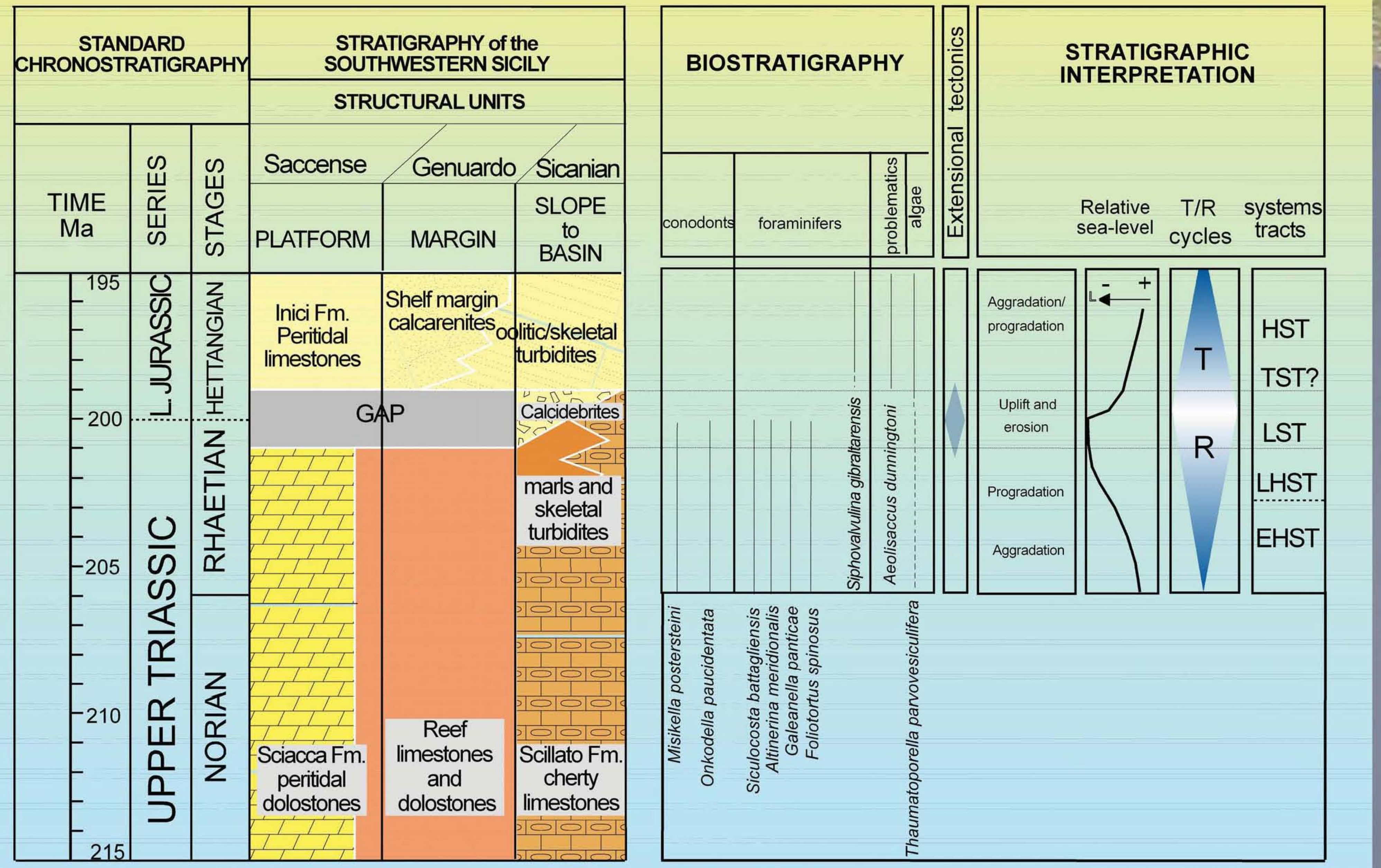
Textural and compositional characters of the calcidebrites



Norian-Rhaetian reef-dwelling foraminifers from the debrite extraclasts

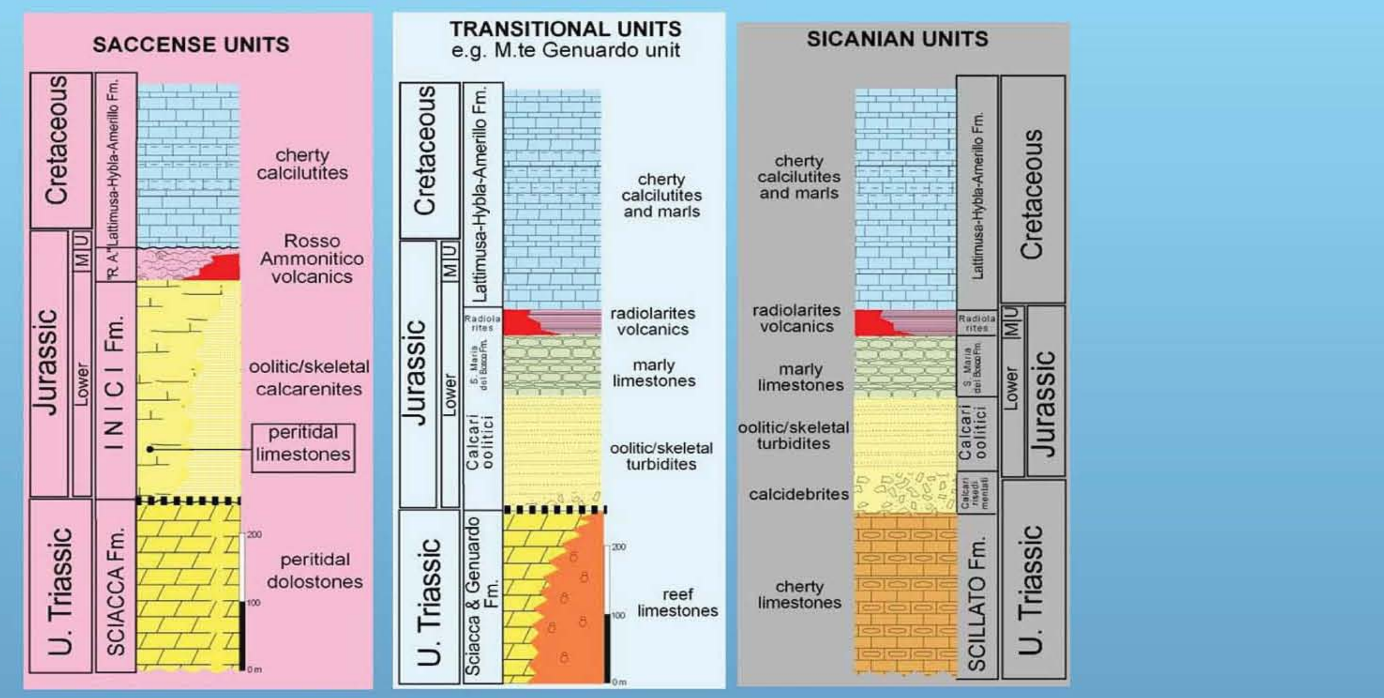
1. a) e b) Galeanella panticae, c) Agglutisolena?
2.7. Galeanella sp.
3. Galeanella tollmanni?
4. 5. Costifera cylindrica
6. Galeanella panticae
8. Trochammina sp.
9. a)Galeanella sp.; b) Siculocosta battagliensis
10. Ophtalmidium martanum
11. 12. Indeterminated
13.16 Siculocosta battagliensis
14. Duotaxis sp.
15. Bispirella ovata?

Stratigraphic Chart of the Upper Triassic/Lower Jurassic successions from southwestern Sicily



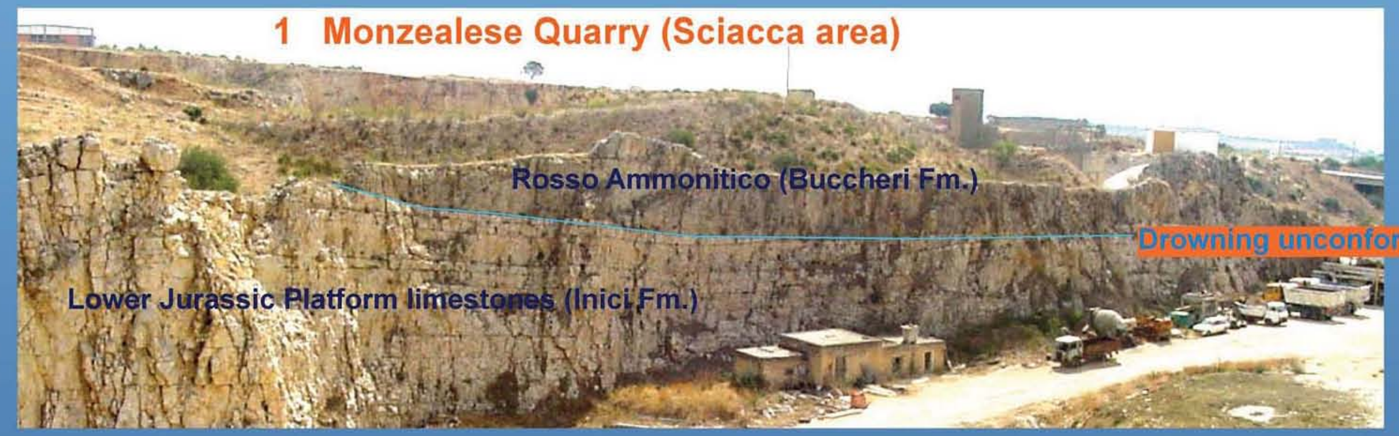
MIDDLE-LATE JURASSIC EVOLUTION

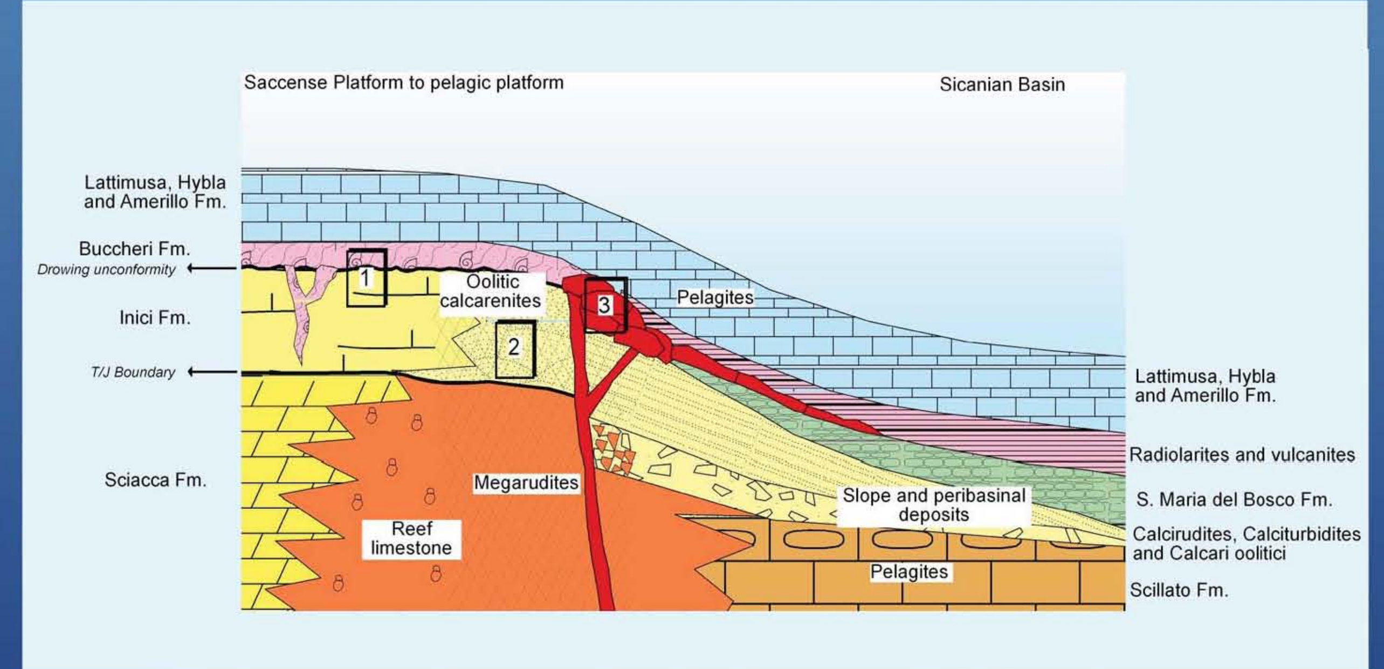
Lithostratigraphic columns of the Upper Triassic-Cretaceous successions across the Sciacca Paleomargin



Pliensbachian drowing unconformity in the Saccense succession.
The unconformity is marked by a "hardground" between the Inici Fm. and the overlying pelagic limestones (Buccheri Fm.). Neptunian dykes and sills cross-cutting the shallow water carbonates and filled up with pelagites are evident across the walls of the quarry.

1 Monzealese Quarry (Sciacca area)



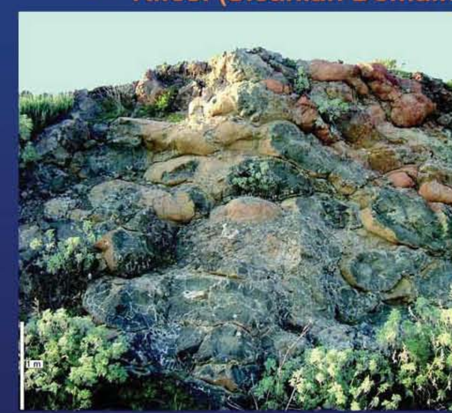


2D Mesozoic lithostratigraphy across the Sciacca paleomargin

2 Megarudites "Muso di Vitella" (Saccense Domain)

Large polyphasic dykes and giant clastic zones consisting of megarudites with elements of platform limestones in a matrix of grey-greenish ammonitic wackestone of Middle-Upper Jurassic age are common in the eastern sector of the Pizzo Telegrafo unit, pointing to an intense tectonic activity along the Sciacca paleomargin.

3 Basaltic pillow lavas Rifesi (Sicanian Domain)



Jurassic "within-plate" tholeites occur as pillow lavas associated to the Jurassic deposits confirming the tensile stress-field along the Sciacca paleomargin