Geological Field Trips

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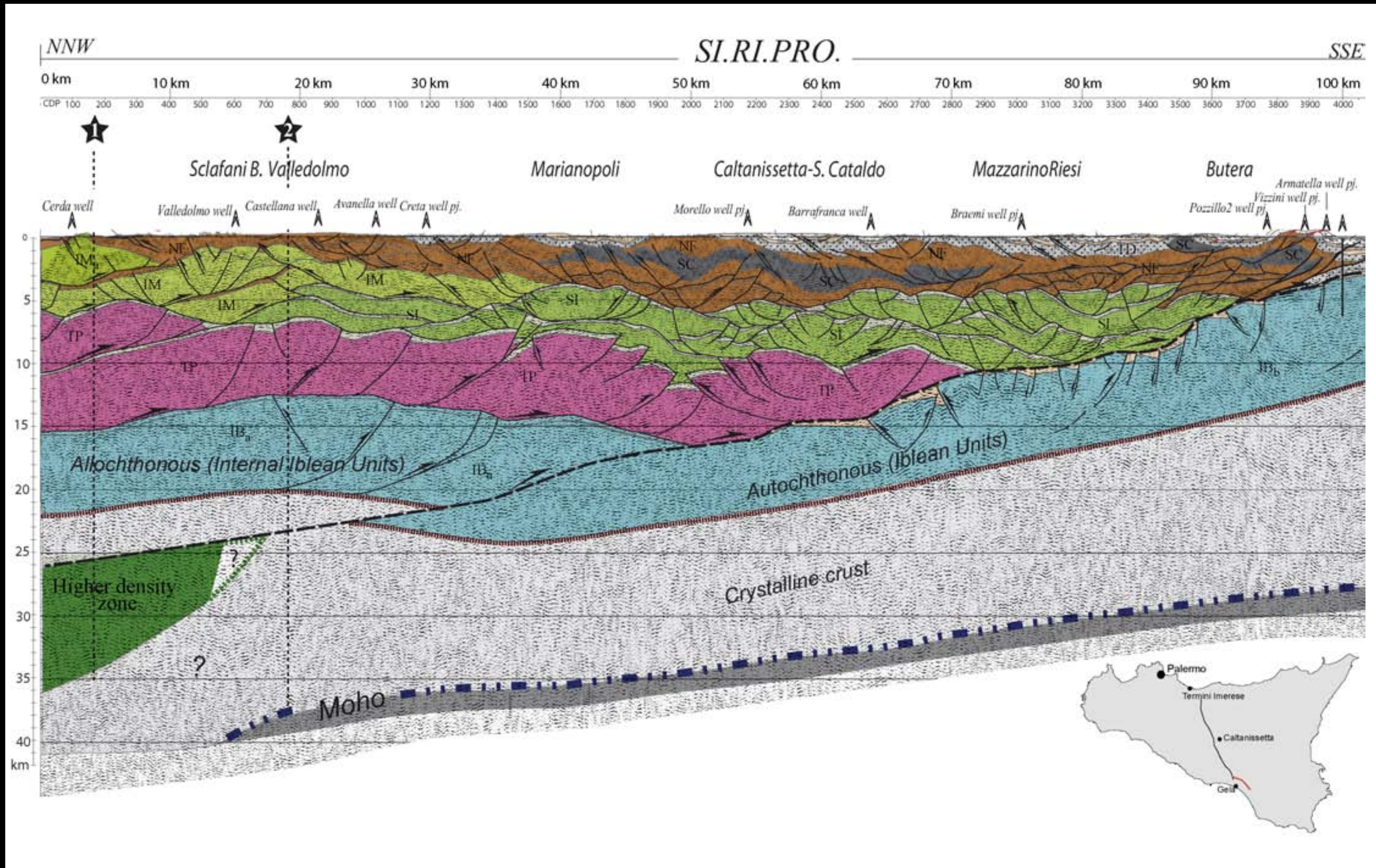
Organo Cartografico dello Stato (legge N°68 del 2-2-1960)
Dipartimento Difesa del Suolo



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Walking along a crustal profile across the Sicily fold and thrust belt

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Walking along a crustal profile across the Sicily fold and thrust belt

AAPG International Conference & Exhibition, 23-26 October 2011, Milan
Post Conference Field Trip 4, 27-29 October 2011, Palermo

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Safety

The aim of this document is to collate key information into a simple format for use by field and on-call staff in the event of an incident.

Safety in the field is closely related to awareness of potential difficulties, fitness and use of appropriate equipment. Safety is a personal responsibility and all participants should be aware of the following issues.
- The excursion takes place at relatively low altitude (less than 1000 meters). Most of the outcrops are along the road and we will not make long walks.
- All participants require comfortable walking boots. Trainers or running shoes are unsuitable footwear in the field.
- A waterproof coat/jacket is essential. In October, the weather is relatively stable although changes with rain are possible.

Participants should inform the excursion leaders (in confidence) of any physical or mental condition, which may affect performance in the field (e.g. asthma, diabetes, epilepsy, vertigo, heart condition, back problem, ear disorder, lung disease, allergies etc.).
- Special diets are available on request (vegetarian, etc.).
- Each vehicle will carry one basic first aid kit.
- Mobile/cellular phone coverage is good although in some places it can be absent.

Local Emergency Services

Outline what is available with contact No.
- Medical Emergency/Ambulance (valid all over Italy): 118
- Police (valid all over Italy): 113 or 112
- Fire Brigade (valid all over Italy): 115
- Local Medical Facilities: see nearest doctor or medical centre below.

Hospitals

Nearest doctor or medical centre:
Outline Facility name, address, contact numbers and capability for each phase of the trip (e.g. at Outcrop/on-route to activity etc).
Outline travel time - List Alternative options:

Day	Stops	Locality of the Stop	Hospital	Hospital address	Phone number
1st	1-4	Cerda-Scillato-Sclafani Bagni	**Osp. S.Cimino**	Via S. Cimino, 90018 Termini Imerese (PA)	0918151111
			Osp. S. Raffaele G. Giglio	C.da Pietra Pollastra, 90015 Cefalù (PA)	0921920111
2nd	1-5	Cammarata-Capodarso	**Osp. M. Immacolata Longo**	Via Dogliotti, 93014 Mussomeli (CL)	0934962219
			Osp. S. Giovanni di Dio	C.da Consolida, 92100 Agrigento	0922442111
			Ospedale S. Elia	Via L Russo, 93100 Caltanissetta	0934559111
3rd	1-2	Settefarine Piana di Gela	**Osp. V. Emanuele**	Via Palazzi 171, 93012 Gela (CL)	0933831111

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Accommodation

Address (24 Hr Contact numbers with Country code). Consider Early arrivals and late departures.

Day 1: Hotel Tonnara, Largo Tonnara S.S.113 - 90019 Trabia (PA). Ph.+39.091.8147976 e-mail: booking@tonnaratrabia.it
Day 2: Hote Villa Giatra, C.da Passo Barbiere Pantano SS 189 km 18.6 - 92022 Cammarata (AG). Ph. +39 0922905200, e-mail: info@villagiatra.it
Day 3: Hotel Riviera, Villaggio Pergusa, 21 - 94010 Pergusa (EN). Ph. +39 0935541267, e-mail: riviera.hotel@tiscali.it

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Riassunto

L'escursione proposta fornirà nuove conoscenze sull'evoluzione cinematica del sistema catena-avampaese e sulle geometrie crostali e loro rapporti con le strutture tettoniche affioranti in un'ampia fascia della Sicilia centrale.
La correlazione tra affioramenti e strutture sepolte sarà mostrato grazie ai risultati del profilo sismico crostale SI.RI.PRO. (nel filone dei profili CROP), recentemente acquisito nella Sicilia centrale, dalla costa tirrenica alla Piana di Gela.
Quest'ultimo ha fornito nuove conoscenze a) sul sistema di thrust carbonatici della catena settentrionale, b) sulla fossa di Caltanissetta, più profonda di quanto previsto, sulla geometria e natura dei corpi geologici ricadenti nella stessa, e c) sulla significativa flessura della crosta nell'avampaese ibleo.
Nei tre giorni di escursione saranno mostrati, lungo quattro transetti principali a decorso N-S, le Madonie occidentali con le successioni carbonatiche ed i bacini sintettonici miocenici, sistema a thrusts dei Sicani orientali, le strutture delle evaporiti messiniane, ampiamente diffuse in Sicilia centrale, i bacini di thrust-top, di piggy-back e di avanfossa del Pleistocene e l'avampaese ibleo deformato.
Recenti rilievi geologici e stratigrafie di nuovi pozzi per idrocarburi, combinati con analisi geofisiche (sismica a riflessione e a rifrazione, gravimetria e magnetotellurica) hanno prodotto nuove informazioni che si sono sommate al lavoro svolto dagli anni settanta dal leader più anziano e di recente dai suoi collaboratori.
La catena siciliana è un cuneo di accrezione costituito principalmente da unità tettoniche carbonatiche meso-cenozoiche di mare profondo, sovrascorse su carbonati di piattaforma, spesso 10 km. Questa pila tettonica mostra caratteri strutturali simili sia in Sicilia occidentale che orientale ed è ben illustrata nelle strutture affioranti tra i Monti di Palermo e di Sciacca nella Sicilia occidentale (Western Sicily bridge, Catalano & D'Argenio, 1978).

I dati preliminari del profilo crostale SI.RI.PRO., recentemente acquisito, consentono una ricostruzione crostale del sistema catena-avanfossa-avampaese della Sicilia centro-orientale precedentemente poco noto. Il profilo crostale SI.RI.PRO. permette una buona correlazione tra il settore occidentale e quello orientale della catena siciliana.
Pur convinti che molte problematiche geologiche debbano ancora essere risolte, questo itinerario ha lo scopo di stimolare il dibattito sulle questioni ancora aperte. Ad integrazione, si rimanda ai dati più recenti raccolti da alcuni di noi e brevemente illustrati nel capitolo "Regional geological setting" di R. Catalano.

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Confidiamo nel contributo nuovo che i risultati ottenuti porteranno nel campo delle ricerche energetiche e nella ricerca petrolifera, nonché nella valutazione delle risorse idriche e geotermiche.
Accanto agli aspetti geologici, le regioni attraversate dall'escursione offrono paesaggi belli e ben noti resti archeologici degli ultimi 3000 anni della storia siciliana.
I partecipanti avranno la possibilità di visitare i mosaici romani di Piazza Armerina per godere di un evento emozionante antico 2000 anni.

Parole chiave: Sicilia, strutture, stratigrafia, paleogeografia, ricostruzioni palinspastiche

Abstract

The field trip here proposed will provide new insights into the deep structures, their geometric relationships and the kinematic evolution of the chain-foreland system in a N-S large belt of Sicily.
Correlations between outcropping and buried structures will be performed showing the results of the SI.RI.PRO. crustal seismic profile recently acquired in Central Sicily from the Southern Tyrrhenian coast to the Gela field area. It has provided new insights on the a) embricated carbonate thrust system of the Northern chain, b) the huge, deeper than expected, Caltanissetta trough consisting of deep seated thrusts and nappes, and c) the dramatic flexure of the Iblean foreland crust.
The 3-days field trip will develop along four main N-S transects, to visit the W-Madonie Mountains shallow- and deep-water carbonates, the Eastern Sicanian thrust system, the Central Sicily widespread Messinian Evaporites structures- the Pleistocene thrust top basins and the deformed Iblean foreland.
Renewed field data and borehole stratigraphy combined with a geophysical approach (seismics, paleomagnetism, gravimetry, and magnetics) have been added to the work done since the seventies by the older leader and recently his coworkers.

The Sicily chain grew as an accretionary wedge mainly made up of basinal meso-cenozoic carbonate thrust sheets overriding a 10-km-thick platform carbonate thrust wedge. This thrust pile has common structural grain in both Western and Eastern Sicily and is well illustrated in the Western Sicily outcrops (Western Sicily bridge, Catalano & D'Argenio, 1978).

In Central Eastern Sicily the recently acquired crustal profile SI.RI.PRO. is able to give a crustal reconstruction of the FTB -foreland system in an area only recently investigated. The new crustal profile will be able to show a good comparison with the Western and Eastern side of Sicily FTB.
Conscious as we are that many geological problems must still be solved, this Field Trip has the aim of provoking debate that aptly relate to the observed features. To that end, the reader is referred to the most recent data collected by some of us and briefly illustrated in the “Sicily regional geological” setting by R. Catalano.
On the whole, the results obtained certainly lead to a new deal in the petroleum perspectives as well as geothermal and fresh water evaluation.
As well as their geology, the crossed regions offer beautiful landscapes and well known archaeological remains of the last 3000 years civilization in Sicily.
The participants will reach the Piazza Armerina Roman Mosaics to enjoy of a emotional event.

Key words: Sicily, Structure, Stratigraphy, paleogeography, palinspastic restoration

摘要

此次野外考察将提供一个全新的视角，观察西西里岛一个南北向较大条带内前陆盆地链的深部构造、它们互相的几何关系，以及运动学演化。
我们将运用最近获得的西西里中部从伊特鲁里亚（Tyrrhenian）南部海岸到杰拉（Gela）盆地的斯里普洛（SI.RI.PRO.）地震剖面的成果，进行露头和埋藏构造之间相关性探讨。在以下方面将会有新的见解：a)北部链的叠瓦状碳酸盐岩逆冲体系，b)比预期更大更深、由位于深层的逆冲推覆体组成的的卡尔塔尼塞塔（Caltanissetta）海槽，c)伊贝林（Iblean）前陆陆壳的强烈挠曲。
为期三天的野外地质实习主要围绕四条南北向的大剖面展开，包括：W-马多尼埃（Madonie）山脉的浅水和深水碳酸盐岩沉积，东西西里岛的逆冲体系，西西里岛中部广泛发育的米辛尼亚（Messinian）期蒸发岩构造—更新世逆冲系统顶部盆地和变形的伊贝林（Iblean）前陆。
年长的教授和他最近的合作者对该区的工作可追溯到上世纪七十年代，目前的工作中更引入了更新的现场数据、井眼地层学，以及地球物理方法（地震、古地磁、重力测量，以及磁力学）。
西西里岛链为一增生楔状体，主要由盆地中新生代碳酸盐岩逆冲席覆盖在一个一万米厚的碳酸盐岩台地形成的逆冲楔体上形成。逆冲体在西西里岛东西部均有共同的构造纹理，且在西部露头有很好的显示（西西里岛大桥，卡塔拉诺（Catalano）和阿根尼奥（D’Argenio, 1978）。
在东西西里岛的中部，近期的斯里普洛（SIPIPRO）地壳剖面可以对一个近期才开始做研究的地区内的FTB-前陆系统进行地壳重建。该地壳剖面可以很好地显示西西里岛FTB的东西部有很好的可对比性。
众所周知，仍有很多地质问题亟待解决，因此，我们组织了此次野外地质考察，旨在唤起对所观察到现象的讨论。为此，大家将会见到由我们近期收集的最新数据，卡塔拉诺（Catalano）将这些数据显示在区域地质背景中。
总体来说，这些结果无论对石油预测，还是地热和淡水评价，都有一定的启发。
考察涉及除了地质现象，还有美丽的地貌，以及举世闻名的体现西西里岛三千年前文明的考古文化遗产。
实习参与者将到达亚美林娜罗马马赛克广场（Piazza Armerina Roman Mosaics）享受动人之旅。

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Program Summary

First Day

The tour leaves the Trabia surroundings and leads eastward to the Madonie Mts.

Stop 1, will take place near the Cerda town to show a panoramic view of the Scillato Upper Miocene thrust-top basin deposits growing on its deformed substrate.

Stop 2, geometry, facies and structures of the Scillato basin will be observed in detail. Packed lunch in the field.

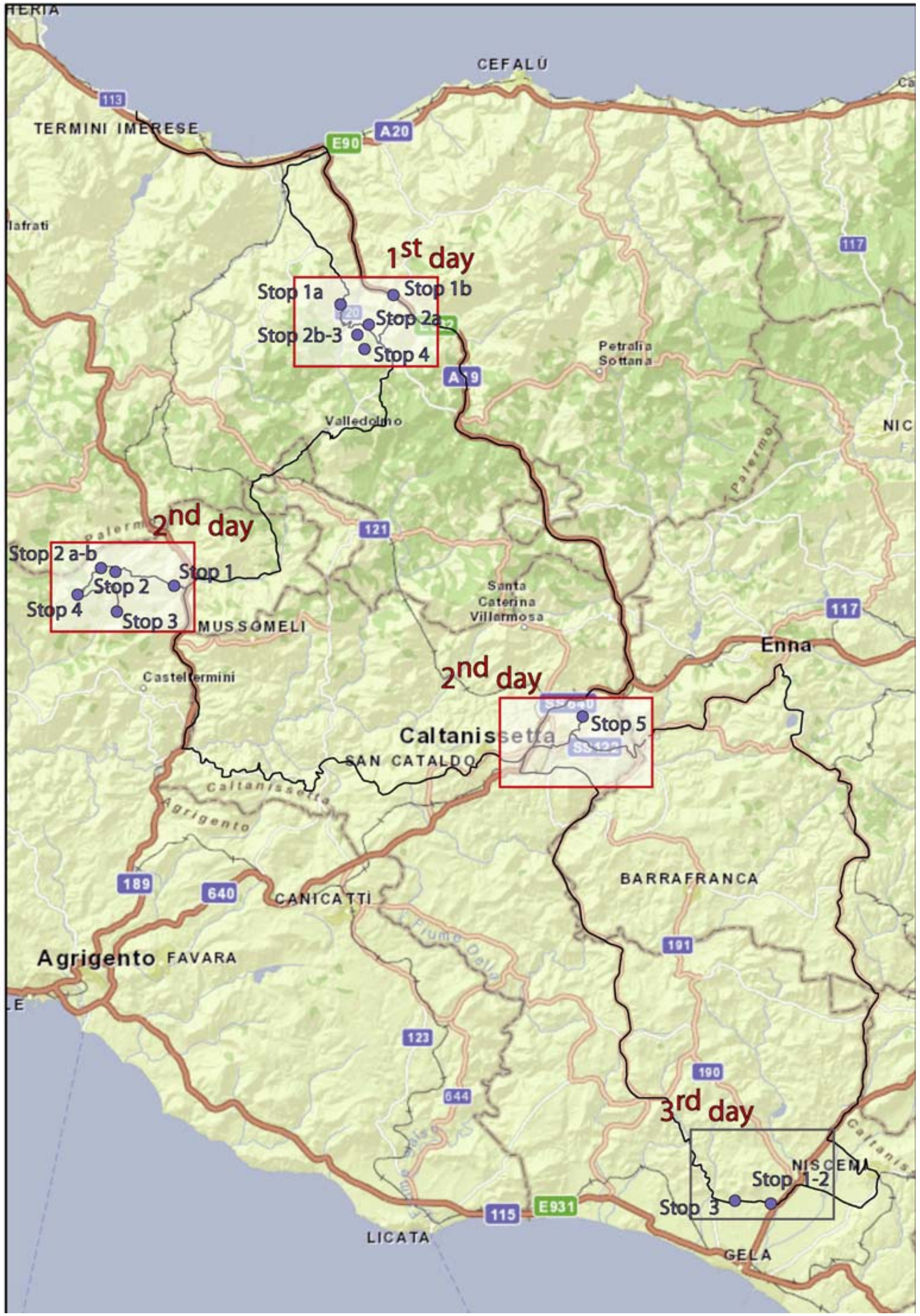
Stop 3, at Sclafani Bagni, will show a complete section of the Meso-Cenozoic Imerese deep-water carbonates and bedded cherts.

Stop 4, in the Valledolmo surroundings, will show the Numidian flysch turbiditic lithofacies and the correlation of the shallow structural setting to the subsurface structures seismically imaged by the SI.RI.PRO. crustal profile.

Second Day

Stop 1 is a visit to the Mesozoic carbonate deep-water section of La Montagnola to evidence the similarities with the Imerese Sclafani Bagni section.

Stop 2 is a walk along the Triassic-Miocene carbonate section of the Sicanian deep-water domain; comparison with the previously visited La Montagnola Imerese section wil be made to evidence the major differences between the two deep-water carbonate successions.



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Stop 3 will illustrate the tectonic relationships of the Cammarata Sicanian unit with the adjacent Meso-Cenozoic units. A comparison of the structural setting, as observed in outcrop and imaged in seismic profile, will be attempted.

Stop 4 focuses on an embricated thrust system and related folds, mostly involving Messinian evaporites, sited not very far from a recently drilled "Prospecting area".

Stop 5, close to the Caltanissetta town, shows the Capodarso section, exhibiting spectacular Quaternary sedimentary stacking pattern in the thrust-top basin fill. Synsedimentary tectonics deformation will be illustrated both on outcrop and seismic lines. The SI.RI.PRO. crustal profile will show the impressive crustal regional monocline plunging underneath the Sicilian thrust-belt.

Third Day

This excursion starts in the heart of Sicily with an exciting visit to the famous roman remains of Villa del Casale and its magnificent mosaics (Unesco heritage since 1997) sited in Piazza Armerina.

Stop 1 and 2, along the road to Gela, are devoted to both the foreland outcrop and the Gela Nappe front along the Settefarine thrust. Comparison with the subsurface setting, imaged by the SI.RI.PRO. profile, will show their evolution.

Stop 3, heading to the north, provides one of the best examples of a wedge-top basin developing on the Gela Nappe, as well as, its complex structural setting and the Messinian evaporite succession.

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Sicily's fold/thrust belt. An introduction to the field trip

Raimondo Catalano

This paper introduces the fundamentals of the Sicily mainland structure and stratigraphy, as acquired during more recent research campaigns. A list of open problems is presented taking into account the different Research contributions and comparing the results. In view of fact that the field trip develops along the chain-foreland system, in a wide N-S belt of Sicily, it will be performed mostly through the results of a crustal seismic profile recently acquired in Central Sicily (SI.RI.PRO. Project) from the Southern Tyrrhenian coast to the Gela offshore (Accaino et al., 2011). The project has provided new information about a) the embricated carbonate thrust system of the Northern Sicily chain, b) the huge, deeper than expected, Caltanissetta depression and c) the dramatic flexure of the Iblean foreland crust. For sake of clarity we will firstly describe the results as reached before the SI.RI.PRO. contribution (i.e. stratigraphic schemes and geological cross sections). The outstanding results of the SI.RI.PRO. Project do not really contradict the bulk of the previously regional knowledge, acquired by the Author and his co-workers, but add new insights into the deep structures, their geometric relationships and the kinematic evolution of the foreland fold and thrust belt, making correlations between outcropping and buried structures clearer.

1. The Apennines-Tyrrhenian system

Sicily is a segment of the Apenninic-Tyrrhenian System (see map in Fig. 1) whose upbuild refers to both the post-collisional convergence between Africa and a complex "European" crust (Bonardi et al., 2001) or AlKaPeKa region (for Alboran, Kabylies, Peloitains, Calabria, Boullin, 1986) and to the coeval roll-back of the subduction hinge of the Adriatic Ionian-African lithosphere (Doglioni et al., 1999; Faccenna et al., 2004; Chiarabba et al., 2005). This geodynamic process is believed to be also related to the two-phase opening of the Ligurian/Provençal basin and the Tyrrhenian Sea respectively (see Faccenna et al., 2002) and the continuing northward slow advance of the African lithospheric plate (Gueguen et al., 1998; Goes et al., 2004).
The system, on the whole, is the result of the juxtaposition of a) the E-ward and NE-ward vergent Southern Apennine segment (Patacca & Scandone, 2007); b) the Calabrian-Ionian sector deriving from the original drifting

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of the calabrian terranes above the Ionian Ocean (Finetti & Del Ben, 1986; Cernobori et al., 1996; Catalano et al., 2001; Finetti, 2005) and c) the Sicilian sector with its general southwards (SW to SE) vergency.
The main compressional movements, after the Paleogene Alpine orogeny, began with the latest Oligocene-Early Miocene counter-clockwise rotation of Corsica-Sardinia, believed to represent a volcanic arc, and its collision with the African-Adriatic continental margin (Bellon et al., 1977; Channell et al., 1979; Dercourt et al., 1986).
In this sector of the Mediterranean area, a southeastward subduction is indicated a) by a North-Northwest dipping Benioff zone (Caputo et al., 1970) west of Calabria and the Apennines, as deep as 400 km, and b) the related calc-alkaline volcanism in the Eolian Islands (Barberi et al., 1984). Subduction and thrusting

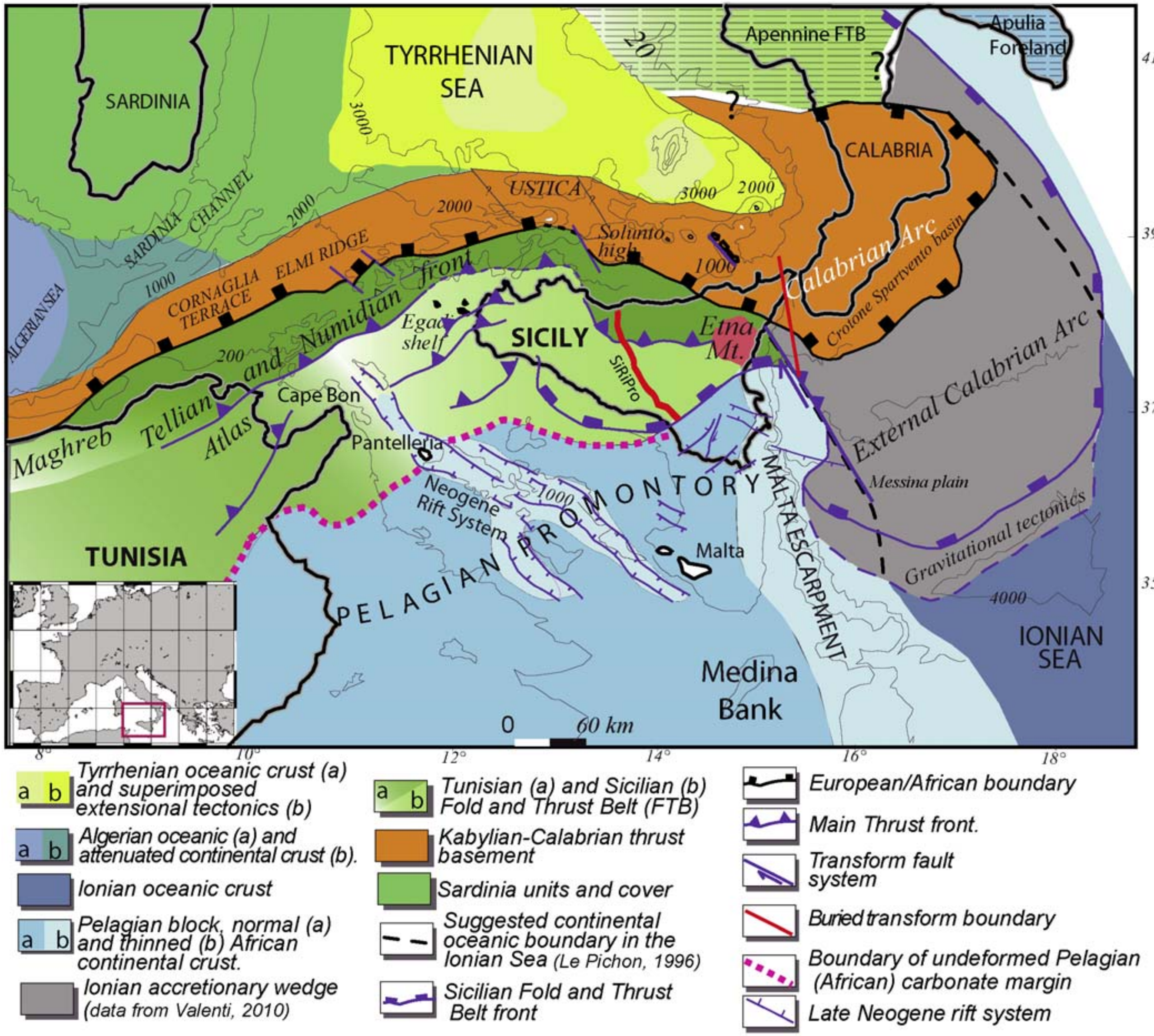

Fig. 1 - Schematic structural map of the central Mediterranean (modified after Catalano et al., 2000a; Catalano et al., unpublished data; Ionian detailed data from Valenti, 2010, 2011). Inset map shows the location of the study area.

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are contemporaneous with a back arc-type extension in the Tyrrhenian Sea (Malinverno & Ryan, 1986; Doglioni et al., 1999). The extension started about 8 My ago in the Western Tyrrhenian Sea, migrating east-south east-wards. The oceanic crust formed into two basins (Kastens et al., 1988), its age appearing to decrease towards the eastern Tyrrhenian Sea, is claimed to be synchronous with the radial southward migration of the adjacent orogenic belt.
The crustal geometry and the lithospheric slab kinematics of the Sicilian sector is poorly known since the crustal lateral continuity with the Ionian Oceanic slab is not well documented.
Chiarabba et al. (2008) noted the lack of consensus among different geodynamic models that range between two end-members: 1) a continuous arcuate slab underlying the Southern Apennine and Maghrebide salient (Doglioni et al., 1994) and 2) a seismically active Calabrian slab solely driving the whole back-arc zone evolution, being the Southern Apennines and Sicily only lateral rootless belts (Faccenna et al., 2004).

2. Location and growth of the Sicily orogen

Sicily links the Southern Apennine and the Calabrian Arc to the Tellian and Atlas systems of Northeastern Africa. The orogen is located in the centre of the Mediterranean (Figs 1-4), at the NE corner of the Pelagian platform of North Africa, and is tenuously connected across the straits of Messina with the Apennine-Alpine orogenic system of Europe (Fig. 1). Sicily is bounded to the east by the Ionian Sea of the Eastern Mediterranean, i.e. an oceanic basin that formed in the wake of the early Mesozoic (Catalano et al., 2001) or older separation of the Adriatic block from Africa (e.g. Stampfli & Borel, 2004). Offshore, to the north Sicily, is the Tyrrhenian Sea, a mid-late Neogene partially oceanic sub-basin of the Western Mediterranean basin (for a summary see Carminati & Doglioni, 2012).
The orogen of Sicily is known as having been formed in the context of the above mentioned complex south-southeastward subduction-rollback of a continental/transitional lithospheric slab (the African slab). This was associated first with the counter-clockwise rotation of Corsica and Sardinia, but more importantly with the counter-clockwise rotation of the now allochthonous basement-involved of the Calabrian/Peloritani Kabylian units, during the late Neogene (Faccenna et al., 2001).

Fig. 2 - Geological structural map of Sicily (modified after Catalano & D’Argenio, 1982; Catalano et al., 2000a, b; Catalano et al., unpublished data). The inset shows the structural map of the Central Mediterranean.

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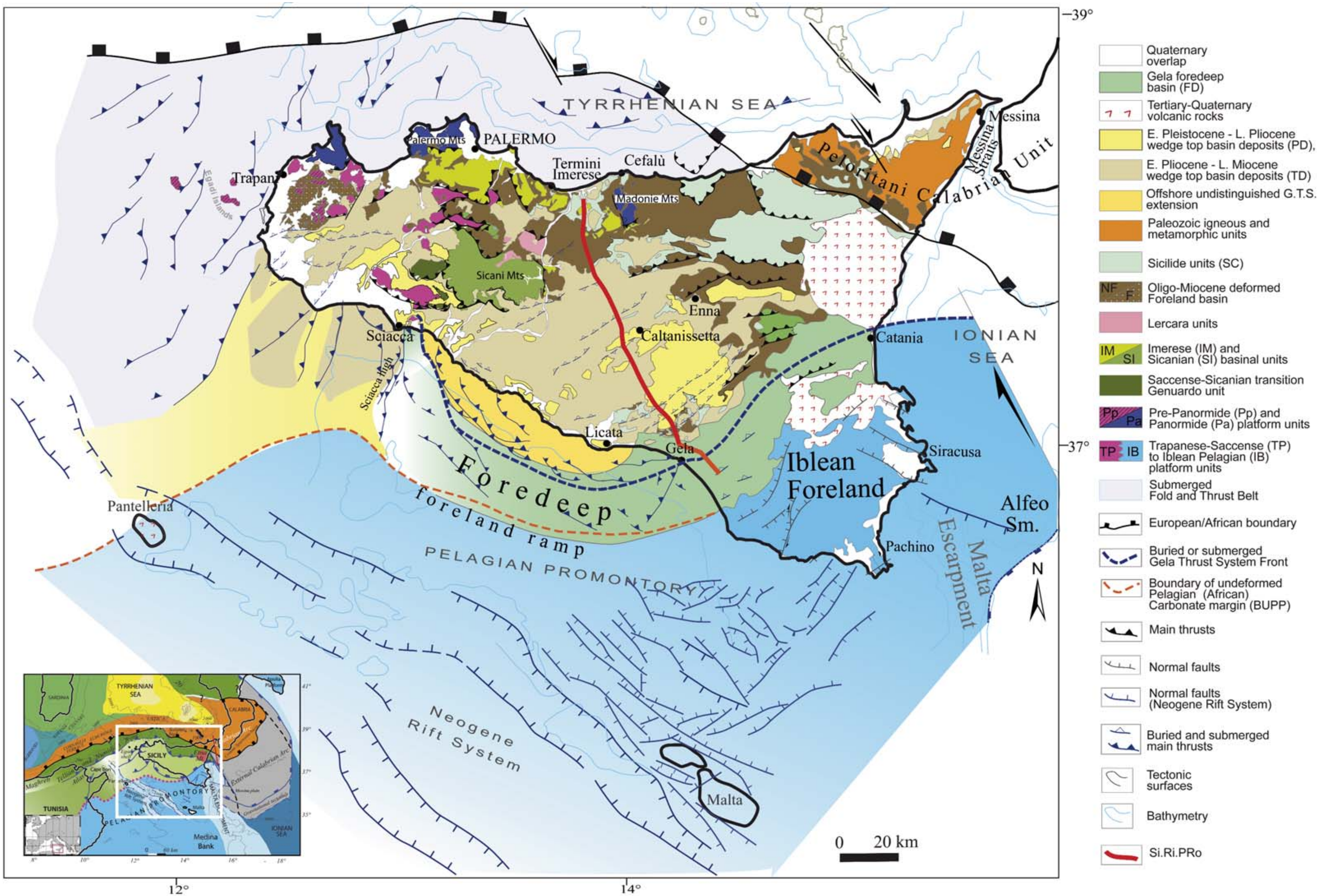

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Fig. 3 - Index map showing the bathymetry of Sicily offshore and the principal mainland localities.

The orogen prolongates westward, submerged between the Sardinia block and the Pelagian Platform across the Sicily Straits and the Egadi Islands (Figs 1, 2), northward, beneath the Central South Tyrrhenian, and eastwards into the Ionian Sea, where an accretionary wedge, deriving from the deformation of the sedimentary cover of the old Ionian Oceanic basin (Finetti, 1982, 2004; Catalano et al., 2001, 2005; Catalano & Sulli, 2006 and references thereafter), has been reconstructed based on the interpretation of several seismic profiles (Valenti, 2010, 2011 and references; Torelli et al., 2012 and references). In Figs 2, 4, Neogene thrust fronts (partly buried on land) are traceable into offshore structures, forming a generally arcuate and festoon-like trend (Catalano et al., 1989a).

2.1. Previous studies of the Sicily orogen

A number of qualitative descriptions for the tectono-sedimentary evolution of the collisional system is available for the Sicily mainland.
Based on regional facies studies and structural analyses carried out during the 70s (Broquet, 1970; Giunta & Liguori, 1973; Catalano et al., 1976, 1978; Mascle, 1979), the Western and Central Sicily fold and thrust belt was already known as a deformed embricate wedge of Triassic to early Pleistocene carbonate and siliciclastic rocks (Catalano et al., 1978; Patacca et al., 1979; Catalano & D'Argenio, 1982; Lentini, 1983; Montanari, 1989; Di Stefano, 1990; Grasso et al., 1978; Casero & Roure, 1994; Nigro & Renda, 2000). Several, recently published geological map sheets, compiled in the frame of the CARG Project in both the Western and Eastern Sicily areas have improved the knowledge with field details that do not contradict the general setting suggested by the well known large scale Structural Model of Sicily (Bigi et al., 1991).

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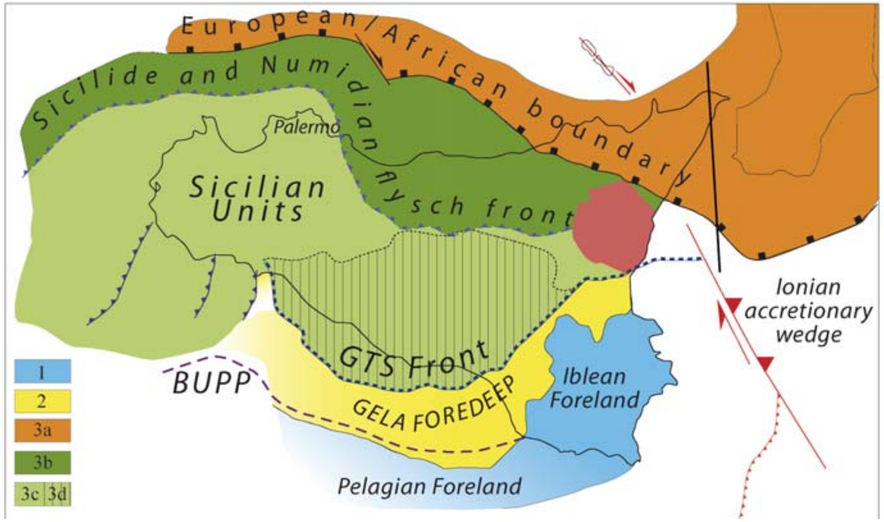

Fig. 4 - Main elements characterizing the collisional complex of Sicily. **1)** the undeformed Pelagian-Iblean foreland; **2)** the present-day foredeep; **3)** the orogenic wedge: the Calabrian-Peloritani units **(3a)**; the main FTB **(3b-c)** southwards buried by the Gela Thrust System **(3d)** in its turn partially covered by the Gela foredeep. **BUPP**: boundary of the Undeformed Pelagian Platform.

The timing of the thrust transport was first documented in Central and Western Sicily by the relations of syntectonic deposits in foreland basins. The nappe transport in Western Sicily is believed as beginning in the Early Miocene through the occurrence of syntectonic deposits (Catalano & D'Argenio, 1978, 1982; Mascle, 1979; Catalano et al., 1989). A contractional deformation was described as accompanied by the development of coeval foreland and foredeep basins (Catalano, 1987; Catalano et al., 1989; Oldow et al., 1990; Roure et al., 1990) also known as "piggyback basins" (Vitale, 1990) or "thrust top basins" (Lickorish et al, 1999) within the chain. Palaeomagnetic studies (Channell et al., 1990) associated with structural investigations (Oldow et al., 1990), confirmed, as previously suggested by Catalano et al. 1976 and Channell et al. 1980, that large-scale clockwise rotations of the thrust sheets had occurred during the late Miocene-Pliocene time interval, accompanied by a progressive shifting in tectonic transport from east to south (Oldow et al., 1990). Field studies in Eastern Sicily (Ogniben, 1960) were further illustrated by a north to south deep cross section (Bianchi et al., 1989; Lentini et al., 1991), running from the Nebrodi Mountains, Northern Sicily to the Iblean foreland. The section is calibrated by exploration wells and seismic data. Using the same borehole and seismic data of Bianchi et al. (1989), Roure et al. (1990) modelled a different structured geological section crossing eastern Sicily that implies hypothesized crustal wedging.

Catalano et al. (1989a, 1995, 1996, and references therein), Grasso et al. (1991), Lentini et al. (1991), Monaco et al. (1996), Nigro & Renda (1999, 2002) and Giunta et al. (2000) utilizing different methodologies and models have interpreted Western and Eastern Sicily as a thin skinned imbricate thrust wedge or as a thick skinned edifice (Finetti et al., 2005). Recently, Catalano et al. (1998, 2000) and Bello et al. (2000), who used several regional cross sections calibrated by deep ENI commercial seismic lines and geophysical modelling, demonstrated how the deep structures of both Western and Eastern Sicily are characterized by a common

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architecture, depicted by some main structural levels. Finetti et al. (2005) published contrasting interpretations of some seismic sections (already illustrated by Catalano et al. (2000) in Western Sicily and Bello et al. (2000) in Eastern Sicily) which were based on poorly documented surface geology and simply hypothesized crustal geometry of deep structures.
Regional facies analysis suggested palinspastic restorations (Catalano & D'Argenio, 1978, 1982a) of the Sicily Mesozoic tectono-stratigraphic assemblages, as characterized by carbonate to pelagic platforms and intervening basins. The lithotectonic assemblages now exposed in the orogen were related to some African margin palaeogeographical domains (Catalano & D'Argenio, 1978; Catalano et al., 1989a; Montanari, 1989; Oldow et al., 1990; Casero & Roure, 1994). At the end of the 80s, further studies of the "Paleozoic of Central Sicily" (the strongly deformed "Lercara fm"), relating to the Sicanian thrust sheets (Catalano & D'Argenio, 1982), yielded a new Permo-Triassic stratigraphy (Catalano et al., 1988). These studies provided data about the existence of a deep-water domain since the early Permian in Sicily that has been related to the Permian Tethys (Catalano et al., 1991a; Di Stefano & Gullo, 1997 and references thereafter; Vai, 2000). The acquired knowledge implied that rifting affecting this sector of the African margin dated back to the early Permian and, thus, offered new perspectives for the late Paleozoic-early Mesozoic palaeogeographical setting of the Western Tethyan region (Catalano et al., 1989b, 1991a; Bernoulli et al., 1990; Stampfly et al., 1990, 2004; Robertson et al., 1991; Blendinger et al., 1992; Finetti, 2005) in the frame of the main Mesozoic geodynamic evolution of the Central Mediterranean (Catalano et al., 2001).

2.2. Previous acquired geophysical data

Due to its complex tectonic setting, Sicily is geophysically characterized by a thick lithosphere of 120 km in the Mesozoic Ionian (oceanic?) basin that thins to about 80 km over the late Neogene Tyrrhenian basin center (e.g. Panza & Raykova, 2008). Two types of crust (thin anomalous Tyrrhenian and normal continental African) are known beneath the Sicily-Southern Tyrrhenian boundary (Fig. 5); values of the African Moho depth (based only on seismic refraction data) were reported from the Northern Sicily edge (Cassinis et al., 1969; Scarascia et al., 1994), the Caltanissetta area (Scarascia et al., 1994; Cassinis, 2003), the Iblean foreland (Chironi et al., 2000), as well from the Southern Tyrrhenian Sea (Scarascia et al., 1994).
New studies of 3 D Moho geometry (Di Stefano et al., 2011) provide information of the Moho depth in the Central Mediterranean (Fig. 5), and point out the location, at a depth, of the "Tyrrhenian Moho" interface just

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from the Marsili abyssal plain (where the mantle reaches about 10 km of depth) to the continent/oceanic transition, north of the Sicilian coast (where values of about 25 km are suggested). Moho topography beneath Central Sicily has been recently integrated

Magnetic basement depth values were inferred as 8 to 10 km beneath the Iblean Plateau, 10-12 km in Western Sicily, more than 12 km in the Caltanissetta area and about 12 km along the northern coasts of the Island (Cassano et al., 2001). These data now appear to underestimate the depth values, as new seismic reflection images and geological reconstructions suggest a deeper location of the top basement.

Heat flow values are generally low (50mW/m^{-2}) throughout the Mesozoic-Cenozoic carbonate units of the Sicilian FTB (Della Vedova et al., 2001). Higher values are present in the Iblean foreland (70mW/ m^{-2}) and in the Tyrrhenian Sea (more than 100mW/m^{-2}). Basaltic volcanism occurs in the Triassic to Cretaceous-Eocene rocks in Western Sicily as well as in the Iblean area rock successions (Patacca et al., 1979). Currently, basaltic volcanism is represented by the active Etna volcano which started its activity approximately 0.7 My ago (Gvirtzman & Nur, 1999). The Etna Volcano has been explained as resulting from the differential flexure or rollback in the subducting lithosphere beneath the Tyrrhenian Sea (Doglioni et al., 1999; Gvirtzman & Nur, 1999; Nicolich et al., 2000). Rifting volcanism has been forming along the Sicily Channel since the Pliocene (Finetti et al., 1986; Corti et al., 2006) suggesting a mantle rising in the Pantelleria Rift.

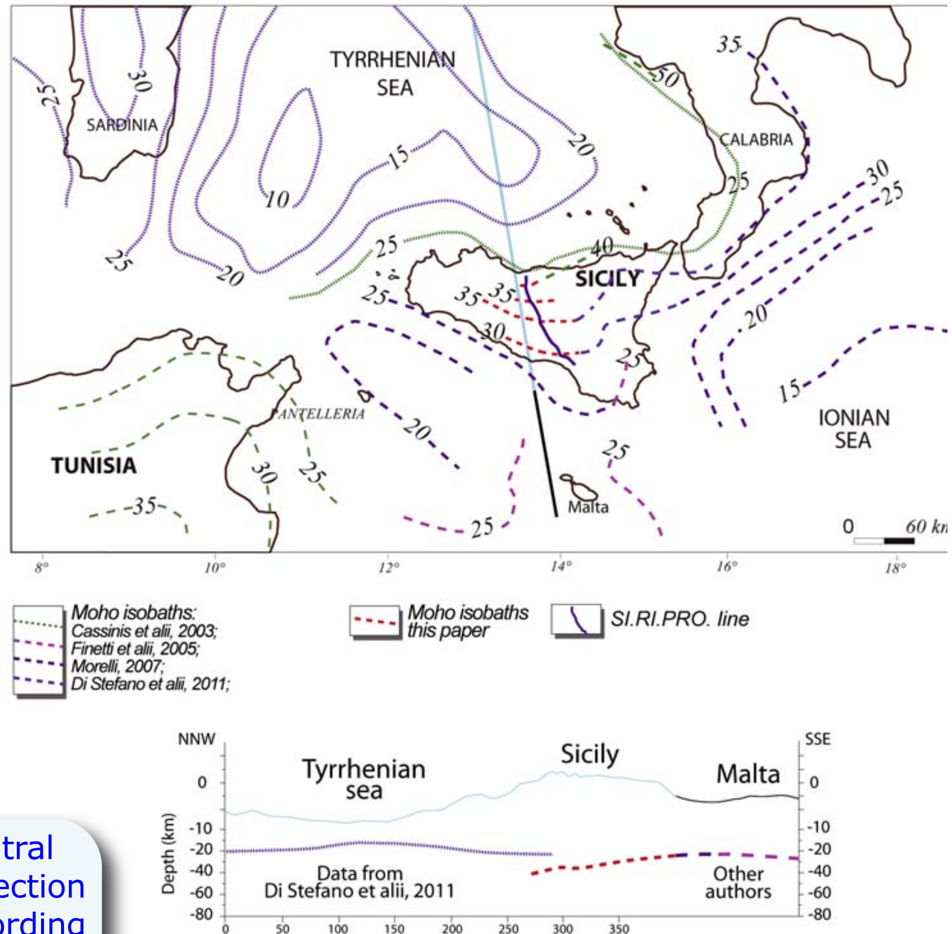

Fig. 5 - Map and contour lines of the Moho topography in the central Mediterranean region based on published data (above). Vertical section through the above Moho map after Catalano et al. (2012) (below), according to the SI.RI.PRO. data (Accaino et al., 2011; Catalano et al., 2012).

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Seismicity is defined by intense, recent, tectonic earthquake activity in Sicily and the surrounding areas. Offshore north Western Sicily, along an E-W trend, earthquakes have been frequent both during historical and also more recent times, indicating the Southern Tyrrhenian Sea as a tectonically active region (Fig. 6). The seismic sequences are characterized by shallow depth (< 15 km) low to medium magnitude (Pondrelli et al., 1998). The focal mechanisms of the major shocks are of a thrust type with horizontal compressive to transpressive axes generally N-S trending (Pondrelli et al., 1998; Agate et al., 2000); but a true vergence is still unknown. This seismic activity likely took place only in the sedimentary thrust pile of the submerged extension of the Sicilian FTB (Agate et al., 2000; Giunta et al., 2004; Vannucci & Gasperini, 2004). Known seismic events from the Northern-Eastern Sicily belt (Madonie to Peloritani Mts) and beneath the Caltanissetta basin, have been related to extensional/transtensional (Billi et al., 2009) or compressional mechanisms (La Vecchia et al., 2007). Reliable fault-plane solutions for the earthquakes are not indicative (at the moment), as there is no obvious expression of the tectonics on surface geological maps.

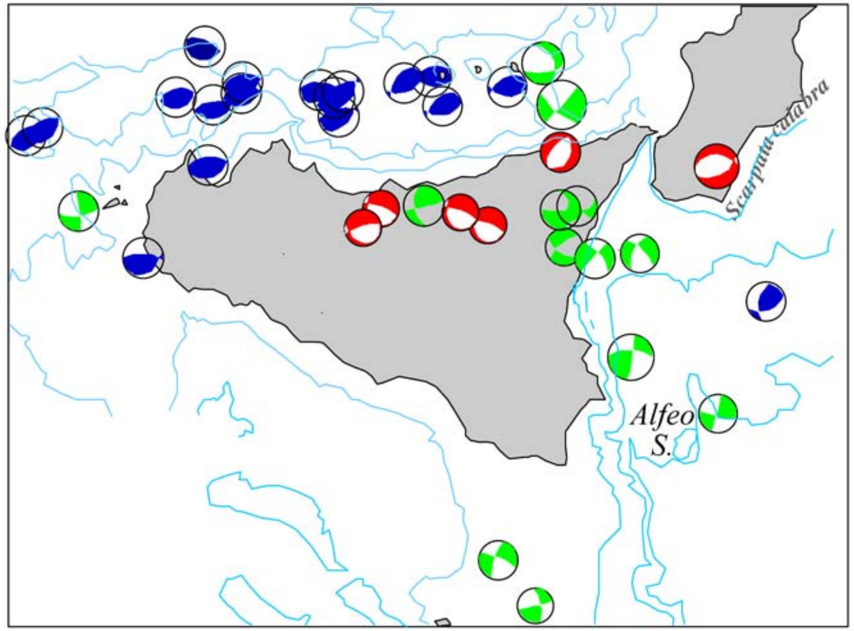

Fig. 6 - Map of CMT (1977-2003) focal solutions from area (after Pondrelli et al., 2006). Earthquake focal mechanisms with hypocentral depth < 50 km and Magnitudo > 4.0 are reported. Focal mechanisms with compressional regime (blu), strike-slipe regime (green) and extensional (red) are shown.

3. Stratigraphic/tectonic setting of Sicily

The data set collected from the more recently published and unpublished informations about the orogen of Sicily is presented here, utilizing some deep geological profiles crossing both Western and Eastern Sicily along preferred, North to South directions and mostly based on recent interpretations (Bianchi et al., 1989; Catalano et al., 1996, 2000, 2002, 2004; Bello et al., 2000, 2001) of several reflection seismic profiles (generously provided by ENI), integrated with the available stratigraphic and structural data (collected in the years by most of the Guide Authors), and calibrated by reinterpreted well logs (Basilone et al., this guidebook), as well as

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several recent geological map sheets 1:50.000 scale, mapped in the frame of the National CARG Project.
The stratigraphic and sedimentary characteristics of the different rock bodies exposed within the foreland fold and thrust belt (lithotectonic assemblages) discussed in next paragraphs are briefly summarized in the synopsis of Fig. 7. This outlines the Permian-Miocene pre-orogenic stratigraphy of most of the lithotectonic assemblages and the stratigraphy of the different Miocene-Pleistocene wedge top and foreland basin (foredeep) syntectonic deposits; both rocks-type are shown along the cross sections.
The structural grain, revealed by the comparison of the geological sections, helps to generate the simplified structural map of Fig. 4 that displays the said before main tectonic elements (foreland, foredeep and the complex accretionary wedge) and the surface distribution of the tectono/stratigraphic units with the aim to illustrate their structural relationship.
The new data and a further information from the adjacent areas (Northwestern Mediterranean margin of Africa, see Frizon de Lamotte, 2011 and references thereafter) suggests to abandon, in Sicily, the term "Maghrebian units", or "Sicilian Maghrebides" that is still largely used to include most of the Northern Sicily belt tectonic units (Sicilide, the thick Numidian flysch tectonic wedge, the Meso-Cenozoic shelf Panormide and basinal Imerese carbonate units, Amodio Morelli et al., 1986; Giunta, 1991; Catalano et al., 1996, 2000; Finetti et al., 2005; Giunta et al., 2007, among the others). Following Oliver et al. (1995) and Boullin (1986) and observing how most of the Maghreb is characterized by the Tell and Atlas systems, we find that much of Tunisia, south of the Tellian front, is well characterized as a fairly conventional folded belt, but the related rock lithologies are absent in the Sicily type thrust sheets, if we exclude the Numidian flysch wedge and the Sicilidi nappes originated in more internal domains (see later descriptions).
The Numidian flysch (Nf) units, outcropping in Northern Central and Eastern Sicily (Fig. 2) as a tectonic wedge, are known as laterally extending westwards, submerged in the straits of Sicily (Antonelli et al., 1992; Catalano et al., 1989, 1995) and outcropping in North Eastern Tunisia (Sami et al., 2010; Thomas et al., 2010). Consequently, we will correlate Sicilide and Numidian flysch units to the Tellian tectonic units (including the Nf), bounded by a common thrust front (Fig.1).

Fig. 7 - Schematic chronology of the main tectonostratigraphic events in Sicily as well as in the central Mediterranean, providing an overview of the many supra-regional episodes that affected the tectonic evolution of Sicily. Stratigraphy and original facies domains of the rock bodies deposited prior to the onset of Miocene deformation are also shown. Miocene-Pleistocene deformed foreland and wedge-top basin deposits, progressively involved in the deformation, follow upwards.

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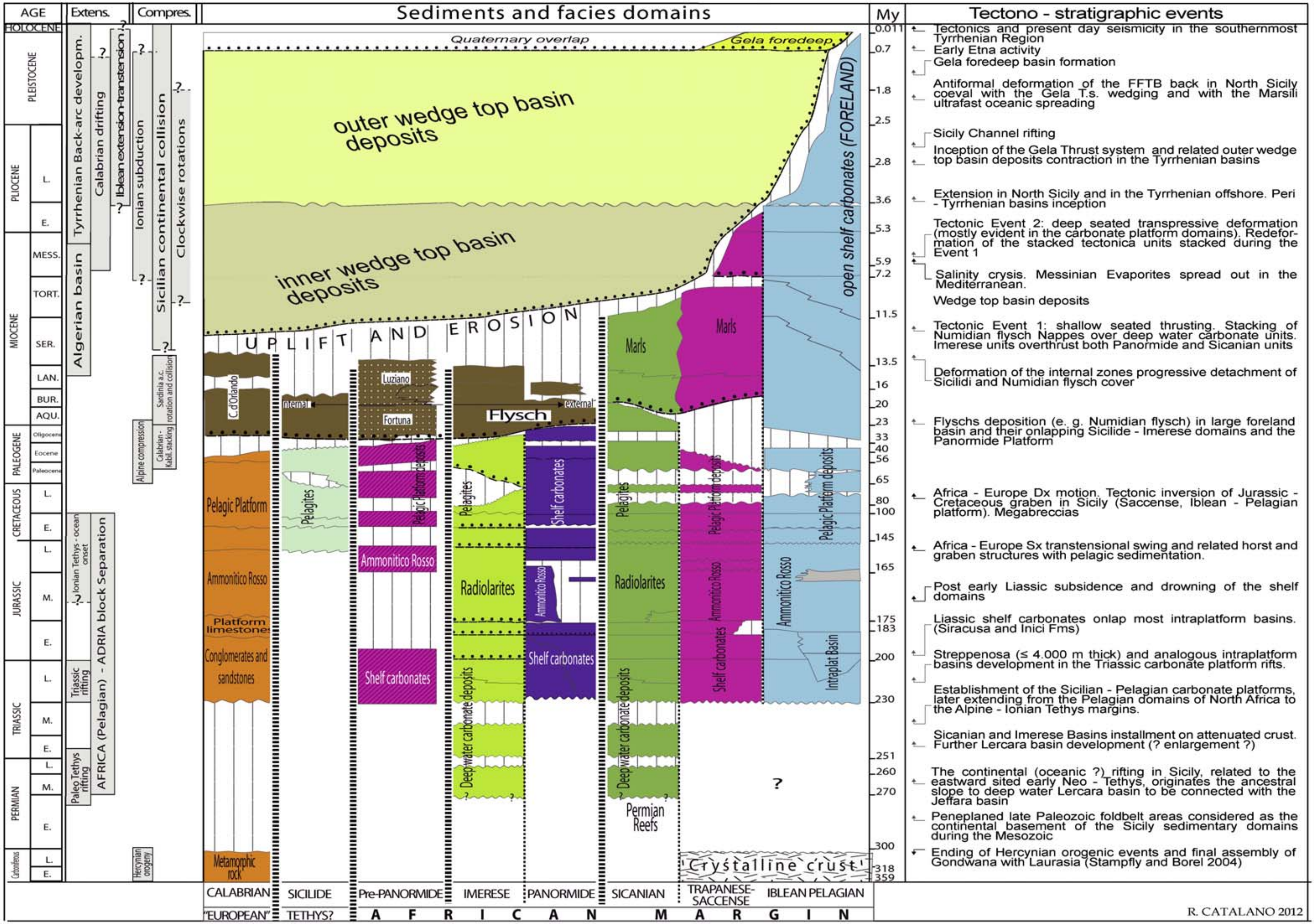

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The "Sicilian" carbonate units include rocks lying above, and detached from, the believed underlying Pelagian crust of African affinities, but are different from the rocks outcropping in Tunisia, to the south and overall to the north of the Tellian front (Sami et al., 2010).
As a consequence, in the collisional orogen of Sicily, we will identify and describe the Peloritani units, the Sicilide and Numidian flysch (Tellian" equivalent units) and the "Sicilian carbonate" units.

3.1. The geological cross sections and the structural grain

The structure of the mainland of Sicily is here illustrated by a number of deep geological cross sections crossing both Westen and Eastern Sicily from North to South. Most of them have been already published (Catalano et al., 1998, 2000a, 2004; Bello et al., 2000). Few have been recently drawn on the base of new field data (see the several CARG sheet maps) and seismic lines re-interpretations.
The geological transects, not always trending parallel to the main tectonic transport direction show nappes, ramp to flat units and duplex structures.
Schematically, the geological cross sections constrain a broadly accepted common architecture for the orogen of Sicily which is characterized by some extended main structural levels (Bello et al., 2000; Catalano et al., 2000a; see also Granath & Casero, 2006) stacked above the autochthonous Iblean foreland crust or its westwards lateral extension (the mildly deformed Saccense successions), located in coastal to offshore Southwestern Sicily (Fig. 2, Pls I-III).
The highest structural level is the Calabrian (Peloritains) backstop wedge (Fig. 2) which overlies a wedge formed by the Mesozoic-Paleogene Sicilide nappes stacked over deformed terrigenous Oligo-Miocene Numidian flysch. The underlying level is a wedge of mostly warped, originally flat-lying Meso-Cenozoic deep-water carbonate thrust sheets (Imerese and Sicanian units) and Miocene terrigenuous; this one overthrusts the lowest level resulting from a Meso-Cenozoic mostly carbonate platform, S-vergent imbricate fan (Pre-Panormide and Panormide, Trapanese-Saccense and internal (present-day north) Iblean units) forming the main bulk of the Sicily FTB. Progressively deformed, upper Miocene-lower Pliocene clastics, evaporitics and pelagics that filled the inner wedge top basins (Pls I-II), unconformably seal the whole underlying tectonic units. These rocks are later involved to build up the Gela Thrust System (the frontal body of the FTB) that, in turn, is overlain by the Plio-Pleistocene "outer" wedge top basin deposits. The Gela Thrust System thins towards both the Iblean foreland and the offshore Southern Sicily, where it is submerged beneath the Pelagian Sea.

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Plate I

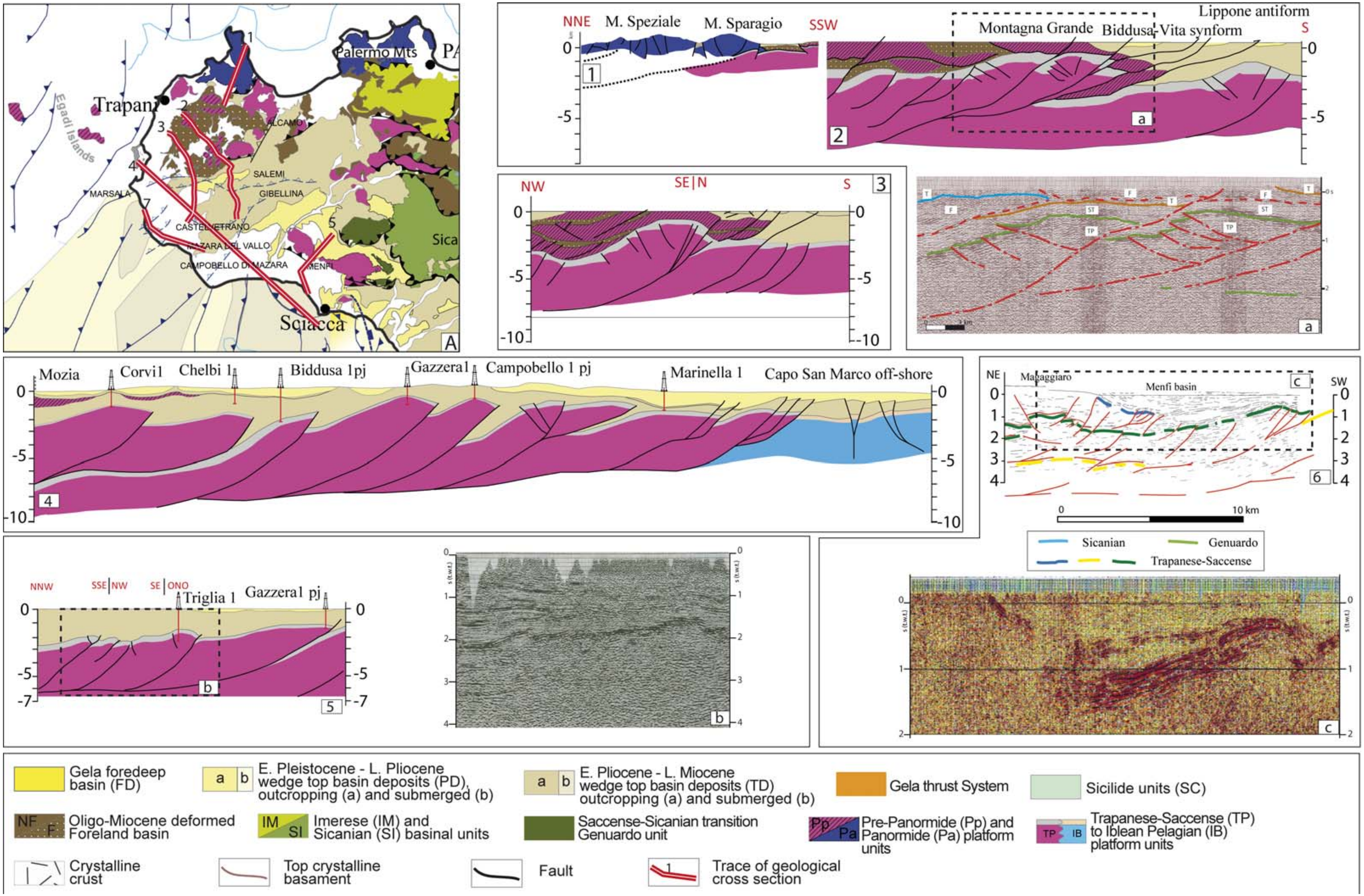

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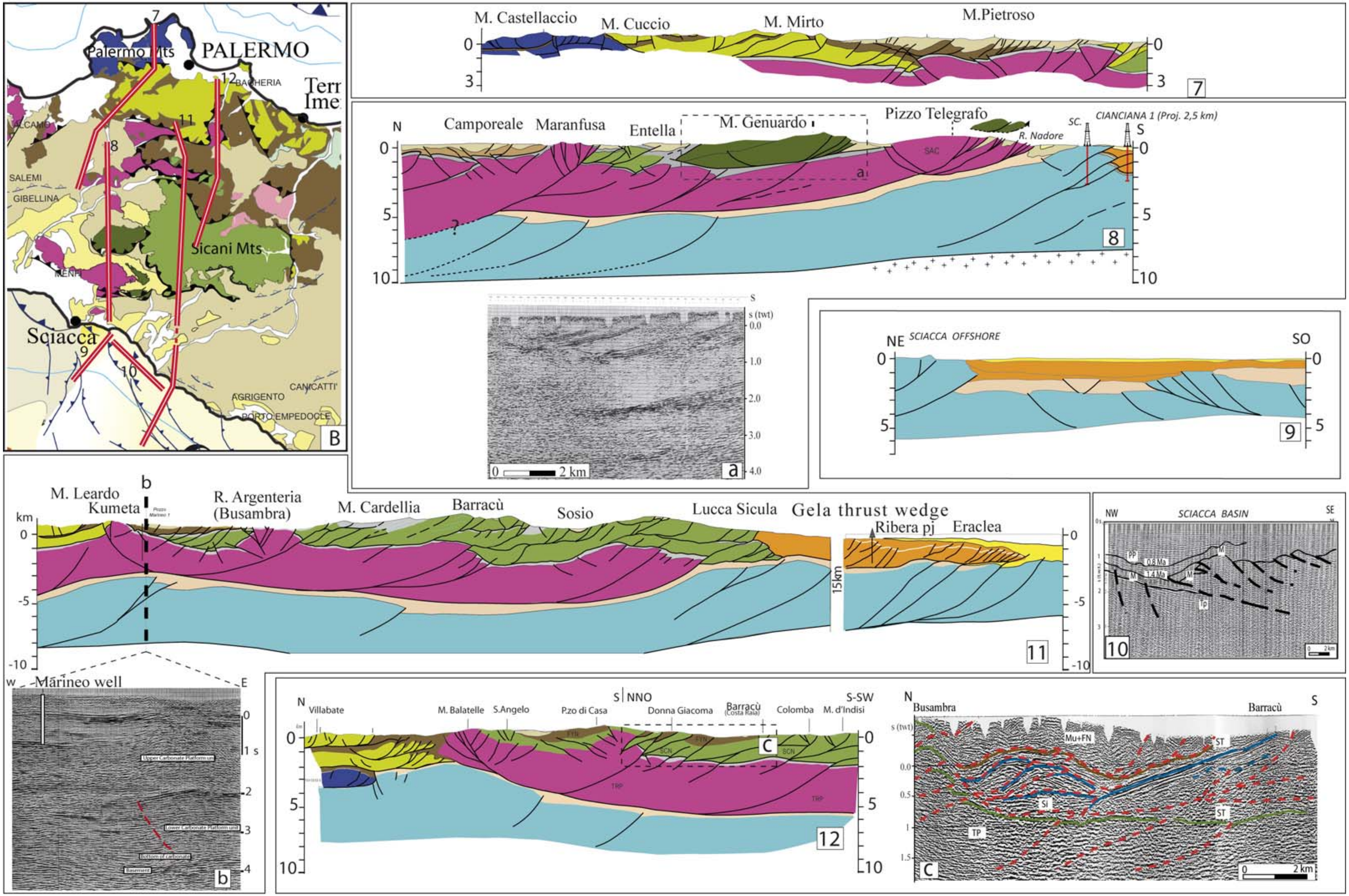
Plate II



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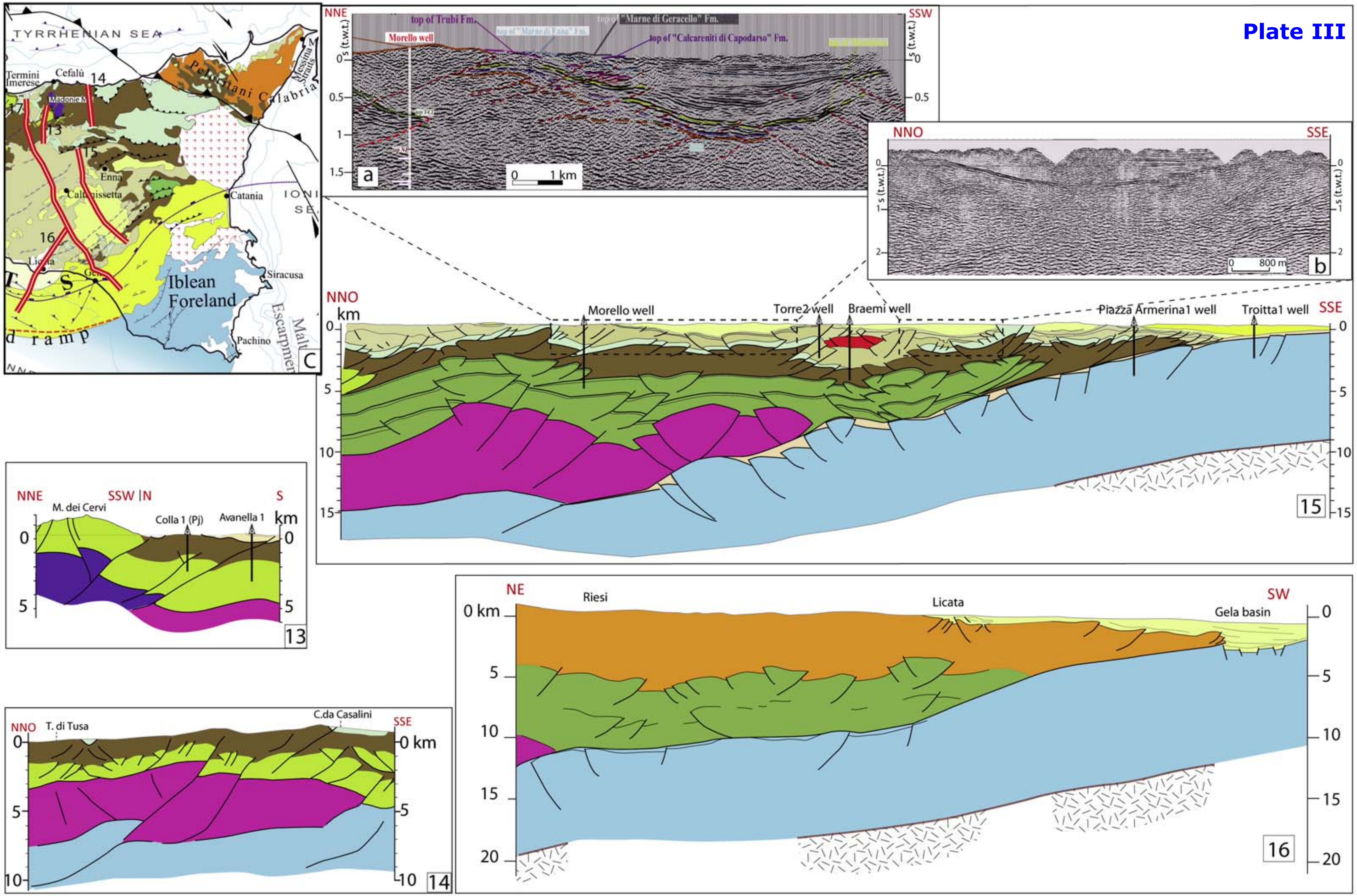

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Plate I - A Western Sicily map including the traces of the cross-sections. **1)** The sections show the geometry relationship between the Panormide and Trapanese units. **2)** Balanced cross-section showing the internal geometry of the Trapanese thrust wedge (see seismic profile in a) underthrusting the Panormide units and their late re-imbrication during the Pliocene. **3)** Balanced cross-section of the Trapanese and Pre-Panormide thrust wedge. **4)** A WNW-ESE transect crossing land and sea and showing the internal structure of the Saccense units. **5)** Saccense deformed foreland. Details of the Pliocene-Pleistocene tectonics as shown by the seismic line (b). **6)** the section crosses the south-western Magaggiaro ridge that bounds the Plio-Pleistocene Belice and Menfi basins (from Catalano et al., 1996, 2000a, 2002; Albanese et al., 2013).

Plate II. The cross-sections illustrate from North to South the structure of the Western Sicily Bridge (from Palermo to Sciacca offshore). **7)** The section partly based on field data shows the main structure of the Palermo Mts confirming the occurrence of the basinal Imerese unit above the Panormide and Trapanese carbonate thrusts wedge. **8)** The section shows as the before illustrated structure develops southwards involving a thick carbonate wedge (Saccense and Monte Genuardo units) towards the southern coast offshore. **9)** The section covers the Sciacca offshore illustrating the submerged carbonate platform structure characterized also by a backthrust. The carbonate stack is well constrained by a seismic line (a). **10)** The geoseismic section shows the relationships between the Gela foredeep northern end and the Gela thrust wedge. **11, 12)** The cross-sections show as the Imerese (to the north) and the Sicanian (to the south) basinal thrust sheets overthrust the platform carbonate thrust wedge (see (b) and (c) for details on seismic grounds). The relationships between the carbonate thrust wedge and the Gela Thrust System are shown on the offshore (from Catalano et al., 2000a, 2004, 2013 and unpublished data).

Plate III. C) Eastern Sicily map. The geological cross sections reveal the structural pattern of the Eastern Sicily. **13** and **14)** Illustration of the Madonie-Nebrodi Mts structural setting showing the Imerese thrust sheets above the carbonate platform thrusts wedge. Pliocene tectonics generate envelopment structures. **15)** The section built up from land and seismic data crosses the central Caltanissetta area showing from the top: the wedge top basins (see (a) and (b) seismic lines), growing on Neogene and Pliocene deposits (the Gela Thrust System) that overlie the main carbonate thrust wedge, in its turn, overthrusting the buried Iblean foreland regional monocline. **16)** Geoseismic section south-westward vergent crossing the undistinguished Gela Thrust Wedge including its thrust front-foredeep seated in the Pelagian offshore. Basement top constrained by the SI.RI.PRO. and CROP Sea lines (from Catalano et al., 2000a, 2004; Ghielmi et al., 2011; Valenti et al., 2013 and unpublished data).

Considering all the data, described schematically before, Sicily appears as formed by three main tectonic elements: the foreland, its recent foredeep and the orogenic wedge. The latter one, a stack of supracrustal strata décollements (main FTB) consists of several thrust systems (structural stratigraphic units) among which the South and South-East verging Gela Thrust System appears the most impressive. To shed light on the structure, sedimentary evolution and paleogeography of the tectonic elements, stratigraphy and tectonics of their rock successions will be illustrated here in detail.

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4. The main Tectonic Elements

4.1.The undeformed foreland

The foreland region is exposed in South-Eastern Sicily (Iblean Plateau, Figs 2, 4) and continues southward offshore into the Sicily Channel-Malta area and the Western Sicily Channel (Pelagian Sea, Fig. 1). The autochthonous sedimentary cover overlying a shallow-seated basement top (nine to ten km deep, Finetti, 1984; Catalano et al., 2000a, 2013; Chironi et al., 2000) consists of a thick Triassic-Liassic shelf carbonate, including heteropic rifted basin carbonates, overlain by progressively deeper marly carbonates of Jurassic-Eocene age (Fig. 7). Uppermost Cretaceous Rudistid reefs and Eocene larger foraminifera banks growing on volcanic seamounts (Catalano & D'Argenio, 1982) are known from the eastern side of the Iblean Plateau. These deposits are followed upwards by Oligocene-Lower Tortonian open shelf carbonates and clastics (Grasso et al., 1991; Pedley & Grasso, 1992), locally replaced by Upper Miocene reefoidal *Porites* limestones. Thin evaporites unconformably follow upwards covered by an ubiquituous sedimentary prism of the Trubi Fm. and younger clastic carbonates progressively involved in the adjacent foredeep sedimentation. A detailed stratigraphy, as schematized in Fig. 7, is based, among others, on the papers of Patacca et al. (1979), Catalano & D'Argenio (1982), Lentini (1983), Bianchi et al. (1989) and Montanari (1989). The Iblean carbonate foreland extends, beneath the thrust stack, to the Northern Sicily and offshore (following Catalano et al., 1995, 1996) where it is the allochthonous internal Iblean unit as confirmed by recent geological cross sections (Bello et al., 2000; Catalano et al., 2000a; Finetti et al., 2005). No rocks older than the Upper Triassic are known to lie above the not yet deformed crustal basement. The Pelagian foreland and its onland Iblean extension have been extensively investigated by oil exploration (Bianchi et al., 1989; Granath & Casero, 2006 and references thereafter). The region underwent the typical evolution of a sunken continental margin in the Mesozoic. Moreover, shape and dimensions of the paleogeographic domains in the region are still preserved (Patacca et al., 1979; Ismail-Zadeh et al., 2003).

The Pelagian-Iblean foreland basement wedge (African basement) is largely believed to be pre-Permian in age (Fig. 7). This crust is firmly connected (or slightly counterclokwise rotated of few degrees during the Plio-Pleistocene (Besse et al., 1984)) with Africa. The sector is bounded to the east by the believed to be oceanic Ionian crust (Fig. 1); consequently the present-day Iblean-Malta foreland is considered a remnant of a Jurassic

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(or older) passive continental margin with its oceanic abyssal plain located in the adjacent Ionian Sea (Catalano et al., 2000a, 2001 and references therein; see also Chamot-Rooke et al., 2005; Finetti et al., 2005; Valenti, 2010, 2011; Polonia et al., 2012 and Valenti, this guidebook).

4.2. The present day Gela foredeep

A latest Pliocene-Pleistocene, mostly north-west-dipping, foredeep, develops from the NNE-SSW Iblean boundary onshore to the Southern and Southwestern-Eastern part of Sicily offshore (Figs 1, 4). In the offshore the foredeep is physiographically represented by the adjacent Sciacca and Gela basins. The Gela foredeep has a narrow (less than 20 km) and elongated depozone extending along the Southern Sicily offshore and turning to the north, where it is bounded, to the west, by the N-S Sciacca offshore Meso-Cenozoic carbonate tectonic high (Figs 2, 4). The outer margin of the basin flanks the uplifting faulted Iblean Plateau to the east: to the south it corresponds to the foreland ramp structure, regionally including the Malta tectonic high (Figs 1, 2). The depression is weakly deformed as well as the NW-dipping foreland ramp involved in a very recent slightly compressional and extensional deformation (Fig. 2 and Ghielmi et al., 2011). The basin developed from the Late Pliocene (Gelasian stage) onwards, as suggested by biostratigraphic analyses (Di Stefano et al., 1993; Ghielmi et al., 2011); it was originally attributed to the inflection of the carbonate substrate related also to the frontal nappe loading (Catalano et al., 1993). The basin fill consists of Uppermost Pliocene-Pleistocene pelagic marly limestones, turbiditic sandstones and sandy clays (see also Ghielmi et al., 2011, for an interesting depositional reconstruction of these productive sediments) unconformably overlying the Messinian evaporites and older deposits.

4.3. The fold and thrust belt

Integrating both the geological cross sections and the geological map data, the Sicily orogen appears well exposed along the N-S “Palermo to Sciacca bridge” (see Catalano & D’Argenio, 1978) and the Northern Sicily mountains belt (Figs 2, 3) that extends from the Peloritani to the Nebrodi-Madonie, Palermo Mountains, and, further west, to the S. Vito Peninsula Mountains. The southward extension of this belt is mostly buried in Central Eastern Sicily beneath the Gela Thrust System (GTS since now) and the Plio-Pleistocene deformed wedge top basins. The main components of the FTB are described below illustrating the main stratigraphic and tectonic characters.

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4.3.1. The Peloritani units.

Stratigraphy. The sedimentary successions involved in the Peloritani thrust wedge, exposed in the North-Eastern corner of Sicily, are known as pertaining to the northern margin of the Tethys. They consist of thin veneers of a mostly carbonate Mesozoic-Cenozoic sediments, covering crystalline rocks, and of carbonates of uppermost Triassic to Paleogene age lying above metamorphosed crystalline Paleozoic basement units (Longi-Taormina unit, Lentini & Vezzani, 1982; Olivier et al., 1995). The carbonate successions (Fig. 7) are unconformably overlain by Oligocene-Miocene syntectonic terrigenous deposits (flysch di Capo d'Orlando).

Tectonics. The Peloritains units (as part of the AlKaPeCa (Boullin, 1995) or Kabilian-Calabrian Arc) are also known as "the European" tectonic element. The thick-skinned allochthonous Hercynian crystalline rock units structured in three main nappes (Duée, 1969; Amodio Morelli et al., 1976 and more recently Bonardi et al., 2001; De Capoa et al., 2004) are superimposed on a wedge of thick-skinned thrust sheets made of very thin metamorphosed crystalline Paleozoic basement slices, covered mostly by the Longi-Taormina carbonates and clastics.

The Peloritani units extend westward beneath the Southern Tyrrhenian Sea (Fig. 1 and Catalano et al., 1985, 1989; Finetti, 2005; Pepe et al., 2005) and are submerged in the Ionian Sea eastwards (Catalano & Sulli, 2006; Valenti, 2010 and reference therein). Their present-day setting is believed to be the result of a SE "tectonic drifting" of the Calabrian block following the Tyrrhenian back arc opening; its final "docking" (Goes et al., 2004) with Southern Apennines and Sicily is dated to be as old as about 1 My (Fig. 7). Their timing of compressional deformation and internal thrusting is generally believed to be late Paleogene (Fig. 7); their emplacement onto the African continental margin is assumed to be late Miocene (Duée, 1969; Amodio Morelli et al., 1976; Bonardi et al., 1980; Finetti et al., 2005). The crystalline units are believed to merge along a sole thrust lying above the Sicilide nappe units (Ogniben, 1960; Lentini et al., 2002). Unfortunately, no useful subsurface data are known to figure out the depth location of this important structure.

4.3.2. The Sicilide nappes and Numidian flysch wedge stack (Tellian-equivalent units).

Stratigraphy. The Sicilide rock section (Fig. 7) consists of Uppermost Jurassic-Oligocene deep-water carbonates and sandy mudstones (Monte Soro unit, North-Eastern Sicily), Cretaceous to Eocene "Argille Varicolori", Eocene-Oligocene, pelagic to allodapic limestones (Polizzi fm), Oligocene to early Miocene volcaniclastic arenites (the Tusa Tuffite Fm) unconformably overlain by the volcaniclastic Reitano flysch, of

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either Langhian or Serravallian age (De Capoa et al., 2000, 2002). The Troina Tusa flysch (Troina Tusa nappe), a micaceous sandstone with volcaniclastic intervals is coeval with the Numidian flysch and crops out in northeast and Central Sicily (Lancelot et al., 1977; Barbera et al., 2009). A lower Mesozoic sedimentary substrate is unknown either in the outcropping or buried successions of the Sicilide domain. Based on the present-day structural setting and the stratigraphic characters, these rocks have been deposited in a domain comprised between the advancing AlKaPeCa and the African continental margin. The larger part of the Numidian flysch has been later deposited in such a domain as generally invoked by most Authors.

Tectonics. The Sicilide thrust nappes are widespread in Northern and Eastern Sicily (Fig. 2) where these repeated imbricated slice stacks reach their greatest thickness (Pls II-III). The Monte Soro and Troina Tusa units (Ogniben, 1960; De Capoa et al., 2002 and references thereafter) are believed by some Authors (Roure et al., 1990, among the others) to be a "Tethyan" derived thrust element. The Troina Tusa nappes structurally rest above (and to the north) of the Numidian flysch units.

4.3.2a. The Numidian flysch Domain.

Stratigraphy. Terrigenous, mostly turbiditic, rocks are included in two well known formations: the Numidian flysch s.s. and the Tavernola fm (Catalano et al., 2000a). The Numidian flysch consists, starting from the bottom, of a facies association of mudstones and arenites with breccia intercalations (whose elements are mostly shallow-water derived carbonates), quartzose sandstones and conglomerates with clayey intercalations (see also Johansson et al., 1998). These deposits, dated as Late Oligocene to Aquitanian-Burdigalian, are followed, through a sharp unconformity, by sandy and clayey pelites with abundant glauconite and mica (Tavernola fm, Langhian-earliest Serravallian in age). The formation is well exposed in Northern Sicily, from the Palermo Mts to the Nebrodi Mts Field geology, sedimentology and physical stratigraphy suggest how a part of the Numidian flysch l.s. lies paraconformably above the Oligocene mudstones of the deep-water Imerese domain and unconformably onlaps (downlaps) the Triassic to Oligocene Panormide section (Fig. 7 and Pl. II). Most of the Numidian flysch sedimentary prism appears detached also from its external carbonate substrate; only the lower part of the section at place remains linked to its original external substrate (the probably sunken, at that time, Panormide carbonate platform and the Imerese basinal domains). In a Western Mediterranean frame, this rock unit is a part of the Numidian flysch deposited in a large and W-E directed depression ("Maghrebian Flysch Basin" MFB, Frizon de Lamotte, 2000) during the Upper Oligocene-Lower

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Miocene (Langhian) time interval. This basin was comprised between the southward advancing AlKaPeka tectonic wedge (Durand Delga, 1980; Olivier, 1986) (during early to middle Miocene) and the North African passive margin.

Tectonics. The Numidian flysch thrust stack developed after Langhian times and is sealed by Serravallian-Tortonian syndepositional clastics (Castellana Sicula unit, Catalano et al., 1989a, see Fig. 7). The units form, regionally, a southwards embricate wedge "sandwiched" between the Sicilide units (at the top) and the Mesozoic carbonates thrust stack (at the bottom, Pls II-III). The tectonic wedge overthrusts also the more external Trapanese and Sicanian units, progressively southwards; the southern extension of the Numidian flysch and the Sicilide thrust systems are buried beneath the Caltanissetta Pliocene-Pleistocene wedge top basins or are involved in the deformation of the Gela thrust wedge towards the south (Fig. 2).

4.3.3. The Sicilian carbonate thrust units.

Stratigraphy. The "Sicilian" carbonate rocks originate from some marine sedimentary successions formerly located in a space now occupied by the Tyrrhenian Sea. Each of these units is characterized by its own Mesozoic-Cenozoic stratigraphy/facies distribution in different and adjacent domains. The related depositional environments consisted of a wide carbonate platforms (locally known as Pre-Panormide, Panormide, Trapanese, Saccense and Iblean-Pelagian, Fig. 7) probably flanked (to the present-day northeast) by deep-water carbonate basins (Imerese and Sicanian) believed to represent a part of the African passive continental margin during the Mesozoic (Jenkins & Bernoulli, 1974; Catalano & D'Argenio, 1978; Montanari, 1989; Catalano et al., 1991, 2000a, b and reference therein) and recently described as forming the Pelagian Promontory (Catalano et al., 2012), the Sicilian branch of the original southern margin of the Western Tethys (Catalano & D'Argenio, 1978).

4.3.3a. Permo/Meso-Cenozoic deep-water carbonate successions (Imerese and Sicanian domains).

Facies analysis and stratigraphy let to distinguish two different rock-type successions. The Imerese succession consists of Permian to Oligocene, thin-bedded, deep-water limestones and bedded cherts, with Jurassic-lower Oligocene carbonate platform-generated debris flows and resedimented shallow-water carbonates (Fig. 7). The carbonate and siliceous section is paraconformably onlapped by the Upper Oligocene-Lower Miocene Numidian flysch.The Sicanian rock assemblage includes Lower Permian to Middle Triassic deep-water clastic and

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carbonatic deposits, with shallow-water carbonate olistoliths, located in the outcrop or detected in the subsurface by boreholes (see Basilone et al., this guidebook). Carnian to lower Miocene deep-water carbonates, overlain by late middle Miocene (Serravallian-Lower Tortonian) clastic carbonates, marls and thin bedded arenites. When compared, the Imerese and Sicanian sections have the basal Middle to Upper Triassic marls and cherty pelagic facies in common (Mufara and Scillato fms) but the Sicanian section clearly differs from the Imerese one in the Jurassic-Miocene rock interval as well as in the lack of Numidian flysch deposits that appear to overlap only the Imerese section (Fig. 7).

4.3.3b. Meso-Cenozoic carbonate platform successions.

- The Pre-Panormide section cropping in Westernmost Sicily (Catalano, 1987; Antonelli et al., 1992; Catalano et al., 2002) is also submerged in the Egadi Islands zone and further north offshore (where it is called Nilde facies, Antonelli et al., 1992). Triassic-Lower Liassic carbonate platform dolostones and limestones are passing upwards into Jurassic slope-to-basin or pelagic carbonate platform deposits and Cretaceous to Upper Oligocene pelagic, marly limestone, sandstones (Fortuna fm), shallow-water glauconitic limestones and Miocene carbonate and sandstone deposits. The main bulk of the rock body extends offshore towards SW along the Nanda ridge and could continue to the Capo Bon sector (Eastern Tunisia, see also Granath & Casero, 2006).
- The Panormide type successions crop out in the Capo San Vito Peninsula as well as in the Palermo and Madonie Mountains (Grasso et al., 1978; Abate et al., 1979; Bianchi et al., 1989; Catalano & Di Maggio, 1996; Santantonio Ed., 2002) and their northern offshore extension. The late Triassic-Middle Liassic carbonate platform, mostly consisting of fringing reef facies, and their onlapping Jurassic pelagic platform rocks (Rosso Ammonitico) are onlapped by Upper Jurassic-Lowermost Oligocene reefoidal and shelf slope limestones. An Upper Oligocene-Lower Miocene Numidian flysch appears to onlap the Panormide type section discontinuously. As clearly pointed out by the facies analysis, the Panormide is the only section that maintains the characteristics of a continuous carbonate shelf through the Mesozoic-Paleogene time interval briefly interrupted by a Middle Jurassic foundering episode. Most of the Panormide rocks are resedimented as breccia elements in the Mesozoic deep-water Imerese section.
- The Trapanese type succession outcrops in Western Sicily and is buried in Central-Eastern Sicily where it has been penetrated by some boreholes. Upper Triassic-Middle Liassic carbonate shelf dolomites and limestones are followed by Jurassic-Lower Oligocene pelagic platform deposits (Rosso Ammonitico with intensive

neptunian dykes, Mn-crust condensed lithofacies, pelagic limestones). Upper Oligocene-Middle Miocene coastal to open shelf glauconitic, resedimented biocalcarenites, sandstones and pelagic marls, unconformably cover the Mesozoic-Paleogene substrate. A lateral transition between the Trapanese and Panormide domains is suggested by the common characteristics of the Triassic shelf carbonates and Jurassic ammonitico rosso lithofacies (found in the Capo S. Vito peninsula and Palermo Mts). Main differences result in the Cretaceous-Eocene rock section (shelfal in the Panormide and pelagic in the Trapanese domain (see Fig. 7).

- The Saccense carbonate platform section crops out to the south, in the Sciacca area; it is buried in Southwestern Sicily (the Castelvetrano-Mazara area, Fig. 2, Pl. I) and submerged in the Adventure Bank. The Saccense type succession shows Mesozoic affinities with the northerly seated Trapanese section, but displays different oligo-miocenic open shelf carbonates. Similar and coeval rocks have been sampled in the Iblean Plateau section (see Di Stefano, 2002) supporting a west to east lateral transition between the said domains. These correlations have been recognized also on seismic profiles in the Southern Sicily offshore (Catalano, 1987; Antonelli et al., 1992).

In Southwestern Sicily, the Monte Genuardo section and other adjacent deposits (Figs 2, 7 and Pl. II) offers a documented transition shelf-to-basin of stratigraphic interest (Mascle, 1979; Catalano & D'Argenio, 1982; Di Stefano & Vitale, 1987). The section shows how the Upper Triassic carbonate peritidal and reef-spongid deposits are unconformably onlapped by Jurassic to Middle Miocene slope to basin carbonates. The latter can be laterally correlated to the coeval deep-water Sicanian succession (Catalano & D'Argenio, 1982).

Tectonics. The Sicilian carbonate tectonic edifice (earlier known as the African element of the Sicily FTB (Catalano & D'Argenio, 1978; Roure et al., 1990 and references therein) results of the stacking of Mesozoic-Paleogenic carbonates involving at place also their Neogene clastic cover.

The Panormide, Imerese and Trapanese carbonate thrust systems outcrop in the central and western side of the belt, as major structural culminations, and are buried eastwards (in the Nebrodi Mts) beneath the Numidian flysch and Sicilide nappe wedge (Fig. 2, Pl. III). The Sicanian thrust system, exposed in the Sicani Mountains (Western and Central Sicily, Fig. 2, Pls I-II) is bounded to the west by a complex lateral ramp (Triona-Colomba range, Fig. 2, Pl. II, and Hill & Hayward, 1988) and continues eastwards, buried beneath the Caltanissetta basin. The thrust system emerges in South-Eastern Sicily, in the Judica and Scalpello ridges (Fig. 2) as duplex structures (Bianchi et al., 1989; Roure et al., 1990); it overthrusts, along a partially buried main sole thrust, both the more external Saccense units to the west (Pl. II) and to the south and remnants of the

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"Gela Thrust System" to the southeast (Figs 2, 7 and Catalano et al., 2000a). The Imerese units, stacked above the Sicanian deep-water carbonate thrust systems (see Avellone et al., this guidebook), are buried in Northern-Central Sicily beneath the Gela Thrust System as pointed out by field relationships and high penetration seismic reflections data (Catalano et al., 2008).

Three main thrust systems are stacked in Westernmost Sicily, structurally underlying the Panormide tectonic units that outcrop to the north in the San Vito Peninsula and its offshore (Fig. 2, Pl. I).

The structurally higher unit is a southeastward vergent pile of Meso-Cenozoic carbonate shelf to pelagic platform with their clastic oligo-miocenic sedimentary cover (Pre-Panormide or Nilde units, Catalano et. al., 1989; Antonelli et al., 1992; Casero & Roure, 1994). This thrust wedge, whose main thrust front is located in Western Sicily, extends into the Egadi Islands and the adjacent submerged region in the Straits of Sicily (Fig. 2), and appears to overthrust the Trapanese tectonic units (Pl. I), mostly buried in Westernmost Sicily; parts of them, detached from their lower section, are located eastwards up to the Roccamena area (Catalano et al., 2010a, b). The Trapanese units outcropping at the Montagna Grande near Salemi (Catalano et al., 2002) overthrust the Saccense units that appear moderately deformed (Pl. I).

The Saccense thrust units, emergent in the Sciacca region (Southern Sicily), extend towards south westernmost Sicily (Fig. 2, Pls I-II) as well as eastwards (between the Agrigento to Gela area) where they are buried below the southernmost front of the Sicanian thrust system and the Gela Thrust System (Pl. II). The Saccense carbonate wedge becomes the autochthonous foreland ramp in the South Central Sicily offshore (Pls I-II and Catalano et al., 1989a; Di Stefano & Vitale, 1993). A fair deformation is also present in the offshore (Pl. II and Catalano, 1987; Argnani et al., 1989; Antonelli et al., 1992).

4.3.4. Neogene - Pleistocene sedimentation.

Miocene-to middle Pleistocene wedge-top basin deposits are mapped both in Western and Eastern Sicily. These rocks are deformed and incorporated in the Gela Thrust System as part of the orogenic wedge.

Stratigraphy. Terrigenous, evaporitic pelagic and clastic carbonate rocks (listed in Fig. 7), deposited, during the contractional deformation, in foreland, wedge top and foredeep basins. The Serravallian to lowermost Tortonian, terrigenous, mostly clayey and marly deposits (Castellana Sicula fm), crop out all over Northern Sicily, generally unconformably overlapping (Fig. 7) the post-collision emplaced Peloritani units and the already stacked Sicilidi units and Numidian flysch tectonic wedge. This sandy marl unit is, in turn, capped

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unconformably by reddish to yellow polygenic conglomerates, clayey sandstones and marls (Terravecchia fm, Late Tortonian-Early Messinian). Large outcrops of Lower Messinian coral reefoidal limestones lie over an eroded sandy substratum of the Terravecchia fm all over Western (mostly) and central Eastern Sicily (Catalano, 1979; Esteban et al., 1982) as well as above the eastern Iblean succession (Lentini, 1983).

The described clastic and carbonates units appear already folded and faulted by syn and post depositional tectonics and, with few exceptions (see Gugliotta, 2011 and Gugliotta & Gasparo, 2012), do not preserve the wedge top basin original physiography.

Evaporites, due to the widely known Messinian "salinity crisis", overlap an erosional surface, at place, cutting the underlying older strata. The Messinian evaporitic succession (Decima & Wezel, 1971; Roveri et al., 2007), predominantly eroded in the northern areas, becomes widespread to the South and the east of Southern Sicily. The evaporitic strata are overlain disconformably by the well known lower Pliocene Trubi, pelagic marl-limestone couplets, deposited during the well known Mediterranean "falls" (Cita, 1973). Locally, sedimentary Upper Pliocene-Lower Pleistocene wedges of mostly carbonate-clastic rocks, unconformably sealed the already deformed Trubi limestone both in Western and Eastern Sicily. From the bottom upwards, the Pleistocene rocks are composed of fine turbiditic sandstones and biocalcarenites, hemipelagic shales with interbedded calcarenite and mudstones. Middle-Upper Pleistocene sandy shales and shallow-water carbonates overlap the westernmost and eastern areas of the Island (Fig. 2).

4.3.5. The Gela Thrust System.

The Gela Thrust System (Catalano et al., 1993), long believed to be an olistostrome and locally known as the falda di Gela ("Gela Nappe", Ogniben, 1960; Argnani et al., 1989), in its furthest transported portion (i.e. towards the foreland) consists of a thick group of structures developed in uncompetent sedimentary rocks (late Mesozoic-early Pleistocene). This allochthon occurs predominantly from Catania to Sciacca (Figs 2, 3) in Eastern, Central and Southern Sicily where it is known to be up to 3-4 km thick, according to the exploration borehole stratigraphy (see also Bianchi et al., 1989; Catalano et al., 1993; Bello et al., 2000; Ghisetti et al., 2009; Ghielmi et al., 2011).

Stratigraphy. The GTS (Pls I-III) is composed of two types of tectonic elements as follows: a) an internal element consisting of allochthonous deformed siliciclastic Miocene Numidian flysch and clay carbonate Mesozoic-Cenozoic Sicilidi rock units (NF and SC) and Tortonian-to-Pliocene deposits, and b) an external element involving Tortonian-to-Pleistocene deposits.

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Tectonics. The Gela thrust wedge ramps progressively over Upper Pliocene-Lower Pleistocene deposits (Pls II-III); its basal detachment bends above the underlying deformed carbonates (see also Bello et al., 2000). The arching of the basal detachment clearly suggests that compression took place also after the wedging of the GTS (between 1.5 and 0.8 Ma).

The detailed structural relationship of the late deformation of the ill-defined Gela Thrust System is still enigmatic: the inner element of the GTS is characterized by NNW-verging thrusts. The striking northern vergence of the younger faults could be also explained as a complex variation of a triangle zone (Jones, 1996) or else a pervasive late orogenic wedge.

5. Discussion

5.1. Some thoughts on the kinematic evolution of the Orogen

It is well known that the general advance of thrusting is recorded in the chronostratigraphy of the foreland and wedge top basin deposits. As a consequence the timing of thrust imbrications in Sicily could be closely bracketed (see Fig. 7).

Following the early Miocene "collision" of the Sardinia block with the African margin, the evolution of the Sicily thrust belt-foredeep system started with the internal imbrication of the already far travelled outcropping crystalline Calabrian (Peloritani) "backstop" units (AlKaPeCa) and its emplacement over the Sicilide and Numidian flysch domain (Fig. 8). In a Western Mediterranean frame, the compressional emplacement of the AlKaPeCa units is believed to have occured in the context of the rollback/tearing and delamination of the Ligurian/Adriatic slab and the associated normal faulting (Faccenna et al., 2001; Carminati & Doglioni, 2012).

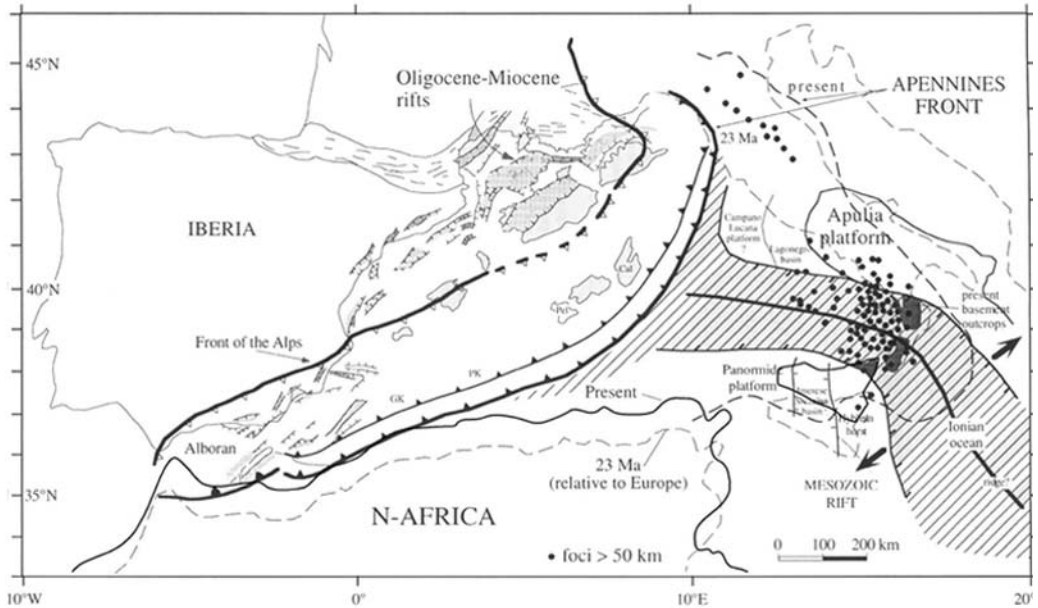

Fig. 8 - Late Oligocene-Early Miocene palaeogeography of the Central Mediterranean.

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In the whole fold and thrust belt, the Lower Miocene flyschs and Sicilide rocks units appear as the structurally highest units beneath the Peloritain units. The decoupling from their substrate and the transport over the more external Sicilian domains is bracketed between Langhian to earliest Tortonian; it is supported by the occurrence of the middle Miocene sandy clays (Castellana Sicula fm) that unconformably seal the already deformed Sicilide nappe-Numidian flysch/stack complex.

The early phase of thrusting, during the Middle-Late Miocene, involved the Imerese and Sicanian deep-water carbonate derived rock units (Fig. 7) with duplex geometries, original flat lying lower thrust boundary and major tectonic transport. The Permian clastic and carbonates (Lercara complex), upper Triassic marls with dolomites (Mufara fm) and Lower Tertiary pelagic carbonates and turbiditic siliciclastics are the preferred detachment levels. The deep-water carbonate tectonic units overthrust the more external carbonate platform domains that appear as progressively reached by the later, forward migration of the deformation. These carbonate platform rock units were detached from their basement by younger deep-seated decollement thrusts that offset, from underneath, the overlying earlier faults, overthrusts or folds (Fig. 9).

The wedging at depth of the carbonate platform units from underneath was appropriately described as faulted thrust faults (not "*fault reactivations* (Bello et al., 2000) or else *out of sequence* (Roure et al., 1990)); its activation implied re-imbrication and folding into the overlying previously emplaced deep-water carbonate thrust sheets, as well as in the overlying Sicilidi and Numidian flysch stack to accomodate their original extent in several stacked thrust sheets. The progressive underthrusting of more external platform units (Catalano et al., 1989; Roure et al., 1990; Oldow et al., 1990) beneath the already deformed tectonic wedge,

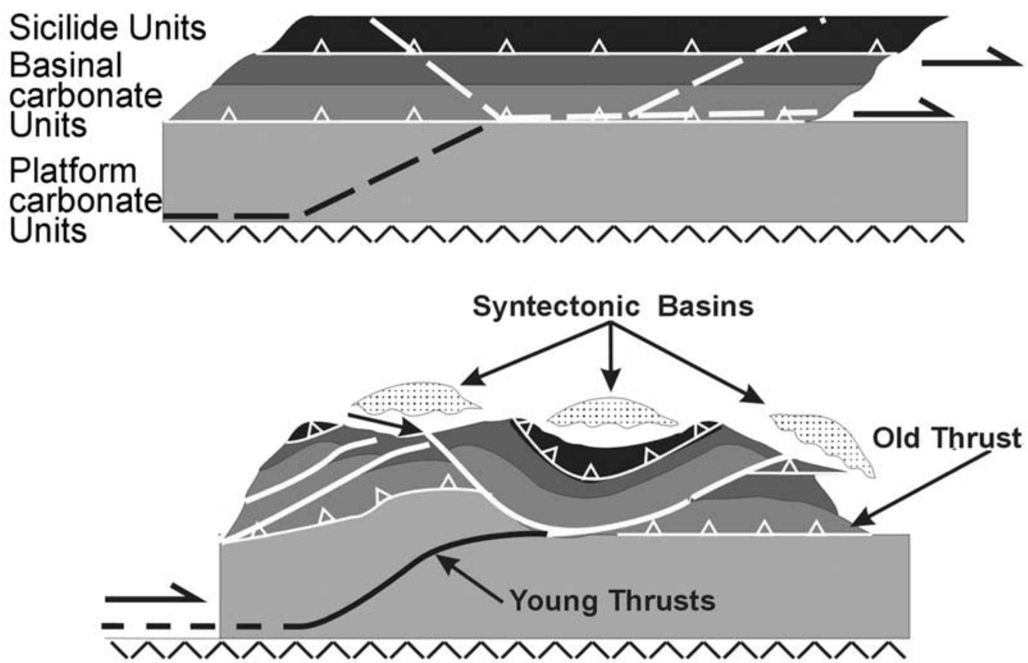

Fig. 9 - Kinematic model for the study area (adapted from Roure et al., 1998; Bello et al., 2000).

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reflects an orderly progression of the deformation from higher to lower levels of the original multistrate (Bally et al., 1985; Catalano, 1987). Most of the thrusting involving the carbonate platform units occurred during the latest Miocene-middle Pleistocene. This deformation timing is supported by the age of the overlying late Pliocene-Pleistocene wedge top basin deposits and by their successive tectonic involvement.

Mesotectonic data collected in the field all over in Sicily, yielded folds and thrusts that show a) south-west-verging, NW-SE and b) south-east-verging, NE-SW dominant orientations that appear to have been originated by two main, non-coaxial (Oldow et al., 1990; Avellone et al., 2010) compressional events (Fig. 7). The older structures appear, in outcrop, refolded by the younger ones. Both develop at different structural levels (shallow- and deep-seated thrusts). They have been generated in different time intervals (respectively middle to late Miocene and latest Miocene to middle Pleistocene, Catalano et al., 1989, 2000b; Oldow et al., 1990; Roure et al., 1990; Bello et al., 2000; Avellone et al., 2010).

The thrusting was coupled with lateral movements related to a right oblique transpression accompanying the latest Miocene-early Pleistocene clockwise rotations (Oldow et al., 1990, Fig. 10). Given that the two types of structures are not coaxial, their present-day setting can only be explained by the occurrence of the syn-kinematic nappe clockwise rotations, paleomagnetically (Channell et al., 1980, 1990; Speranza et al., 2000, 2003) and tectonically evidenced by Oldow et al. (1990) and Avellone et al. (2010).

The wedging at depth of the allochthonous (mostly carbonate platform) units is believed (Catalano et al., 2011) to have built up the Gela Thrust System on the surface. Thrusting, originating from underneath, decoupled part of the already emplaced uncompetent Sicilide and Numidian flysch imbricates and progressively involved the overlying syntectonic deposits (upper Miocene-middle Pleistocene) previously filling the wedge top basins. The allochthon thins towards the submerged thrust front in the Southern Sicily offshore (Catalano, 1987; Argnani et al., 1989; Catalano et al., 1989) where a detailed chronology of thrust transport has recently been developed (Di Stefano et al., 1993; Ghielmi et al., 2011). The main transport direction appears to be toward south and south-east, with important components of back-thrusting in the northern and onland sectors (Grasso et al., 1991; Catalano et al., 1993a; Ghisetti et al., 2009). Southerly displacement of the wedge was active in the most external thrust front up to the late middle Pleistocene as suggested by the stratigraphic age of the deposits that are progressively involved in the deformation (Ghielmi et al., 2011). "Wedging" is the likely reason for the whole GTS to overlie the earlier/shallower more rotated allochthonous units of Sicily.

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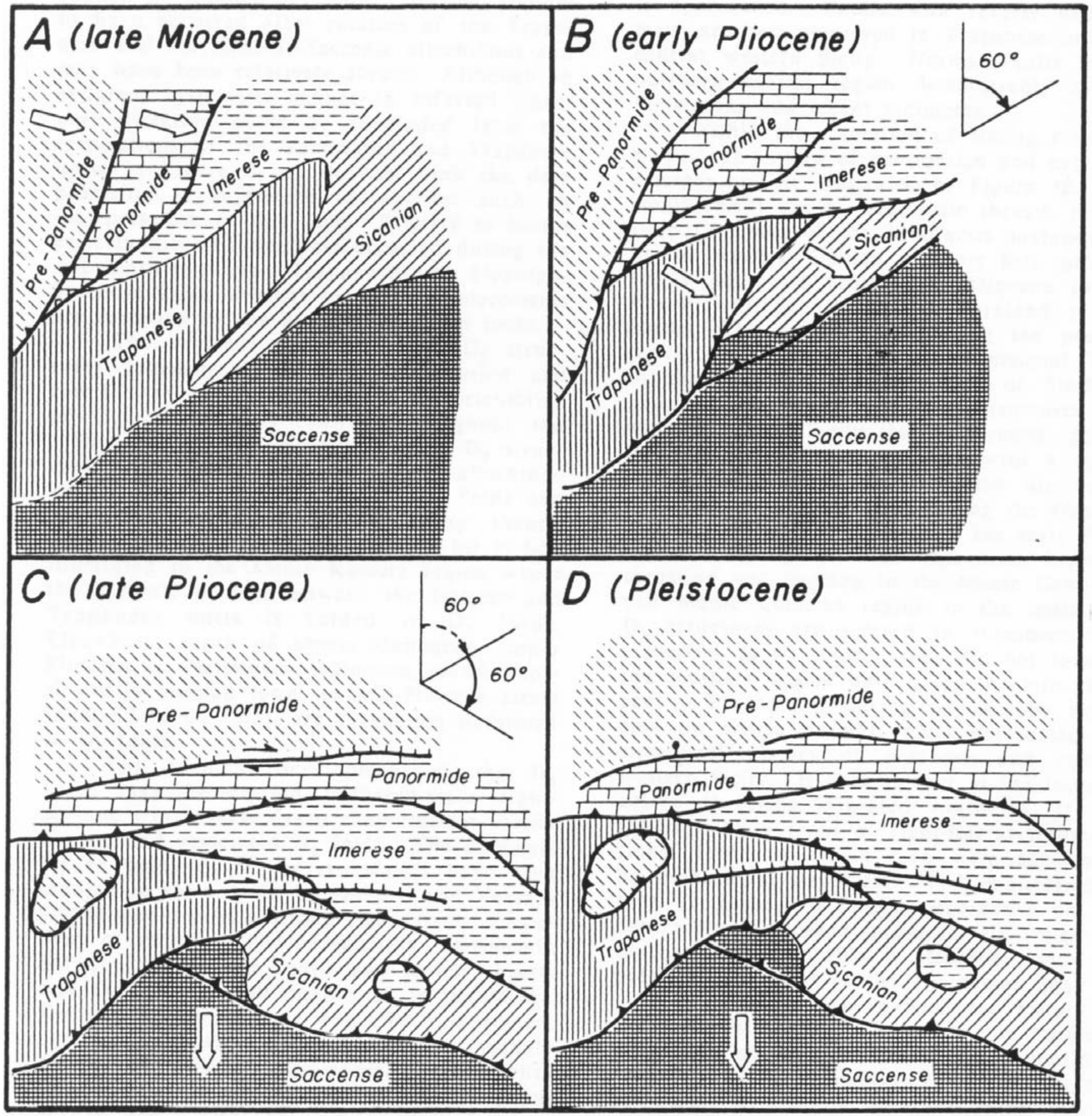

The onset of the syntectonic latest Pliocene-Pleistocene outer wedge top basins (rapidly subsiding) begins at the end of the Trubi deposition (end of early Pliocene). The age of the event could be fixed at about 2.4 Ma that is also believed to be the beginning of the GTS accretion. The same time interval is generally suggested for the Tyrrhenian spreading event (Marsili basin) believed to have taken place between 2.1 and 1.6 m.y. ago, at the rate of 19 cm/yr (Nicolosi et al., 2006).

Fig. 10 - Model illustrating thrusting and rotation thrust sheets, during the progressively deformation of Sicilian margin. After rotation northerly allochthons are involved in right oblique transpression (from Oldow et al., 1990).

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Northwards in the belt (Northernmost Sicily and Southern margin of the Tyrrhenian Sea), the already imbricated substrate was eroded and block-faulted, after the Messinian, along listric and normal growth faults (Agate et al., 1993). The extensional event opened half grabens that were progressively filled by clastic wedges. Later, a structural inversion of the half graben deposits took place between 2.5 and 1.4 Ma (Catalano & Milia, 1990): it was followed by an extensional structural setting that dissected the basins, between 1.4 to 0.8 Ma. The two main extensional events and the generated basins are probably linked to the opening of the Tyrrhenian Sea (Sartori, 1991). The resulting structures again experienced compressive to transpressive deformation between 0.8 and 0.5 Ma (Agate et al., 1993). The last 0.5 Ma involved vertical tectonics. Present-day contractional deformation, supported by seismicity (see Fig. 6 and references), propagating from west to east at the Northern Sicily offshore, could imply (according to Giardini et al., 2007; Doglioni et al., 2012) geodynamic scale variations. Back in the Sicily coast and its hinterland it is accompanied by extensional to transtensional movements. To the South, in the foreland, Plio-Pleistocene normal faulting appears associated with the SE tilting of the Iblean Plateau and the graben systems of the Malta/ Sicily Channel (Fig. 2).

5.2. Paleogeography

Palinspastic restoration of the present-day structural edifice envisages the occurrence of two main crustal domains that took place in the area defining its pre-Tertiary history:
a) a Permian to Lower Triassic deep-water basin in Sicily (Catalano et al., 1991 and references therein) probably bounded by a shelf environment, connecting Sicily to the Jeffara (Tunisia) zone (Fig. 11a). The occurrence of circumpacific radiolarians in the Permian deep-water siliciclastic and carbonatic deposits of Sicily (Catalano et al., 1991; Vai, 2000) documents that the deep-water basin was connected eastward to the Permian Tethyan domains (Neotethys or Mesogea according different authors, see Stampfli & Borel, 2004). The connection must have passed across the present Ionian Sea, separating Apulia from Gondwanian Africa at that time and later in the Triassic (Catalano et al., 1991, Fig. 11b). The Permo-Triassic stratigraphy of Sicily implies that rifting along the North-Africa margin started at least in Permian times developing onto the African continental crust. Sicily could therefore belong either to the passive margin of the Permian ocean or to a Permian rift with extremely thinned continental crust; in both cases, this sector was the westward continuation of the Permian Tethys (Neotethys) (Catalano et al., 1989a, 1991; Bernoulli et al., 1990; Stampfli et al., 1991).

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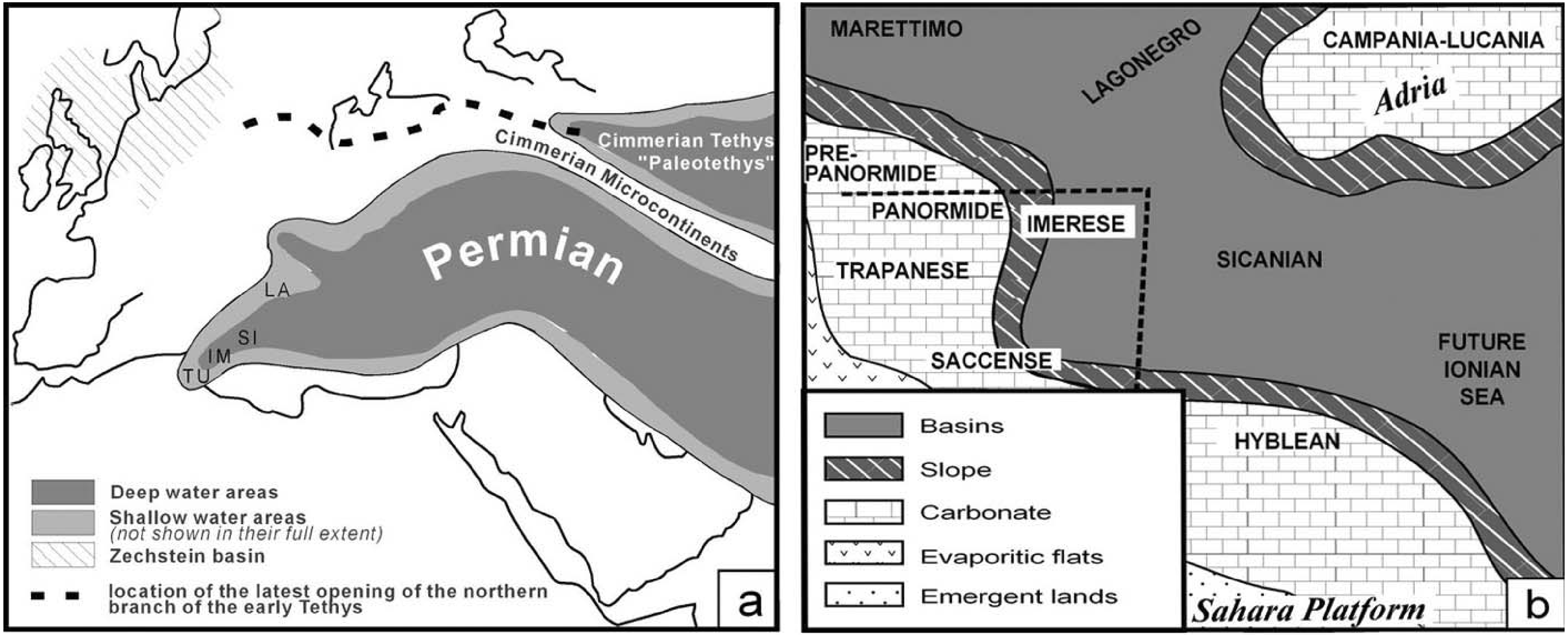

Fig. 11 - Paleogeographic reconstructions during the Permian and Triassic: **a)** Middle Permian; **b)** Late Triassic (modif. from Catalano et al., 1991, 1996). Dashed lines are the traces of the sections in Fig. 12.

This opened new perspectives on the Late Paleozoic-Early Mesozoic paleogeographic setting of Sicily and on the inherited crustal characteristics of the central Mediterranean area.
b) a Mesozoic domain was characterized, during the early Mesozoic, by a wide carbonate platform (including the now deformed Pre-Panormide, Panormide, Trapanese-Saccense and the autochthonous Iblean domains) flanked to the (present-day) northeast by a subsident attenuated crust (Fig. 11b) where a large deep-water embayment (Imerese and Sicanian basinal domains) developed (Pelagian Promontory). An attenuated, pre-hercynian possibly, Panafrican crust, underlies the Pelagian-Iblean foreland (Vai, 2000). New data (Accaino et al., 2011; Catalano et al., 2012) on the attenuated Central Sicily crustal thickness suggest that the African

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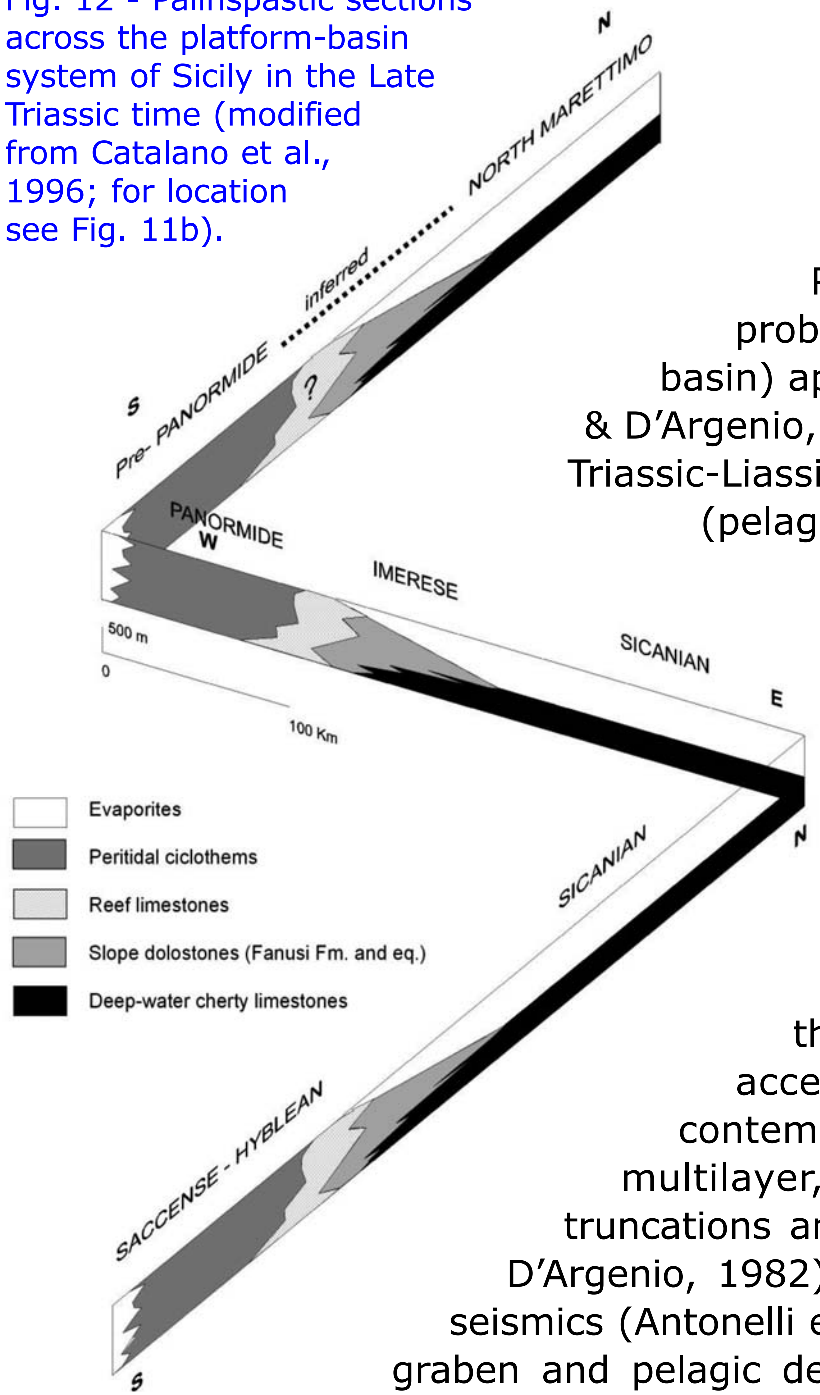
Fig. 12 - Palinspastic sections across the platform-basin system of Sicily in the Late Triassic time (modified from Catalano et al., 1996; for location see Fig. 11b).



basement wedge was influenced by earlier extensional events (see also Turco et al., 2007; Zarcone et al., 2010 and references thereafter) followed by mostly thermal subsidence (e.g. the Pelagian crust could have been extended during the late Permian-Triassic Jeffara and Lercara basins formation, see Figs 7, 11a).

Rifting events locally involved the large shallow-water domain, probably starting from late Triassic times (see the large Streppenosa basin) apparently opened inside a large shelf domain (Fig. 13 and Catalano & D'Argenio, 1982). Major extensional features appear to dissect the top of the Triassic-Liassic carbonate platform with the formation of margins and troughs (pelagic carbonate platform, Fig. 7). Pelagic facies spread out in the nearby areas (Sicanian basin) that extended to the east, bordering the shelf domain (Trapanese-Saccense-Iblean carbonate platform, Fig. 12).

During the Jurassic, the Sicilian carbonate shelf was affected by profound modifications of the paleogeography and lateral facies shifts (see Santantonio Ed., 2002) in response to N-directed extension tectonics probably linked to the eastward sinistral transcurrent motion of Africa relative to fixed Europe (Dewey et al., 1989). Jenkins (1970) illustrated the foundering of sectors of the carbonate platforms due to accelerated subsidence, uplift and erosion, all developing contemporaneously. Folding and faulting of the pre-Middle Eocene multilayer, occurrence of large carbonate megabreccia bodies, deep truncations and regional gaps at the Cretaceous-Eocene boundary (Catalano & D'Argenio, 1982), all correlated to some offshore structures imaged by reflection seismics (Antonelli et al., 1992; Casero & Roure, 1994), suggest that the Jurassic half-graben and pelagic deposits have often been inverted as antiformal structures. These

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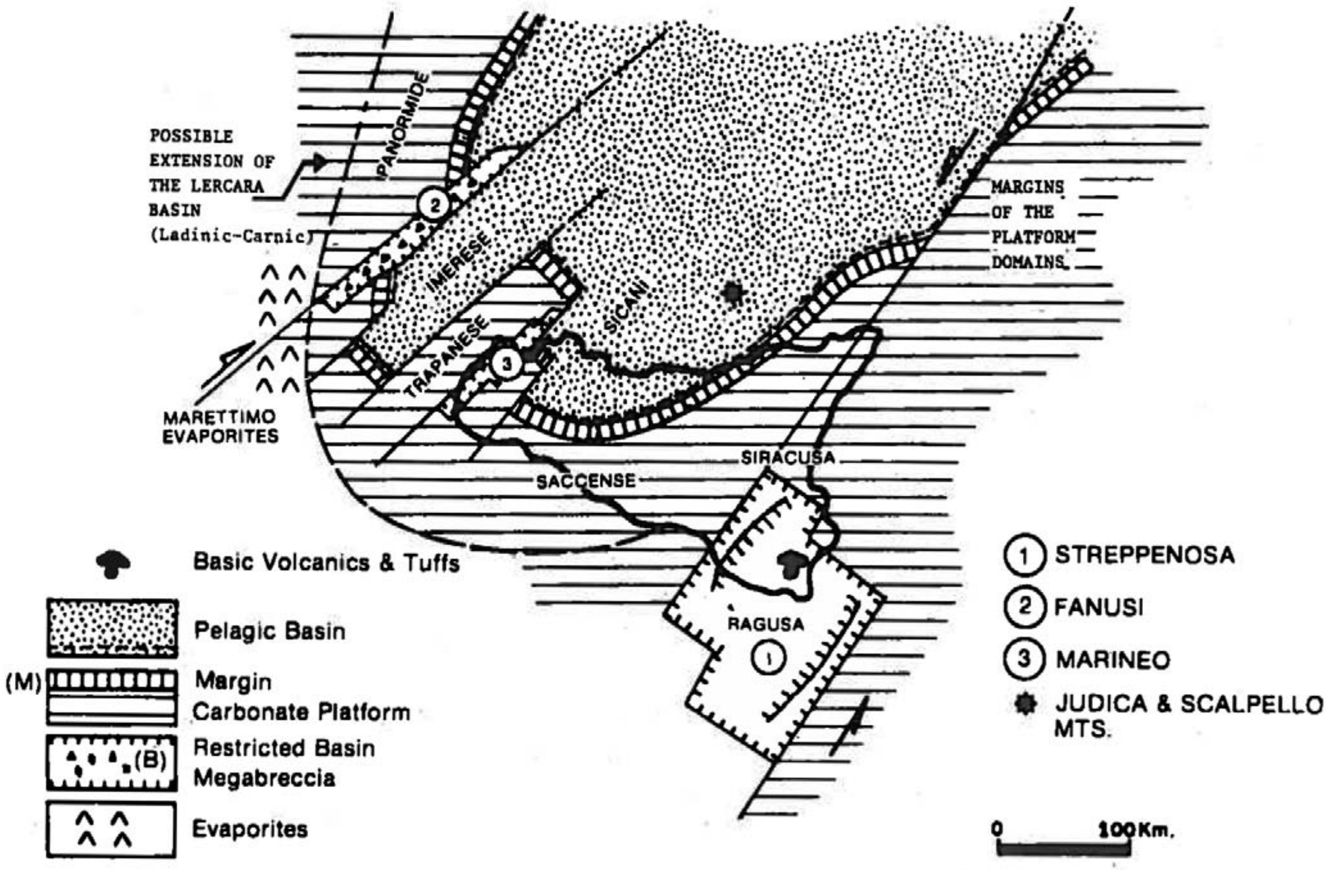
Fig. 13 - The original palinspastic map of the Mesozoic of Sicily, published by Catalano & D'Argenio (1982b). This map has been conceived taking in account the views predominant at the end of the seventies. It was restored using rhegmatic mechanisms to explain contemporaneous features as restricted basins, rapidly subsiding within extension dominated carbonate platform domains, versus strong relief and catastrophic carbonate megabreccia accumulation. The Sicilian embayment was linked to the North Africa evaporites by the Marettimo (Egadi Islands) sabkha deposits. Note that the orientation of the paleogeographic units has been modified according to the clockwise rotations calculated on the base of the already published paleomagnetic data (Catalano et al., 1976; Channell et al., 1980).



events could be correlated into the relative dextral (or N-S convergence) motion of Africa with respect to fixed Europe, due to the Cretaceous opening of the South Atlantic ocean (Rosenbaum et al., 2002). New and recent data from the adjacent Pelagian-Ionian region (Catalano et al., 2000b, 2001; Finetti, 2005; Torelli et al., 2011) are particularly important to understand the early Mesozoic history of this area. The present-day SE-NW trending location of the Ionian Ocean as well as the Sicilian and Southern Apennines mesozoic paleogeography (Catalano et al., 2001), suggest that the deep-water realm (located on the believed oceanic crust) could continue west-northwestward as already depicted by Catalano et al. (1991, 2001) and Stampfli et al. (2000).

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6. Conclusions

Based on the previously described characteristics, the Sicily structural grain consists essentially of a carbonate accretionary wedge, mainly made up of deep-water Meso-Cenozoic carbonate units, overriding a more than 10 km-thick platform carbonate thrust wedge which is, in turn, detached from a crystalline basement. The tectonic wedge is the result of the underthrusting of the carbonate platform units, that acted through deep-seated progressively younger thrusts in the carbonate platform sedimentary prism, inducing late stage refolding, further shortening of the previously emplaced nappes, and fault propagation folds in the Neogene cover. This geological setting was previously interpreted by Catalano et al. (2000), Bello et al. (2000) as a result of "thin skinned" tectonics (leaving out the Peloritains (Calabrian) sector clearly turning out to be a "thick skinned tectonics" crustal wedge).

The resulting FTB is overthrust on a gently northwestward dipping slightly deformed, carbonate foreland (Iblean-Pelagian). Both imbrication geometry and internal deformation of the original units point out a tectonic evolution due to a combination of underplating and clockwise rotation of the thrust units towards the Pelagian foreland. The timing of the deformation of the ancient continental margin deposits is bracketed between Miocene and middle Pleistocene and probably still continues today. The progressive detachment of the more internal Meso-Cenozoic deep-water carbonate units from their basement and their transport above the still rooted external carbonate platform units occurred during the middle-late Miocene. The uncoupling of the carbonate platform rocks from the basement and their duplexing took place during the latest Miocene middle Pleistocene, giving rise to the re-imbrication and shortening of the overlying deep-water thrust sheets in a typical pattern that shows how younger faults offset overlying earlier structures (faults and folds) from underneath. This pattern of faulted thrust faults does not imply any reactivation faults or else "out of sequence structures"(as defined by Roure et al., 1990; Finetti et al., 2005 among the others). The true progression of deformation is confirmed as the real structured sequence ends with the sealing of the allochthons units by an onlapping foreland basin or else a wedge top basin sequence as our cross-sections show (see Pls I-III).
In the growing chain, the simultaneous development of thrusts, backthrusts and lateral displacement and the occurrence of clockwise nappe rotations during the Late Miocene-Early Pleistocene, originate syncline structures or wedge-top basins filled by Pliocene-lower Pleistocene syntectonic deposits (Pl. III) in the frame of a continuous forward migration towards the foreland.

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The shortening inferred for the whole Sicily and offshore fold and thrust belt exceeds the values calculated for the convergence motion of the Africa-Europe plates. As a consequence, the remaining shortening can be accounted for by the roll back of the subducting Pelagian crust.

7. The open problems and the contribution of the SI.RI.PRO. crustal profile

The previously described studies (based on outcrop studies constrained only by commercial seismic lines, in turn calibrated by boreholes) have illustrated and mapped the outcropping orogen, without anchoring surface geology into the crustal and lithospheric structure. Typically the deepest data onshore Sicily were shallower than 10 km or else 4.5 s in two-way travel time (TWT). Aside from limited refraction data, little is known about crustal characters, even if some geometry hypothesis or schematic cartoons have been presented in the recent past (Finetti et al., 2005).

The geological setting already schematically outlined, generates some open problems, such as

- the internal architecture and the thickness of the FTB and its interaction with the basement whose structural doubling has been recently proposed (e.g. Finetti et al., 2005);
- the crustal flexure hypothesized in Central Sicily (Caltanissetta synform) according to the strong gravimetric low;
- the occurrence of a subduction hinge zone beneath the orogenic wedge or, alternatively, a crustal delamination at deeper (Channell & Mareschal, 1989) or shallower (Doglioni, 1991) crustal levels;
- the deflection magnitude of the possible retreating continental crust;
- the boundary between the African-Pelagian and the Tyrrhenian-European crust;
- the location and depth of the Moho beneath Sicily;
- the variability of the thickness of the crust along a N-S transect;
- the occurrence of regional transcurrent crustal lines crossing the orogenic wedge east-westwards believed to explain how the FTB could originate from simple shear tectonics;
- composition and thickness of the thrust stack filling the Caltanissetta depression (Ghisetti & Vezzani, 1984; Giunta et al., 2000);
- mode of accommodation at depth of the main fault zones;
- the kinematics of the deformation and its interaction with deep subsurface investigations;
- the significance of the paleomagnetically identified rotations of the thrust units in the crustal stacking at depth.

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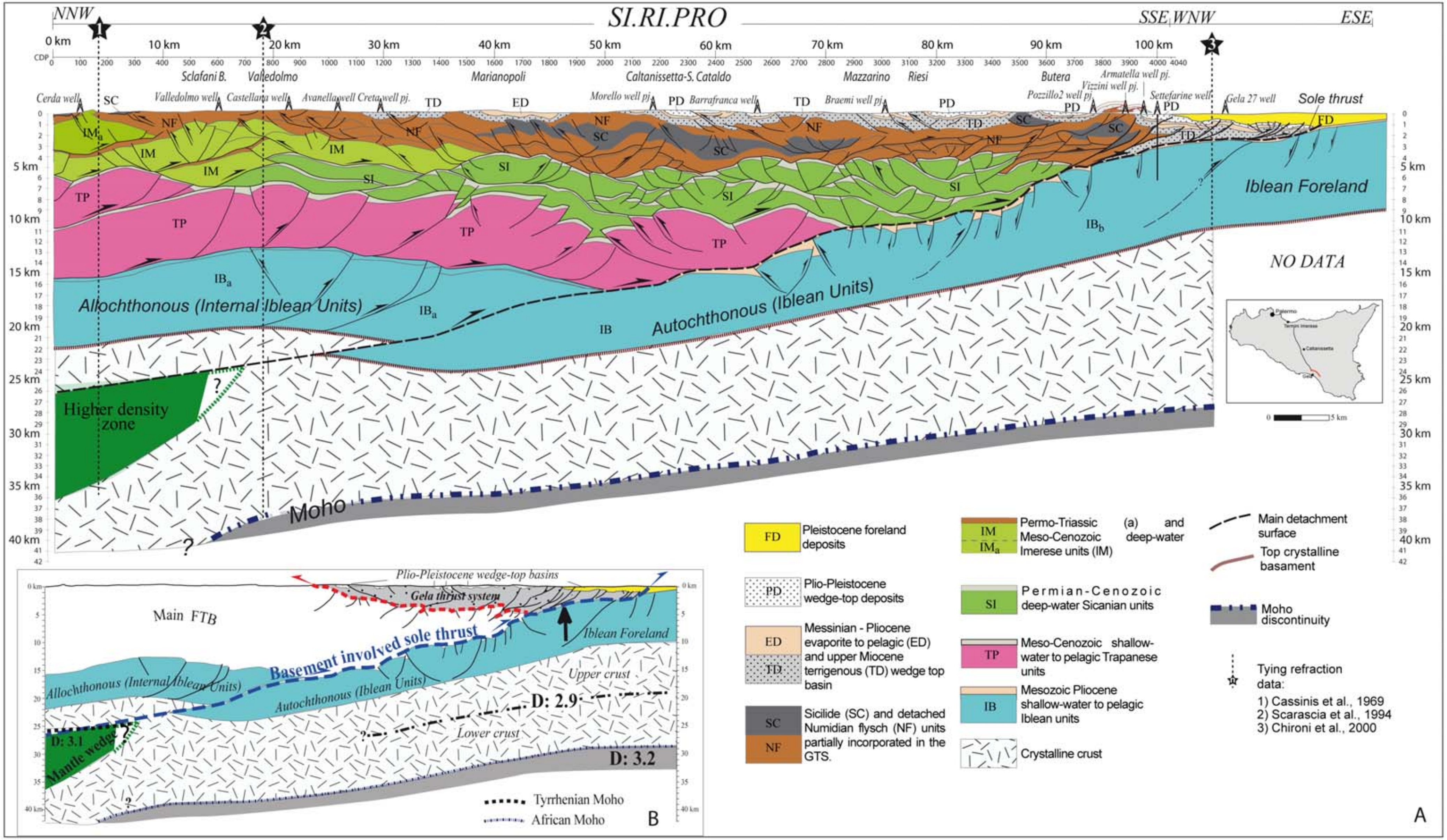

The need to compensate for the lack of knowledge of the crustal characteristics promoted the SI.RI.PRO. project (scientific coordinator R. Catalano) recently granted by the MIUR. The preliminary results of a crustal seismic profile SI.RI.PRO. (Accaino et al., 2011; Catalano et al., 2012; Catalano et al., this guidebook) acquired

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Fig. 14 - **(a)** Geological cross-section resulting from the interpretation of the seismic stack section of the SI.RI.PRO. crustal profile and its southeastern commercial multichannel seismic extension. The geological cross-section reconstruction benefits from the main geophysical (refraction and gravity) data. **(b)** Geological sketch illustrating the regional monocline that underlies the whole orogenic wedge. The latter includes a basement-involved fault that merges into the overlying allochthonous units. The thrust emanates from the leading edge of the northern basement-involved fault. It carries the leading edge of the units of the overlying orogenic wedge to emerge as a thrust plane that underlies the external units of the GTS. The dark arrow indicates the arching of the basal detachment. Density values (g cm^{-3}) are from the gravity model (see Catalano et al., 2013).

during 2008 between the Northern coast of Sicily and the Gela onshore, together with refraction seismic, gravimetry and magnetotelluric data, have strongly improved the knowledge of the deep crust characteristics beneath the very poorly studied Central Sicily. The profile starts near Termini Imerese on the Tyrrhenian coast (Figs 1, 2), crosses the Northern Sicilian chain, the Caltanissetta area in Central Sicily, and ends on the southern coast just near the outcroppings of the Iblean plateau, foreland of the Sicilian fold and thrust belt.
The preliminary results (more extensively reported in Catalano et al., this guidebook), point out the proposed region as a key sector for restoring the original lithospheric characteristics, evaluating the chain shortening, defining the geometries of the subduction, anchoring the partly outcropping thrust pile and revealing the meaning of some discontinuities (such as the tops of the basement and lower crust, or the Moho unconformity) and the Caltanissetta synformal deep crustal structure.
The interpreted geological cross-section (Fig. 14) illustrates the regional setting consisting of a foreland monocline that underlies the whole thrust stack, including a northerly thickening basement wedge. Unlikely the previous collected results (Catalano et al., 2000; Bello et al., 2000), the thickened crust is interpreted as a continental basement repetition by a “basement-involved fault” underlain by a basement. The sole thrust merges into - and remobilizes -also the overlying allochthonous units (Fig. 14).
This setting is in agreement with the model that suggests a blend of supra-crustal strata décollement (thin-skinned style) combined with a basement-involved fault (thick-skinned style); the latter merges with the base of the overlying wedge including the frontal portions of the Gela Thrust System.
Crustal geometries and gravimetric constraints support a basement involved, orogenic wedge model in Central Sicily. This wedge has been stacked prior to formation of the basement thrust (an unconventional “fault-bend-fold”-like structure, Suppe (1983)). If this overthrust merges with the southern and frontal termination of the GTS sole thrust, we can deduce that this termination is coeval (Late Pliocene-Early Pleistocene) with the

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basement thrust and the associated uplift in the northern crustal antiform. The occurrence of this sole thrust could confirm how most recent displacements take place along the basal thrust, flooring the whole orogen as expected in a collisional belt (Boyer & Elliot, 1982).
The crustal features, highlighted by the SI.RI.PRO. profile, provide answers to some of the questions pointed out above:
1) the orogenic wedge (almost 20-24 km thick) is almost entirely buried below a low topographic elevation;
2) a strong flexural bending of the crustal monocline down to about 20 km forms the Caltanissetta depression;
3) the more than 20 -25 km thick orogenic wedge in north Sicily recalls the 25 km thick, low Vp value feature (Chiarabba et al., 2008) that these Authors put in evidence as a continental "uppermost crust rocks orogenic wedge underlying the whole Apenninic-Ionian-Sicilian arc;
4) a significant negative gravity anomaly (more than -100 mGal) is associated to the steepest part of the monocline;
5) the positive gravity anomaly in the Northern Sicily coast, is linked to a high density body inside the crust;
6) the Pelagian African Moho, shallows from NNW to SSE, and can be identified in the northern sector at around 40 km, while beneath the Caltanissetta synform and the Iblean southern sector it can be imaged, respectively, at 35 and 27 km;
7) the crust appears generally attenuated (between 14 and 16 km thick) in the Iblean foreland to approximately 12-14 km in the Caltanissetta depression; it then thickens towards the Northern part of Sicily;
8) gravity anomalies validate the geological interpretation as the negative Bouguer anomaly in the Caltanissetta depression corresponds to a mass deficit, while the positive gravity anomaly, in Northern Sicily, can be interpreted to either higher density rocks within the crust and/or to an uplift of the Tyrrhenian crust-mantle discontinuity.

Epilogue

The regional interpretation offers two main alternatives of the northerly thickening basement wedge: in one it is interpreted as a thin lithospheric wedge edge involving part of the underlying mantle; the other alternative proposes a continental basement repetition by a basement-involved fault. Both the models encourage the hypothesis of continental subduction processes in the study area, improving knowledge about the relationships between the African and the Tyrrhenian/European crusts.

This paper owes much to the scientific support of M. Agate, G. Avellone, L. Basilone, M. Gasparo, C. Gugliotta, A. Sulli, V. Valenti.

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The sunken Pelagian–Ionian continental margin in the frame of the Sicily geodynamic evolution

Vera Valenti

This note will provide a summary of information about the main features characterizing the region between the emerged Iblean-submerged Pelagian and the Ionian Sea area (Fig. 15), that represented a Late Jurassic (Finetti, 1982; Catalano et al., 2000b, 2001; Gallais et al., 2011) or Permian/Triassic (Stampfli, 1989; Vai, 1994; Finetti, 2004; Stampfli & Borel, 2002; 2004) passive continental margin.

Crustal pattern and geometries of the continental margin-to-ocean transect, still preserved (Patacca et al., 1979; Ismail-Zadeh et al., 2003), are an important constraint to study subduction processes of the Ionian lithosphere beneath the Calabrian.

The passive continental margin extends from the Iblean-Malta shelf, through the Malta Escarpment (ME), towards the deep abyssal plain of the Ionian Sea (Figs 15, 16, 17).

The deep Ionian abyssal plain is a deep, triangular basin, roughly 5000 km^2 in area (Hieke et al., 2003), well-defined by the -4000 m depth isobath and bounded to the south by the Medina Seamounts (Fig. 17); it is an almost flat domain, but not free of reliefs.

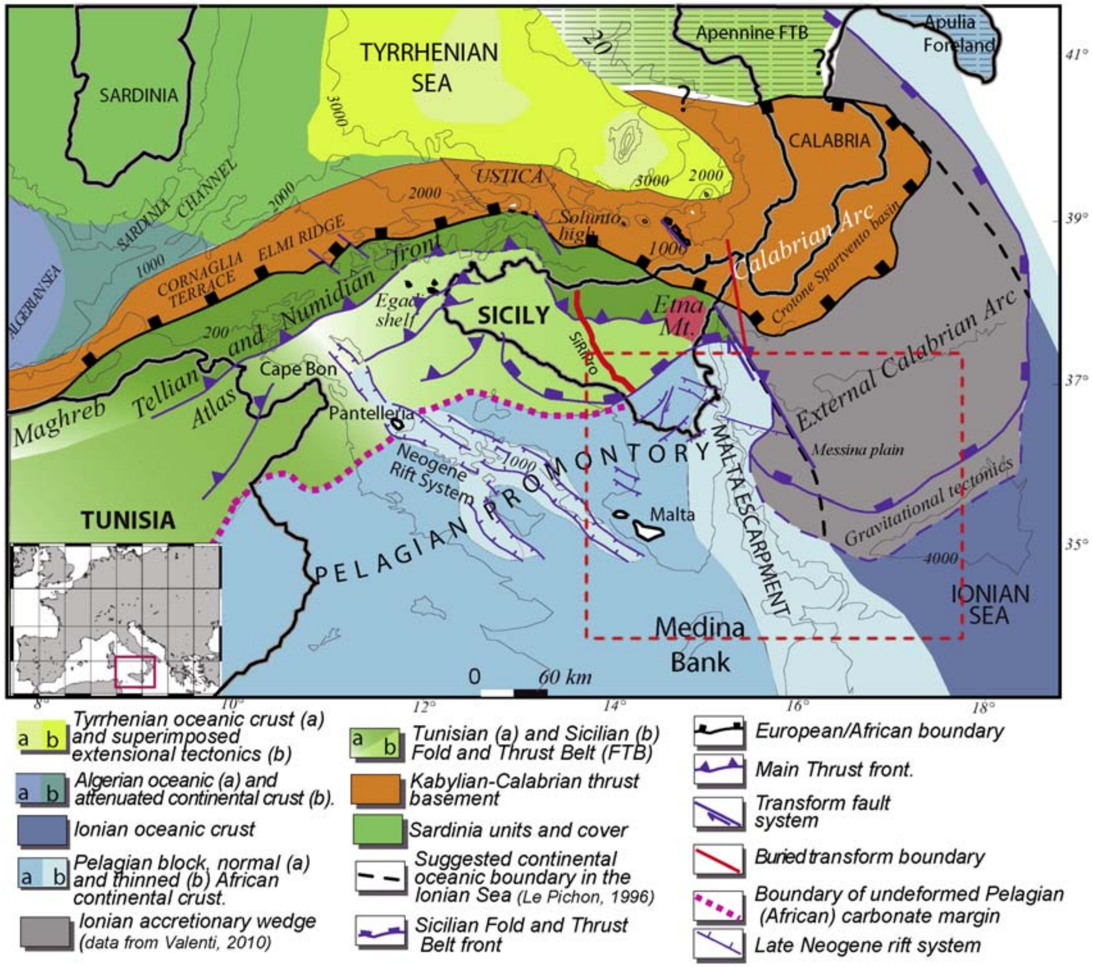

Fig. 15 - Schematic structural map of the Central Mediterranean (Catalano, this guidebook, pag. 14.). Dotted red square represents the reference area.

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The Iblean-Malta shelf is also the present-day foreland of the Sicilian chain (already discussed in Catalano, this guidebook, pp. 13-50) and its prolongation towards the deep abyssal plain represents the foreland of the Ionian accretionary wedge (Fig. 15).
Rifting events probably started in pre-Late Triassic time, later evolving to oceanic spreading.
Following, we have summarized the most recent data from the investigated area to provide an overview of the current state of the art.

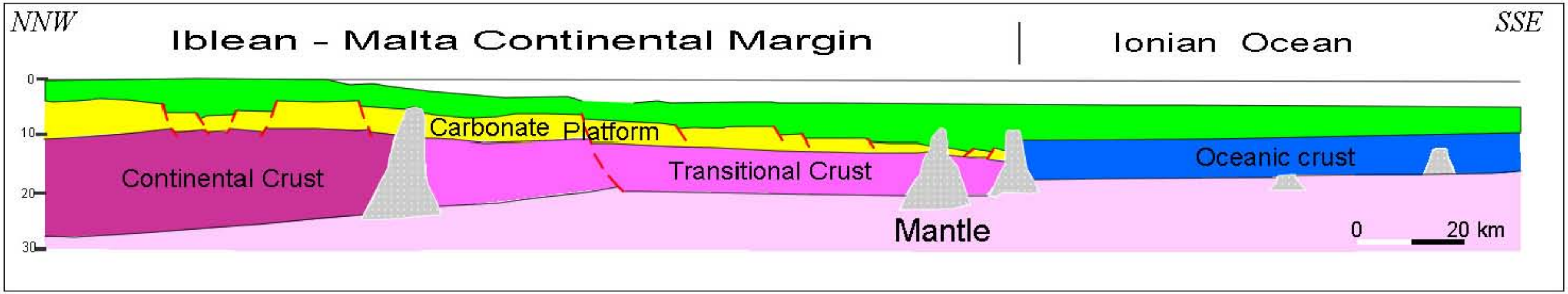

Fig. 16 - Simplified geological cross section from the Iblean–Malta shelf to the Ionian abyssal plain (Catalano et al., 2000). It shows the transitional crust and the geometry of the interpreted crust. For the location see Fig. 17.

1. From the Iblean Pelagian continental shelf to the Ionian abyssal plain

1.1. The Iblean (Pelagian) shelf

The Iblean-Pelagian domain is thought (Catalano, this guidebook, pp. 13-50) to correspond to a 'promontory' of the African plate that includes SE Sicily, the Maltese and Pelagian Islands, Eastern Tunisia, and the Northwestern Libya offshore (Figs 15, 17). The present-day structural setting of the Pelagian domain is characterized by a complex array of shallow shelves and intervening fault-controlled basins (Argnani & Torelli, 2001 and references therein).
An impressive extensional tectonic regime across the Pelagian domain occurs between the Late Miocene and Late Quaternary, supporting the rifting mechanism of the Sicily Channel (Jongsma et al., 1985; Grasso, 1993; Goes et al., 2004).

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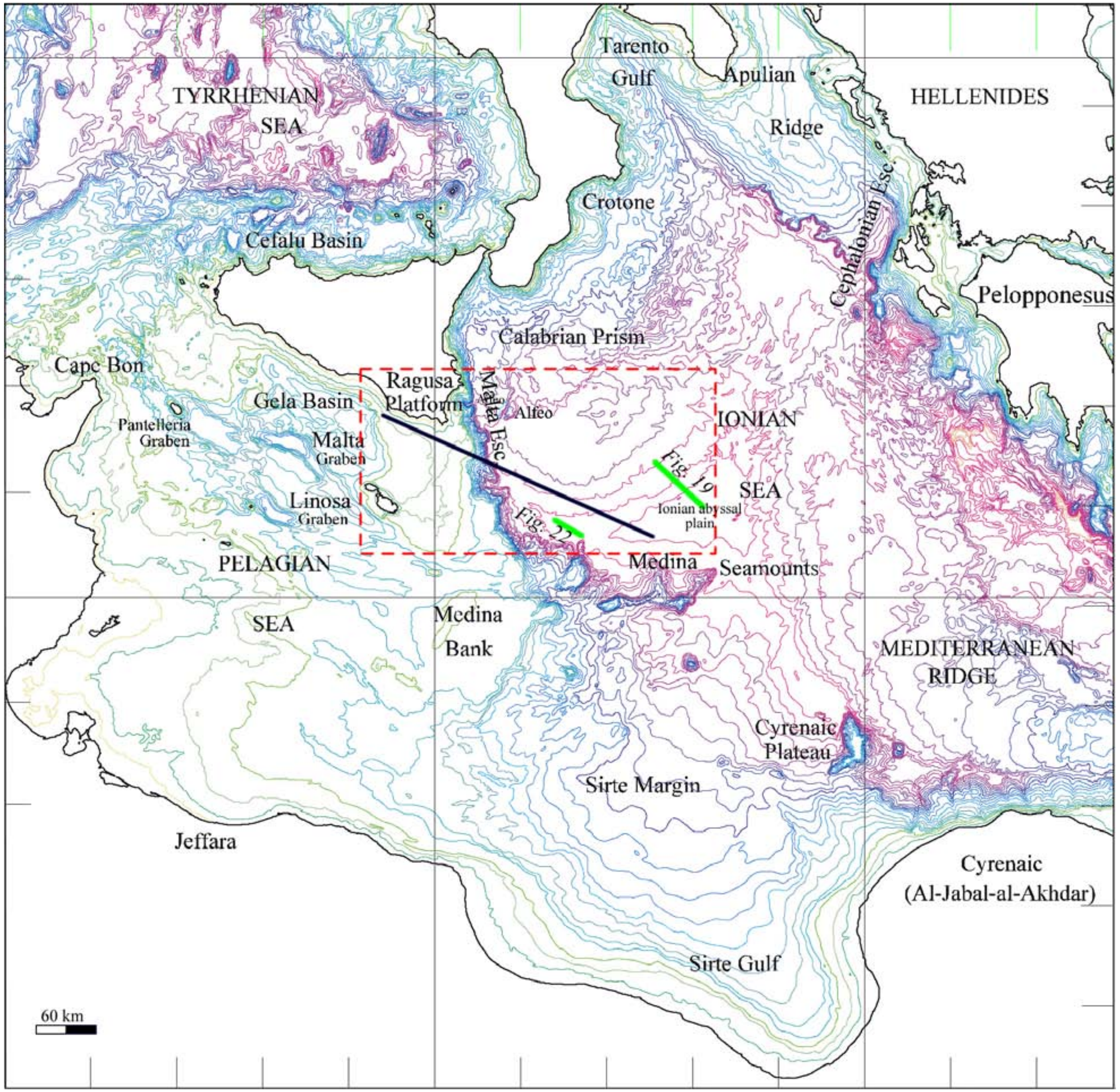

Fig. 17 - Bathymetry map of study area and surrounding seas (after Chamot-Rooke et al., 2005). Inset shows a detail of the central portion of the Malta Escarpment. Dotted red square represents the reference area; dark unbroken line represents the trace of the simplified geological cross section shown in Fig. 16; green unbroken lines represent the trace of the profiles shown in Figs 19, 22.

The Pelagian domain forms a shallow shelf separating the deep Ionian Basin from the Western Mediterranean. It is crossed by a NW-trending, complex structure of horsts and grabens, some still active, about 100 km wide (the Pantelleria Rift System, Illies, 1980), under which the crust was thinned to 10–15 km. The system features three grabens of Miocene-Pliocene age (Pantelleria Graben, Malta Graben and Linosa Graben, Figs 15, 17) where the water depth reaches a maximum of around 1700 m (Reuther & Eisbacher, 1985).

The lithology and stratigraphy of the Iblean-Pelagian succession is known from several subsurface data. Cumulative thicknesses of 5-to-7 km of Triassic-Lower Liassic, shallow-water dolomites and limestones (Vizzini borehole, Bello et al., 2000) or intraplatform carbonate turbidites (Streppenosa fm) occur, together with a 1-to-2 km

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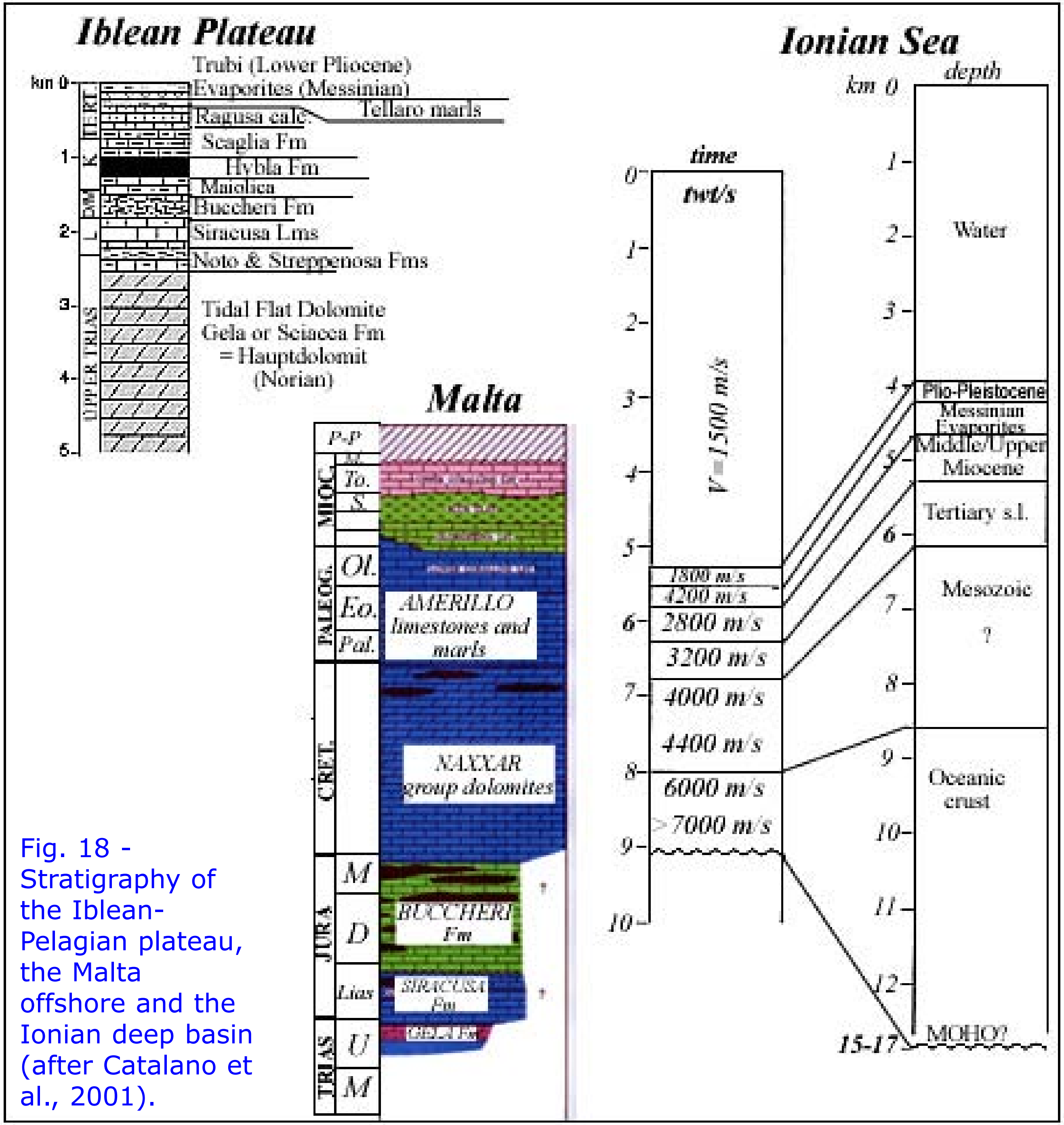

Fig. 18 - Stratigraphy of the Iblean-Pelagian plateau, the Malta offshore and the Ionian deep basin (after Catalano et al., 2001).

Jurassic–Upper Miocene pelagic platform slope and open-shelf carbonates with frequent, thick basaltic intercalations (Patacca et al., 1979; Bianchi et al., 1989; Montanari, 1989, Fig. 18). Upper Cretaceous and Jurassic hydrocarbon–generative source rocks are described by Granath & Casero (2006) and Lipparini et al. (2009).

The sedimentary overburden overlies an about 20-22 km thick continental crust, whose top is constrained at a depth of 8 km by refraction data (Makris et al., 1986; Morelli, 2007). The depth of the Moho is 30-33 km deep. The brittle-ductile boundary in the crust was located at about 20 km (Chironi et al., 2000), taking into account the stretching of the continental crust in this area.

1.2. The Iblean Pelagian continental slope and rise and the Western Ionian Sea

The sedimentary prism thickens from 4-5 km in the upper slope to 7.5 km in the Western Ionian abyssal plain. Stratigraphy of the nearby boreholes and the age and facies of samples dredged at the base of the ME (Biju Duval et al., 1977; Cita et al., 1980; Scandone et al., 1981; Casero et al., 1984) suggest the occurrence of the Triassic-Jurassic carbonate platform across the ME (Fig. 18). An Eocene-Mesozoic succession was noted in the inner abyssal plain by Casero et al. (1984). These Authors pointed out that post-Middle Eocene neritic deposits are also present along the ME both westwards and eastwards, suggesting a lateral continuity (Fig. 18).
Catalano et al. (2000b) highlighted a seaward prograding sigmoidal geometry of Triassic–Upper Jurassic carbonate platform deposits, overlain by onlapping transgressive deposits of Upper Cretaceous – Eocene pelagic limestones/Messinian deposits. The deposits, lying on the hanging-wall of the ME and correlatable to the Triassic–Upper Jurassic carbonate platform, thin out while the flat lying pelagic deposits thicken seawards.
The Moho discontinuity rises up eastwards from 30 to 20 km (Scarascia et al., 1994) and reaches a depth of about 18-19 km in the Western Ionian (Makris et al., 1986).
The continuity of the sedimentary and crustal rock bodies is interrupted by conical shaped bodies, interpreted as igneous intrusions by Catalano et al. (2000b).

1.3. The Malta Escarpment (ME)

The ME, part of the passive margin (Catalano et al., 2000b, 2001, 2002; Chamot-Rooke et al., 2005; Catalano & Sulli, 2006), is a 250 km long, major NNW-SSE trending faulted zone, running from the Messina strait to the Medina “Mounts”, which separates the Ionian Abyssal plain and the Ionian accretionary wedge, to the east, from the shallow marine platforms of the Iblean-Pelagian shelf and onshore Sicily, to the west (Figs 15-17).
It is characterized by a system of normal faults, ENE dipping, with second-order strike components (Grasso, 1993). These components would be a) dextral according to Ghisetti & Vezzani (1982; their Figure 8(c)), Monaco & Tortorici (1995), Nicolich et al. (2000), Doglioni et al. (2001), active only in its northern part (north of Siracusa, Argnani & Bonazzi, 2005), b) sinistral following Ben-Avraham & Grasso (1990) and Reuther et al. (1993).
Its tectonics were interpreted as being due to the right-lateral transtension generated by the differential roll-back between the Ionian Sea and the Eastern Sicily lithospheres (Doglioni et al., 1998, 2007), allowing a mantle uprise beneath the Etna (Doglioni et al., 2001). Its development dates back to the Mesozoic, when it

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corresponded to a hinge zone delimiting a lateral change of depositional facies (Charier et al., 1987). Post-Tortonian and Late Pliocene–Pleistocene extensional tectonic “reactivation” (faulted faults) yields high angle and listric normal faults in the eastward-tilted blocks (Scandone et al., 1981; Makris et al., 1986; Torelli et al. 1998).

1.4. The deep Ionian abyssal plain

Towards the south-east, the Ionian abyssal plain occurs (Fig. 16), showing a generally flat morphology, at times rough (“cobblestone topography”, Fig. 19, because of km-sized, convex-upward, features in seismic profiles, Rossi & Sartori, 1981; Barone et al., 1982), with a slow sedimentation. Such morphology is present only at the shallowest levels of the thick Ionian sedimentary cover; it has been attributed to deformation along blind thrust faults controlled by the presence of Messinian evaporites (Bonardi et al., 2001).
Geophysical data constrain the Moho at a depth of ~15-18 km (Makris et al. 1986; Ferrucci et al. 1991; de Voogd et al., 1992; Truffert et al., 1993; D’Anna et al., 2008) and the top of the crystalline basement (reflector 2a of de Voogd et al., 1992 and Le Meur, 1997) at about 9 km. The thickness of the crystalline crust has been evaluated to be 7-8 km.
In the absence of boreholes penetrating the rock overburden, both seismic facies analysis and comparison with the north-westernmost Ionian sedimentary succession have led to the identification

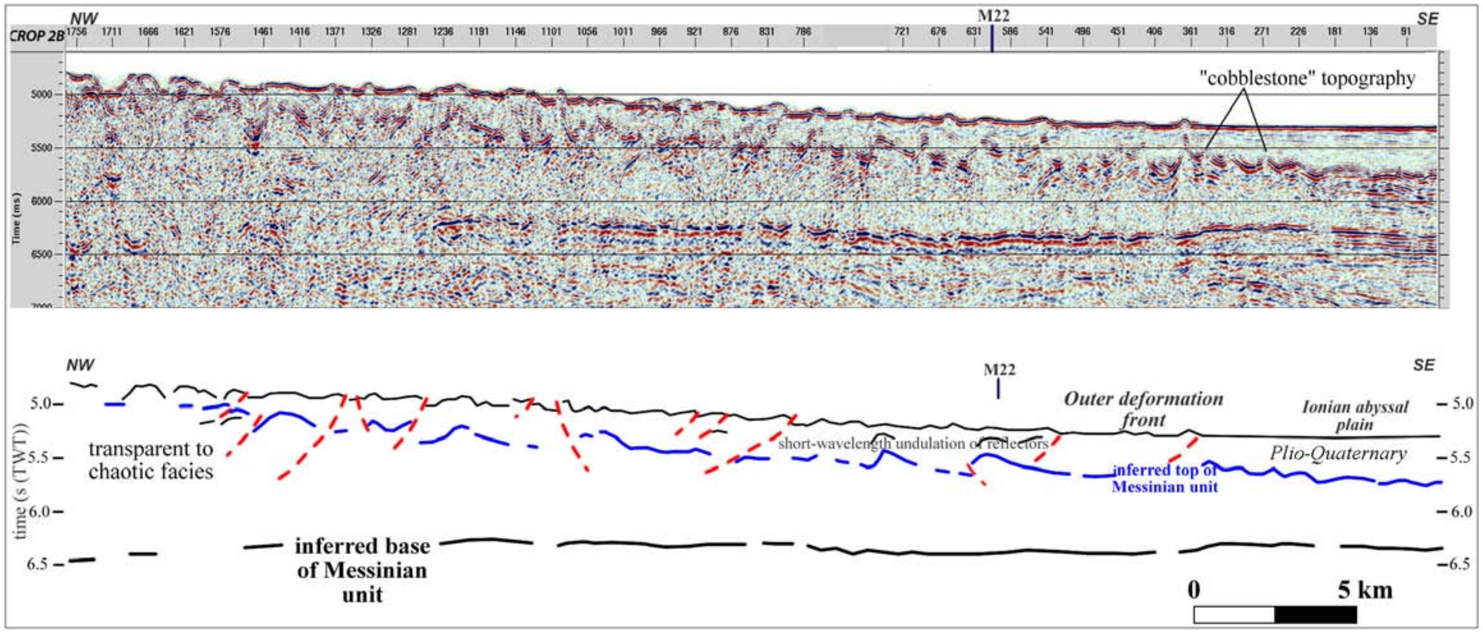

Fig. 19 - Seismic time-migrated section (above) and line drawing (below) of part of the CROP M2B profile, across the boundary between the Ionian abyssal plain and the present-day wedge’s front of deformation. Location map in Fig. 17.

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(Catalano et al., 2000b, 2001; Catalano & Sulli, 2006) of two main sedimentary wedges separated by a regional discontinuity (base of Messinian, Fig. 18). The lower, with a thickness of about 5 km, is seismically interpreted as pelagic deposits (radiolarites, mudstones and marls) from the Mesozoic (?) to early Messinian. The upper sedimentary wedge consists of the Plio-Quaternary sequence (about 400 m) and a 1300 m thick Messinian sequence.

1.5. Crustal characters of the Iblean-Malta-Ionian continental margin to the Ionian Ocean

The continental margin crust becomes progressively thinner eastwards (Fig. 16), as revealed by the rising of the Moho depth from 28-30 km in the Iblean shelf to about 20 km in the Westernmost Ionian Sea, and reaches a depth of about 15 km in the Ionian abyssal plain (Makris et al., 1986), where an oceanic crust occurs.
In addition to Early Mesozoic block-faulting of both the basement and the sedimentary cover (Fig. 16), the large igneous intrusions generating strong magnetic anomalies (Finetti & Morelli, 1973) support the “transitional” nature of the crust flooring the margin (Malta slope and the westernmost Ionian sector).
The lateral continuity across the ME of the sedimentary facies and the depositional relationships between the carbonate platform and the basinal deposits enable us to locate the original edge of the Mesozoic continental margin in the Western Ionian (Figs 15, 16).

1.5.1. The location of the Continental/Oceanic boundary

It is worth nothing that the ME does not separate the continental from the oceanic crust (as believed by many Authors e.g. Finetti, 2004; Cernobori et al., 1996; Minelli & Faccenna, 2010); the original Continent/Ocean boundary is located eastwards, well beyond the ME (Catalano et al., 2000b) as highlighted by both an abrupt change in seismic-acoustic characters, the topography of the basement and the geometry of the sedimentary cover. The age of the initial spreading is still uncertain, due to the lack of deep stratigraphic data, but it can be proposed as Upper Jurassic or Cretaceous, when the sedimentary cover of the continental margin is correlated to the oldest deposits resting above the supposed basement.
Valenti (2008) suggests a more recent reactivation of this fault (or better, faulted zone) marking an older separation of two lithospheric domains having different thicknesses, heat flow and tectonic evolution. It is a still active crustal-scale structure limiting the Ionian wedge on its western side (Fig. 15), with a dextral component of displacement (according to the focal mechanisms of Pondrelli et al., 2006).

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2. The Ionian accretionary wedge

Deep reflection seismic lines clearly image a flexure of the Ionian oceanic lithosphere beneath Calabria (Fig. 20 and Finetti, 1982, 2004, 2005; Cernobori et al., 1996; Catalano & Sulli, 2006; Minelli & Faccenna, 2010; Polonia et al., 2011) continuing into a seismogenic NW- more than 70°-dipping slab (Gasparini et al., 1982). The latter extends down to some 500 km beneath the SE Tyrrhenian basin (Fig. 21), as demonstrated for the Aeolian Islands by mantle tomography and calc-alkaline magmatism (Anderson & Jackson, 1987; Selvaggi, 2001; Piromallo & Morelli, 2003; Faccenna et al., 2004; Peccerillo, 2005).
The high angle of the subducting slab, in the SE Tyrrhenian, is believed to be due to the roll-back of the subduction hinge of the Ionian lithosphere (Caputo et al., 1970; Malinverno & Ryan, 1986; Doglioni, 1991; Doglioni et al., 1999, 2007; Faccenna et al., 2001, 2011; Chiarabba et al., 2008) that retreats south-eastwards, causing an extension in the Southern Tyrrhenian.
Offscraping, progressive deformation and piling up of i) the thick (up to 7 km) Mesozoic and Cenozoic sedimentary cover of the descending Ionian plate (Rossi & Sartori, 1981; Finetti, 1982, 2004, 2005; Tramutoli

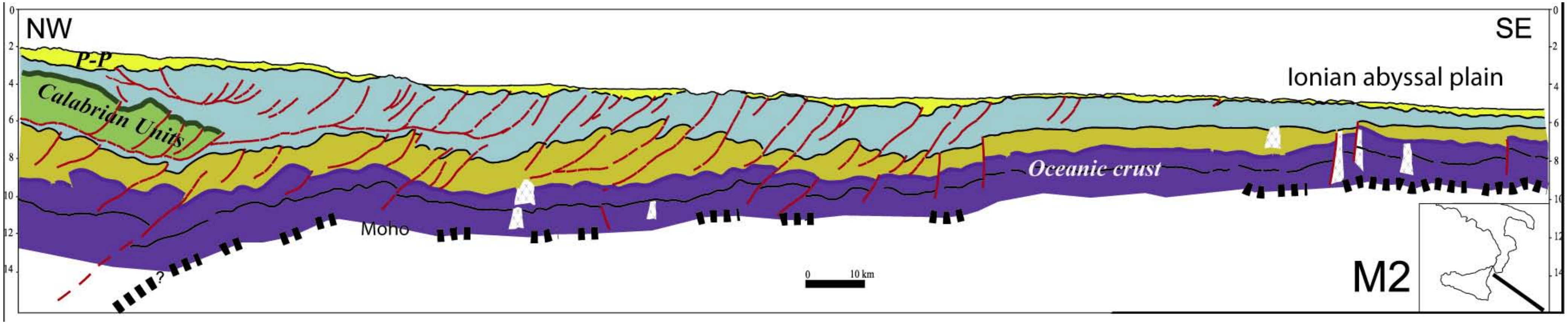

Fig. 20 - Line drawing of the NW-SE trending, CROP M2B profile (after Catalano et al., 2002), crossing the continental margin from the Ionian abyssal plain to the upper continental slope near the North-Eastern Sicily-South Calabria coastline, for a length of about 309.5 km. The profile returns an image of a both well developed SE-vergent accretionary wedge and a NW-dipping oceanic basement. PP: Plio-Pleistocene deposits.

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et al., 1984; Pescatore & Senatore, 1986) and of ii) slices of likely oceanic crust (Catalano & Sulli, 2006) concur to form a sequence of several imbricate thrust sheets of the SE-verging Ionian accretionary wedge (Fig. 15). It has been interpreted as an active (Gutscher et al., 2006; D'Agostino et al., 2008, 2011), arc-shaped, thick (up to 10 km) accretionary wedge (Sartori, 1982), about 200-300 km long and 120 km wide (Polonia et al., 2011).
Some Authors have speculated that the accretionary wedge is presently inactive, and that shortening and large scale deformation of the wedge could be the result of passive gravity-driven processes, leading to a collapse of post-Messinian sediments over the evaporites (Chamot-Rooke et al., 2005).
In its outermost portion, the accretionary wedge is imaged as a salt-bearing complex (Valenti, 2010, 2011; Polonia et al., 2011), with a very low surface angle (0.6°). The décollement level is located at the inferred base of the Messinian evaporites, along a relatively flat and gently landward-dipping (about 0.8°, within 50 km from the leading edge of the wedge, producing a taper of about 1.5°) reflector with negative polarity (Valenti, 2010, 2011).
Below the inner parts of the wedge, the détachment becomes progressively deeper and cuts down into the Mesozoic carbonates (Fig. 19), more deeply and markedly northwestwards.

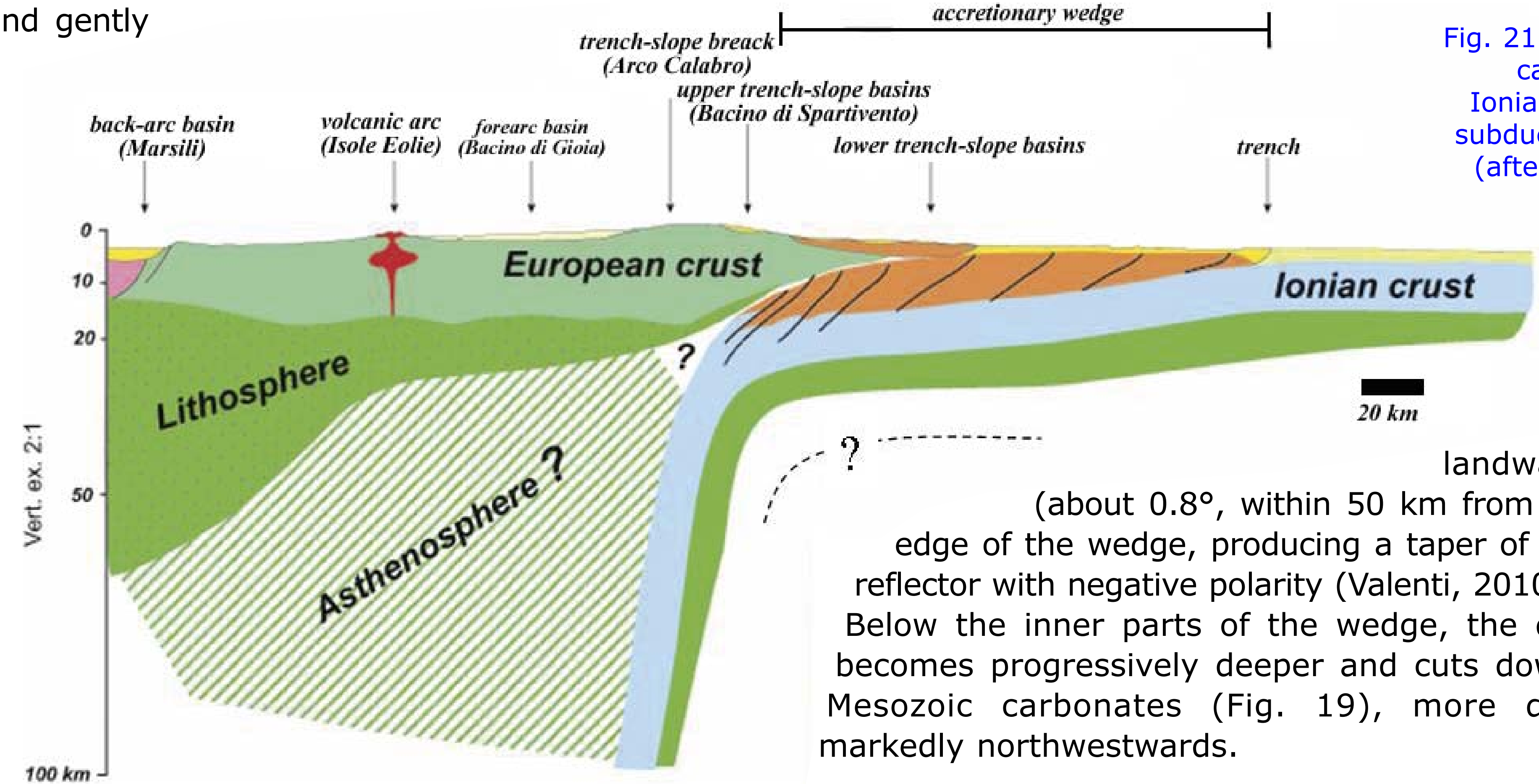

Fig. 21 - Geological cartoon of the Ionian-Tyrrhenian subduction system (after Catalano & Sulli, 2006).

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A general bipartition of the Messinian evaporite unit was highlighted, for the outermost accretionary wedge, by Valenti (2010), consisting of 1) a transparent subunit showing evidence of ductile deformation and the development of salt-cored thrusting structures, at the bottom and 2) a layered subunit showing evidence of brittle deformation, at the top (Fig. 22).

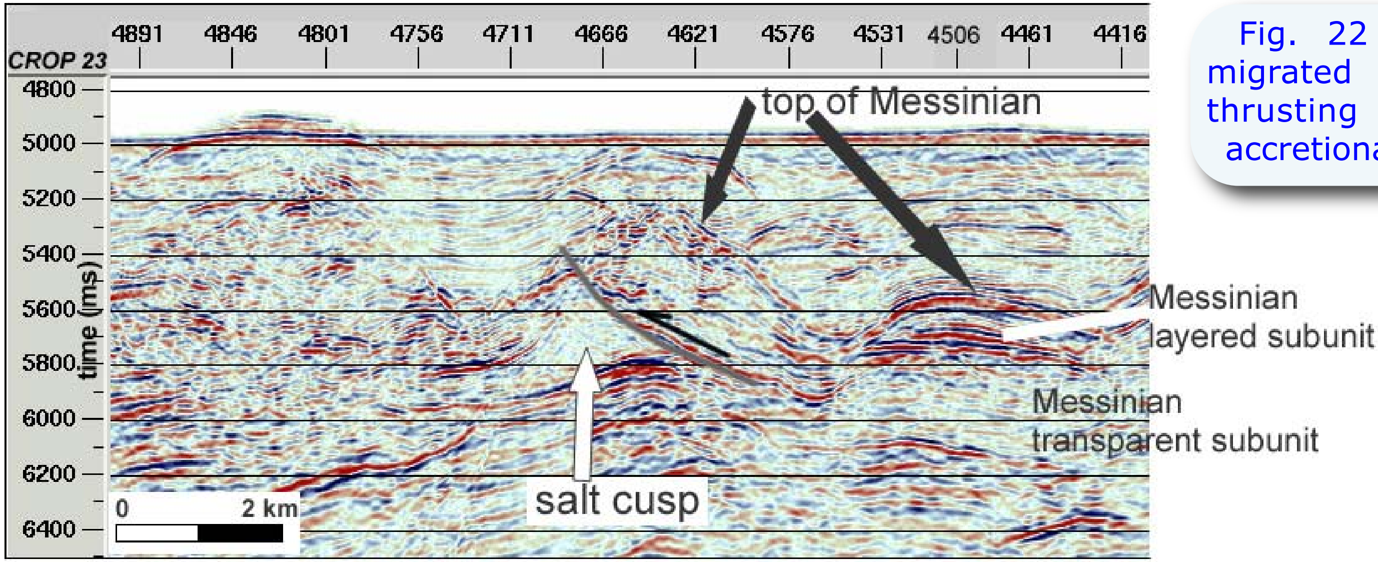

Fig. 22 - Seismic closeup from the time-migrated CROP M23 profile showing salt-cored thrusting structures at the outermost Ionian accretionary wedge. Location map in Fig. 17.

The difference in both seismic facies and the deformational style, imaged for the Messinian evaporite, allows a better defined stratigraphy that results of a salt layer, below, and a layered body of gypsum and marls, above.

Such an observation agrees well with the low taper value detected for the Ionian accretionary wedge (Clift & Vannucchi, 2004; Lenci & Doglioni, 2007), and the fast forward propagation of the frontal thrust.

The occurrence of an oceanic crust certainly favours subduction in this area, generating the Aeolian volcanic arc and the deep seismicity in the South-Eastern Tyrrhenian, as well as the ascent of the Etna magmas.

The comparison with the crustal setting of the adjacent continental crustal sector (Sicily) highlights the importance of the crustal and lithospheric heritage of the downgoing foreland. The convergence of a continental crust causes more difficulty in the subduction of the Sicilian crust with respect to the Ionian sector where a greater convergence rate facilitates both a southward advancing of the deformation front (arcuate shape of the Apenninic front) and a vertical separation between the Ionian and Sicilian crusts. The surface expression of this behaviour is the shorter propagation of the Sicilian frontal accretion and the building of a chain with a greater topographic relief than the accretionary wedge of the Calabria-Ionian sector (Catalano et al., 2001; Catalano & Sulli, 2006).

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Stratigraphy in the study area

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Facies analysis and physical stratigraphy, accompanied by biostratigraphy, have been used since the seventies to study the outcropping carbonate and terrigenous rock bodies in Sicily.

This approach has allowed (Catalano & D'Argenio, 1978) to define the concepts of a "paleogeographic unit" (large original rock bodies deposited in a specific setting) and a "paleogeographic domain" (a group of deposition isopic zones not yet deformed by the tectogenesis).

Old studies have envisaged the occurrence of different Paleozoic-Neogene successions pertaining to different crustal paleodomains of the ancient African continental margin, Tethys ocean (?) and "European plate" (Calabrian arc) (Catalano et al., 1989a; Roure et al., 1990; Bianchi et al., 1989).

After the detachment from their basement, most of the geological bodies were deformed and are, at present, exposed in the Sicily fold and thrust belt (FTB), forming a stack of tectonic units (structural-stratigraphic units, D'Argenio & Scandone, 1970; Catalano & D'Argenio, 1978).

In this note, the rocks outcropping along the large North to South study belt, as represented in a large-scale field map (shown in the GFT Map), are schematically illustrated. For a useful general background, we have summarized a recently available stratigraphy of the Sicily FTB and its foreland in a regional stratigraphic scheme (Fig. 23).

This schematic diagram shows the relationships between the Mesozoic-Cenozoic rocks of the African continental margin, pre-orogenic paleogeographic domains and the syn-orogenic terrigenous evaporitic and carbonate Neogene-Pleistocene deposits partly filling in the foreland basins formed during the thrust stacking.

The scheme displays the lithostratigraphic units recognized in the Meso-Cenozoic shallow- and deep-water carbonate sections. The Imerese and Sicanian units are Permian-Cenozoic, deep-water carbonate domains, the Panormide and Trapanese-Saccense units represent the Meso-Cenozoic carbonate platform paleodomains, as well as the Iblean carbonate platform unit that is now the foreland of the chain.

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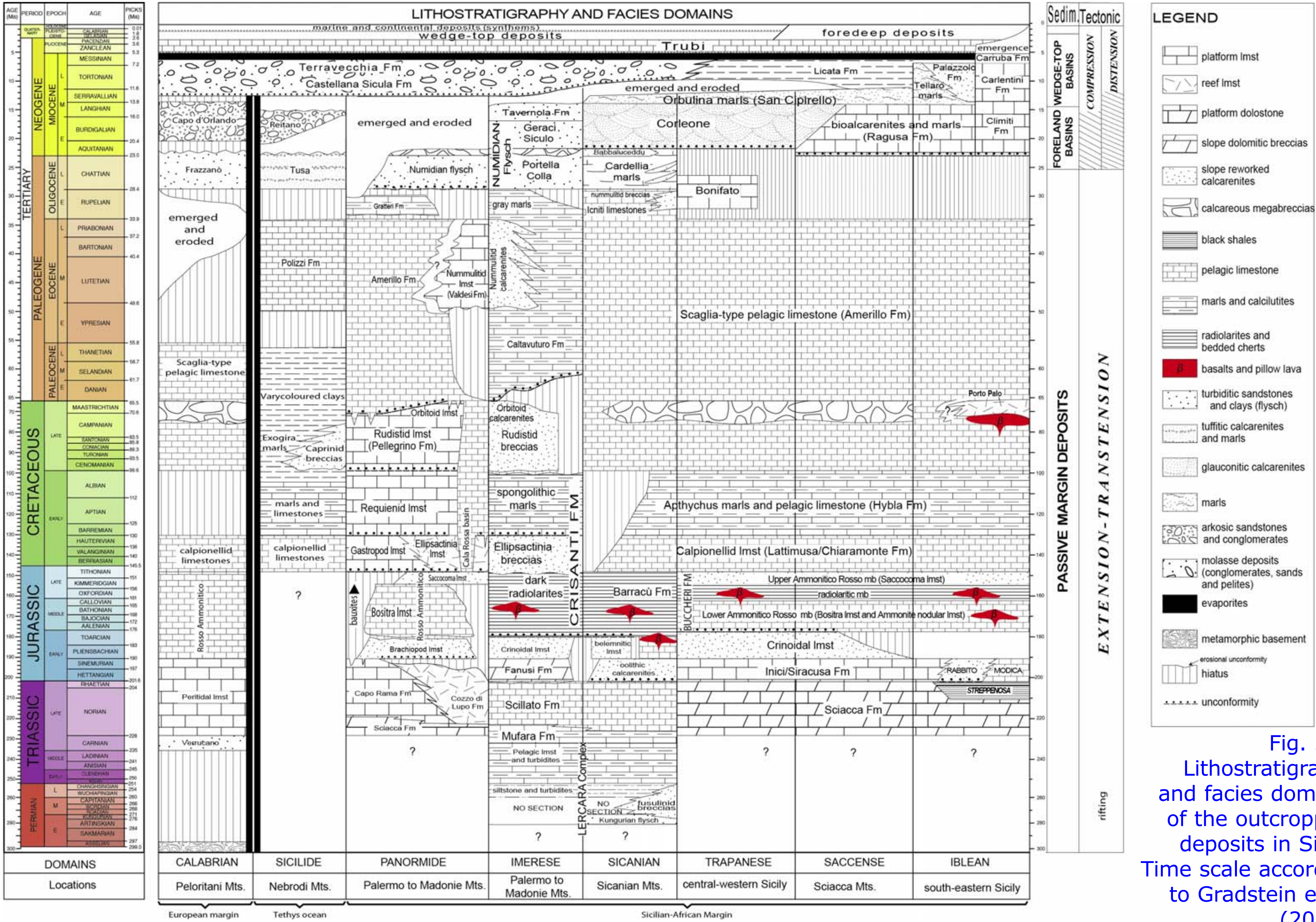

Fig. 23 - Lithostratigraphy and facies domains of the outcropping deposits in Sicily. Time scale according to Gradstein et al. (2004).

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Ten's of boreholes have been drilled in Sicily in the past. Some of them (Colla 1 (2238m TD), Avanella 1 (3051m TD), Valledolmo 1 (3197.3m TD), Castellana 1 (1076m TD), Creta 1 (3203m TD), Casteltermini 1 (5710m TD), Platani 2 (3378.5m TD), Settefarine 1 (4630m TD), Vizzini 1(4096m TD), Armatella 1 (3365m TD) are located in the study area (Fig. 24). Recently, borehole stratigraphy has been revised in cooperation with Eni e&p (Frixa & Triancianti, 2006; Catalano et al., 2008, 2009) and redefined on the basis of the new Sicilian lithostratigraphical nomenclature (Basilone, 2012).

These results, together with recently revised field mapping (Catalano et al., 2010a, b; 2011a, b) covering the study area, have been used to calibrate the lithofacies with seismic horizons of the intermediate-resolution seismic reflection lines (generously provided by Eni e&p). Well velocity surveys help to calibrate seismic data. Direct seismic calibration was performed using Platani 2, Castellana 1, Avanella 1, Valledolmo 1, Vizzini 1 and Armatella 1 wells. Neighbouring boreholes help to characterize the seismic response of the studied geological intervals.

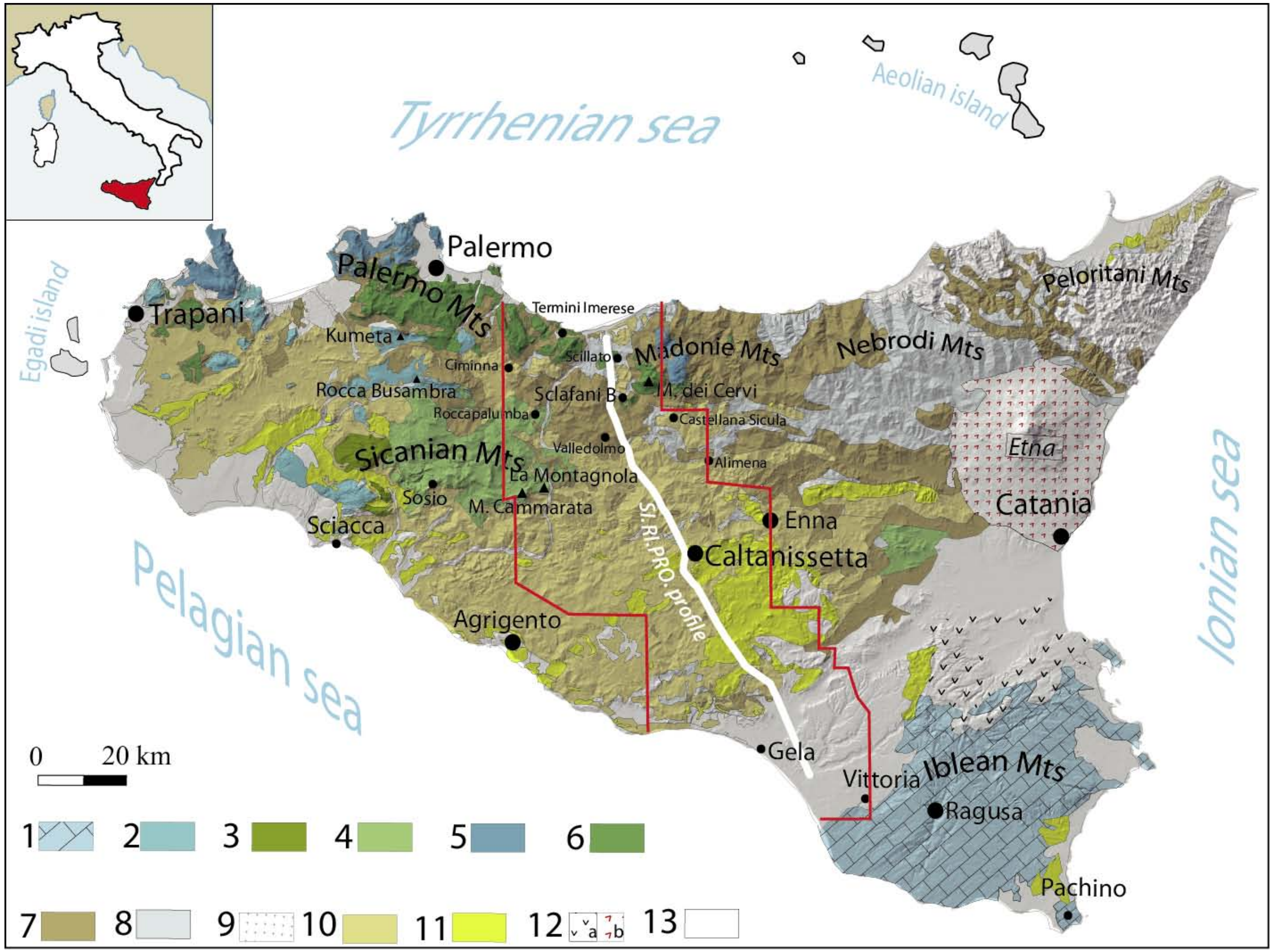

Fig. 24 - Index map.
1) Iblean units; **2)** shelf to pelagic carbonate units (Trapanese–Saccense); **3)** shelf to deep-water carbonate units (Monte Genuardo); **4)** deep-water carbonate units (Sicanian); **5)** shelf carbonate units (Panormide); **6)** slope to deep-water units (Imerese); **7)** Miocene flyschs; **8)** Sicilide units; **9)** Calabrian–Peloritani units; **10)** Miocene-Pliocene syntectonic deposits; **11)** Plio-Pleistocene syntectonic deposits; **12)** Plio-Quaternary volcanic rocks; **13)** Pleistocene deposits.

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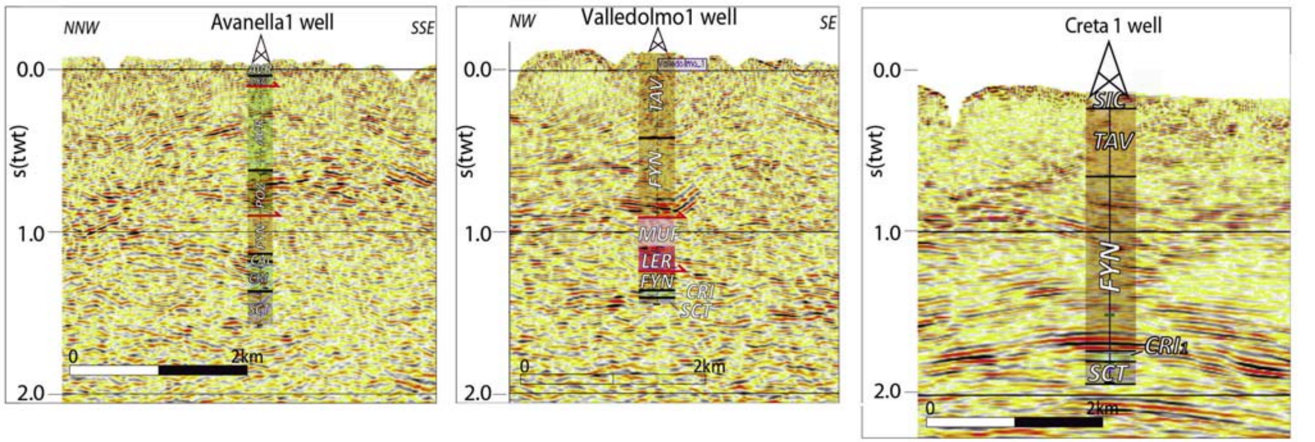
The revised lithostratigraphical analysis benefited from geological and geophysical integration, using the synthetic record (sonic, gamma log, synthetic seismogram) and time–depth conversion of lithological data from boreholes (Fig. 25).

The occurrence in the study area of deep-water Meso-Cenozoic carbonates, both in the outcrop and when crossed by some boreholes, has offered the possibility of comparing their stratigraphy and facies characteristics and reconstructing their original location in the ancient continental margin domains. The carefully analyzed outcropping sections have been calibrated with the borehole sequences (Fig. 26).



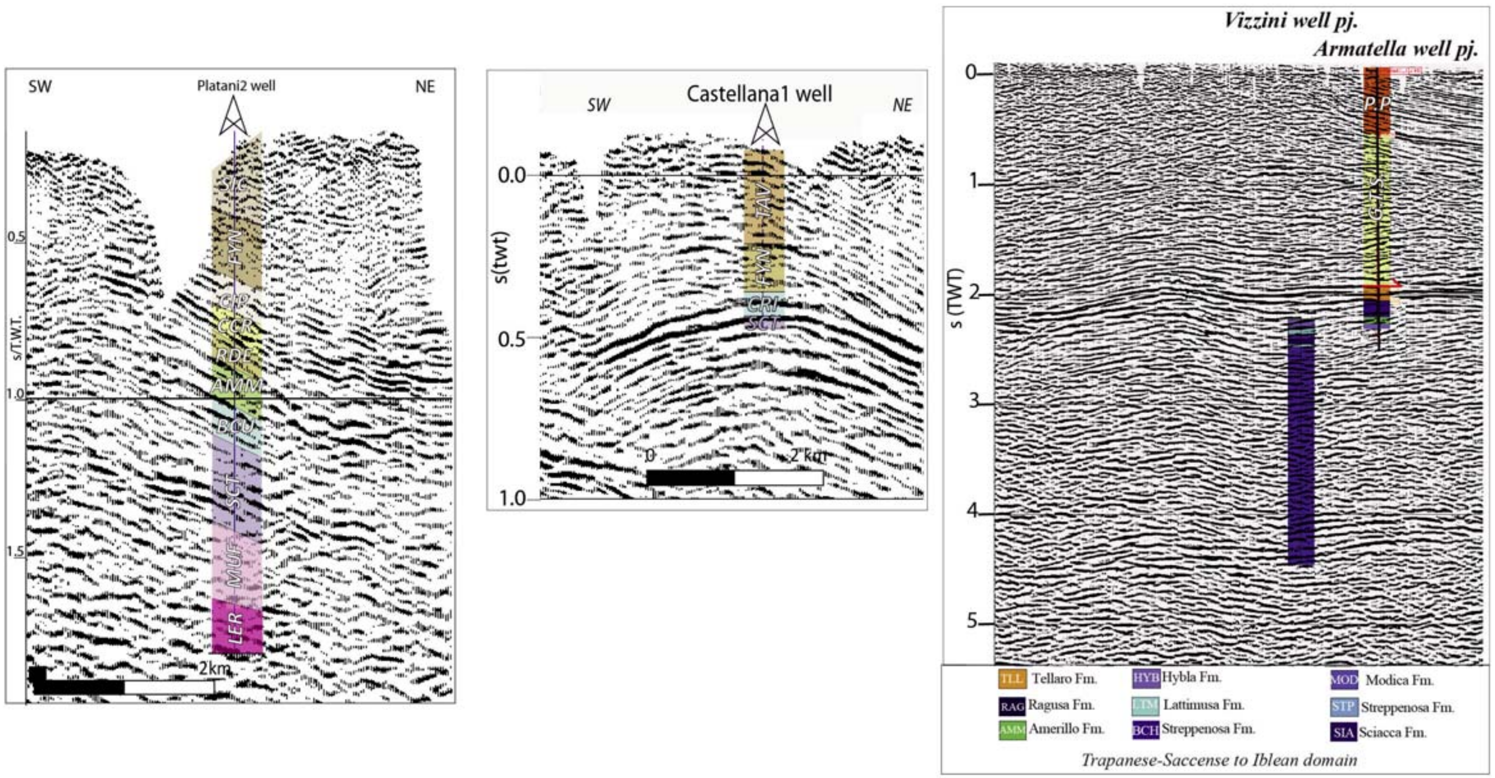


Fig. 25 - Calibration of the revised lithofacies with seismic reflection horizons.

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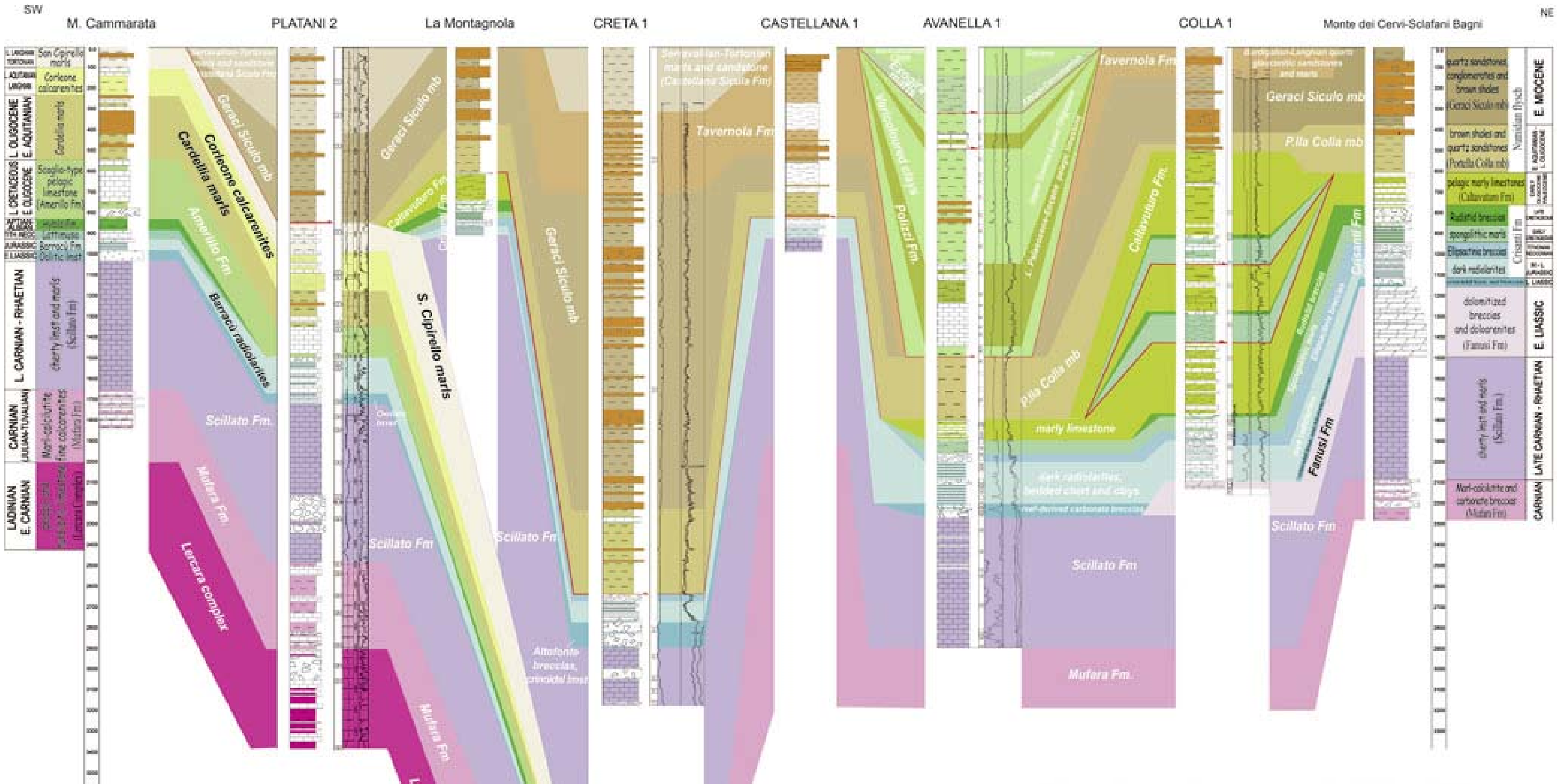

Fig. 26 - Comparison and correlation of the outcropping deep-water Imerese and Sicanian sections visited and the synthetic log stratigraphy of some boreholes drilled in the visited area.

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This note aims to illustrate the stratigraphic terminology, geological lexicon and the main stratigraphic subdivisions that may not be familiar to the field trip partecipants. Further on, subsurface methods will be used to describe the Meso-Cenozoic deep-water deposits and the link with their outcropping omologous deposits.

Stratigraphy of the visited area

Boreholes, field geology, seismic stratigraphic interpretation calibrated with well logs and stratigraphic analyses allow us to recognize, in the visited area (GFT Map), several sedimentary successions consisting of both syn-orogenic deformation deposits, spanning from the Pleistocene to the Miocene, and the Neogene to Permian pre-orogenic deep- and shallow-water carbonate deposits.
Starting from the most recent, they consist of:
a) Recent continental and marine sediments.
b) Holocene-Pleistocene foredeep pelagic marly limestones, and sandy clays (Catalano et al., 1997), mostly outcropping in the Gela region (GFT Map) and along the foreland margin (Ghielmi et al., 2011).
c) Pleistocene-Upper Pliocene carbonate-clastic deposits (Enna marls and Capodarso calcarenites), that characterize the infilling of the Plio-Pleistocene wedge top basins. The deposits largely outcrop in the Caltanissetta-Enna region, in the Gela area and its offshore (see Fig. 24 and GFT Map). Most of them are involved in the local Gela "nappe" tectonics. They will be visited during Stop 5 of the second day and during the third day of the Geological Field Trip (from now on GFT).
d) The underlying, Lower Pliocene Trubi which are well known pelagic marly limestones outcropping all over Sicily and, largely, in the southern sector of the study area, from Caltanissetta-Enna to the Gela regions. The marl-limestone couplets unconformably overlie: **e)** Messinian evaporites and clastics, formed during the Messinian Salinity Crisis in the Mediterranean. The strongly deformed evaporite layers outcrop along a SW-NE alignment from Agrigento to Caltanissetta and in the Gela region as well in its offshore. Unconformity to paraconformity surfaces separate them from the underlying.
f) Lower Messinian-upper Tortonian conglomerates, sands and pelites (Terravecchia fm), unconformably resting on lower Tortonian-upper Serravallian sandy clays, marls and sandstones (Castellana Sicula fm, Platani 2 and Creta 1 well constraints, Fig. 25, **g** in the map). Both these units are interpreted as a molassa-type filling wedge top basins, in turn, deformed; the deposits, widely outcropping in the study area (GFT Map), will be

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visited in detail at the Scillato basin during Stop 1 of the first day of the GFT. The present-day, strongly deformed, clastic unit, overlies a stack of tectonic units (see GFT Map).

The carbonate and clastic meso-cenozoic tectonic units consist, from the geometrically highest, of: **h)** Sicilidi units made of lower Miocene-upper Oligocene tuffitic marlstones (Tufiti di Tusa), lower Oligocene–Cretaceous varicoloured clays and Eocene white marly limestones (Polizzi fm). These rocks largely occur in the northeastern corner of the map (GFT Map). In the study area, the rocks outcrop to the south of the Madonie Mts and in the Caltanissetta-Gela region, where they underlie the Miocene-Pleistocene thrust top deposits. The Sicilidi tectonic units, frequently strongly tectonized (Avanella 1 well constraints, Fig. 25), overthrust:

i) a Numidian flysch nappe wedge formed by repeated slices of turbiditic sandstone. The type section consists of Langhian-Burdigalian marlstones and quartz-glauconitic sandstones (Tavernola fm) and lower Burdigalian-upper Chattian pelites, sandy mudstones and turbiditic quartzarenites. The original depositional setting of the Numidian flysch is believed to be either a “highstand” passive margin deposit controlled by a hinterland uplift (Thomas et al., 2010) or a foreland basin (Catalano et al., 1989a), where it unconformably took place above the Mesozoic-Paleogene deep-water Imerese, Panormide platform carbonates and a more internal substrate (Sicilide domain). The rock unit was successively partly detached, deformed and stacked to form a tectonic wedge. The stratigraphical and sedimentological characteristics of the terrigenous rock body, largely outcropping in the northern sector of the study area, where it reaches 1000-2000 m in thickness, will be observed during Stop 4 (Valledolmo area) of the first day and the second day in the Cammarata region. The deformed Numidian flysch wedge overthrusts at place: i) the Permian-Triassic deposits, both in the outcrop of the Roccapalumba region (GFT Map) and in the subsurface, as demonstrated by the Cerda 2, Roccapalumba 1 and Valledolmo 1 borehole stratigraphy (Figs 25 and 26); ii) the Imerese and Sicanian deep-water carbonate units, observable both in the outcrop (Madonie and Sicani Mts, GFT Map) and detectable in the subsurface (Castellana 1, Creta 1 and Platani 2 wells, Figs 25 and 26).

j) The wedge stack of Triassic-Permian siliceous turbidites, deep-water limestones and reef-derived resedimented carbonates form the locally named Lercara lithostratigraphic complex (Catalano et al., 1991) or “broken formation”, due to the strong Tertiary contractional deformation that hides the true stratigraphic relationships. The allochthonous thick wedge, largely outcropping in the Cerda and in the Roccapalumba regions (GFT Map), is buried beneath the Valledolmo region, where it has been encountered for a thickness of more than 1000m by the Cerda 1, Lercara Friddi 1, Lercara 1, Roccapalumba 1, Valledolmo 1 boreholes.

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l) Oligocene to Middle Triassic Imerese rock units (see section type in Fig. 26). They consist of Meso-Paleogenic carbonate and silico-carbonate pelagic deposits with intercalations of resedimented carbonate breccias with carbonate platform-derived elements (Figs 23 and 27). The Imerese rock units largely outcrop in the Termini Imerese area and the western Madonie Mountains (GFT Map), where a well-exposed section will be visited at Stop 2 during the first day of the GFT (Sclafani Bagni section). These rock units were encountered by the Colla 1, Avanella 1, Valledolmo 1, Castellana 1, Creta 1 wells (Figs 25 and 26). They also outcrop in a restricted area near Cammarata (easternmost side of the Sicanian Mountains, GFT Map), where they will be visited at Stop 1 during the second day of the GFT (La Montagnola section).

m) Lower Tortonian-Permian Sicanian rock units (see section type in Figs 23 and 26). They consist, mostly, of a succession of Permian-Paleogene carbonate and silico-carbonate pelagic deposits (Figs 26 and 27) with minor reworked deposits with shallow-water derived elements and Oligo-Miocene clastics.

Sicanian deep-water successions are exposed in a large area, west of Cammarata town (western side of the GFT Map), where they will be visited at Stop 2 during the second day of the GFT. These rock units extend eastwards into the subsurface, where they are drilled by Platani 2 and Casteltermini 1 wells (Fig. 26).

n) Lower Tortonian-Upper Triassic Trapanese rock units. The Trapanese section type (Fig. 23) includes Lower Liassic-Upper Triassic platform carbonates, Paleogene-Mesozoic pelagic carbonates and Lower Miocene, open-shelf, clastic-carbonate deposits. In the investigated area, they are represented by the small outcrop of the Vicari and Roccapalumba rock units and are buried beneath the Caltanissetta basin, as suggested by the SI.RI.PRO. profile interpretation which envisaged a thick body of what are believed to be carbonate platform deposits, at a depth between 9 and 15 km (see Catalano, this guidebook, pp. 13-50).

o) Pleistocene-Upper Triassic Iblean deposit unit (Fig. 23). They outcrop at Noto, near the town of Vittoria (see GFT Map) and in the south-easternmost sectors of the Island of Sicily (Ragusa and Pachino areas). In the south-eastern sector of the study area, beneath the Gela Thrust System and the Plio-Pleistocene marly deposits, several boreholes (see Fig. 25 for borehole constraints) have crossed the Miocene-Mesozoic shallow-water to the pelagic carbonate of the Iblean platform domain, constraining both lithology and stratigraphy. Cumulative thicknesses of 5-to-7 km of the Triassic-Lower Liassic shallow-water dolomites and limestones (Vizzini 1 borehole, Fig. 25, Bello et al., 2000) or intraplatform carbonate turbidites (Streppenosa fm) occur, together with a 1-to-2 km Jurassic–Upper Miocene pelagic platform slope and open-shelf carbonates with

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frequent, thick basaltic intercalations (Patacca et al., 1979; Montanari, 1989; Bianchi et al., 1989) which represent the almost ten km thick autochthonous Iblean foreland.
Heteropic relationships between the Trapanese-Saccense and Iblean paleogeographic units have been already demonstrated (Catalano & D'Argenio, 1982b; Frixa et al., 2000).
p) Other well known carbonate platform rocks are the Panormide units (Fig. 23) outcropping mostly in Western Sicily and in the Madonie Mts As these rocks outcrop farther from the study region we only briefly illustrate their main characteristics. The type section consists of Late Triassic to Late Eocene age carbonates, 900-1200 m thick, mostly characterized by shelf facies, with alternation of continental (few) and marine condensed deposits due to periodic subaerial exposure and pelagic sedimentation episodes.

The Imerese and Sicanian Meso-Cenozoic deep-water carbonates. A comparison

In the N and SW sectors of the study area well-preserved, deep-water carbonate sections, pertaining to both the Imerese and Sicanian basinal succession (GFT Map and Fig. 24), outcrop.
Boreholes, drilled between or just close to the carbonate outcrops, reveal how the exposed rocks widely occur in the subsurface.

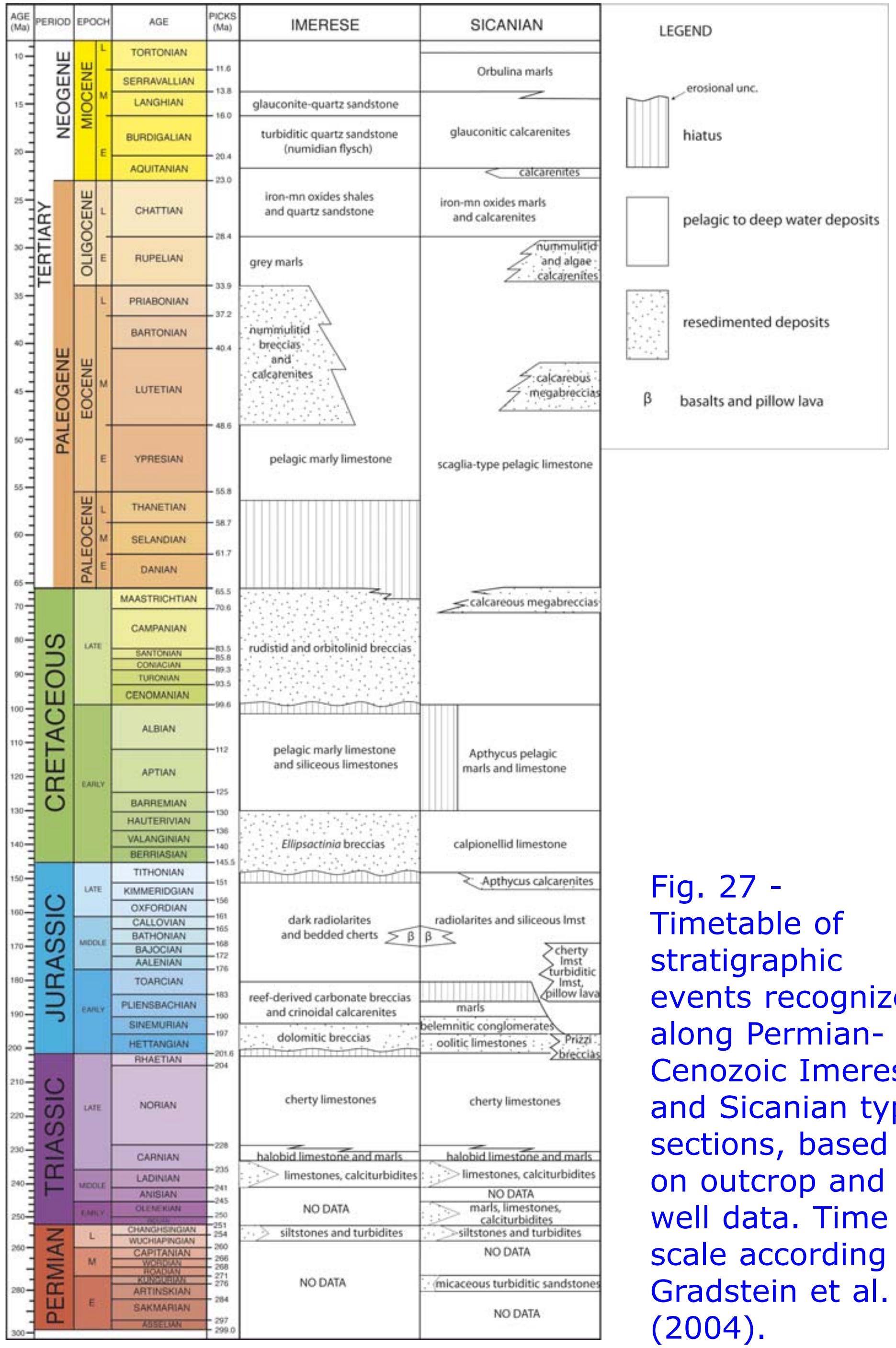

Fig. 27 - Timetable of stratigraphic events recognized along Permian-Cenozoic Imerese and Sicanian type sections, based on outcrop and well data. Time scale according to Gradstein et al. (2004).

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When correlated and spatially linked, it is possible to mark their sedimentologic and lithologic characteristics, to define their present day tectonic setting in the thrust stack and to restore their mutual paleogeographical relationships

To meet this objective, we compared some outcropping type sections with deep-water carbonates drilled by the investigated boreholes (Figs 25 and 26).

The Imerese basin section

The Imerese basin type-section has been studied along two, end-member field sections: the Sclafani Bagni-Monte dei Cervi composite section and the La Montagnola section (Fig. 26). The study deposits were correlated to the log stratigraphy restored in the Colla 1 (530-2238m interval), Avanella 1 (1920-3051m interval), Castellana 1 (905-1076m interval) and Creta 1 (2752-3203m interval) wells (Fig. 26).

The Sicanian basin section

The Sicanian basin type-section has been studied by comparing the outcropping succession of the Cammarata Mount, believed to be the most complete succession type, and the log stratigraphy of the Platani 2 (844-3378,4m TD interval) and Casteltermini 1 (3203-5710m TD interval) wells.

When compared, the Imerese deep-water carbonate units differ from the Sicanian successions in the Miocene-Oligocene and Paleogene-Upper Jurassic rock intervals (Fig. 27), while the Middle Triassic-Permian clastics and carbonates and the Lower Carnian-to-Rhaetian carbonates are common to both the Imerese and Sicanian successions.

1) *Permian-Middle Triassic deposits*

These rocks are commonly recognized as the oldest rocks of the Sicanian successions outcropping in the Sosio Valley and Lercara region (Gemmellaro, 1878; Trevisan, 1937; Mascle, 1979; Catalano et al., 1991; Di Stefano & Gullo, 1997; Robertson, 2006), while Lower and middle Triassic rocks form the base of the Imerese succession (Valledolmo 1 borehole and Carillat, 2001; Buratti & Carillat, 2002; Carillat & Martini, 2009). A mixing of Permian to middle Triassic rocks, interlocked with the Mufara marly limestone (Carnian in age) yield a “melange” often found as a tectonic unit intimately mixed up with the Sicilidi and the deformed Numidian flysch nappes, as desumed also from the interpretation of the log stratigraphy of the Roccapalumba 1 borehole.

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Based on the log and core samples stratigraphy of some boreholes (Cerda 1, Lercara 1, Lercara Friddi 1, Valledolmo 1, Roccapalumba 1, Casteltermini 1 and Platani 2 wells), we have identified some drilled lithotypes and correlated them to the outcropping rocks. For completeness' sake, we report the main results:

a) Reddish-greenish siltitic marls and clays and mudstones rich in conodonts, radiolarians and palinomorphs with intercalations of micaceous-carbonate siltstones and fine sandstones with quartz, feldspars, glauconite and phosphate in traces (Pl. IV); calcareous bioclastic packstone with rare oolites, calcareous algae, echinoids and mollusc fragments, calcareous breccias in megablocks. The carbonate platform-derived elements are rich in fusulinids, spongid and coral fragments. Locally, grey-green diabases are present. The microflora assemblages (Pl. V) suggest a Late Permian age (Tatarian-Kazanian). These deposits were encountered in the Lercara Friddi 1, Lercara Agip 1 e Roccapalumba 1 wells (Fig. 25). In the Lercara 1 well, some samples have displayed, together with the Upper Permian palynomorphs assemblage, also reworked large-size smooth chitinozoans probably of Ordovician age. Similar deposits were also described in the Sosio Valley (red clay unit and Sosio megablocks), that Catalano et al. (1991) dated as Late Permian;

b) clayey mudstone with radiolarians and pelagic bivalves, locally dolomitized, with thin intercalations of grey-greenish to reddish clays and siltitic clays and fine quartzitic sandstones with carbonate cements (Pl. VI). Calcareous breccia and resedimented bioclastic packstone, with elements of grey, intra-bioclastic and oolitic packstone and fossiliferous mudstone, locally recristallized, are interlayered (Pl. VI). The matrix of the breccias consists of red, green and grey marls, sometimes localized in thin layers. A lower Triassic microflora has dated these deposits encountered in the Roccapalumba 1 well (1635-2707 m TD interval);

c) radiolarians and pelagic bivalve-bearing, mudstone-wackestone, alternated with green and dark grey clays and marls with interlayered intraclastic turbiditic packstone with small bioclasts, ooids, peloids and algae (Pl. VII). Based on their palynological content (Pl. VIII), the rocks were assigned to the Late Ladinian-Early Carnian time interval. These lithotypes were encountered in Platani 2 and Valledolmo 1 boreholes; in both boreholes they pass upwards into the Carnian halobid marly limestone (Mufara fm). Similar and chronoequivalent deposits were also described in the Sosio Valley (*Daonella* limestone and radiolarites unit, Catalano et al., 1991).

The Upper Triassic, deep-water pelecypod bearing marly limestones (Mufara fm) and cherty limestones (Scillato fm), well known in the Sicanian Mts and in the Madonie Mts (see GFT Map), appear to have been drilled by several boreholes, showing how these rocks are common to both successions, notwithstanding some differences that surfaced by comparing them, such as: a) the occurrence of basaltic lavas and fractures filling

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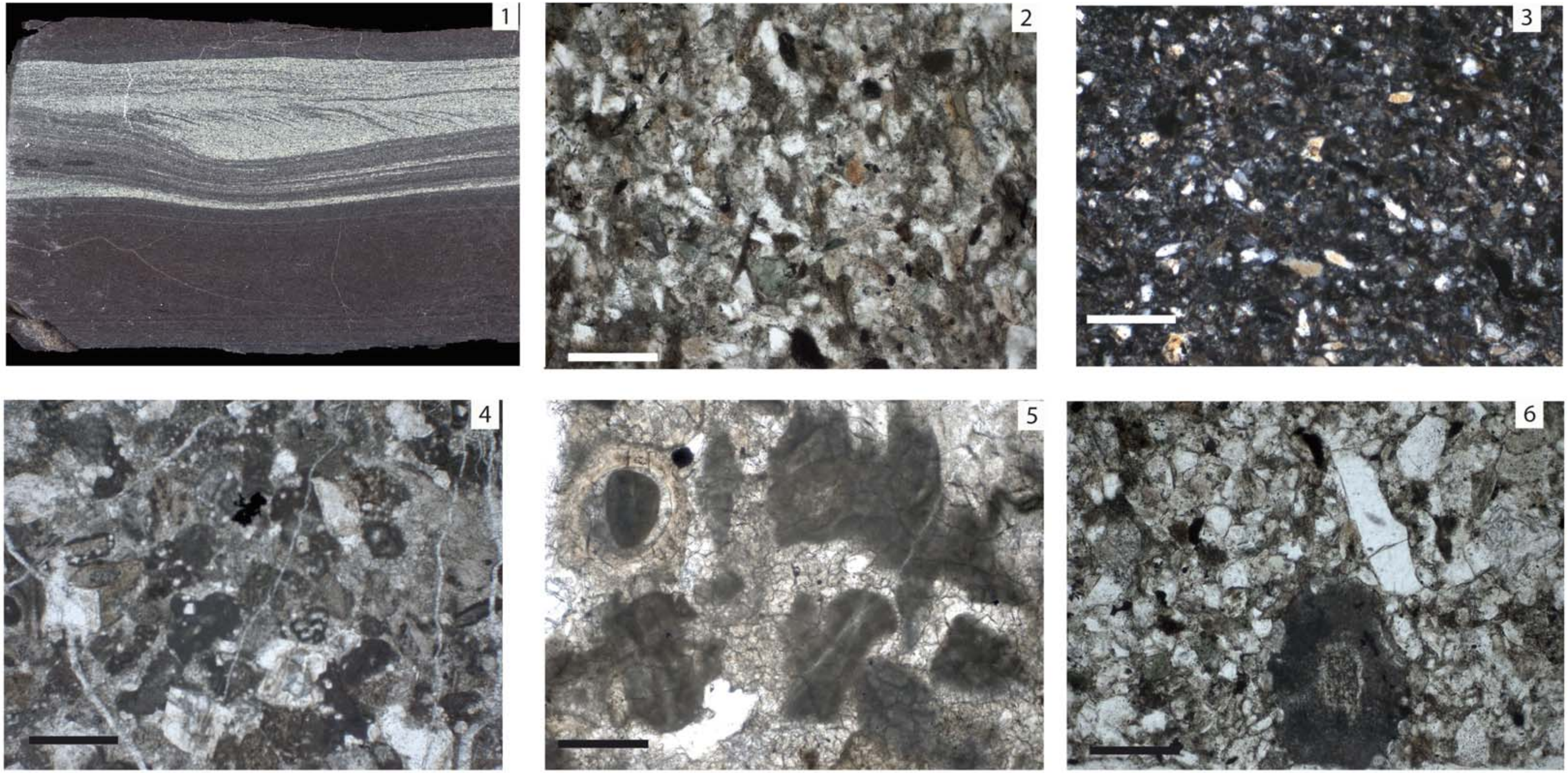

Plate IV - Characteristic microfacies of the Late Permian siltitic marls and mudstone with intercalation of calcareous bioclastic reworked limestones. Fig. **1**. red brown clay siltstone with intercalations of cm-thick layers of greenish siltsone-sandstone and siltitic mudstone (core 2, 708-711 m., Roccapalumba 1 well, macroscopic sample); Fig. **2**. quarzitic siltstone with glauconite and phosphate fragments (cutting 405-409 m, Lercara Friddi 1 well, PPL, scale bar 0,4 mm). Fig. **3**. fine sandstone and coarse siltstone with quartz, feldspar, miche, glauconite and phosphate fragments interlayered in to red siltitic clay (core 1, 484.6-485.9 m, Lercara Agip 1 well, PPL and PPX, scale bar 0,4 mm). Fig. **4**. reworked fossiliferous packstone with benthic foraminifers (core 5, 915-916 m., Lercara Agip 1 well, scale bar 1 mm). Fig. **5**. recrystallized oolithic and bioclastic grainstone/packstone (cutting 214-216 m., Roccapalumba 1 well, scale bar 0,4 mm). Fig. **6**. quarzitic sandstone with glauconite fragments and bioclasts (cutting 64-67 m., Lercara Friddi 1 well, scale bar 0,4 mm).

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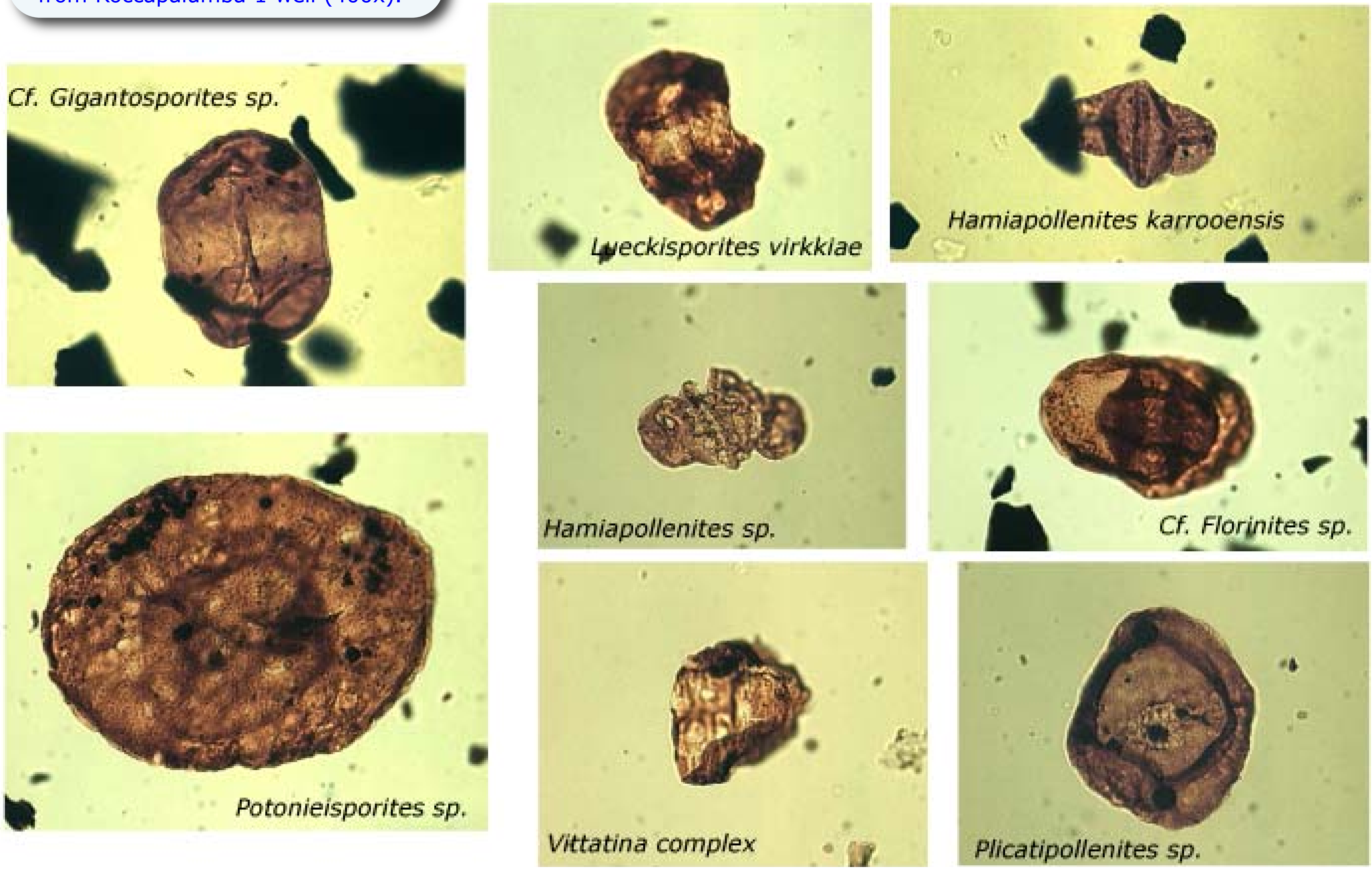
Plate V - Late Permian microflora from Roccapalumba 1 well (400x).



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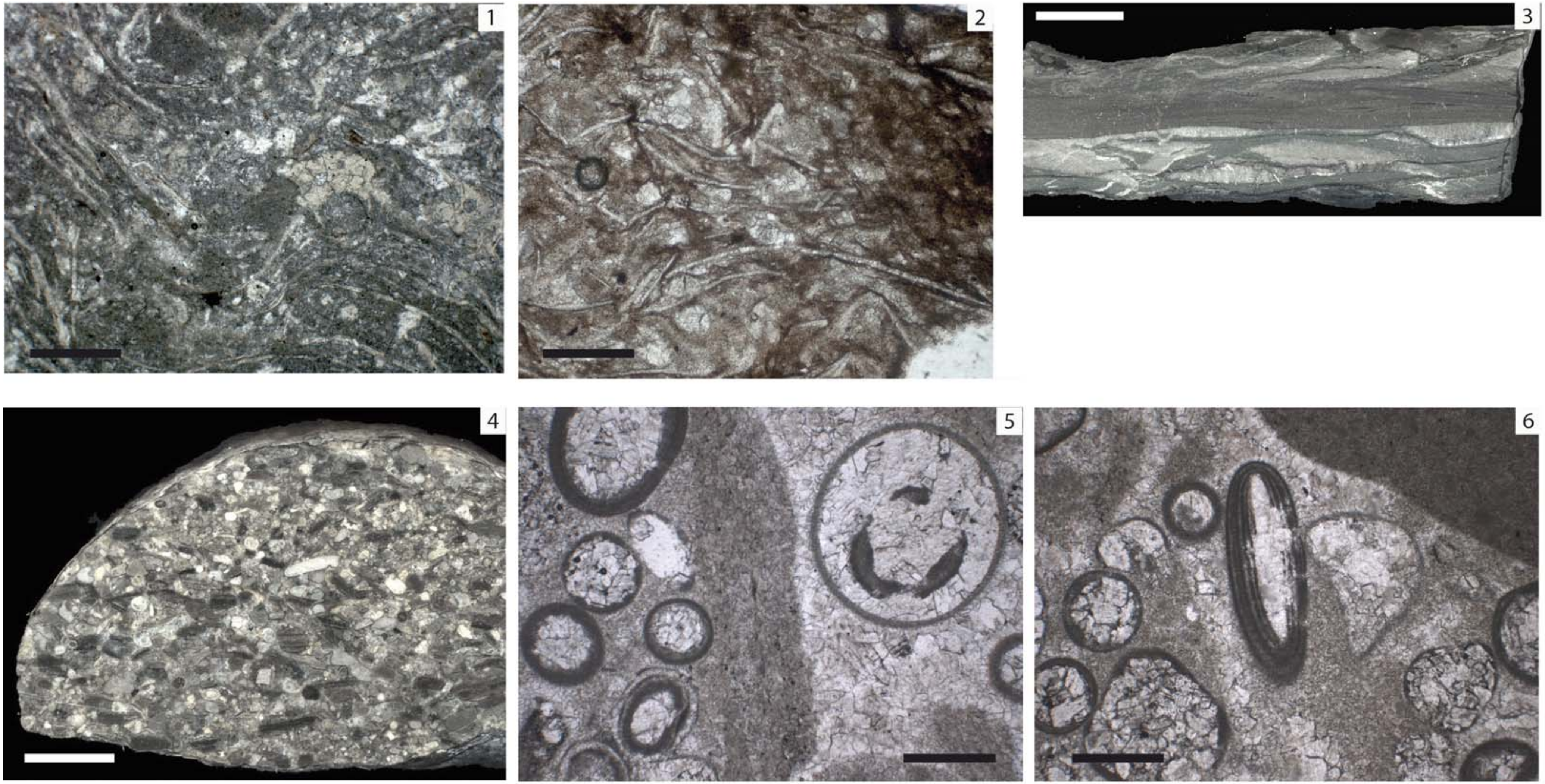

Plate VI - Characteristic microfacies of the Lower Triassic marls-calcilutites alternations with intercalations of oo-bioclastic calcarenites. Fig. 1: wackestone-packstone with pelagic pelecypods (core 14, 2336-2339, 7 m., Roccapalumba 1 well, scale bar 1 mm). Fig. **2**: red clays with pelagic pelecypods (cutting: 2402-2405 m., Roccapalumba 1 well, scale bar 0,4 mm). Fig. **3**: laminated clayey mudstone with rare detrital quartz (upper part), interlayered to gray-greenish clays (middle part) and green recrystallized mudstone (lower part) with cross lamination (ripples?) of siliceous sandstone (core 6: 1635,5-1637,5m, Roccapalumba 1 well, macroscopic sample, scale bar 1 cm). Fig. **4**: calcareous breccia with carbonate platform derived elements (core 8: 1724-1727 m., Roccapalumba 1 well, macroscopic sample, scale bar 0,5 cm). Figs **5-6**: grainstone/packstone with surficial oolite, pelecypods fragments and coated grains (core 8: 1724-1727 m., Roccapalumba 1 well, scale bars 1 mm).

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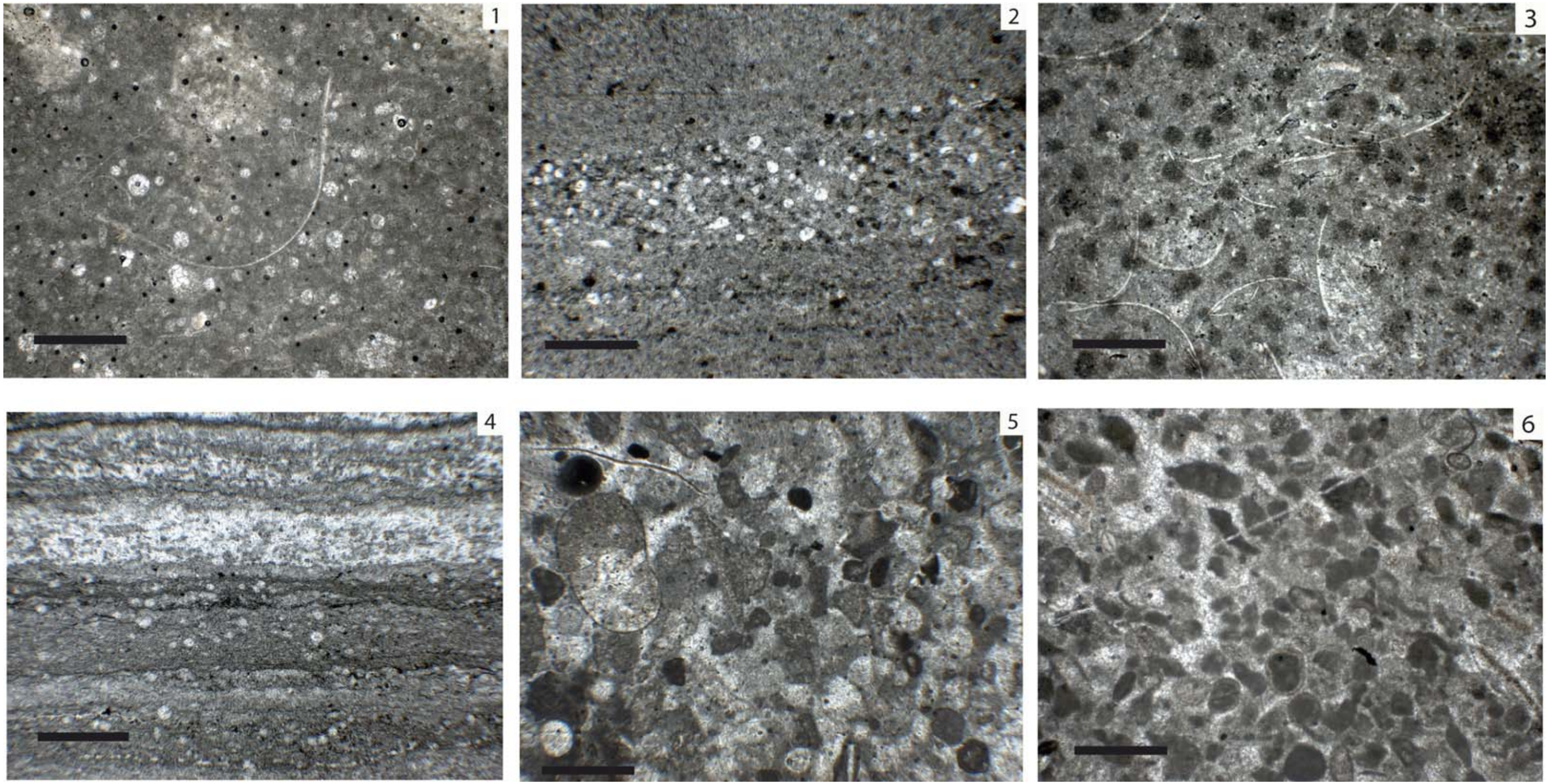

Plate VII - Characteristic microfacies of the Ladinian dark and brown clay and cherty limestone with calcareous turbidites intercalations. Fig. **1**: wackestone with radiolarians and pelagic pelecypods (core 26, 2979,1-2981.5m, Platani 2 well, scale bar 1mm). Fig. **2**: mudstone with intercalation of siltstone-wackestone with radiolarians (core 25, 2882-2884m, Platani 2 well, scale bar 2 mm). Fig. **3**: wackestone with pelagic pelecypods (core 26, 2979.1-2981.5m, Platani 2 well, scale bar 1mm). Fig. **4**: gray laminated mudstone with radiolarians, dark gray and greenish clay and recrystallized mm-layers rich in radiolarians (core 27, 3052-3056m, Platani 2 well, scale bar 2mm). Fig. **5**. packstone-grainstone with ammonites, radiolarians, pelagic pelecypods and peloids (core 26, 2979.1-2981.5m, Platani 2 well, scale bar 2 mm). Fig. **6**. fine packstone/grainstone with ooids, intraclasts and bioclasts (core 26, 2979.1-2981.5m, Platani 2 well, scale bar 1mm).

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Plate VIII - Late Ladinian-Early Carnian microflora and Permo-Carboniferous reworking from Platani 2 well (400x).

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ultrabasic dykes (Vianelli, 1970), only in the Sicanian successions; b) the occurrence of rare, fine bioclastic packstone in the Sicanian Carnian halobid limestone (Platani 2 well) versus the thick and massive resedimented carbonates found in the isochronuous deposits of the Imerese section; c) the occurrence of thicker, shallow-water derived, calcareous breccias and calcarenites in the Imerese section (Fig. 27) with respect to the resedimented deposits in the same age, rock interval of the Sicanian section. Moreover, the breccias found along the Sicanian section, consisting mostly of deep-water-derived elements (Di Stefano et al., 1996), differ from the isochronous lithofacies of the Imerese section, where only shallow-water carbonate fragments characterize the rocks.

2) *Jurassic-Paleogene rocks*

Most of the differences between the two deep-water Imerese and Sicanian sections are shown by the Paleogene to Jurassic rocks (Fig. 27).

- The Lower Liassic dolomite breccias (Fanusi fm), as well as the Upper Liassic crinoidal limestone with massive calcareous breccias recognized, only along the Imerese section, are wholly absent in the Sicanian type succession. There the corresponding synchronous rock interval shows resedimented limestones whose elements derive mostly from the disruption of the Upper Triassic deep-water cherty limestone (see also Di Stefano et al., 1996).
- The Jurassic radiolarites and bedded cherts sampled along the Imerese succession clearly differ from the isochronous lithofacies occurring in the Sicanian section, that, on the contrary, display poor cherty levels and are rich in carbonate content. Along the Cammarata section (Fig. 26), the Jurassic, red and green siliceous clays are alternated with wackestone and pelagic calcareous mudstones and onlap the Lower Liassic oolitic calcarenites and breccias (see Stop 2b of the second day of the GFT). In other places (Barracù section in the westernmost Sicanian Mts, see Fig. 24) these beds, unconformably onlap, the Upper Triassic cherty limestones of the Scillato fm (Basilone, 2011) pointing out differences in the paleophysiography and depth.
- Sicanian Paleogene-Cretaceous rocks display the characteristics of a continuous pelagic succession, as suggested by both the Cammarata section study and the subsurface succession drilled by the adjacent Platani 2 well. Differently, the Paleogene-Cretaceous rocks of the Imerese section show a very typical sedimentary succession represented by pelagic and hemipelagic sediments with intercalation of frequent resedimented calcareous breccias whose elements derived from the dismantling and erosion of the adjacent carbonate platform margin. The depositional processes forming these resedimented bodies are either due to gravitational flows or to the progradation of the shallow-water deposits into the deep-water basin.

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3) *Upper Oligocene-Lower Miocene rocks*
The Oligo-Miocene deposits show quite different sedimentological and depositional characteristics (Fig. 27). In the Sicanian *Orbulina* marls, the glauconitic Corleone calcarenites and Cardellia marls differ deeply from the chrono-equivalent terrigenous deposits (Numidian flysch and Tavernola fm) that unconformably rest on the Imerese section (Fig. 25).

Conclusive remarks

The results, obtained by the comparison of the outcropping geology with the several boreholes drilled in the visited area, point out the occurrence of a Pleistocene to Permian succession formed mostly by: 1) Pleistocene to Miocene syn- and post-orogenic terrigenous deposits and 2) Paleogene to Permian pre-orogenic continental margin, mostly carbonates, deposited in shallow- and deep-water paleodomains.
The deep-water successions were studied in detail based on well log stratigraphy and physical stratigraphy both calibrated by biostratigraphy. When compared, the results suggest interesting lateral to vertical facies relationships among the successions pertaining to the deep-water Imerese and Sicanian domains.

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The crustal SI.RI.PRO. profile

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This note gives a summary of the results reached through the SI.RI.PRO crustal seismic profile acquired in Sicily aimed to identify the poorly known deep crustal geometries and characters of the Sicilian segment of the Alpine system (Figs 28, 29, 30a, b and Fig. 14 in Catalano, this guidebook). The data reported here are derived from some papers already published (Accaino et al., 2009a, b; 2010, 2011; Avellone et al., 2009; Catalano, 2009; Sulli et al., 2009; Tinivella et al., 2009; Catalano et al., 2010c) and new unpublished results. The high-penetration seismic line was acquired during the winter of 2008 in the frame of the SI.RI.PRO (SIsmica a RIflessione PROfonda) project (Scarascia et al., 1994), supported by the Italian Research Ministry, with Prof. R. Catalano as scientific leader. The seismic transect was chosen and planned, in agreement with the proposal made by the Italian CROP (CROsta Profonda) Project for the region of Sicily. The project included the acquisition of refraction seismics, gravimetry and magnetotelluric data. The profile, that crosses Central Sicily, starts on the Tyrrhenian coast (Termini Imerese area) crosses the Northern Sicilian chain, the Caltanissetta basin, in Central Sicily, and ends on the southern coast (Gela area) near the outcropping Iblean plateau, the foreland of the Sicily fold and thrust belt (FTB).
The sector was chosen because:
• it represents a link-area between Western and Eastern Sicily;
• it connects the Tyrrhenian coast and the Sicily Channel whose main characteristics are imaged respectively in some CROP Mare (M6 and M39) high-penetration, seismic sections;
• it covers a chain-foredeep-foreland system;
• it represents the largest forward migration sector of the Sicilian FTB.
The primary objectives of the project were:
• to reveal the internal architecture of the chain;
• to shed light on the structures of the crust and the Moho in Sicily;
• to obtain thickness values of the Sicilian continental crust to be compared to the Tyrrhenian one;
• to know whether the basement was involved in the FTB stacking and\or its interaction with the thrust and fold belt;
• to reveal characteristics and structures of the Caltanissetta basin.

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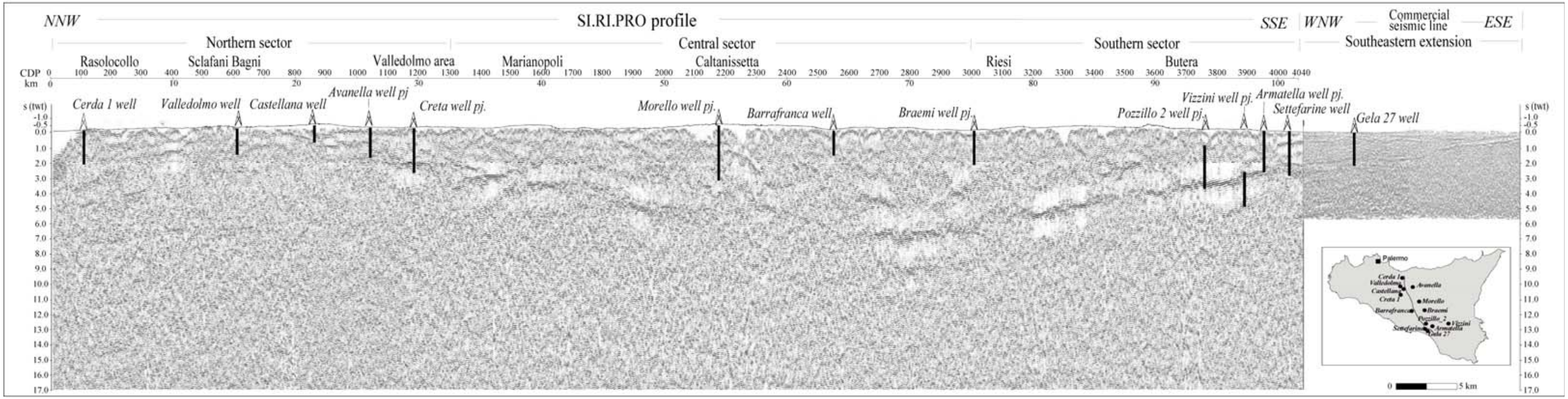

Fig. 28 - Stacked section of the SI.RI.PRO profile. The southeastern extension is a commercial seismic line (courtesy of Eni) that has a 5s recording window, used to include the GTS front and the Gela foredeep in our investigation.

A detailed geology (field mapping, stratigraphy, map scale tectonics, mesoscopic analyses) of the large N to S belt crossed by the profile (Fig. 29) locally calibrated at depth by seismic reflection, commercial lines (courtesy of ENI) and deep, interpreted boreholes (Fig. 30b), has promoted the geological interpretation of the seismic crustal profile. Acquisition parameters, processing and other technical characteristics of the seismic profile are reported in the published original data (Accaino et al., 2009 a, b; 2010, 2011; Catalano, 2009, Catalano et al., 2009, 2010c; Sulli et al., 2009; Tinivella et al., 2009)

The main aim of the paper is the geological description of the structural and stratigraphic, buried features, to improve the understanding of the Central Sicily region crossed during our Field Trip.

Geophysical frame

Previous acquired DSS (Deep Seismic Soundings) and WARRP (Wide Angle Reflection/Refraction Profiling) sections (Fig. 30a) yield data (Cassinis et al., 1969, 2003; Scarascia et al., 1994; Chironi et al., 2000) that reveal different types of crust (thin anomalous Tyrrhenian and normal continental African) beneath the boundary zone of the Sicily-Southern Tyrrhenian margin.

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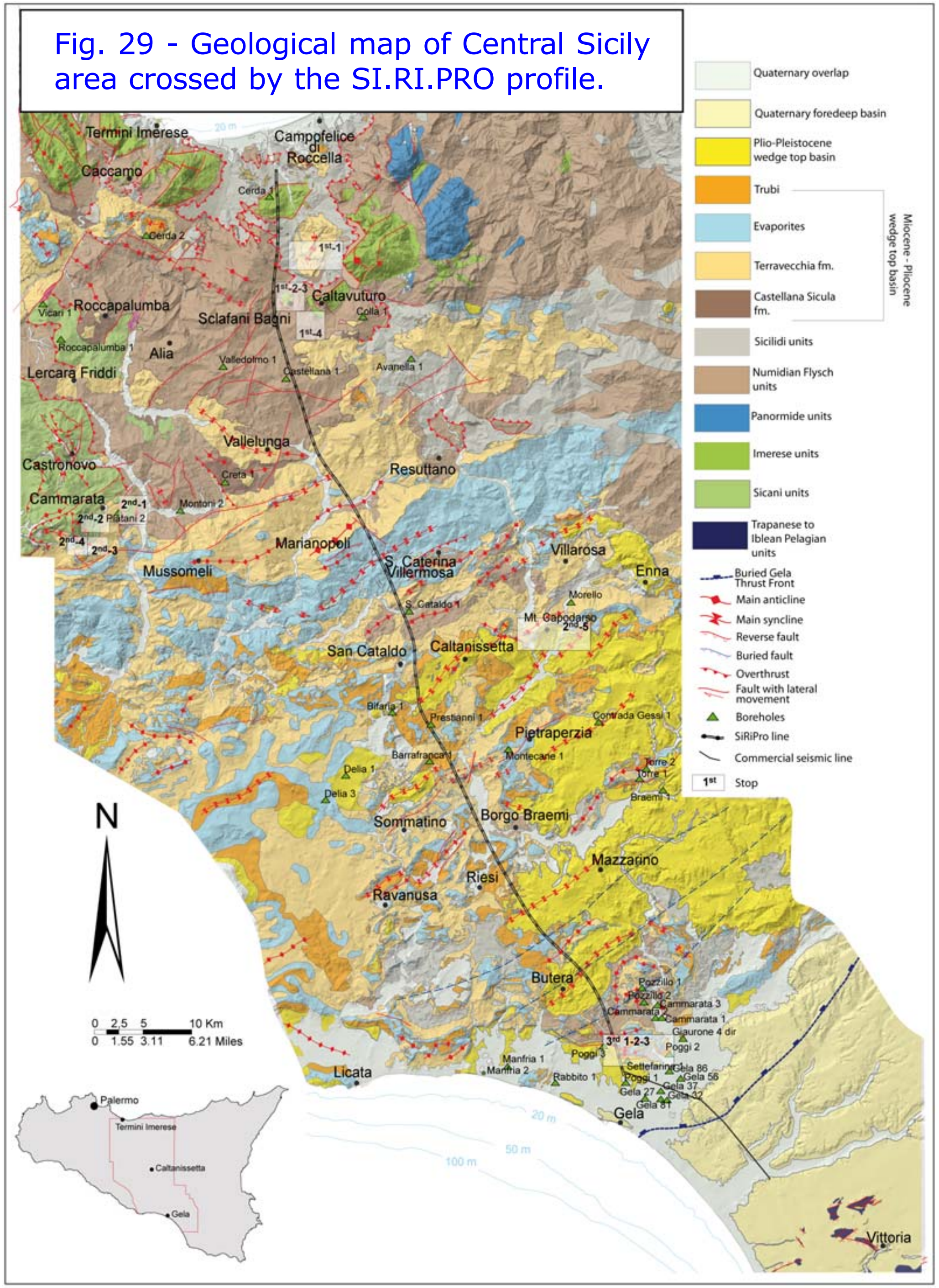

Fig. 29 - Geological map of Central Sicily area crossed by the SI.RI.PRO profile.

Based on seismic refraction data, values of the African Moho depth are known from the Northern Sicily edge (Cassinis et al., 1969; Scarascia et al., 1994), the Caltanissetta area (Scarascia et al., 1994; Cassinis et al., 2003) and the Iblean foreland (Chironi et al., 2000) as well as from the Southern Tyrrhenian Sea (Scarascia et al., 1994).

New studies (Di Stefano et al., 2011) of 3-D Moho geometry, obtained by integrating high- quality, seimic and teleseismic receiver function data, provide information of the Moho depth in the central Mediterranean, and point out the location of “Tyrrhenian Moho” interface just from the Marsili abyssal plain (about 10 km) to the continent/oceanic transition, north of the Sicilian coast (about 25 km) but are unable to define its topography beneath Central Sicily.

The known data do not offer, at present, the opportunity to image the deep structures, as mantle seismic wave velocities are poorly constrained beneath the Sicily orogenic wedge (Chiarabba et al., 2008).

To give details about the deep structural setting of the study area and to support seismic interpretation, gravimetric data were also acquired and processed (see Accaino et al., 2009a, b; 2010, 2011; Catalano, 2009; Tinivella et al., 2009; Catalano et al., 2010c for technical details) in the frame of the SI.RI.PRO. Project.

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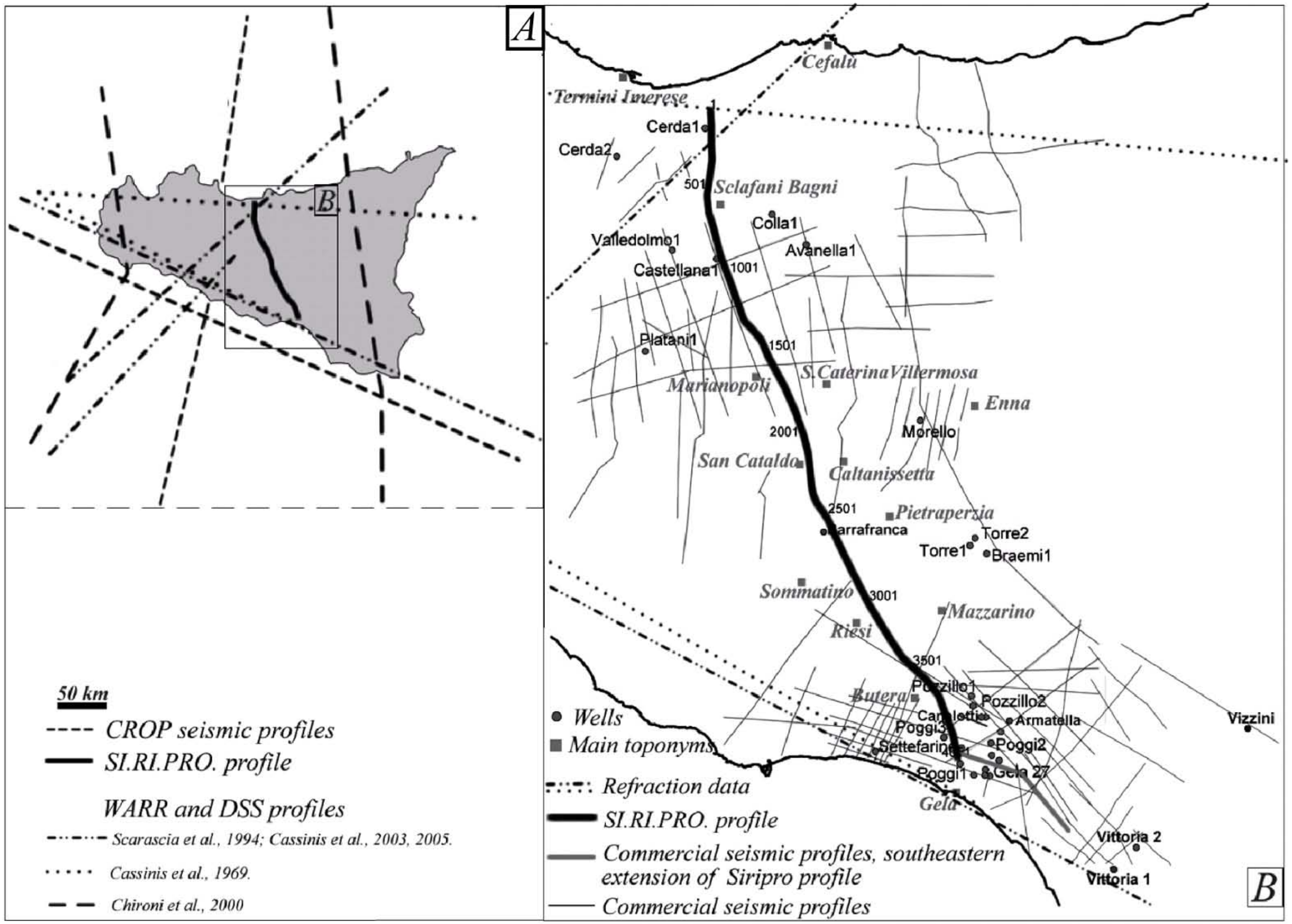

Fig. 30 - **A)** Base map showing the trace of the SI.RI.PRO. profile together with the location of both refraction seismic profiles and marine CROP lines. **B)** Detailed map showing the location of wells, interpreted commercial seismic lines and local segments of refraction data tying the SI.RI.PRO. profile and the commercial profile of its south-eastern extension.

The main results reveal the occurrence of a negative Bouguer anomaly in the Caltanissetta basin (coinciding with the Moho depth imaged by our geological model), and, in the northern sector, of an anomalous higher density zone in the crust, correlated to the higher density Tyrrhenian mantle wedge (see Mele et al., 2006; Doglioni et al., 2007 for the Apennines). We speculate that the top of this unit corresponds to the southern extension of the so-called "Tyrrhenian Moho" interface, well known to the geophysicists in the Peri-Tyrrhenian crust (Cassinis et al., 2003; Di Stefano et al., 2011).

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Geological interpretation

The seismic profile (Fig. 28) is 106 km long. It crosses Northern Sicily in a N–S direction, but turns SSEwards from Caltanissetta to Gela, reaching the Iblean structures (Figs 29, 30a, b). The altitude along the profile varies from 930 m in the northern mountain chain, to less than 25 m at the southern termination. Depth-converted, seismic interpretation, borehole data, field geology (Fig. 29) and stratigraphy as well geophysical data (Fig. 30a) were used to convert the geoseismic interpretation to a crustal geological cross-section (Fig. 31). The following main structural features (from south to north) are summarized below:
a) the foreland, its steep NW-ward dipping regional monocline and the Caltanissetta basin;
b) the orogenic wedge formed by: **1.** the main fold and thrust belt (FTB); **2.** the Gela Thrust System (GTS) with its Plio-Pleistocene wedge-top basins;
c) the crystalline basement;
d) the crust/mantle boundary.

a) The foreland, its steep NW-ward dipping regional monocline and the Caltanissetta basin
The foreland, outcropping in the neighbouring Iblean plateau, is imaged in the southern termination of the SI.RI.PRO. profile and in its south-eastern extension, represented by a 5 s deep commercial seismic line (Figs 28, 29). The foreland consists of Meso-Cenozoic carbonates pertaining to the Iblean unit, as constrained by well data (e.g. Settefarine 1 and other boreholes).
The top of the carbonate body, a seismically reflective, north-westward dipping unit ("a" in Fig. 31), is located at a depth of about 500 m in the SE extension of the profile and gets buried at about 18 km in the Caltanissetta basin (Fig. 31). The structure appears downwarped from the Iblean outcrops to the Caltanissetta basin, with a regional dip of about 16°-18°, a value determined both on the seismic depth-converted reflection profile and on the geological cross-section (see the methodology discussed in Lenci & Doglioni, 2007). The top of the unit is dissected by normal faults, locally "reactivated" as reverse faults (Bello et al., 2000; Ghisetti et al., 2009), enhancing the flexure beneath the chain. The occurrence of reverse faults correlates with an important deformation episode mostly involving the upper part of the Iblean rock unit.
The deformational features of the buried foreland can be put in evidence southeastwards in the outcrop, near the town of Vittoria (Fig. 29) where calcarenites and marls of the Ragusa fm (top of the Iblean foreland) appear folded and displaced by reverse faults.

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The Iblean carbonate unit is lithologically correlated, based on its seismic facies, to an arched shaped carbonate body, buried in the northern sector at about 15-17 km. It represent the internal Iblean unit, partially overthrusting the autochthonous Iblean domain in the Caltanissetta basin (Fig. 31).
The prominent depression in the central sector of the profile is the Caltanissetta synform, marked by a strong gravity anomaly low. This anomaly is partially originated by the lower densities, with respect to the surrounding areas, of sediments in the Caltanissetta basin and partially, by the geometries of the structures of the lower crust. The synform is due to the combination of the northerly-dipping, Iblean-Pelagian crust and southeast verging, Iblean-Pelagian basement-involved thrusts that deformed all the overlying allochthonous units of the Sicily FTB from “underneath” (Fig. 31).
The bottom of the flexure is envisaged down to about 18 km and located on the top of the carbonate Iblean regional monocline. This depth value of the flexure has never been imaged before. The stacked, folded and thrust sheets, added to the underlying unrooted Iblean carbonate rock body, are inferred to be as thick as 24-25 km, suggesting a similar depth for the top of the basement. The latter is far from the Cassano et al. (2001) estimated values.

b) The thrust wedge forming the main FTB

The FTB consists of a stack of décollement thrust sheets that involves mostly Mesozoic carbonates. This stack has been warped, subsequently, into a synform underlying the Caltanissetta area that is associated with the broad antiform, shown on the NNW part of the profile. The wedge stack rises southward, merging with the Gela Thrust System (Fig. 31).
All along the geological cross-section, the structurally highest units are (Fig. 31):
- SW- and SE-vergent folded Numidian flysch and Sicilidi nappes and the thick Permian-Triassic Lercara complex (IMa), south-vergent anticline.
Through the section, the antiformal stack is formed by:
- deep-water carbonates (Imerese and/or Sicanian) thrust units, each thicker than 1500 m; their top outcrops in the Sclafani Bagni tectonic high, showing the Imerese north-dipping thrusts (shallow-seated structures in Catalano et al., 2000b; Bello et al., 2000; Avellone et al., 2010);
- shallow-water to pelagic carbonates (Trapanese-Saccense) units floored by a slightly north-plunging arcuate regional thrust. This carbonate platform imbricate fan, thicker than 5 km, extend towards the central and southern sectors of the geological transect (deep-seated structures, Roure et al., 1990; Bello et al., 2000; Catalano et al., 2000b);

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- the broad arched carbonate unit described previously, is an overthrusted equivalent of the autochthonous Iblean platform domain here. Accordingly, our interpretation suggests that the thrust unit is involved with its basement (Fig. 31).

The basement-involved fault appears to merge with the base of the allochthonous units (comprising the GTS) that were stacked prior to the formation of the basement fault, thus suggesting that:

a) the frontal GTS wedge could be synchronous with the basement thrust;

b) the deep, northern antiformal structure is a very young structure that gently deformed all the stacking allochthonous units.

c) The Gela Thrust System (GTS) with its Plio-Pleistocene wedge-top basins

The Gela Thrust System is the outermost and youngest wedge of the Sicilian FTB (Catalano et al., 1993a; Lickorish et al., 1999; Ghisetti et al., 2009) commonly acknowledged as a thin-skinned, accretionary wedge (Ogniben, 1969; Catalano et al., 1989a, 1993a; Grasso et al., 1991; Butler et al., 1991). The GTS is recognized in the central-southern sector of the SI.RI.PRO profile, from the surface to a depth of about 4 km, and coincides with stacked and repeated packages of discontinuous reflectors (Figs 28; 31). The seismic interpretation suggests that it is composed of two main tectonic elements: a) an internal element consisting of allochthonous, deformed siliciclastic Miocene Numidian flysch and clay-carbonate Mesozoic-Cenozoic Sicilidi rock units and Tortonian-to-Pliocene deposits; b) an external element involving Tortonian-to-Pleistocene deposits (Catalano et al., 1996; Lickorish et al., 1999; Ghisetti et al., 2009).

The GTS outcrops north of the present-day buried front, along the so-called Settefarine thrust, and ramps progressively over Upper-Pliocene to Lower-Pleistocene deposits; its basal detachment, enveloping the internal thrust units to the north and bounding the newly formed unit to the south, bends above the underlying deformed carbonates (see also Bello et al., 2000). The arching of the basal detachment clearly suggests that compression took place also after the wedging of the GTS (between 1.5 and 0.8 M.y.). The GTS gets buried beneath the Piana di Gela, thinning into a “ mini folded foreland thrust belt” toward the end of the profile (Fig. 31) where deformation reaches the foreland and its clastic, modern foredeep basin, as highlighted by its incipient wedging. The most internal GTS tectonic slices have been recognized in the central sector of the profile, where nearby boreholes have constrained their facies and stratigraphy.

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To the south of the Caltanissetta area, Pleistocene deposits fill up some basins progressively formed during the youngest deformational phase that gives origin to the GTS (Catalano et al., 1993a; Lickorish et al., 1999). Local backthrusts accommodate the resulting shortening and indicate the occurrence of double-vergency structural highs (Fig. 31). The striking northern vergence of the younger faults could be also explained as a complex variation of a *triangle zone* (Jones, 1996) or else a pervasive late orogenic wedge.

d) The crystalline basement

The top of the crystalline basement was associated to the high reflective horizons locally recognized on the Si.RI.PRO profile at the bottom of the tectonic units. From the southern sector, where the basement was recognized at a depth of about 10 km (Chironi et al., 2000; Catalano et al., 2000a) it is down-warped to a depth of about 24 km in the Caltanissetta basin and goes up to about 20-22 km in the northern sector (Fig. 31), in agreement with the depth recognized in the Eastern Tyrrhenian coastal areas of Sicily (Bello et al., 2000).
The thickness of the basement ranges from about 16-18 km in the SE of the profile, to about 14 km beneath the Caltanissetta synform (Fig. 31). In the northern sector, beneath the Sclafani Bagni area, the crystalline crust reaches its maximum thickness of about 18-20 km. Seismic interpretation reveals the occurrence of a depth layered reflective pattern imaged as a crustal higher density zone. This anomalous higher density body is estimated through gravimetric modelling (Accaino et al., 2011), in accordance with the refraction data of Cassinis et al. (1969).

e) The crust/mantle boundary

The crust/mantle boundary was detected combining seismic interpretation with refraction data and gravity modelling. Scattered events, generally consisting of two-to-three-cycle signals, recognized at the bottom of the inferred crystalline crust, was imaged as the Moho discontinuity signatures. Their location, confirmed by DSS data (Cassinis et al. 1969; Scarascia et al. 1994; Chironi et al., 2000) reveals a N-dipping horizon, regularly plunging from a depth of about 28 km (southern sector) to about 38 km (Valledolmo area, northern sector) (Fig. 31). The signal was not clearly detected in the northernmost end of the profile.

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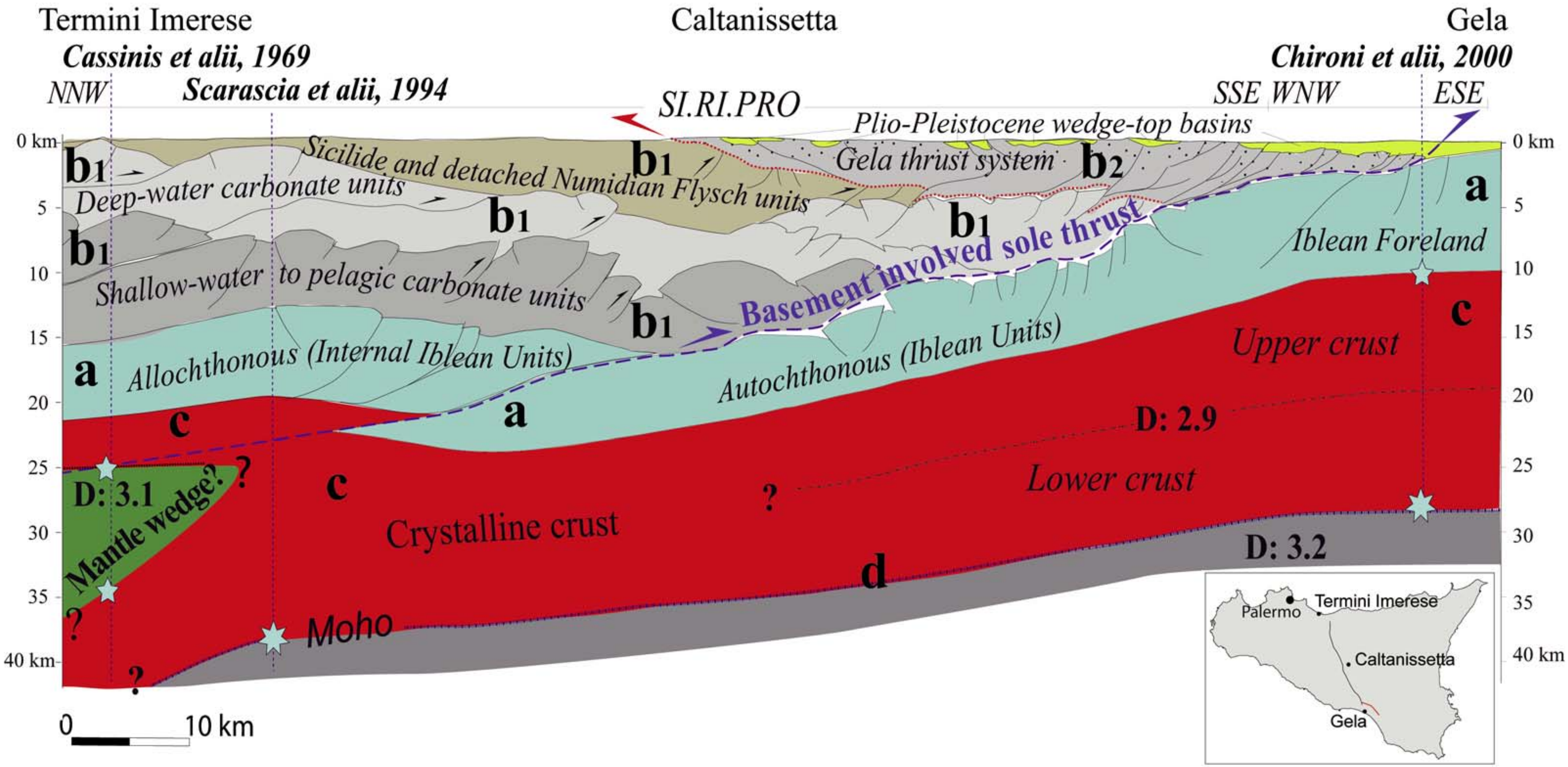

Fig. 31 - Geological cross-section resulting from the interpretation of the seismic stack section of the SI.RI.PRO. crustal profile and its South-Eastern commercial multichannel seismic extension. The geological cross-section shows the dip of the regional monocline **(a)** and the overthrusted geological bodies that form the whole orogenic wedge **(b1, b2)**. The latter includes a basement-involved fault that merges into the overlying allochthonous units. The thrust emanates from the leading edge of the Northern basement-involved fault. It carries the leading edge of the units of the overlying orogenic wedge to emerge as a thrust plane that underlies the external units of the GTS. The geological cross-section reconstruction benefits from the main geophysical (refraction and gravity) data (Cassinis et al., 1969; Chironi et al., 2000; Scarascia et al., 1994) that constrain both the crystalline basement geometry **(c)** and the Moho depth **(d)**.

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Conclusion

The seismostratigraphic analysis carried out along the SI.RI.PRO. crustal seismic transect, integrated with new geological, geophysical and gravimetric data, revealed the image of the shallow and deep crustal structures in Central Eastern Sicily, improving our knowledge about:

1. the Iblean foreland and its regional monocline, northward continuation under the main FTB;
2. the architecture of the buried orogenic wedge;
3. the Gela Thrust System and its Plio-Pleistocene wedge top basins;
4. the relationships between the basement and the overlying FTB;
5. the occurrence of a pronounced crustal flexure in Central Sicily;
6. the crustal features and the African Moho location.

The main crustal tectonic relationships suggest the occurrence of a basement-involved, sole thrust that structurally links the shallowest frontal wedge of the Gela Thrust System to the northern deep crustal uplift. The orogen is the result of the combination of a supracrustal strata décollement (thin-skinned style) and a basement-involved thrust (thick-skinned style).

The anomalous higher density body in the northern sector of the crust is interpreted as corresponding to the southern edge of the Tyrrhenian mantle wedge (see for the Apennines, Mele et al., 2006; Doglioni et al., 2007). We speculate that the mantle wedge splits the subducting African continental slab from the overlying stack of Sicily allochthonous thrust sheets.

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The Late Miocene Scillato basin in the frame of the structural evolution of the Northern Sicily chain

Carlo Gugliotta, Maurizio Gasparo Morticelli

Introduction

During the Middle-Late Miocene (late Serravallian to early Messinian) the Sicilian Fold and Thrust Belt (SFTB) was associated with a Foreland Basin System (*sensu* De Celles & Giles, 1996 characterized, in its innermost sectors, by a wide, wedge-top depozone developing above already emplaced thrust-sheets (Gugliotta, 2010, 2011). Several sedimentary basins were located in this depozone, filled by silici-clastic successions deposited in a continental to shallow-marine environment.
Present day remnants of these original filling syn-tectonic basins, widely outcrop (now deformed) in north-Western and Northern Sicily and are mainly relatable to two main lithostratigraphic units: the Castellana Sicula fm (SIC, upper Serravallian - lower Tortonian) and the Terravecchia fm (TRV, upper Tortonian – lower Messinian). These units outcrop unconformably, covering the already emplaced fold and thrust belt units and are bounded, in turn, by regionally known unconformities. A detailed study of an “inner” wedge-top depozone succession (Gugliotta, 2011) is presented here from the Late Miocene Scillato basin (Northern Sicily) with the main aim of showing the depositional evolution of a sedimentary basin in response to active tectonics.

The Scillato basin

Geological setting

The Scillato basin (SB) is located in the central-northern sector of the SFTB, along the western edge of the Madonie Mts (Fig. 32 and Fig. 51 - first day). The stratigraphic succession of the SB consists of about 50m of Castellana Sicula fm (SIC) deposits unconformably covered by about 1200m of upper Tortonian Terravecchia fm (TRV).
The whole succession unconformably overlays a deformed substrate made of Sicilide (Su), Numidian flysch (NFu) and Imerese (IMu) units (Fig. 32). The SB consists of an approximately NE-SW oriented structural depression, bounded SE-ward by major carbonate structural highs (Fig. 32b; Mt dei Cervi and Rocca di Sciara).
This structural high has been interpreted as partially outcropping, NW–SE-trending ramp anticlines related to shallow-seated, SW-ward verging, low-angle refolded thrusts that developed during the Middle Miocene

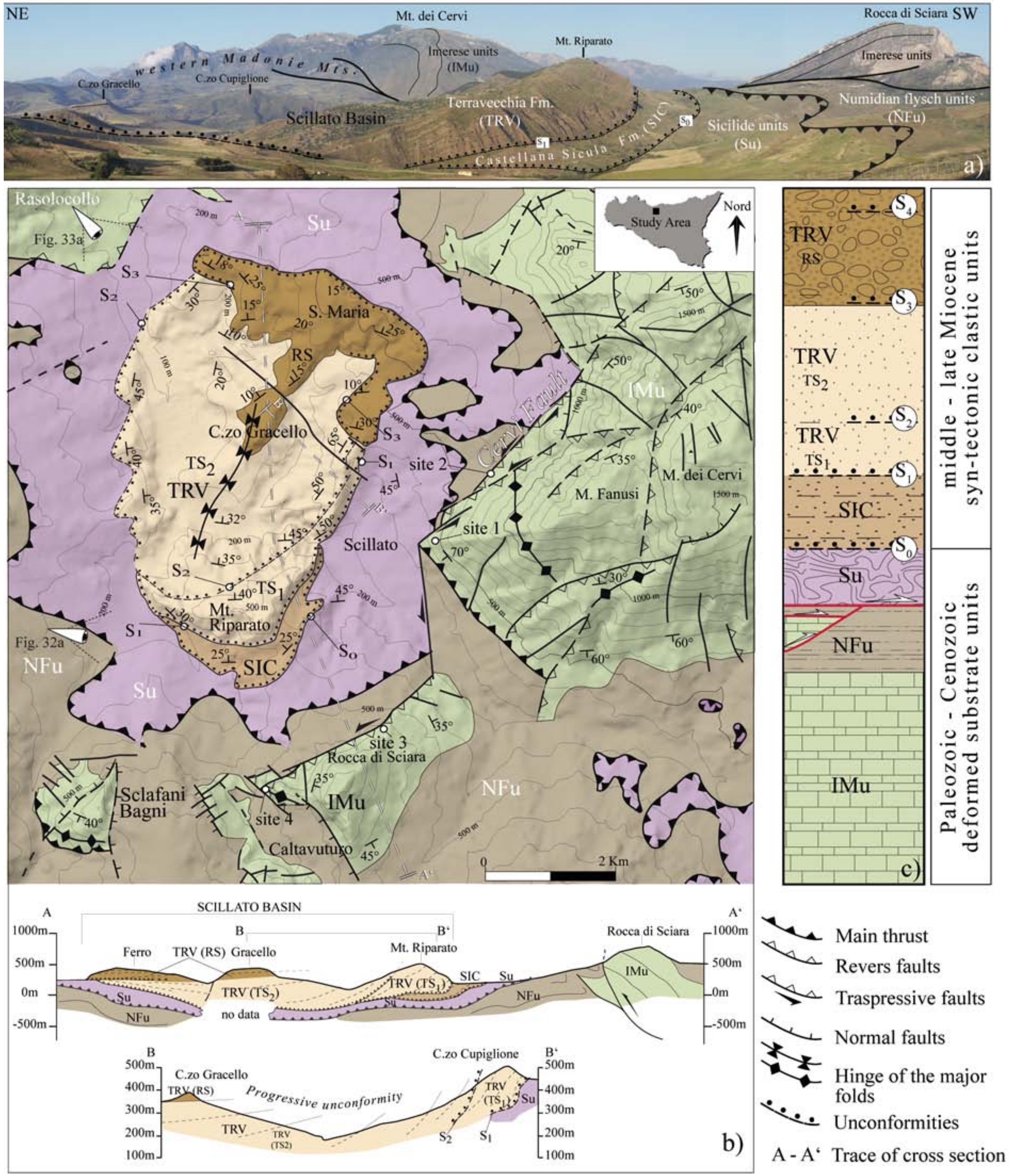


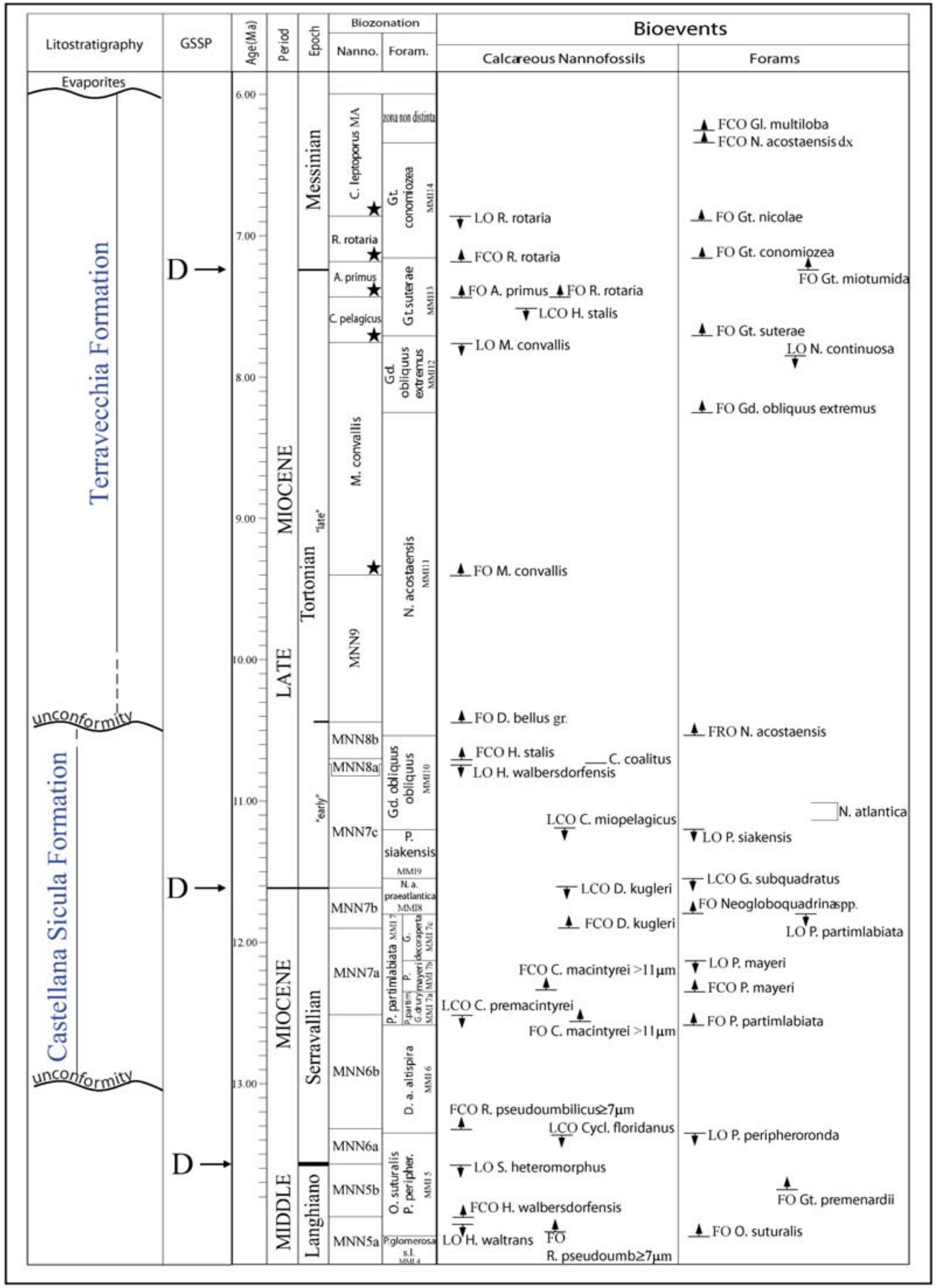
Fig. 32 - **a)** Panoramic view (from the western) of the Scillato basin, showing the main stratigraphic and tectonic setting of the study sector; **b)** simplified geological map and geological cross-sections of the Scillato basin area; **c)** schematic stratigraphic column of the Scillato basin substrate and sedimentary fill. See text for acronyms relatable to the main tectonic units (IMu, NFu, Ler and Su), clastic covers (SIC and TRV) and main unconformities (S0, S1, S2, S3 and S4).

compressional Event I and involving Meso-Cenozoic Imerese units (see Catalano this guidebook, pp. 13-50, for details).

Stratigraphic setting

The Castellana Sicula fm

It still is an informal unit (see Catalano, 1997 and Catalano et al., 2000a) which was originally described in these areas (Ruggieri & Torre, 1987, Catalano & D'Argenio, 1990, Abate et al., 1999) and subsequently revised in the frame of the national CARG Project (Catalano et al., 2010a, b, 2011b and Gugliotta, 2010). It consists of up to 50m-thick hemipelagic clays, siltstones and gravity flow sandstones deposited in a outer shelf to



Tab. 1 - Biozonation and bioevents of the Middle–Upper Miocene lithostratigraphic units outcropping in the study sector (modif. from Catalano et al., 2010).

slope setting. Analyses of the microfossil assemblage, both planctonik foraminifers and calcareous nannofossils (Tab. 1) revealed a late Serravallian to early Tortonian relative age (Catalano et al., 2010a, b, 2011b). The SIC outcrops locally, south of Mt Riparato (Fig. 32a) where it unconformably rests (S_0) above the Sicilide nappe (Fig. 32b). Along the Mt Riparato scarp the SIC is abruptly topped (S_1) by the Terravecchia fm deposits (Fig. 32).

The Terravecchia fm

This formation is a composite lithostratigraphic unit regionally known (see also Bigi et al., 1991) as being made up of conglomerates, sandstones, marls and clays deposited in a continental to transitional sedimentary environment (Flores, 1959; Schmidt di Friedberg, 1962; 1964-65, Catalano, 1979; Catalano & D'Argenio, 1990; Lo Cicero et al., 1997, Abate et al., 1999; Catalano et al., 2010a, b, 2011b). In the Scillato basin, the TRV (upper Tortonian) outcrops, forming an up to 1250m-thick stratigraphic succession that overlies the Castellana Sicula fm and laterally spreads out covering the deformed substrate (Fig. 32a). Detailed sedimentological and

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Tab. 2 - Table summarizing the main sedimentological features and facies arrangement of the Terravecchia fm in the Scillato basin.

Lithostr. unit	Sed. stages	Dep. systems	Lithoacies associations	Lithofacies description
Terravecchia Formation	*Regressive stage - RS*	*River-dominated Delta System (RDS)*	"f" delta-top	F2: medium to coarse-grained, cross-stratified sandstones. Interpretation: sandy bedforms in sandy-gravelly braidplain setting. F1: Massive pebble to boulder reddish and yellowish conglomerates with erosional base. Interpretation: channel bed-load in sandy-gravelly braidplain setting.
			"e" delta slope	E3: tabular- to slightly lens-shaped conglomerate bodies with erosional near horizontal base.Mass-flow-related structures,, normal gradation and load casts occur. Interpretation: gravity-driven sedimentation in delta slope setting. E2: yellowish sandstones with horizontal-planar to trough-cross lamination. Interpretation: delta slope setting. E1: brownish clayey-siltstones. Interpretation: prodelta to delta slope setting.
	Trangressive stage - TS		"d" prodelta	D2: greyish to yellowish centimetre thick, sheet like or lens-shaped sandstones layers showing horizontal lamination and normal gradation. Interpretation: flood-generated deposits in prodelta setting. D1: centimeter-thick, light blue - grayish to brownish siltites and clayey-siltstones with brackish fauna. Interpretation: prodelta.
			"c" river-dominated delta front (retrograding)	C3: very coarse sandstones and pebbly sandstones showing well developed through cross- and planar cross lamination in centimetres thick sets. Interpretation: proximal delta front locally incised by small braid channels developed in response to the delta lobe progradation. C2: medium- to coarse-grained yellowish sandstones with horizontal to through- and planar-cross lamination. Interpreta-tion: flood-generated sandstones lobes in the intermediate delta front. C1: centimetre thick, sheet like clayey to sandy siltstones. Interpretation: distal delta front setting during the low-energy stage of river activity.
		Entrenched Valley Fill System (EVF)	"b" floodplain	B2: tabular to lens-shaped conglomerate and sandstones showing erosional base and cross-lamination. Interpretation: ephemeral channel fill. B1: non fossiliferous, massive dark grey, pinkish to yellowish silty mudstones and clays. Interpretation: floodplain with ephemeral ponds and overbank areas.
			"a" gravelly braidplain	A4: reddish to brown-yellow clayey siltstones, few centimetres thick, ending fining upward sequences. Interpretation: waning flood or abandoned channel fill deposits. A3: reddish to brown-yellow very coarse- to medium-grained sandstones showing large- to medium-scale cross bedding and/or horizontal planar lamination. Interpretation: two-dimensional sandy bedforms developed within fluvial channels during the low energy stage of flow. A2: poorly sorted, clast-supported reddish to yellowish conglomerates arranged forming up to 2meters thick beds bounded by erosional surfaces. Normal and inverse gradation and pebble cluster structures are often observable. Interpreta-tion: bed-load charge of braid channels. A1: crudely stacked tabular conglomerate beds. Conglomera-tes are reddish, very coarse, poorly sorted, showing clast supported texture. Clasts are poorly sorted, pebble- to boulder- often "out-size", well rounded. The conglomerate beds are superposed through erosional amalgamation surfaces. Interpretation: bed-load charge of braided fluvial channels with migrating gravelly longitudinal braid bars.

facies analyses pointed out that the TRV outcrops in the Scillato basin forming a fining to coarsening upward succession along which an early "transgressive" (TS) and a late "regressive or oversupplied" stage (RS) were differentiated (Fig. 32b and Tab. 2).

Six main facies associations were outlined along that succession:

- gravelly braidplain "a";
- alluvial plain with ephemeral ponds "b";
- sandy-gravelly, river-dominated delta front "c";
- brackish prodelta clayey siltstones "d";
- prograding delta slopes and delta front "e"
- delta top conglomerates and sandstones "f".

The facies associations are relatable to two main depositional systems (Tab. 2): the Entrenched Valley fill system (EVF) and the River-dominated Delta system (RDS). The EVF is a reddish to yellowish-coloured sedimentary rock body (locally up to 250m-thick) which outcrops along the southern and south-eastern margin of the Scillato basin (Mt Riparato Fig. 32a). This depositional system is interpreted as a floor lag deposited in a NW-SE-oriented valley, incised in the deformed substrate since the late Tortonian. A two-step evolution of the valley infilling is envisaged from the two facies associations (facies associations "a", "b"). The overall fining upward trend images an increase of rate of

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accomodation space creation through time, accompanied by a decrease in the streams' power (bedload size), in channel amalgamation and in the inferred rate of sediment supply.
The RDS represents the main bulk of the Terravecchia fm in the Scillato basin. The deltaic wedge reaches the maximum thickness (up to 950m) in the central Scillato basin area (around Cozzo Gracello; Fig. 32a) and abruptly thins to about 300 m along the eastern and north-eastern margin of the basin (Fig. 32). The RDS is interpreted as the sedimentary record of a sandy-gravelly flood-dominated fan delta environment (*sensu* Galloway, 1975; Wescott & Ethridge, 1980, 1990; Mutti et al., 2000, 2003). The vertical stacking of the main facies associations allowed us to recognize (Tab. 2):
- a retrograding stage of deltaic apparatus, imaged by backstepping delta front sequences ("c") merging laterally and upward with prodeltaic siltstones ("d");
- a prograding stage characterized by a delta slope and prograding delta front sequences ("e"), capped by delta-top deposits ("f").

Structural setting of the Imerese units bordering the Scillato basin

The Scillato basin is bounded by a structural high, consisting of carbonates and siliceous rocks pertaining to the Imerese deformed substrate (Monte dei Cervi to the East, Rocca di Sciara and Sclafani Bagni ridges to the South; Figs 32b and 33).
Field data integrated with previous studies (Grasso et al., 1978; Abate et al., 1988; Bigi et al., 1991; Catalano et al. 2011b), allowed us to interpret the Monte dei Cervi and Rocca di Sciara ridges as NW-SE-trending ramp anticlines (H1 fold system) involving Meso-Cenozoic rocks (Imerese units and their covers). Here, these anticlines are named *Cervi anticline* (CA) and *Sciara anticline* (SA) respectively (Fig. 33).
Regionally, these structures extend so that they are largely buried beneath the Late Miocene Scillato basin. Field and subsurface data, indicate that the Cervi anticline overthrusts, toward the south-west, on the Sciara anticline forming two main thrust sheets (see Fig. 69 in Stop 3, first day of the GFT; Catalano et al. 2011b).
A complete set of new structural data has been collected along the limbs of the major anticlines consisting of both minor folds (h) and cleavage-extensional vein systems (C-J).

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Cervi anticline

Along the slopes of the Monte dei Cervi (Site 1 in Figs 32b and 34a) two minor fold-systems were recognized and named, respectively h1 and h2:

- the h1 system consists of 143/12° hinge-oriented, minor folds showing flank and axial-plane geometries compatible with a drag fold developed along the forelimb of the major *Cervi anticline* (Figs 33a, b and 34c, h).

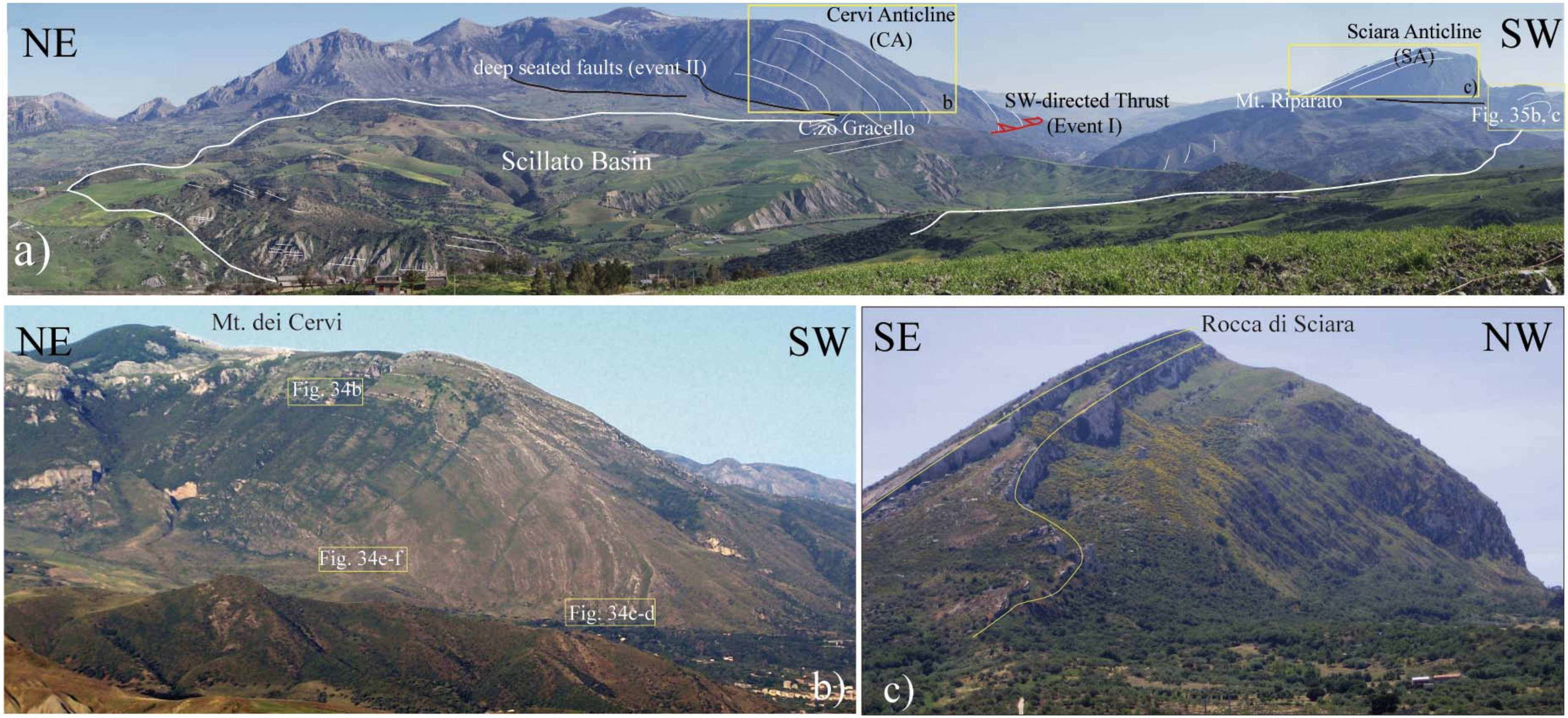

Fig. 33 - **a)** Panoramic view (from the NW) of the Scillato basin where the large-scale structural setting of the study area is shown; **b)** Panoramic view of the Cervi anticline; **c)** Panoramic view of the Rocca di Sciara structural high. (Data from Gugliotta & Gasparo Morticelli, 2012).

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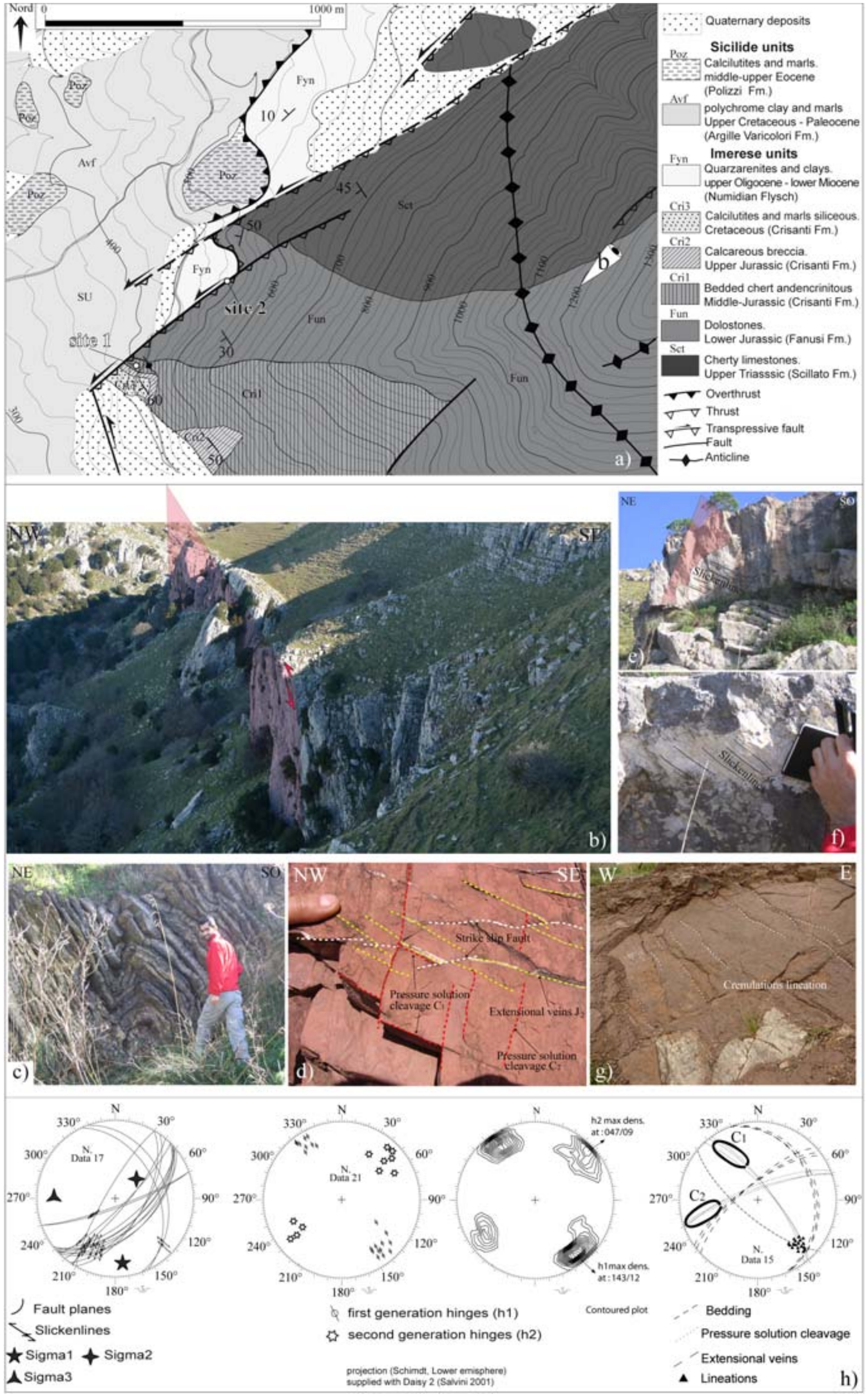

Fig. 34 - **a)** Geological sketch of the Mt dei Cervi area (scale 1:20.000); **b)** major NE-SW-striking transpressional fault along the north-western slope of Mt dei Cervi; **c)** asymmetric folds in the IMu radiolarites along the forelimb of the Cervi anticline (location in Fig. 32b); **d)** pressure solution cleavages and extensional vein systems in the IMu carbonates outcropping along the forelimb of the Cervi anticline (location in Fig. 32b); **e-f)** striated transpressional fault planes outcropping in the IMu carbonates along the north-western slope of the Mt dei Cervi (location in Fig. 32b); **g)** crenulation lineation in the Jurassic rocks of the IMu; **h)** stereographic projection of the structural data (faults, folds and cleavage) and associated stress axes calculated from stress inversion applied to transpressive fauls and slickenlines, collected along the Cervi anticline. (Data from Gugliotta & Gasparo Morticelli, 2012).

A 142/25°-oriented crenulation lineation (*sensu* Davis & Reynolds, 1996) is also present along the flanks of these minor folds (Fig. 34g). The h1 fold system is compatible with an ENE-WSW-oriented maximum palaeo-stress (σ1).
- the h2 system consists of 047/09° hinge-oriented, minor folds compatible with a NW-SE-oriented maximum palaeo-stress (σ1).

The mesostructural analyses also revealed the existence of two main cleavage-extensional vein systems (C-J; Figs 34d, h) named, C_1-J_1 and C_2-J_2, respectively.
- the C_1-J_1 system, consists of a 058/80°-oriented pressure solution cleavage associated with 328/75° extensional veins;
- the C_2-J_2 system consists of a 338/75°-oriented pressure solution cleavage and associated 070/27° extensional veins.

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The orientations of the C_1-J_1 system is compatible with an ENE-WSW (N 60°)-oriented σ1 and thus associated with the development of the h1 fold system while, the orientations of the C_2-J_2 system is compatible with a NNW-SSE (N 160°)-oriented σ1 and thus associated with the development of the h2 fold system. Cross-cutting relationships suggest that the C_1-J_1 systems are older than C_2-J_2 systems (Figs 34d,h) and thus, h1 is older than h2.
The interpretation of the structural data suggests that the h1 fold system includes minor folds of the major (H_1) NW-SE-trending Cervi anticline developed during compressisonal Event I. The Cervi anticline, is, in turn, re-folded along a more recent ENE-WSW plicative trend, represented by the h2 system and considered here as having developed during compressional-transpressional Event II. Other evidence of superposition of tectonic structures of a different age are suggested by the large-scale setting of the Cervi anticline. The major NW-SE-trending anticline shows a clearly observable SE-dipping axis, which, moving north-westward (Site 2 in Figs 32b and 34a), is cut and displaced by a superimposed NE-SW-striking, SE-dipping major transpressive, left-lateral fault system, included here in the *Cervi fault* (Figs 32 and 34b-e-f).

Sciara anticline
Minor and major SW-ward verging recumbent folds, showing a NW-SE-trending hinge (N320°, h1 fold system) have also been recognized along the major Sciara anticline (Figs 32b, 33a,c and 35b). The latter is markedly dissected by more recent high-angle faults (Fig. 35a-c). Data collected in site 3 (Fig. 35a) is compatible with SSE-dipping, high-angle (about 70°) faults showing a SE-dipping, slickenline with an approximate 15° to 45° rake (Fig. 35d-e). The calcite fibers are compatible with a left-lateral transpressive movement. The analysis of the kinematic indicators allowed us to constrain the palaeo-stress field as being compatible with an approximately N170°-oriented and near-to-horizontal (about 12°) σ1, associated with a high-angle σ_2 (about 45°, Fig. 35f).
The faults detected along the Cervi anticline and Sciara anticline can be considered as pertaining to the main NE-SW-oriented structural alignment named Cervi fault (Fig. 32b). Data collected along these planes and kinematic indicators are compatible with SSE-dipping, left-lateral transpressive faults. The statistical analysis of the striated fault planes revealed that the transpressional faults were generated under a maximum horizontal palaeo-stress, oriented as those reconstructed for the h_2 fold nucleation. The stress field orientation is consistent with those calculated elsewhere, along the Kumeta fault, where it is associated with the deep-seated Event II (Avellone et al., 2010).

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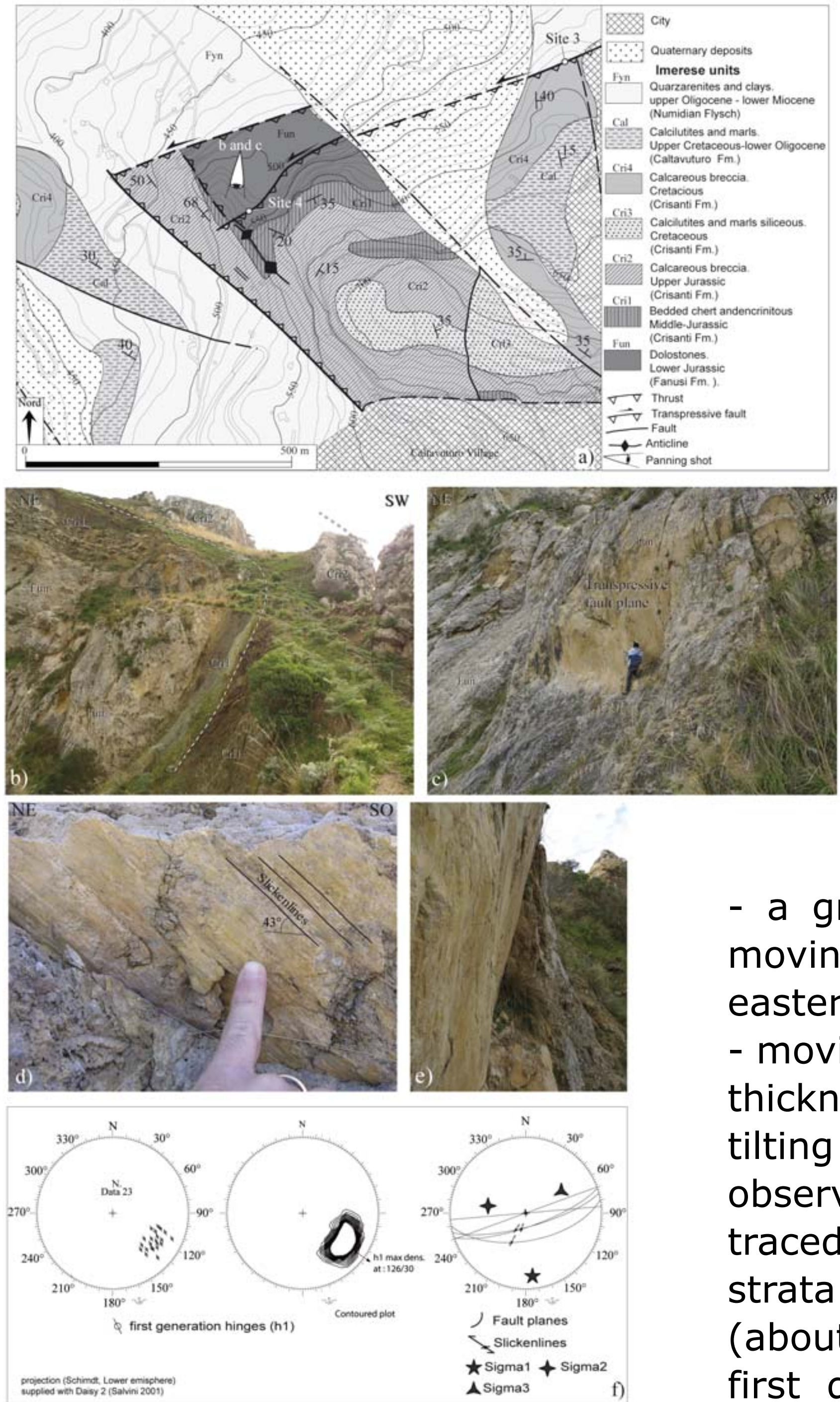

Fig. 35 - **a)** Detailed geological sketch of the Rocca di Sciara area (scale 1:10.000); **b)** major NW-SE-trending overturned anticline along the forelimb of the Sciara anticline; **c** and **e)** major transpressional fault plane cutting the Sciara anticline (location in Fig. 32b); **d)** striated transpressional fault plane outcropping in the IMu carbonates along the northern slope of the Rocca di Sciara ridge (position in Fig. 32b); **f)** stereographic projection of the structural data (faults and folds) and associated stress axes calculated from stress inversion applied to transpressive faults and slickenlines, collected along the Sciara anticline. (Data from Gugliotta & Gasparo Morticelli, 2012).

Evidence for syn-sedimentary tectonics during the Scillato basin deposition

Numerous stratigraphic as well as structural evidence was localized in the Scillato basin thus accounting for a syn-depositional deformation of the Terravecchia fm (Gugliotta, 2010; Gugliotta & Gasparo Morticelli, 2012). The most important are briefly reported below:

- a great variation in thicknesses (Figs 32b and 36d) occurs when moving from the central sectors of the basin (up to 900m thick) to its eastern and north-eastern margins (about 300m thick or less);
- moving upsection, to the Scillato basin succession (from TS to RS) the thickness variation accompanied by a progressive decrease in the mean tilting value of the strata (section B-B’ in Fig. 32b and Fig. 36d) can be observed. An approximate 40° discordance (S3 in Fig. 36d) can be traced between the lower portion of the Terravecchia fm (about 70° of strata attitude at Cozzo Cupiglione - Mt Riparato) and its upper portion (about 15° of strata attitude at Cozzo Gracello; see Fig. 56 in Stop 1a, first day). This peculiar feature accounts for a partially preserved

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growth offlap (Fig. 36b; Ford et al., 1997), coherent with the development of a progressive unconformity (section B-B' in Fig. 32b; Fig. 36c; Riba, 1976; Hardy & Poblet, 1995; Ford et al., 1997). The growth geometry suggests the N- and NW-ward tilting of the eastern and south-eastern limbs of the basin, plausibly in response to the progressive lifting of the deformed substrate units (Fig. 36a-d);

- the occurrence of several syntectonic, intraformational, angular unconformities (named S2, S3, in Figs 32 and 36d) due to the progressive tilting and erosion of the south eastern and eastern basin margins;
- the dispersive distribution of poles to bedding in the *Pi* diagrams, related to two sequences (TS+RS; Fig. 37a), suggests that this structure is compatible with the two main, superimposed, folding trends (Fig. 37a). The occurrence of a local geometric discordance between TS and RS deposits (Figs 32, 36d and Tab. 2) allowed us to

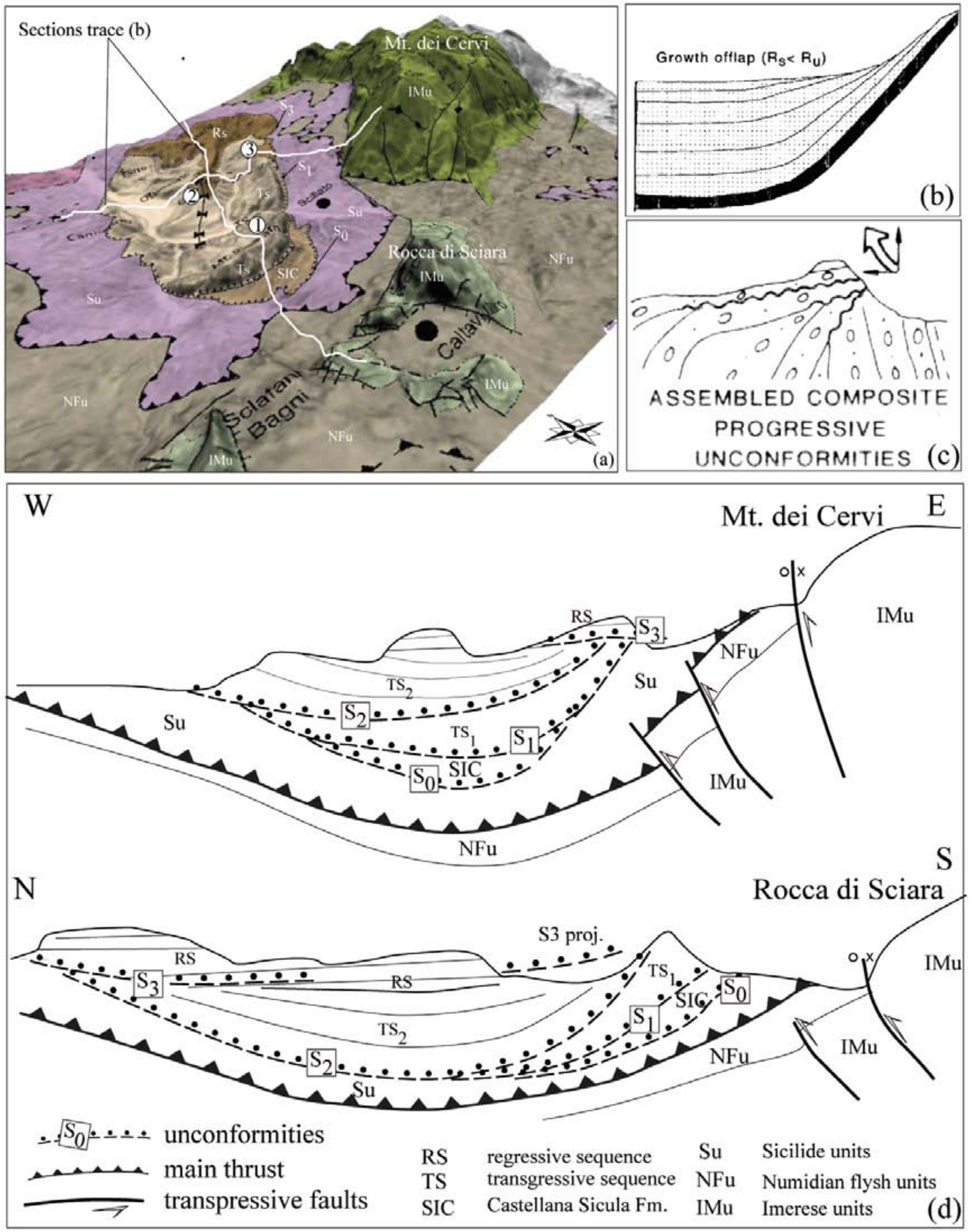

Fig. 36 - **a)** 3D geological map of the Scillato basin area; **b-c)** conceptual models accounting for growth offlap geometry (mod. from Hardy & Poblet, 1995 and Ford et al., 1997) and assembled composite progressive unconformity (mod. from Anadon et al., 1986). **d)** schematic cross-sections (not to scale) crossing the Scillato basin and showing the syntectonic stratal pattern of the Terravecchia fm (traces in a).

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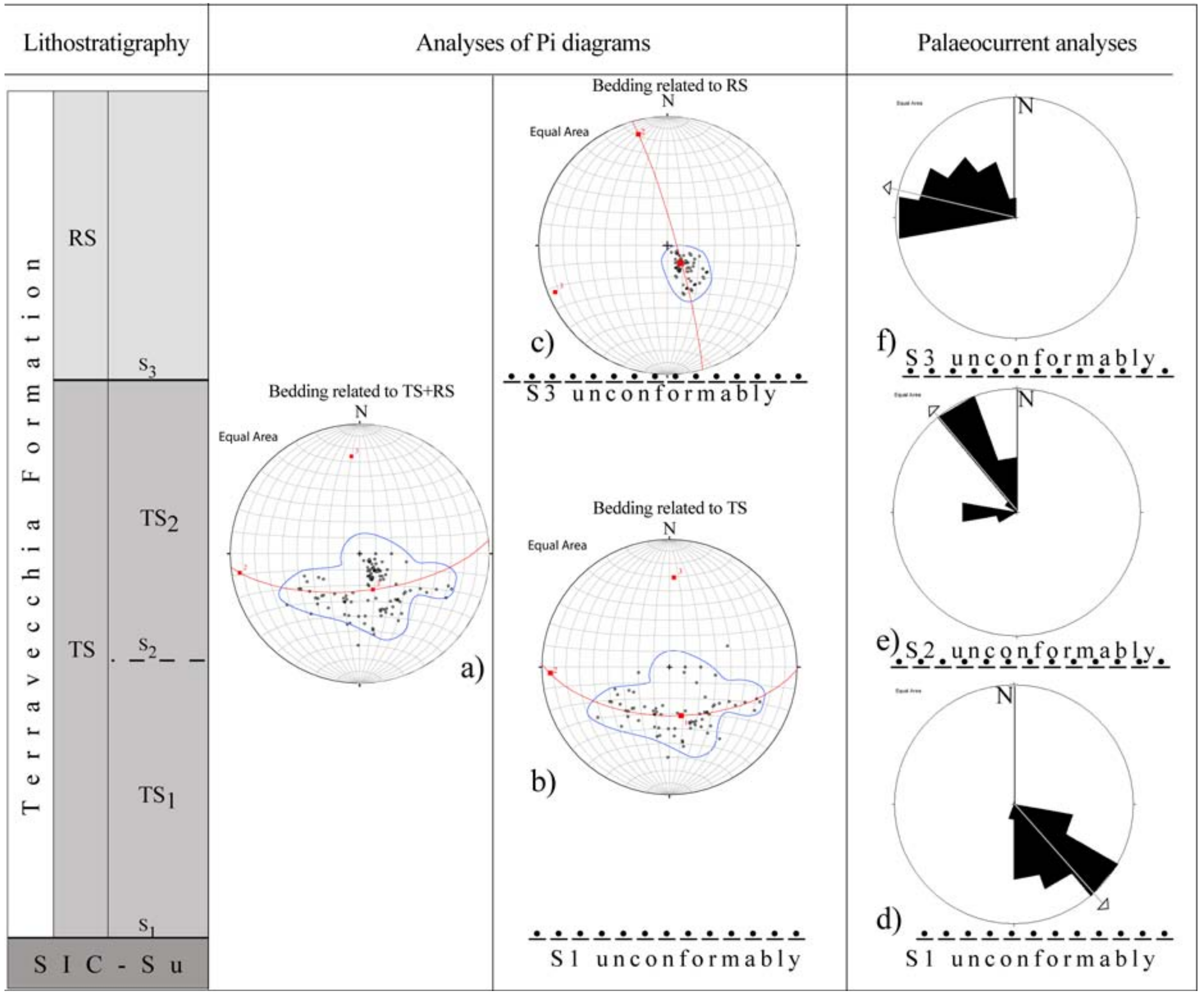
perform a differential analysis of strata separating the data collected in these two sequences. The distribution of poles to bedding in the TS deposits (Fig. 37b) appears compatible with that observed for the TS+RS (Fig. 37a); otherwise, the distribution of pole to bedding resulting from the RS deposits (Fig. 37c) shows a different pattern pertaining to a gently NW-dipping, monoclinal structure. This data suggests that TS and RS recorded a different deformative pattern, allowing us to infer that the RS stage deposits have not recorded the folding related to Event I.

Active, local-scale, tectonic control of the basin's evolution has been highlighted by means of a palaeocurrent analysis (Fig. 37d-e-f).



Three main changes in the palaeoflow direction have been pointed out (Fig. 37d-e-f). Each of these changes roughly develops above an intraformational unconformity. The conglomerate body (EVF) records mainly SE- to S-directed palaeocurrents (Fig. 37d and Tab. 2). Analysis of the mean clast composition reveals a strong "extrabasinal - extraformational" supply for the conglomerates whose fragments reflect the composition of surrounding substrate with a conspicuous occurrence of metamorphic and igneous fragments derived from Sardinia and Kabilo-Calabride

Fig. 37 - Explanation of the data relative to the bedding analyses and palaeocurrent analyses performed in the Terravecchia fm filling the Scillato basin. (Data from Gugliotta & Gasparo Morticelli, 2012).

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crystalline bedrock. The latter data accounts for a N-ward located source area (according to Ferla & Alaimo, 1975; Catalano & D'argenio, 1990; Cirrincione et al., 1995).

Moving upward into the RDS deposits, through the intraformational unconformity S2, the mean dispersal pattern is characterized by N- (according also to Abate et al., 1999) to NW-ward-directed palaeocurrents that are only locally SW-ward-directed.

Thus, a new source area could have developed SE-ward from the basin providing the clastic supply to the basin. In the upper portion of the RDS (above S3, Fig. 37), the palaeoflow pattern appears mainly characterized by mean W- to WNW-directed palaeocurrents.

The increasing abundance in Imerese unit-derived rock fragments and the occurrence of re-sedimented Terravecchia fm grains suggests that both a further shifting of probable source areas toward the E- and NE and a probable "cannibalistic" deposition occurred.

Tectono - sedimentary evolution

All of the above data suggest that the Scillato basin infilling, during the late Tortonian, was controlled by a syn-depositional tilting of the depositional surface, accompanied by a progressive erosion of the south-eastern and eastern basin margins. These processes could be justified if considering the progressive uplift of the Imerse units along the already described SE-dipping transpressional Cervi faults detected along the western Madonie Mts (Fig. 32b).

The data discussed may refer to changes involving both the Scillato basin and its substrate, that occurred during the deposition of the upper Tortonian Terravecchia fm. In particular, these changes concerned:

- tilting of the original Scillato basin margins;
- uplift of local structural highs;

A plausible scenario might imply that the Scillato basin evolution was propelled by the incipient uplifting of the already emplaced deformed substrate units along high-angle, transpressional Cervi faults. As discussed previously, the Imerese units outcrop and form major structural highs, east and south of the Scillato basin (Mt dei Cervi, Rocca di Sciara; Fig. 36a), where they are lifted up along a transpressional fault system (Cervi fault). The activation of the transpressional structures, during the latest Tortonian, could explain the changes of the stratal pattern recognized throughout the Terravecchia fm deposits filling the Scillato basin (Fig. 36d).

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The data presented here also suggest that during the late Miocene the study sector of the Sicilian thrust belt was characterized by a mainly contractional-transpressional tectonic regime not consistent with a late Tortonian back-arc-related extension nor with the orogenic gravitational collapse models nor an extentional fault control by the migration of basement subsidence toward the north, previously invoked by both Abate et al. 1999 and Giunta et al., 2000. The late Miocene Sicilian foreland basin system (*sensu* De Celles & Giles, 1996) is characterized by a wedge-top depozone, split into the "inner" and "outer" sectors (Gugliotta, 2012): the "inner" sectors are characterized by sedimentary basins (e.g. Scillato basin), strongly affected by a localized transpression, at least since the latest Tortonian; the "outer" sectors are characterized by wider basins whose sedimentary infill was not yet affected by compressional and transpressional deformation.

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Carbonate Platform/Basin system during the Mesozoic: stratigraphic evolution, erosional surfaces and sequence stratigraphy framework

Luca Basilone

Introduction

Most of the carbonate successions of the Mesozoic-Cenozoic shallow- and deep-water facies outcrop in Western Sicily in two main areas: the Termini Imerese-Madonie Mts and the Western Sicily belt, spanning between the Palermo Mts and the Sciacca deformed foreland (Fig. 38).

These regions are the places where well preserved outcrops and intense facies analyses and stratigraphic studies have recognized rocks pertaining to different paleogeographic domains originally located along the Southern Tethyan continental margin.

To understand the relationships between the two major Panormide and Imerese paleodomains we will discuss their sedimentary evolution and the main patterns, describing and comparing (Fig. 39) the Imerese Upper Triassic-Lower Oligocene pelagic carbonates, mudstones with radiolarians and reworked shallow-water facies deposits, widespread outcropping in the Termini Imerese and western Madonie Mts, and the Panormide Upper Triassic-Eocene, mainly shallow-water carbonate successions (shelf environment), with thick, deeper water facies intercalations well exposed in the Palermo Mountains region and in the eastern Madonie sector.

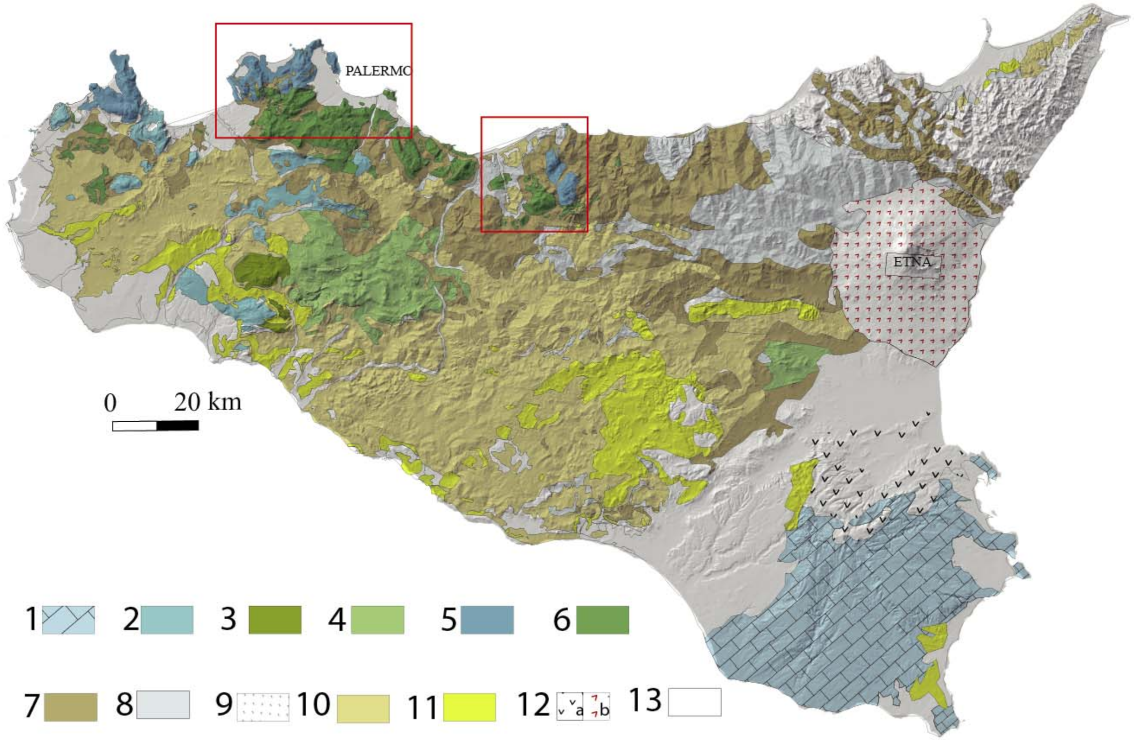

Fig. 38 - Location of the study areas in the structural map of Western Sicily (mod. from Catalano et al., 2004). For the legend see Fig. 24.

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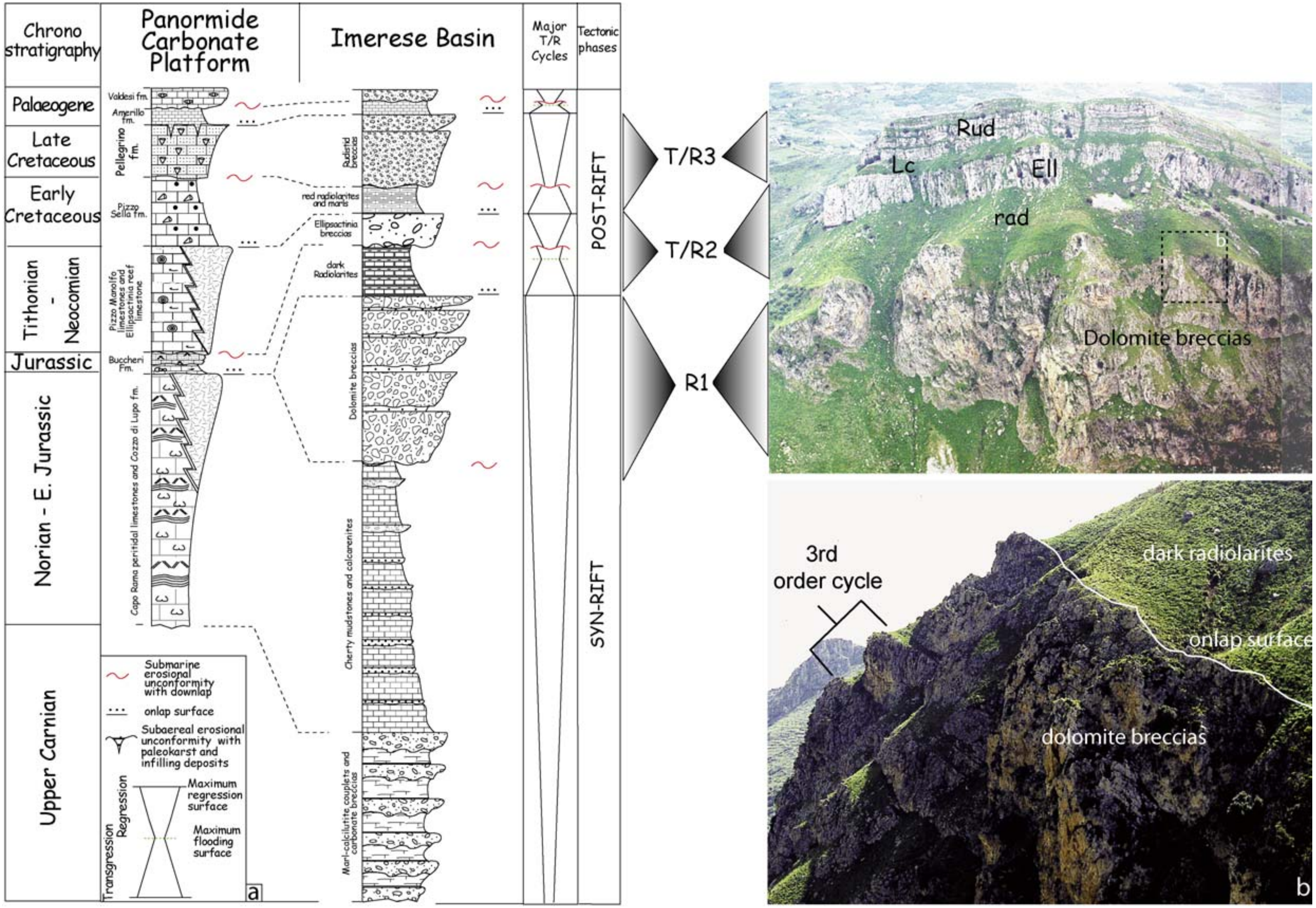

Fig. 39 -
a) Cyclic organization of the Imerese succession, viewed on the northern side of Cozzo Famo (Termini Imerese Mts) and correlation with the Panormide carbonate platform succession.

Legend:
dolomite breccias of the Fanusi formation;
rad: dark radiolarites;
Ell: *Ellipsactinia* breccias;
Lc: red radiolarites and marls;
Rud: Rudistid breccias;

b) third order cycles of the Lower Jurassic dolomite breccias of the Fanusi formation.

Stratigraphic evolution

Palaeoenviromental reconstruction refers the deposits of the Panormide Carbonate Platform succession to a Bahamian-type carbonate platform (Catalano et al., 1974), with rimmed shelf-margin (Late Triassic and Late Jurassic) and open platform with ramp geometries (Late Cretaceous and Late Eocene). Common fossils include

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corals, sponges, hydrozoans, rudists and large benthic foraminifers. The Imerese deep-water succession is dominated by spectacular gravity-flow deposits which include: a) breccias, megabreccias and megaconglomerates, b) bioclastic turbidites, c) laminated fine-grained limestones (dilute turbidites). The strata display a typical example of a carbonate platform margin, characterized by reworked facies with progradational stacking patterns (Basilone 2000; 2009a; Basilone & Lo Cicero, 2002).
Although it is not known whether the location of the Imerese Basin is internal or external with respect to the Panormide Carbonate Platform, there is general agreement about an original adjacent location of the two paleodomains (Broquet, 1968; 1970 Catalano & D'Argenio, 1978, Catalano et al., 1996, 2004; Montanari, 1989; Nigro & Renda, 2000).

The investigated rock bodies are incorporated into the Sicilian fold and thrust belt that originated from the deformation of the Mesozoic-Cenozoic sedimentary cover of the Sicilian sector of African continental margin. The resulting tectonic units were stacked during the Miocene-Pliocene, verging south and south-eastwards (Catalano et al., 2000b and reference therein).
The accurate sediments correlation that have been synchronously deposited at the margin of carbonate platforms in shallow- and deep-water environments is required in order to reconstruct ancient oceanic environmental conditions and sea level changes (Bosellini, 1984; Fouke et al., 1996; Whalen et al., 2000; Eberli et al., 2004; Schlager, 2005, and among others). Unfortunately, accurate correlation between these types of sedimentary units is full of difficulties for several reasons, including: (1) physical destruction of the rocks during syn- and post-depositional tectonics and associated differential erosion; (2) differences in the quality and resolution of the biostratigraphic records preserved in basinal and platform limestones (Bralower et al., 1994; Erbacher et al., 1996); 3) synsedimentary tectonic effects of the original sedimentary basin.
The lack of a well-preserved physical continuity between Sicilian carbonate platform and basinal facies domains, that has been described in other studied margins (e.g. the Maiella section, Bernoulli et al., 1992; Vecsei et al., 1998; Eberli et al., 1993); Vercors Mountains (Jacquin et al., 1991; Everts et al., 1995; Fouke et al., 1996); Cantabrian Mountains (Della Porta et al., 2004); Great Bahamas Bank (Eberli & Ginsburg, 1989; Eberli et al., 2004) means that the shelf and basin successions should be study separately. Correlation between isolated basin and platform stratigraphic sections can be accomplished using changes in sedimentological composition and using the main unconformity surfaces (Everts et al., 1995, Everts & Reijmer, 1995; Whalen et al., 1993, 1995; Fouke et al., 1996).

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The comparison and correlation between the unconformity surfaces, facies and geometric stacking patterns, recognized both in the shelf and basin successions, have let to restore the stratigraphic architecture of the Mesozoic shelf-to-basin system (Basilone, 2009a). This study has revealed a close relation between sedimentary evolution and cyclicity. The tectono-stratigraphic features recognized (e.g. tilted fault block of the Triassic shallow-water limestones, subaerial erosion, Fig. 40), point out a tectonic influence in the sedimentary evolution of the Panormide/Imerese platform-to-basin system. The tectonic control on sedimentation has been related to the syn-rift and post-rift phases that involved the Tethyan continental margins during the Mesozoic (Castellarin, 1972; Bernoulli & Jenkyns, 1974; Patacca et al., 1979; Catalano & D’Argenio, 1982b; Eberli, 1988; Alvarez, 1990; Santantonio, 1993, 1994; Basilone 2009b; Basilone et al., 2010).

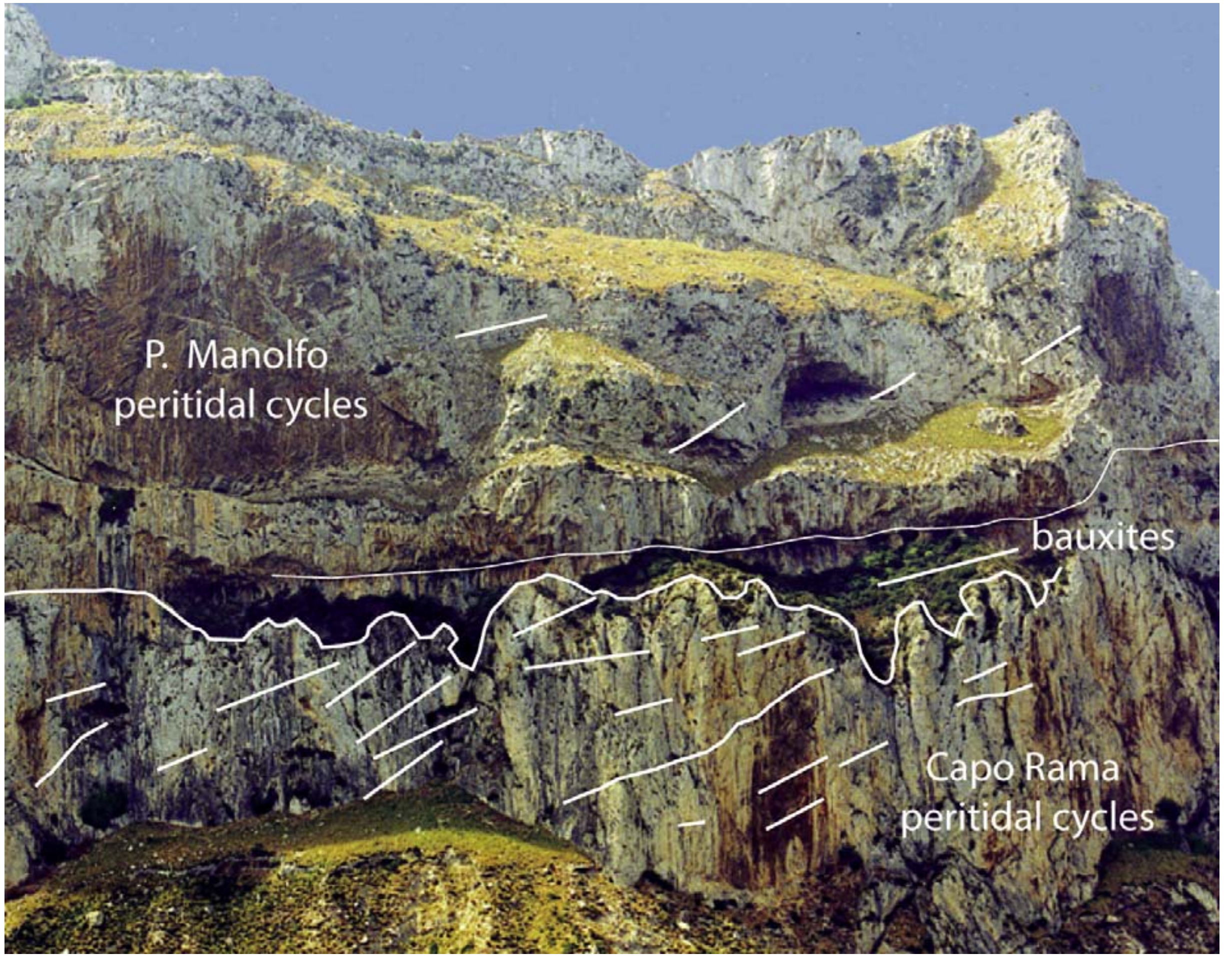

Fig. 40 - Angular unconformity between Upper Triassic Capo Rama fm peritidal limestones and the upper Jurassic Pizzo Manolfo peritidal limestones. On the irregular erosional and karstic unconformity surface, bauxite deposits are presented (northern side of Monte Gallo, Palermo Mountains).

Unconformity surfaces

The main unconformity surfaces, largely characterized by widespread erosion or non deposition, are recognized both in platform and basin succession and correlated each one:

a) The Upper Triassic peritidal carbonates of the Panormide succession are cut by a subaerial erosional surface. This surface is, generally, accompanied by karst processes, continental

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sedimentation (bauxites), large erosion and block faulting and tilting (Fig. 40). In the Imerese basin the time equivalent cherty limestones (Scillato fm) are cut, upwards, by a submarine erosional surface, accompanied by widespread downlap stratal termination of the Lower Liassic prograding dolomitic breccias (Fanusi fm, Fig. 41); the breccia elements consist of shallow-water fragments derived by the dismantling of the adjacent platform sedimentation domain. These surfaces are strictly related to the tectonic fragmentation of the Tethyan platform domains (Bernoulli & Jenkyns, 1974) and to the sea level fall (Hallam, 1977; Vail, 1987; Haq et al. 1987; Jacquin et al., 1991; Jacquin & Vail, 1995).

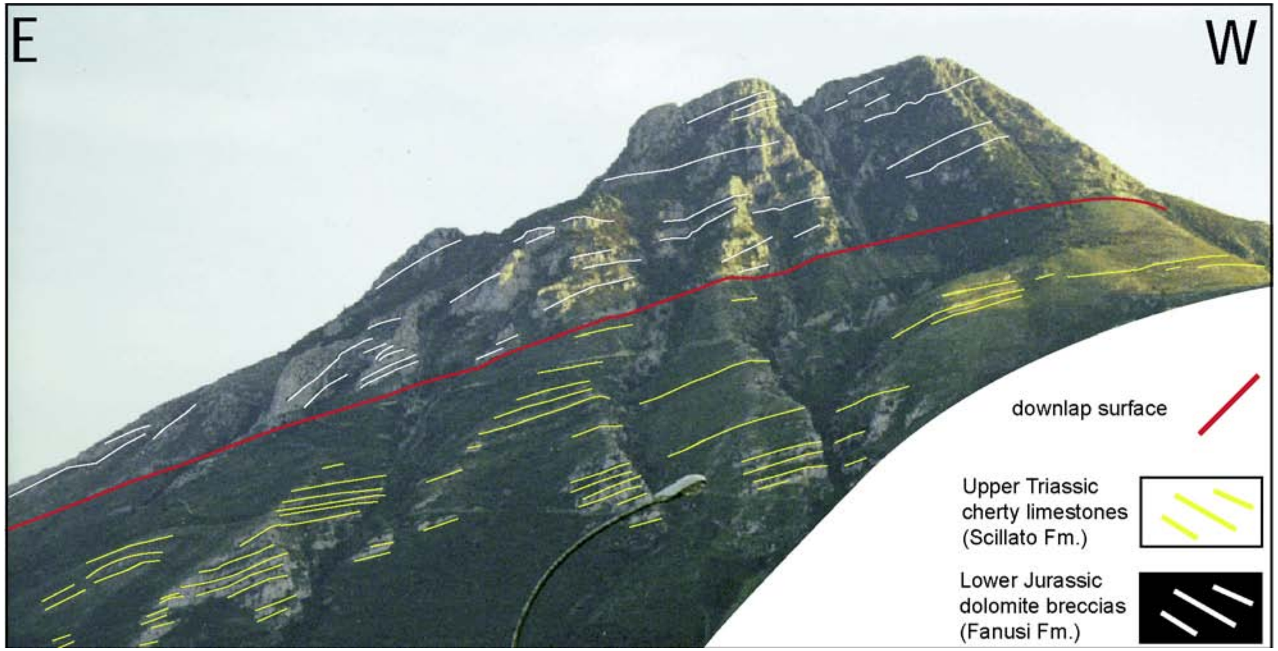


Fig. 41 - Downlap relationships between the megabeds of the lowermost Jurassic dolomite breccias (Fanusi fm) and Upper Triassic cherty limestones (Scillato fm). San Calogero Mountain (Termini Imerese Mts).

b) The top of the Upper Triassic/Lower Liassic shallow-water deposits and the top of the dolomitic slope breccias is often characterized by Fe-Mn oxides crusts (hardground), accompanied by onlap stratal termination of the above Jurassic Rosso Ammonitico beds (in the carbonate platform domain) and radiolarian cherty limestones (in the basin). These non-depositional surfaces are related to a widespread transgression and sea level rise occurred during the Jurassic (Fig. 41).

c) A correlative platform-to-basin submarine erosional surface, separating Jurassic deep-water deposits (Rosso Ammonitico and radiolarian cherts) from Tithonian-Neocomian aggrading-to-prograding *Ellipsactinia* reef limestones and their lateral reef-derived debris (*Ellipsactinia* breccias mb), grows towards the slope of the carbonate shelf deposits (Figs 42, 43 and 44).

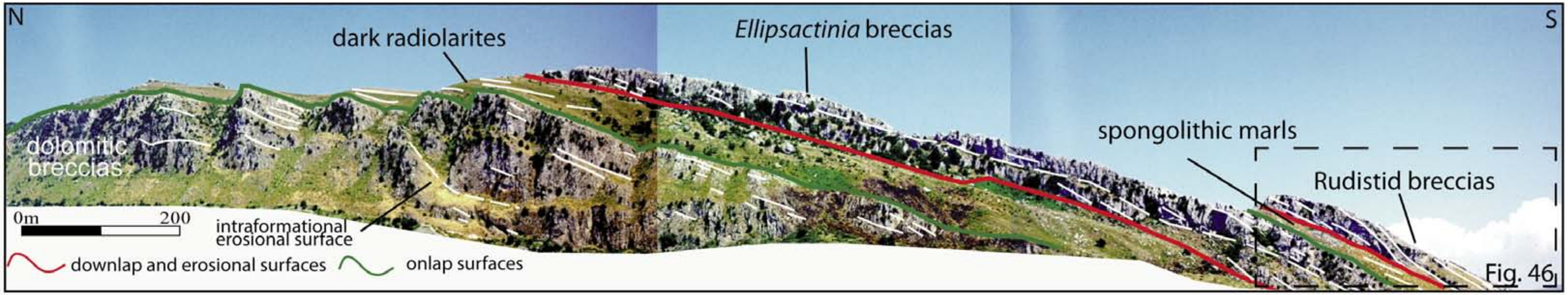


Fig. 42 - Physical-stratigraphic relationships of the Jurassic-Cretaceous Imerese succession viewed in a panoramic photomosaic of the western flank of Rocca di Mezzogiorno (S. Calogero Mountain, Termini Imerese Mountains). It is possible to see the onlap and downlap surfaces of the major T/R facies cycles.

d) The upper boundary of the previously described Tithonian-Neocomian *Ellipsactinia* deposits appears, in platform setting, as an erosional surface, slightly tectonically enhanced, associated with fractures and neptunian dykes and a maximum regression surface in basinal setting. This surface may evolve either into a drowning surface with neptunian dykes filled by upper Cretaceous pelagic limestone (Amerillo fm), or, along the inner platform succession, into an onlapping unconformity surface covered by Barremian-Aptian shallow water deposits (Monte

Fig. 43 - Erosional contact between the *Ellipsactinia* breccia mb. and the Jurassic black radiolarites mb. of the Crisanti fm (Cozzo Petroso, Trabia Mts).

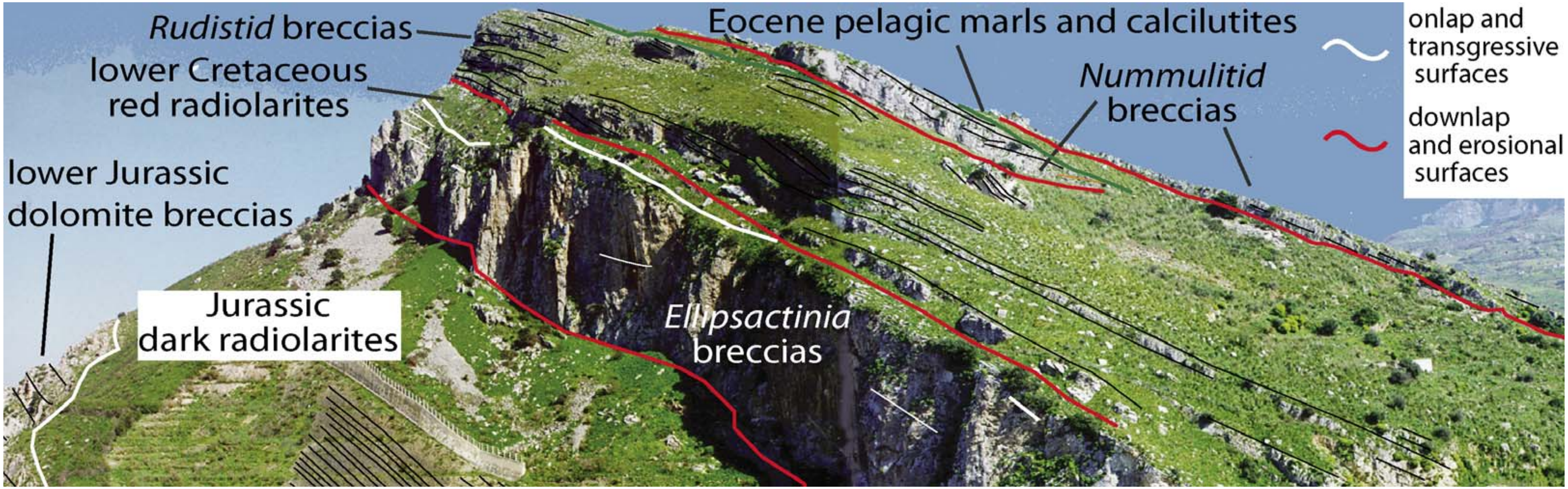
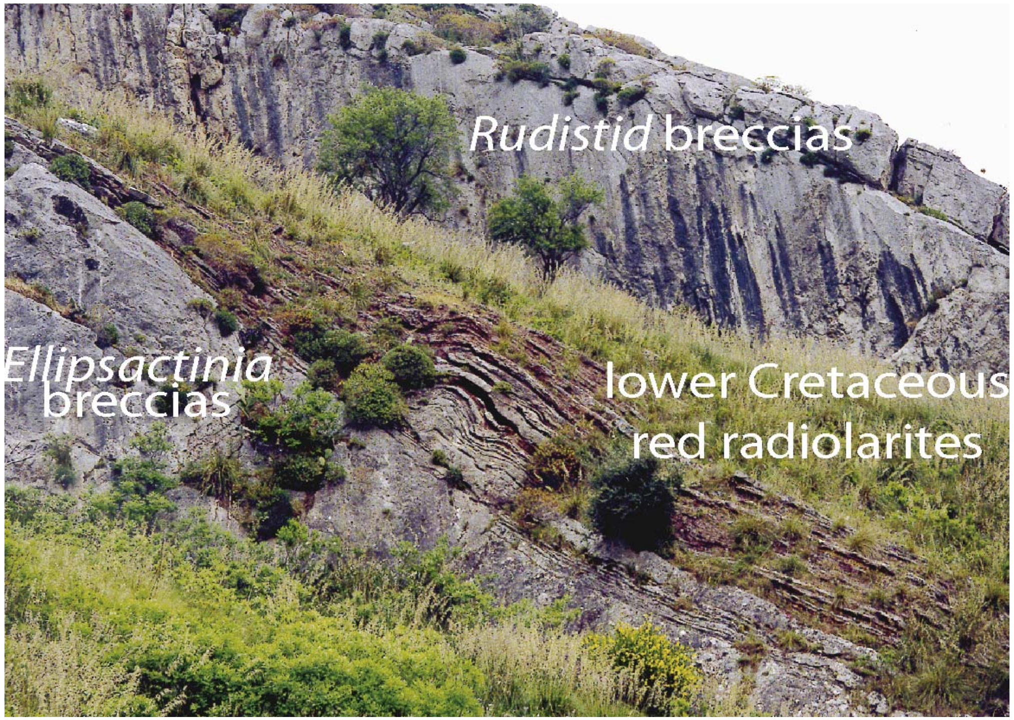


Fig. 44 - Panoramic view of the western side of Cozzo Famo (Termini Imerese Mountains), where the geometric relationships of the Jurassic-Eocene units of the Imerese slope succession are visible. The Lower Cretaceous red radiolarites and marls mb of the Crisanti fm is here 5 metres thick and, laterally, disappear.



Gallo, Palermo Mts). A transgressive surface (Figs 42 and 44), with onlap terminations (Fig. 45), between lower Cretaceous radiolarian pelagic deposits (red radiolarites and marls mb of the Crisanti fm) and the regressive *Ellipsactinia* breccias mb, marks the lower boundary in the basin.

Fig. 45 - Onlap relationships between the Lower Cretaceous red radiolarites and marls member with the *Ellipsactinia* breccia mb of the Crisanti fm.

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e) A major downlap surface, associated with submarine erosion and hiatus observed both in platform and in slope settings, characterize the lower boundary of the Upper Cretaceous (mostly Cenomanian) rudistid limestones and associated prograding reworked deposits in the basin (Fig. 46, Rudistid breccias).

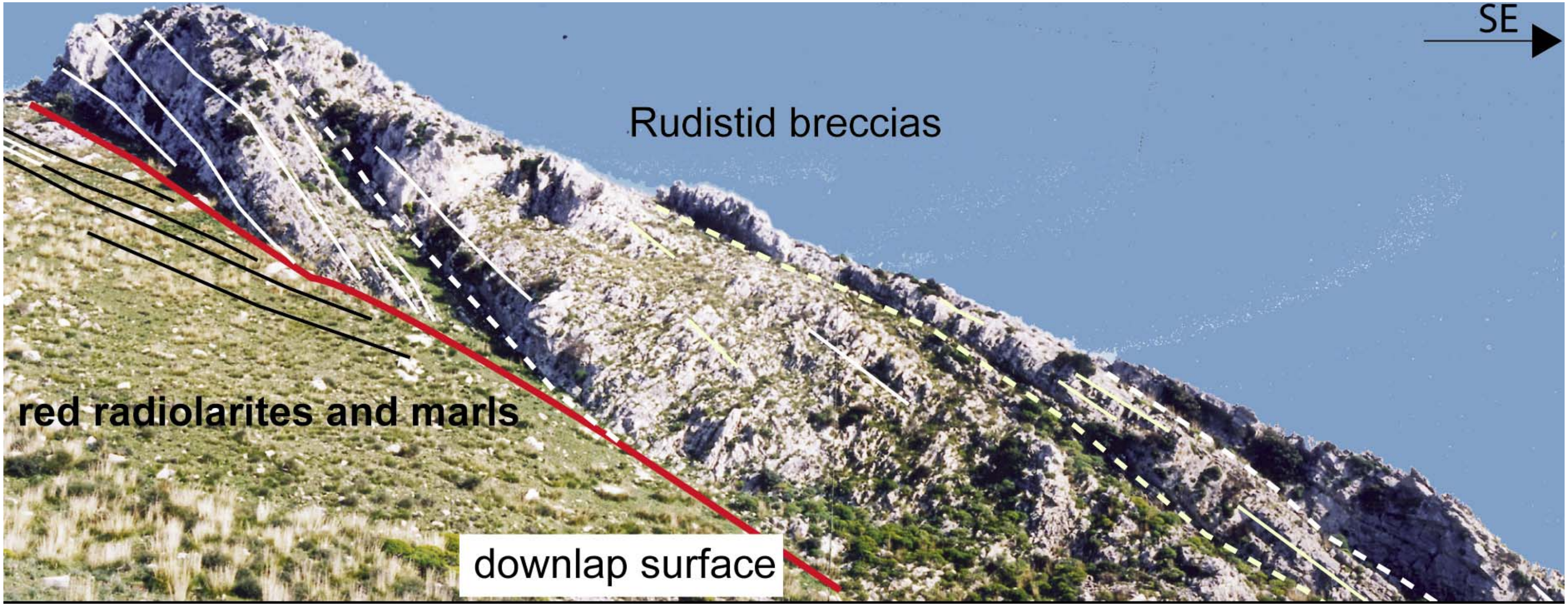

Fig. 46 - Panoramic view of the southern side of Rocca di Mezzogiorno. Erosional unconformity at the base of the breccias and turbidites (Cenomanian Rudistid breccias mb. of the Crisanti fm) highlighted by downlap geometry; truncation of the older strata (Lower Cretaceous red radiolarites and marls mb. of the Crisanti fm) is also present. The white dashed lines are the sequence boundaries of the 3rd order cycles.

f) The upper boundary of the Late Cretaceous deposits is a tectonically-enhanced erosional unconformity, evidenced by the occurrence of several dykes, cutting the top of the Upper Cretaceous platform deposits; the correlative surface, in the basin, is a maximum regression surface on top of the Upper Cretaceous Rudistid

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breccias. This boundary is associated with a drowning unconformity, overprinting the Maastrichtian erosional surface, characterized by hiatuses, paleokarst features and neptunian dykes and onlap stratal termination of the Eocene planktonic foraminifera bearing-mudstone (Amerillo and Caltavuturo fms deposits).

Cyclicity

Sequence stratigraphic studies of the Triassic through Paleogene carbonate successions of platform, slope and basin in Western Sicily (Palermo and Termini Imerese Mountains) have identified a sedimentary cyclicity mostly caused by relative sea-level oscillation (Fig. 39). Physical stratigraphy and facies analysis appear as powerful methods to reconstruct the stratigraphic architecture and the sedimentary evolution of the Sicilian Mesozoic-Paleogene carbonate rock units deposited on a shelf-to-basin system (e.g. Panormide-Imerese).
Results of the study have shown that the occurrence of correlative strata from shelf to basin are organized in four major transgressive/regressive cycles which span from late Triassic to Eocene time. These cycles are characterized, both in platform and basin setting, by transgressive deposits that onlap older regressive deposits.
The latter, characterized by progradational geometries, downlap the older transgressive deposits (Basilone, 2009a). The platform-to-basin system original physiographic profile was interrupted by scarp-margins and discontinuities, produced during the major tectonic events. The whole slope succession consists of more than 50% of shallow water (mostly reef) derived debris. Sedimentary evolution, of the slope-to-basin depositional systems, was partially guided by vertical and lateral growth and retreat of the carbonate platform margins. The sedimentary evolution of the carbonate platform was controlled by long-term relative sea-level change (tectonic subsidence and eustasy).
The main tectonic events, obtaining by means of the analysis of the stratigraphic relationships and the help of biostratigraphy, appear frequently, synchronous to the sequence boundary of the major T-R Sicilian cycles.

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Wedge-top and foredeep basins in the frontal sector of the Sicilian chain

Attilio Sulli

Introduction

The structural characteristics of the Gela Thrust System and its relationships with the underlying foreland units and the overlying syntectonic basins are hidden by recent deposits in the Gela plain and surrounding area (Fig. 47).

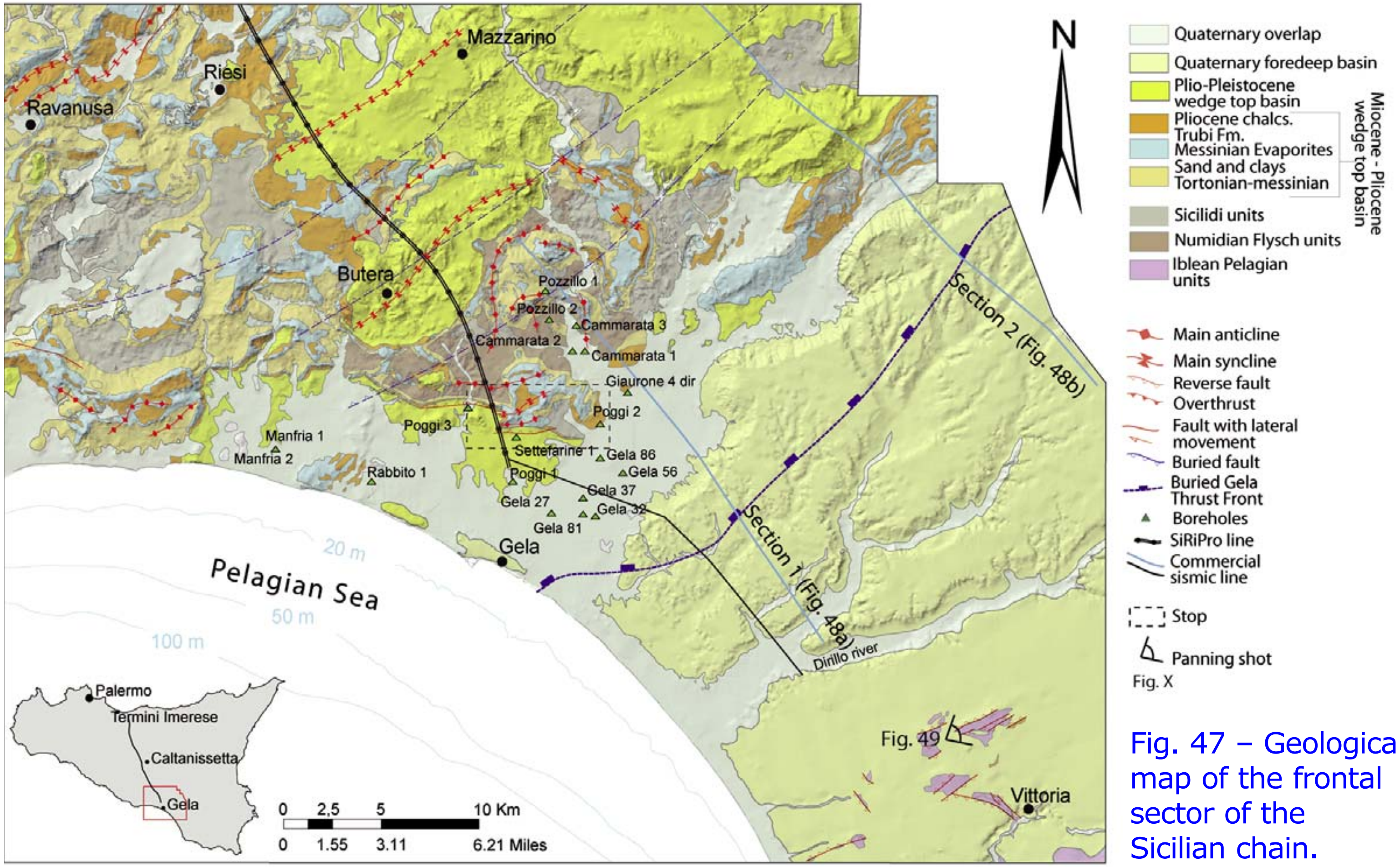

Fig. 47 – Geological map of the frontal sector of the Sicilian chain.

The interpretation of the available subsurface data, occurring in this sector of Southeastern Sicily, allows us to frame this setting to the main geometries suggested by the SI.RI.PRO. profile. The collected data (Figs 47, 48a, b, 49) reveal the occurrence of: 1) the deformed foreland, dipping towards NW, 2) the frontal portion of the Gela Thrust System, with local SE vergence, 3) the foredeep basin, filled by Plio-Pleistocene deposits, 4) the syntectonic basins, on the back of the deformed units of the chain.

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The Iblean foreland

The foreland consists of Triassic-Neogene shallow-water successions pertaining to the Iblean domain. The SI.RI.PRO. profile (see Catalano et al., this guidebook, pp. 79-88) shows as it is a reflective body, more than a 2 s/twt thickness (up to 10 km), which dips towards NW, beneath the strongly deformed Gela Thrust System. Previous studies have imaged this sector of the foreland as a weakly deformed body, whose top represents the regional monocline that plunges towards the chain. Several Authors highlighted the occurrence of normal faults that downthrow the succession northwestwards, favoring the flexure beneath the units of the chain. Reverse faults of small throw were pointed out and interpreted as the result of the tectonic inversion of previous normal faults (Ghisetti et al., 2009). Our subsurface data highlight a strong deformation of the topmost Iblean succession, folded and dissected by reverse faults with a throw greater than a hundred meters (a in Fig. 48b). These structures, which dip towards both the NW and SE directions (a and b in Fig. 48a), can be seen also in the outcrop in the Vittoria area (Fig. 49). This deformed body is locally detached with respect to a strongly layered substrate. Furthermore, in the study area a SE-dipping buried thrust displaced the Iblean units towards NW (Fig. 48a).

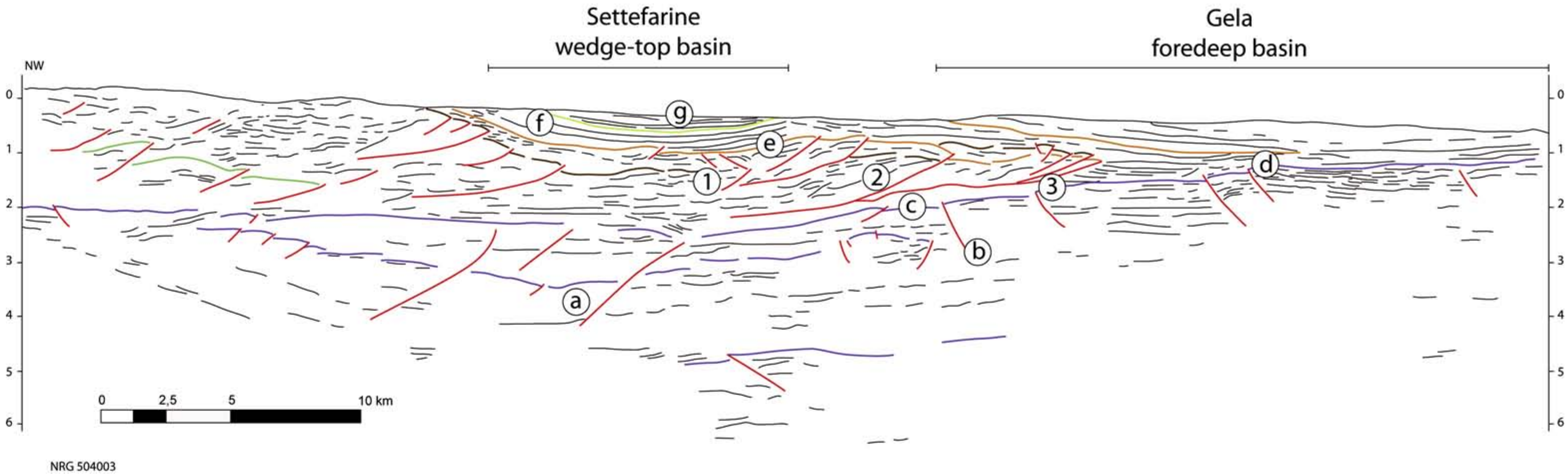

Fig. 48a – Geoseismic section (1 in Fig. 47) that illustrates from NW to SE the chain-foredeep-foreland system and the relationships with wedge-top and foredeep basins. For letters see text.

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The frontal region of the chain

The Gela thrust wedge

The SI.RI.PRO. line shows how the frontal portion of the chain consists of a tectonic wedge, more than 3 s/twt thick (more than 5 km), thinning towards SE, where it slightly overthrusts the foredeep deposits.
The wedge, known also as Gela Nappe (Ogniben, 1960), is composed of thrust imbricates of variable thickness, organized in at least four overlapping layers, separated by detachment surfaces. A regional sole thrust separates the wedge from the Iblean foreland monocline. Well data point out that these units derive from the deformation of the original covers of the Iblean succession, as evidenced by the lack of the most recent (Mio-Pliocene) strata at the top of the regional monocline, particularly where it is shallower (c in Fig. 48a), as well as of the inner and higher units of the chain. On the whole, they consist of upper Miocene to Pleistocene terrigenous, carbonate and evaporitic rocks, tightly deformed, resting on rock successions resulting from the deformation of the Sicilide (Cretaceous-Oligocene age) and Numidian flysch (Late Oligocene-Early Miocene) rock units. Along the seismic section in Fig. 48b

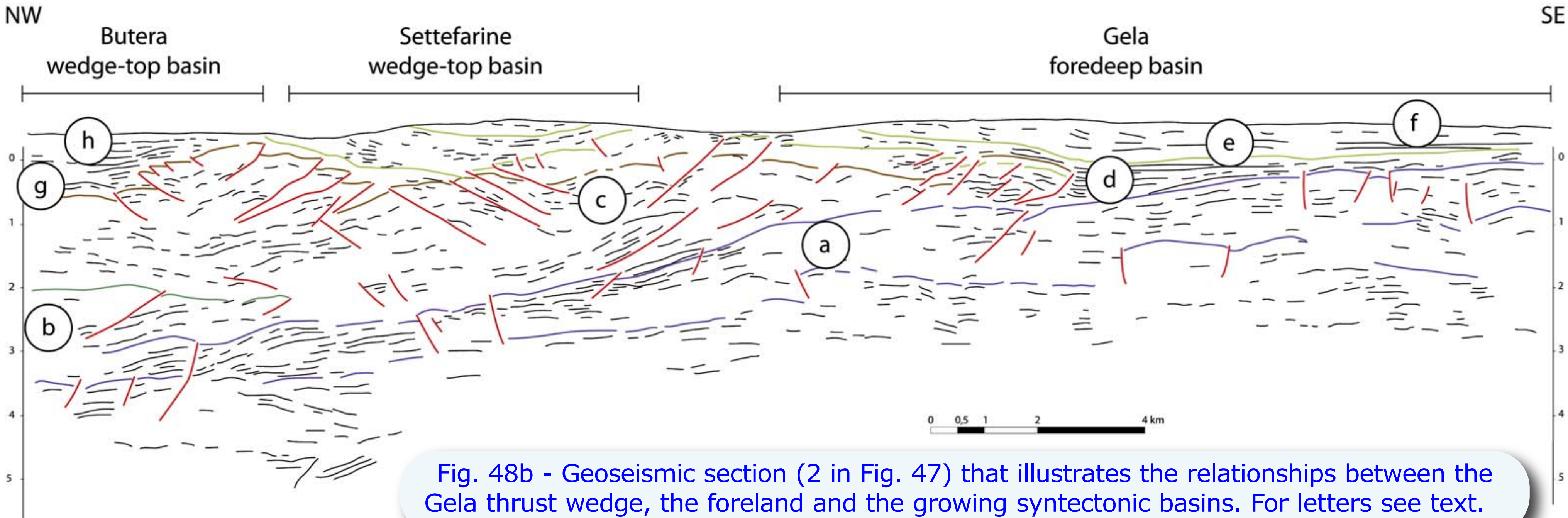

Fig. 48b - Geoseismic section (2 in Fig. 47) that illustrates the relationships between the Gela thrust wedge, the foreland and the growing syntectonic basins. For letters see text.

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the Gela Nappe overthrusts interpreted Sicanian, deep-water carbonate thrust sheets. In the investigated area, the Gela Nappe shows three main thrust systems (1, 2 and 3 in Fig. 48a), whose progressive deformation is outlined by the involvement of progressively younger rocks going towards the present-day foredeep. As evidenced by the stratal geometry, the thrust units are sealed by younger deposits that, in turn, exhibit a deformation due to the new forward thrust faults. The highest thrust units are also characterized by several backthrusts recalling a triangle zone geometry (c in Fig. 48b). In the most external frontal area, buried beneath the Gela plain, an incipient deformation of the present day foredeep deposits occurs, giving rise to the most external ramps of the Sicilian chain. The composition of the Gela Thrust System, outcropping just north of the present-day buried front, along the so-called Settefarine thrust, is crossed by the Settefarine well (see Itinerary section, Third Day). The submerged extension of the Gela Thrust System has already been highlighted by seismic profiles as occuring offshore, along the Southern Sicily continental shelf and upper slope (Catalano et al., 1993b and references thereinafter).

The Gela foredeep

Along the WNW-ESE direction, the foredeep basin occupies the south-east portion of a wide depression located between the deformed units of the Gela Nappe, to the NW, and the outcrop of the carbonate successions of the Iblean foreland, to the SE (Fig. 47). The foredeep infill is imaged as a sedimentary wedge, up to almost 1500 m thick, which lies on top of the Iblean succession and onlaps the frontal unit of the Gela Nappe. Near the thrust front the deposits image a divergent pattern and can be divided into three levels:
a) the oldest, about 300 m thick, dips towards the NW and represents the already settled package, before the advancing of the local thrust front (d in Fig. 48b). This package, which is Pliocene in age, appears overthrusted by the wedge of the deformed Gela Thrust System, partly consisting of the same deposits of the foredeep;
b) the intermediate level (e in Fig. 48b), up to 800 m thick, dipping SE-wards, represents the portion of the foredeep which simultaneously made deposits on the advancing Gela thrust front (Pliocene-Middle Pleistocene and maybe Present);
c) the uppermost level (f in Fig. 48b), up to 400 m thick, post-middle Pleistocene in age, images sub-horizontal beds settled after the emplacement of the thrust body. The stratified unit extends laterally towards SE, to the sedimentary isochronous deposits resting on the Iblean foreland. The onlap contact between the foredeep deposits and the foreland units is represented by a stepped unconformity, due to the marked and progressive deformation in this sector (d in Fig. 48a).

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The wedge top basins

In Southeastern Sicily, the syntectonic basins that appear as symmetrical depressions are usually elongated parallel to the front of the chain and filled with upper Pliocene-Pleistocene deposits, up to 800 m thick. In particular, along the visited region we will describe the Butera and the Settefarine basin.
i) The Butera basin is crossed by the SI.RI.PRO. section (see Fig. 47) that images the basin infill, separated into two sedimentary units by an unconformity:
a) the oldest (g in Fig. 48b), about 400 m thick, displays divergent geometries forming a large synform and onlaps above the piled thrust sheets of the Gela Nappe, clearly showing a syntectonic pattern;
b) the uppermost portion (h in Fig. 48b), about 300 m thick, displays sub-horizontal bedding and onlaps the previously mentioned, older syntectonic deposits. It represents the post-deformational deposits. It is probably post-1.6 Ma in age (see Itinerary section, Third Day, Fig. 119). The basin depocenter coincides with the tip of a thrust, dipping towards SE. Due to its geometric characteristics and stratal pattern this basin can be considered as a wedge-top basin.
ii) The Settefarine basin occupies the northwestern sector of the wide depression that extends parallel to the NE-SW trending front of the Sicilian chain. The basin infill displays three main sedimentary units:
a) the lower unit (e in Fig. 48a), about 150 m thick, is arranged to form a wide synform. Deposits rest on the envelope surface formed at the top of the underlying tectonic splays of the Gela Thrust System. This surface is mostly the top of the Messinian evaporites. Laterally, the unit can be correlated to the lowermost part of the intermediate unit mentioned before, as identified within the foredeep basin. The deposits settled prior to the advancing of the front of the Gela Thrust System;
b) the intermediate unit (f in Fig. 48a), about 300 m thick, forms a large synform and has a divergent geometry, thicker on the north-western shoulder of the basin. The unit appears to have been deposited simultaneously with the deformation of the frontal units of the Gela Thrust System;
c) the highest unit (g in Fig. 48a), about 250 m thick, displays horizontal and parallel bedding. The deposits onlap the underlying units. The unit appears to have been deposited subsequent to the deformation of the frontal units of the chain.
This basin can be considered a wedge-top basin for its geometric characteristics and its stratal pattern. The deposits of the lower units can be interpreted as the filling of the original foredeep since it was developing before the emplacement of the present-day front of the Sicilian chain.

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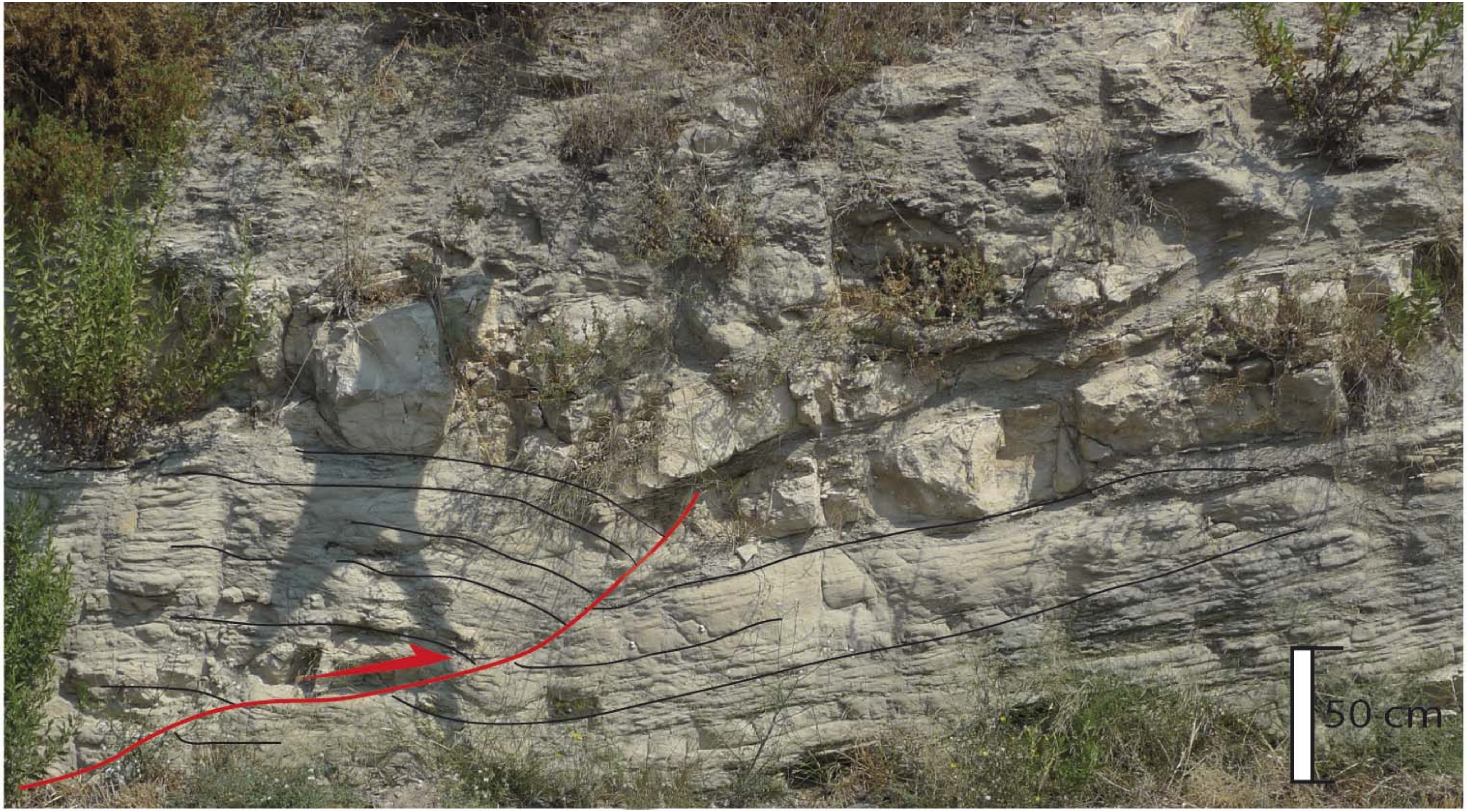
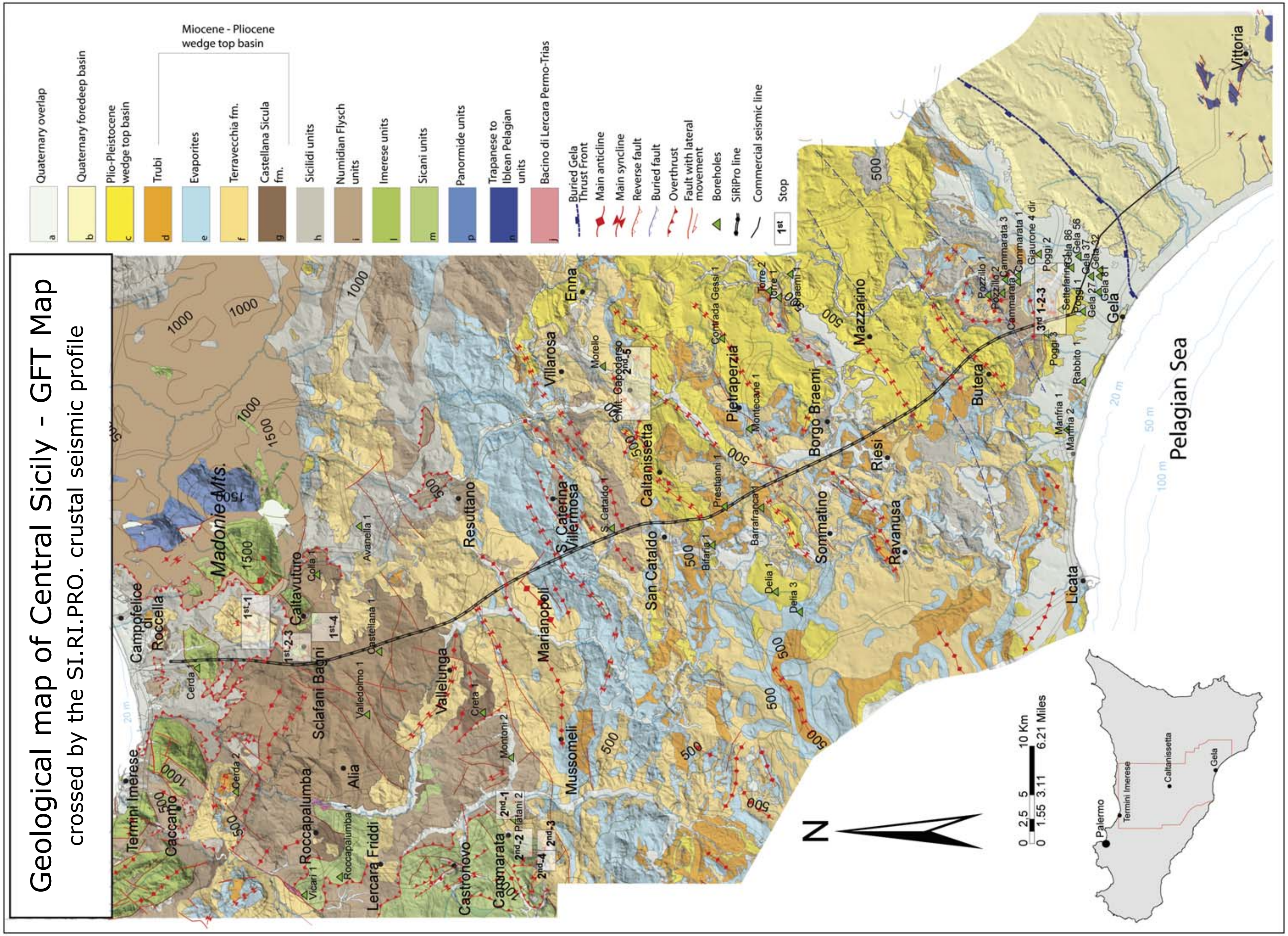


Fig. 49 - Deformation and faulting in the Oligocene-Miocene calcarenites and marls of the Ragusa formation.



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Field Trip

FIRST DAY

Northern sectors of the Sicilian fold and thrust belt

Luca Basilone, Raimondo Catalano, Maurizio Gasparo Morticelli, Carlo Gugliotta

Main purpose

To observe the stratigraphic setting of the Late Miocene Scillato syn-tectonic basin terrigenous infilling. To show both the stratigraphic and facies features of the Meso-Cenozoic deposits pertaining to the deformed substrate.

To discuss the regional tectonic setting in the frame of the results imaged by the SI.RI.PRO. Profile.

Itinerary

- **Stop 1a** (Road from Cerda to Caltavuturo; Fig. 50). After a brief introduction about the regional geological framework, the stop will focus on the description of the sedimentary and structural setting of the Middle-Late Miocene wedge-top Scillato basin and on the relationships between tectonics and sedimentation.
- **Stop1b** (Imera River gorge; Fig. 50). The sedimentological and facies characteristics of the lower portion of the Scillato basin succession and the possible implication for hydrocarbon exploration is discussed here.
- **Stop 2** (Sclafani Bagni town; Fig. 50). Stratigraphic and facies characteristics of the Mesozoic carbonate and cherty deposits pertaining to the Imerese succession are shown and discussed.
- **Stop 3**. Presentation of the large-scale, structural setting of the area and a correlation between subsurface and outcropping structures is performed in a panoramic overview (Fig. 50).
- **Stop 4** Road to Valledolmo (Fig. 50). To visit the Numidian flysch outcrop and observe lithologies and their sedimentological characteristics.

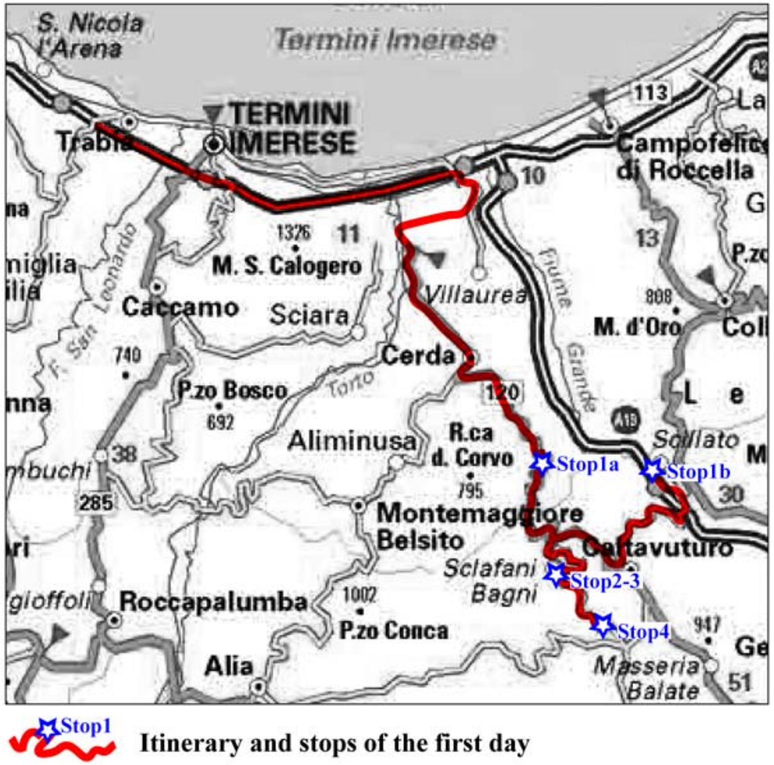

Fig. 50 - Road map of the visited area.

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Geological framework and background concepts

The study region is a sector of the Northern Sicily chain (Fig. 51). The tectonic stack consists of northward-dipping, tectonic units bounded by major decollement surfaces. From the top, we can recognize: a tectonic wedge consisting of (a) upper Oligocene-lower Miocene deposits (Numidian flysch nappe) detached from their Imerese substrate and overthrusted by (b) Cretaceous–Oligocene varicoloured clays, limestones and tuffitic marlstones (Sicilide nappe); a tectonic body (c) made up of Permian to Triassic rocks (revealed by the Cerda1 well, Lercara complex). In turn, the composite wedge overthrusts the (d) Meso-Cenozoic slope-to-basin carbonates and radiolarites with interbedded carbonate breccias (Imerese units) and upper Oligocene-lower Miocene argillites and turbiditic quarzarenites (Numidian flysch). The tectonic stack reaches the main culmination along the western Madonie Mountains (at Monte dei Cervi, Rocca di Sciara and in the Sclafani Bagni area, Figs 51, 52) where well exposed Imerese units form major structural highs. The above-mentioned tectonic stack is unconformably overlain by Middle-Upper Miocene siliciclastic deposits. These deposits are comprised in two main lithostratigraphic units (Fig. 53) locally known as the Castellana Sicula formation (upper Serravallian – lowermost Tortonian) and the Terravecchia formation (upper Tortonian – lowermost Messinian). These latter are exposed in the Scillato basin, in a wide outcrop, deeply incised by the Imera River, that provides excellent exposures. Their main stratigraphic features are briefly described as follows.

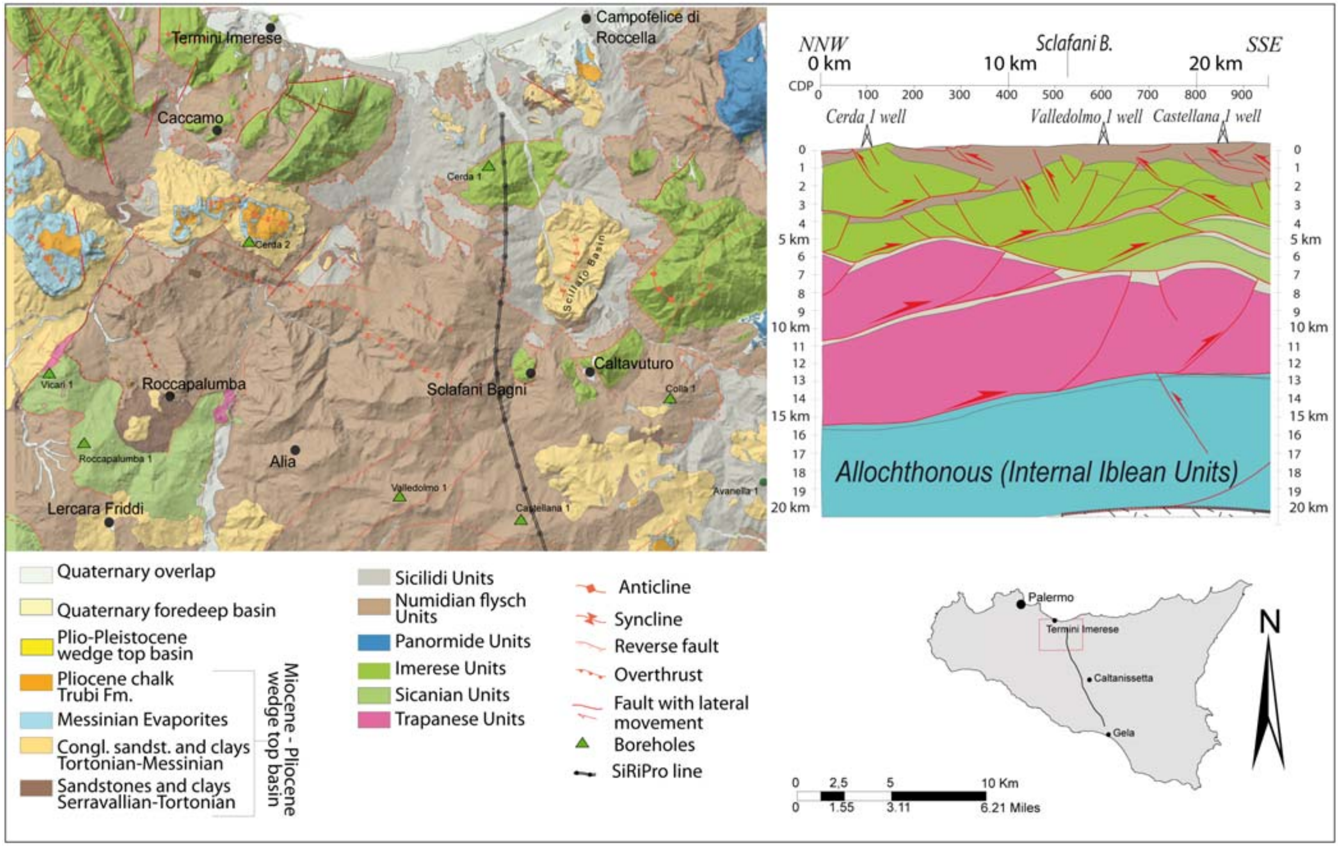

Fig. 51 - Geological map (left) of the visited area. Depicting the trace of the northern transect (right) of the SI.RI.PRO. geological cross section.

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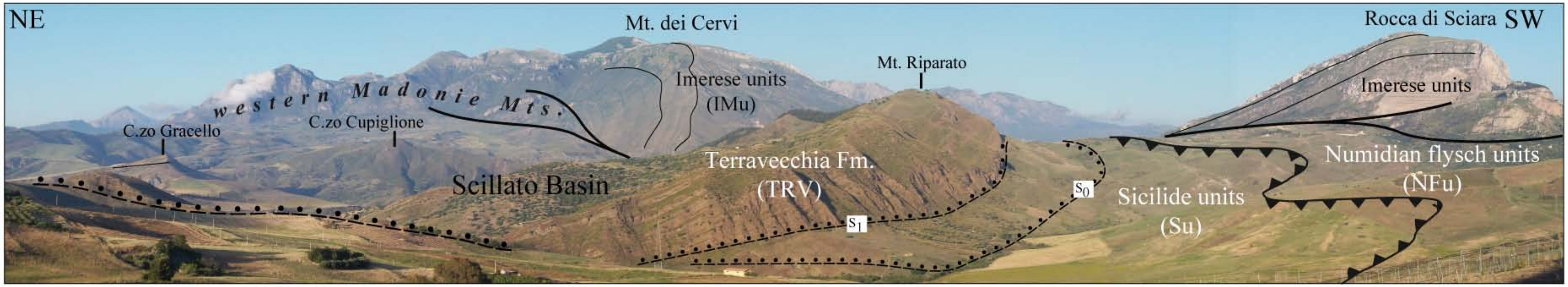

Fig. 52 - Panoramic view (from the western) of the Scillato basin, showing the stratigraphic and tectonic setting of the sector crossed.

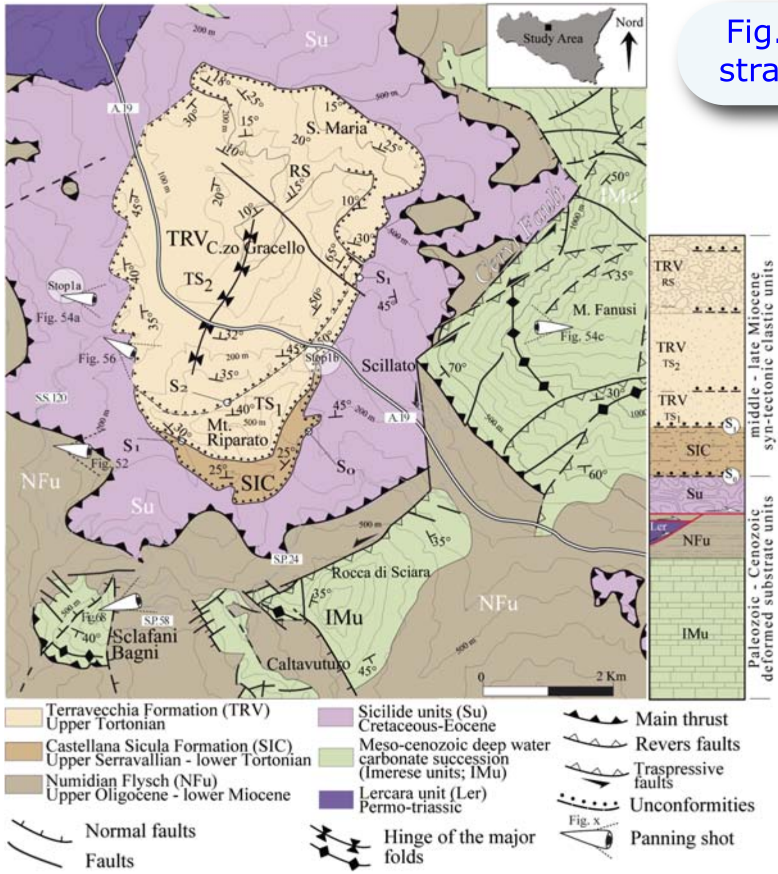

Fig. 53 - Simplified geological map and stratigraphic column showing the main stratigraphic and structural setting of the Scillato basin area.

STOP 1 - Stratigraphy, sedimentology and structural setting of the Late Miocene Scillato basin

Carlo Gugliotta, Maurizio Gasparo Morticelli

Stop 1a – The Late Miocene Scillato basin

Main purposes

To illustrate the stratigraphic and depositional characterstics of the Terravecchia formation and the relationships between sedimentation and tectonics in the Late Miocene Scillato basin.

Itinerary

Along the SS120 from Cerda to Caltavuturo (Stop 1a; Figs 50 and 53) a well exposed panoramic view of both the Scillato basin and the western border of the Madonie Mountains can be observed (Fig. 54).

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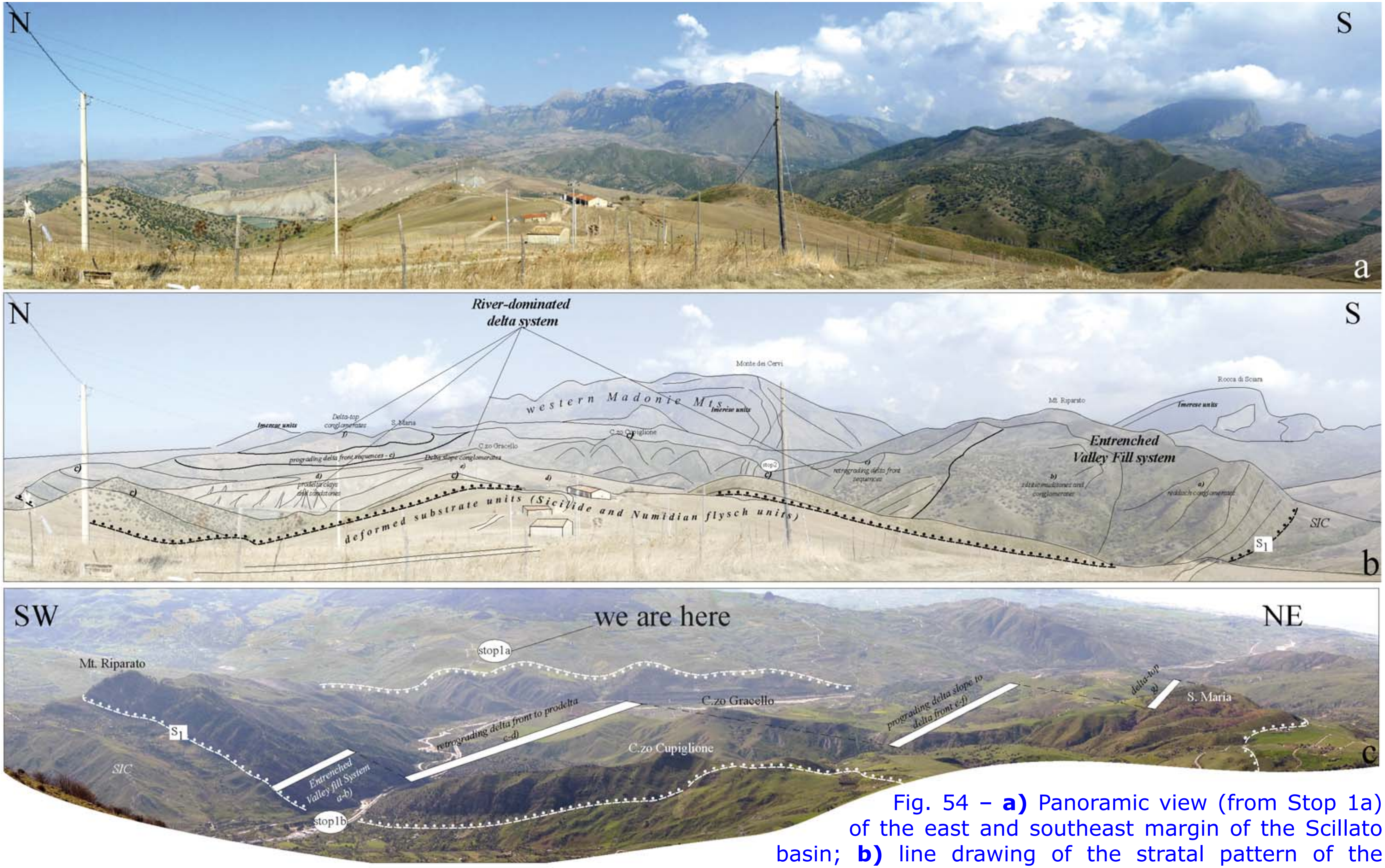

Fig. 54 – **a)** Panoramic view (from Stop 1a) of the east and southeast margin of the Scillato basin; **b)** line drawing of the stratal pattern of the Terravecchia fm and its relationships with the deformed substrate units; **c)** panoramic view (from the East) of the Scillato basin. The several transects (white bars), are used to reconstruct the composite stratigraphic section of Fig. 55. The points of observation of the a and c panoramic view are located in Fig. 53.

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Geological setting

From a standing point (Figs 54a and 56), looking east and southeastward, the landscape shows the geological setting of a terrigenous deposit section forming the Serravallian-Tortonian so-called Scillato basin (SB).

The SB is interpreted (Catalano & D’Argenio, 1990; Abate et al., 1999; Gugliotta, 2010) as the remnant of a syn-tectonic basin developing above the mobile thrust belt (Fig. 51). As can be observed in the geological map (Fig. 53), the upper Serravallian–upper Tortonian clastics unconformably cover the deformed substrate units along some angular unconformities (S0 and S1, Figs 52 and 53). The Terravecchia fm deposits (TRV) are arranged in the area forming a fining to coarsening upward stratigraphic succession (Fig. 55). A well preserved and almost complete section of the formation is exposed along the Imera River gorge (Stop 1b). Detailed sedimentological analyses (Abate et al., 1999; Gugliotta, 2010; Gugliotta & Agate, 2010), performed along the Scillato basin section, allowed us to highlight the stratigraphic and facies architecture, later described. Analyses of the microfossil assemblages, both planktonic foraminifers and calcareous nannofossils, reveal that their relative age is no younger than the latest Tortonian.

Depositional arrangement of the Terravecchia formation

Six main facies associations, showing a lateral and vertical relationship, recognized in the Terravecchia fm, suggest the

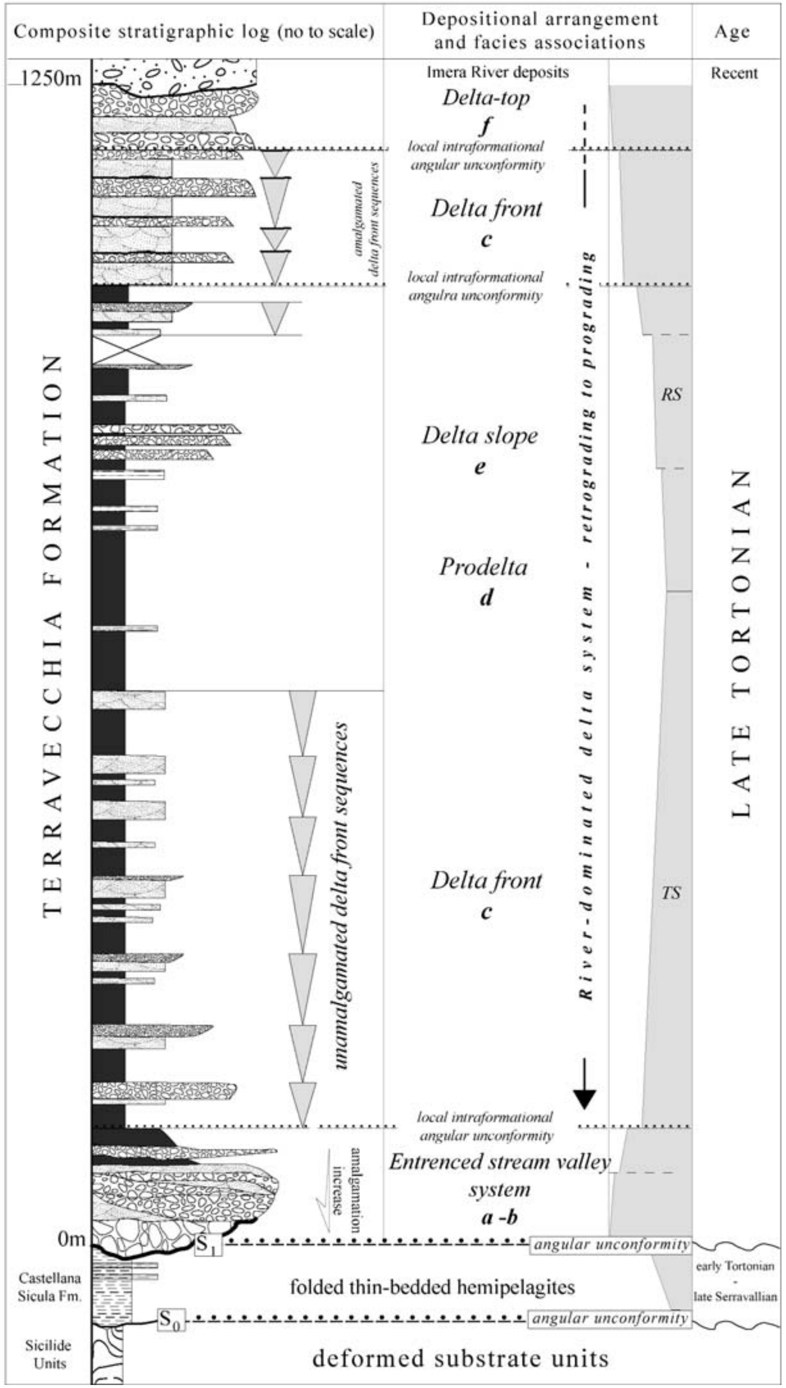

Fig. 55 - Composite stratigraphic log of the Late Miocene Scillato basin succession. The main lithofacies recognized are reported. See text for acronyms. (Data from Gugliotta & Gasparo Morticelli, 2012).

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occurrence of two main successive depositional systems: the entrenched valley fill system (EVF; right portion of Figs 54a, b and 55) and the river-dominated delta system (RDS; central portion of Fig. 54a, b) developed during an early “transgressive, TS” and a late “regressive, RS” sedimentary stage (Figs 54 and 55).
The entrenched valley fill system is a reddish-coloured sedimentary wedge that outcrops along the southern edge of the Scillato basin (Mt Riparato – Imera River gorge in Figs 54 and 55).
It consists of:
- massive or crudely bedded braidplain conglomerates and cross-bedded sandstones (a in Fig. 55)
- floodplain siltitic mudstones, siltstones and clays interbedded with lens-shaped bodies of conglomerates and sandstones (b in Fig. 55);
Upwards and northwards, the river-dominated delta system characterized by:
- retrograding portion consisting of “backstepping” delta front sequences (c in Fig. 55);
- blue-to-greyish brackish prodelta clayey-siltites interbedded with sheet-like sandstones (d in Fig. 55);
- conglomerates and sandstones of delta slope (e in Fig. 55);
- prograding delta front sequences (eastern and the north-eastern edge of the basin, f in Fig. 54 and c in Fig. 55) and by gravelly delta-top conglomerates and sandstone (S. Maria area, f in Fig. 55 and Fig. 54b).
- Both the prograding delta front sequences and the delta-top deposits are bounded at their base by intraformational unconformities that also cut the deformed substrate units (Sicilide units).

Syn-tectonic stratal pattern
The lower portion of the Terravecchia fm, outcropping at Cozzo Cupiglione - Mt Riparato (Fig. 56), is separated from its upper portion (exposed at Cozzo Gracello Fig. 56b) by an about 40° unconformity, accounting for a growth stacking pattern coherent with the development of a progressive syntectonic unconformity (Anadon et al., 1986). This structure, together with other evidence of syn-depositional tectonics (see Gugliotta & Gasparo Morticelli, this guidebook, pp. 89-101) is in favour of a strong tectonic control during the deposition of the Terravecchia fm (late Tortonian) in the Scillato basin. The growth geometry suggests the tilting of the basin margin (Anadon et al., 1986; Hardy and Poblet, 1995; Ford et al., 1997), reasonably in response to the progressive rising of the deformed substrate (pertaining the Imerese units), as pointed out by the Cervi anticline. This structure is uplifted along a high-angle, SE- and S-dipping transpressional Cervi fault (Fig. 53; central portion of Fig. 56) that faulted the older SW-vergent ramp anticline (Cervi anticline). A detailed description of these structures is discussed in Gugliotta & Gasparo Morticelli, this guidebook, pp. 89-101 and in Stop 3, First day.

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Hydrocarbon exploration

The Terravecchia fm represent a productive hydrocarbon reservoir as suggested by the Lippone gas field located in Western Sicily that is known to produces about 360 million Sm^3 of gas (Catalano et al., 2002).

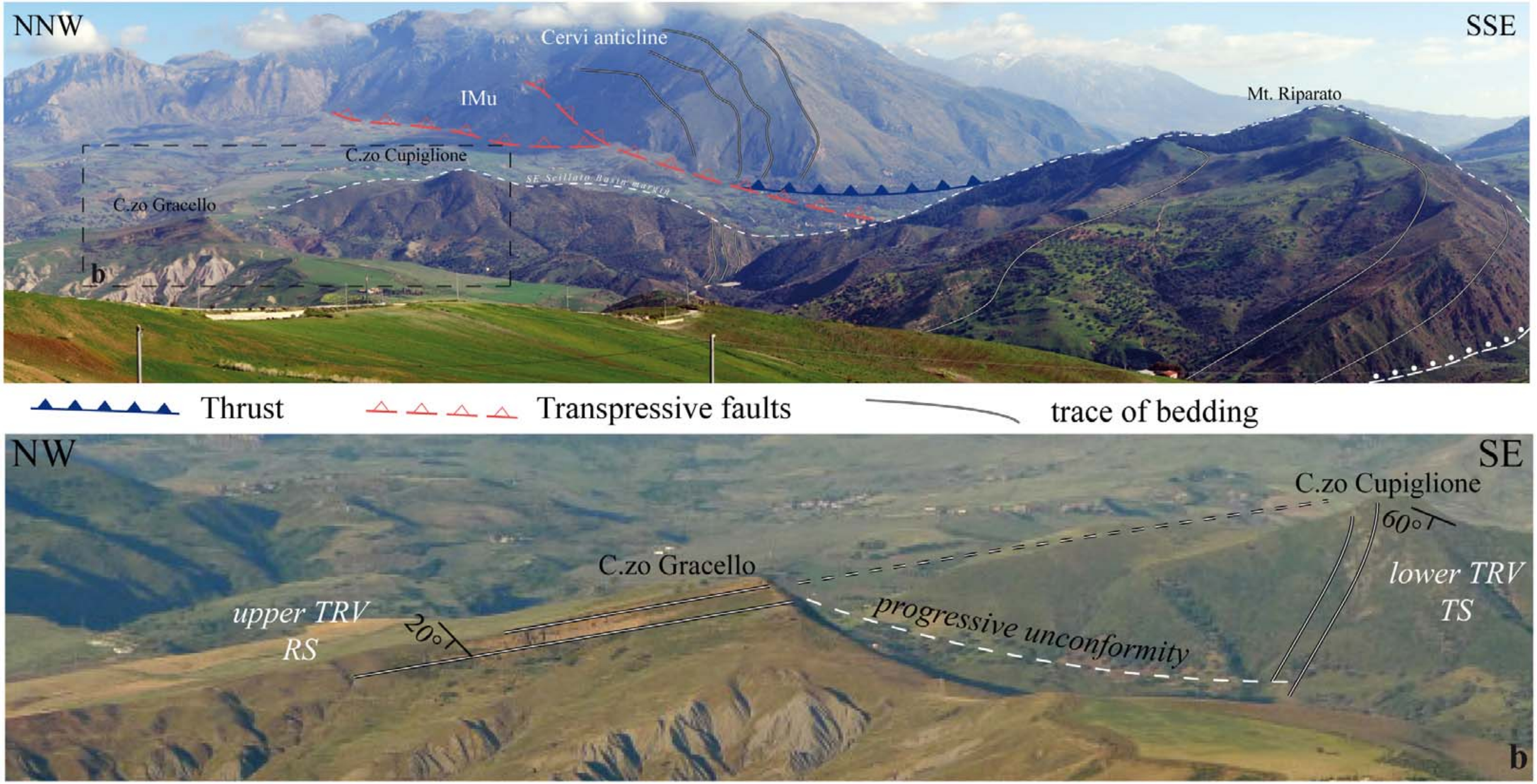

Fig. 56 - Panoramic views (from Stop 1a) of the Scillato basin showing the progressive unconformity imaged by the Terravecchia formation strata between Cozzo Gracello and Cozzo Cupiglione; close up in **(b)**. The dashed white lines represent the trace of the bedding.

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Stop 1b – Sedimentology and facies arrangement of the entrenched valley fill system of the Terravecchia formation

Main purpose

To show the sedimentary layers and facies of the lower portion of the entrenched valley fill system. A stratigraphic section will be shown and described in detail while walking along the Imera River gorge.

Itinerary

We will travel across the SS120 road and then the SP24 road toward the Scillato village and the petrol station adjacent to the Palermo-Catania highway (A19). Here, after a short walk, we will reach the Imera River gorge (Figs 50, 53 and 57).

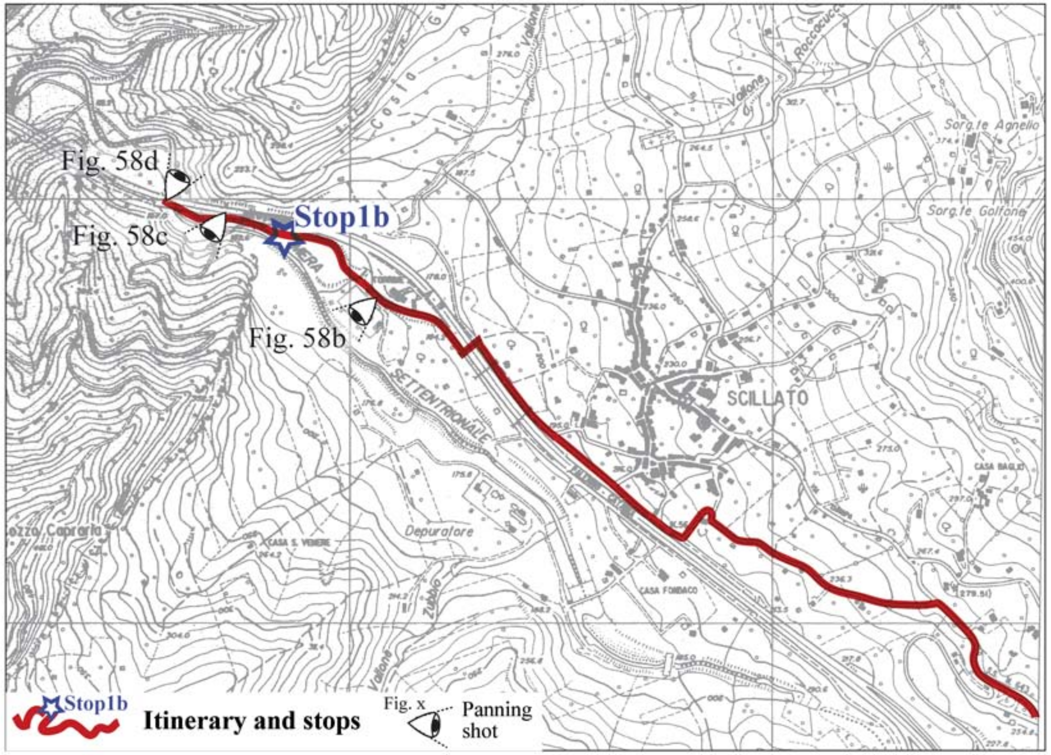

Fig. 57 – Road map showing the location of Stop 1b.

The Entrenched Valley fill system (EVF): general features

In the Imera River gorge, the EVF, displays a NW-dipping, reddish to yellowish-coloured rock body consisting of conglomerates and interbedded sandstones followed by silty mudstones and clays with sporadic conglomeratic and sandy bodies (Fig. 58). The inferred thickness of the EVF varies strongly, moving laterally away from the Mount Riparato area, rapidly decreasing and disappearing toward the north and north-east. Several lithofacies associations are differentiated here applying Miall's (1977; 1978; 1985) facies classification (Tab. 3).

Lithofacies description and interpretation

The entrenched valley fill system consists of two main superimposed lithofacies associations: confined gravelly braidplain (A) and floodplain (B) stacked one ontop of the other, forming an overall fining and thinning upward sequence, up to 250m thick (Fig. 58). Each lithofacies association is characterized by the assemblage of several lithofacies: A1) Massive to crudely-bedded reddish conglomerates; A2) Stratified, clast-supported conglomerates;

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A3) Coarse to medium grained sandstones; A4) Clayey siltstones; B1) Silty mudstones and clays; B2) conglomerate and sandstone- forming, lens-shaped bodies, reported in Fig. 58 and in Tab. 3. The same are also described in Gugliotta & Gasparo Morticelli, this guidebook, pp. 89-101.

Brief account on hydrocarbon potential

Valley-fill deposits form a significant class of hydrocarbon reservoirs in many basins of the world (Dolson et al., 1991), but few, well-documented examples of heterogeneity within ancient valley fill successions are available (e.g. Kirschbaum & Schenk, 2010). The entrenched valley fill system described here exhibits heterogeneities at different scales that could affect the fluid flow in similar subsurface reservoirs. The largest scale of heterogeneity is represented by the present day setting of the EVF enclosed between the sandy to clayey deposits of the overlying, river-dominated, delta system and the underlying clays and siltstones pertaining to the deformed substrate units. At a smaller scale, the heterogeneity is also related to the amalgamated conglomerate beds (lithofacies association A) sealed by floodplain mudrocks (lithofacies association B) and potentially forming individual reservoir compartment. Contacts between the individual channel bodies are erosional and might create permeability differences. In the overlying lithofacies association B, conglomerate and sandstone channelized bodies interbedded with mudrocks could create an additional factor of heterogeneity.

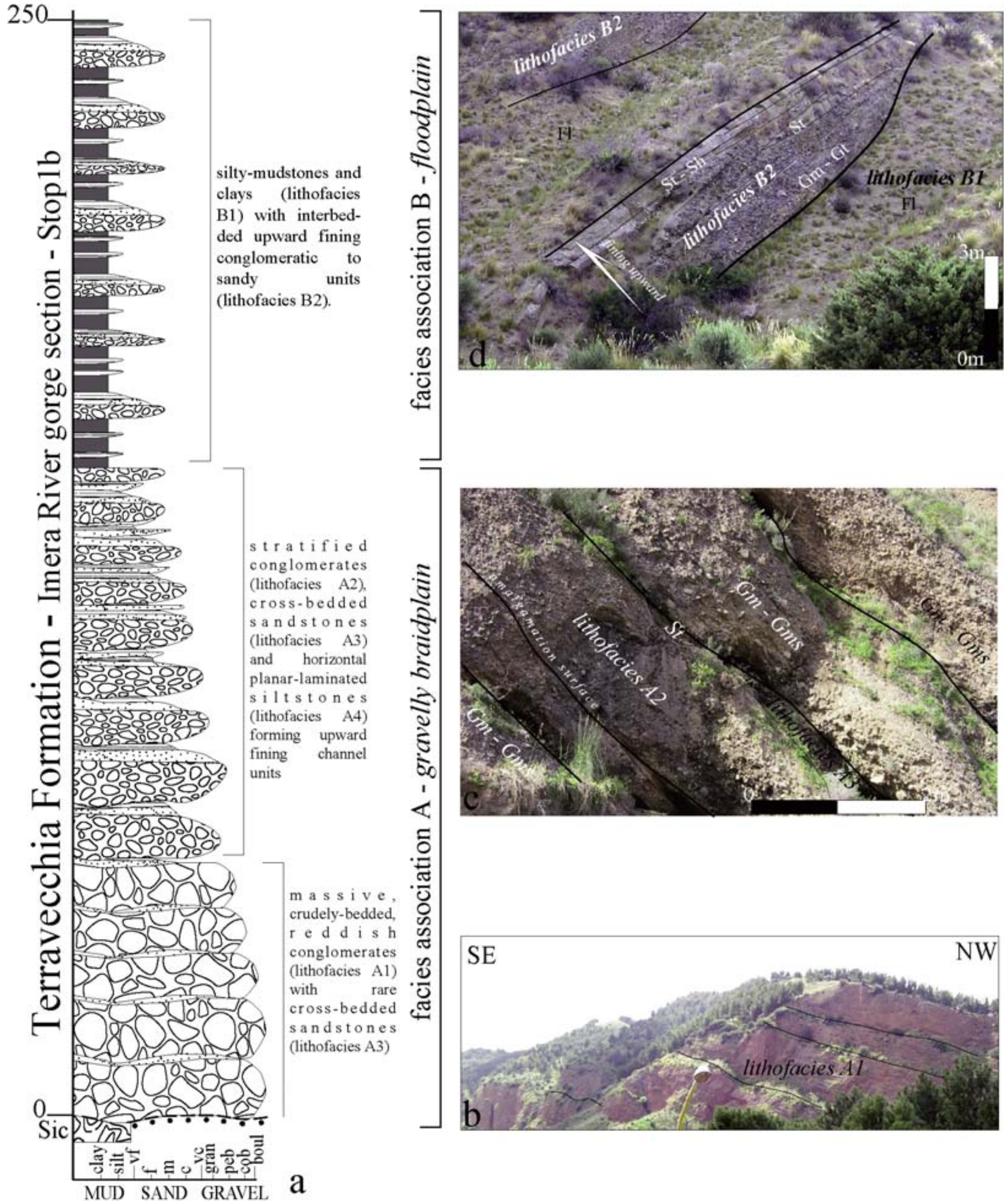

Fig. 58 – Simplified stratigraphic log of the entrenched valley fill system as described along the Imera River Gorge.

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Tab. 3 - Table resuming the main lithofacies recognized in the entrenched valley fill system.

Lithofacies	Description	Sedimentary structures	Depositional Process and Interpretation
A1- Massive, clast-supported conglomerates	Coarse-grained, clast-supported reddish conglomerates with fragments from pebble to cobble in size with common "out of size" clasts. Sorting is poor, fragments are made by crystalline rocks , quartzarenites and carbonates.	Clast embrication, pebble cluster, large scours, large-scale cross-beds, inverse to normal gradation.	High energy tractive currents, stream-, surge or flash-flows, bed-load charge of braid channels with migrating gravelly braid bars
A2- Poorly stratified, clast-supported conglomerates	Poorly stratified clast-supported conglomerates with fragments from pebble to boulder in size clasts.	Clast embrication, pebble cluster, erosional scours, inverse to normal gradation.	High energy tractive currents, stream-, surge or flash-flows, bed-load charge of braid channels with migrating gravelly braid bars
A3- Very coarse- to medium-grained sandstones	Reddish to brown-yellow sandstones, poorly sorted, often pebbly. This facies overlies lithofacies A2 forming upward fining sequences	Large- to medium-scale cross bedding mostly throug-cross type. Horizontal planar lamination.	High energy tractive currents; large to medium scale sandy bedforms (dunes or megaripples).
A4- Fine-grained silty-sandstones and clayey siltstones	Reddish to brown-yellow clayey siltstones; This facies locally overlies lithofacies A3 ending the upward fining sequences.	Massive to laminated	Low energy tractive currents, waining flood deposit or abandoned channel fill
B1- Silty mudstones and clays	Dark grey, pinkish to yellowish silty	Massive or laminated, unbioturbated	Floodplain
B2- conglomeratic to sandy, upward fining units	Yellowish conglomerates and sandstones forming lens-shaped bodies	Clast embrication, cross bedding, normal gradation	Deposition into ephemeral channels crossing the floodplain

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STOP 2 - Mesozoic and Cenozoic carbonates of the Imerese basin along the Rocca di Sclafani Bagni outcrop

Luca Basilone

Main purpose

To describe the Meso-Cenozoic deep-water carbonates of the Imerese domain in their stratigraphic setting and sedimentogic features, along the Sclafani Bagni impressive field section.

Itinerary

Road to Sclafani Bagni (Fig. 59). Stop in a panoramic view point of the Mesozoic Imerese succession (Stop 2a). Stop on the southern side of the Rocca di Sclafani Bagni to see the rock succession in detail (Stop 2b); walking along the main street of the town, we will reach “il Castello” and then stop in the “Belvedere” square (Stop 2c) to observe the lowermost portion of the outcropping succession.

Introduction

The Upper Triassic-Lower Oligocene carbonate succession, found within the Sclafani Bagni outcrop, is well exposed along an S-dipping monoclinal. The rock body outcrop is the southern flank of an S-vergent ramp anticline. The Imerese Basin is characterized by a carbonate and siliceous-calcareous succession (Fig. 60), 1200-1400 metres thick, Late Triassic to Lower Oligocene in age. The

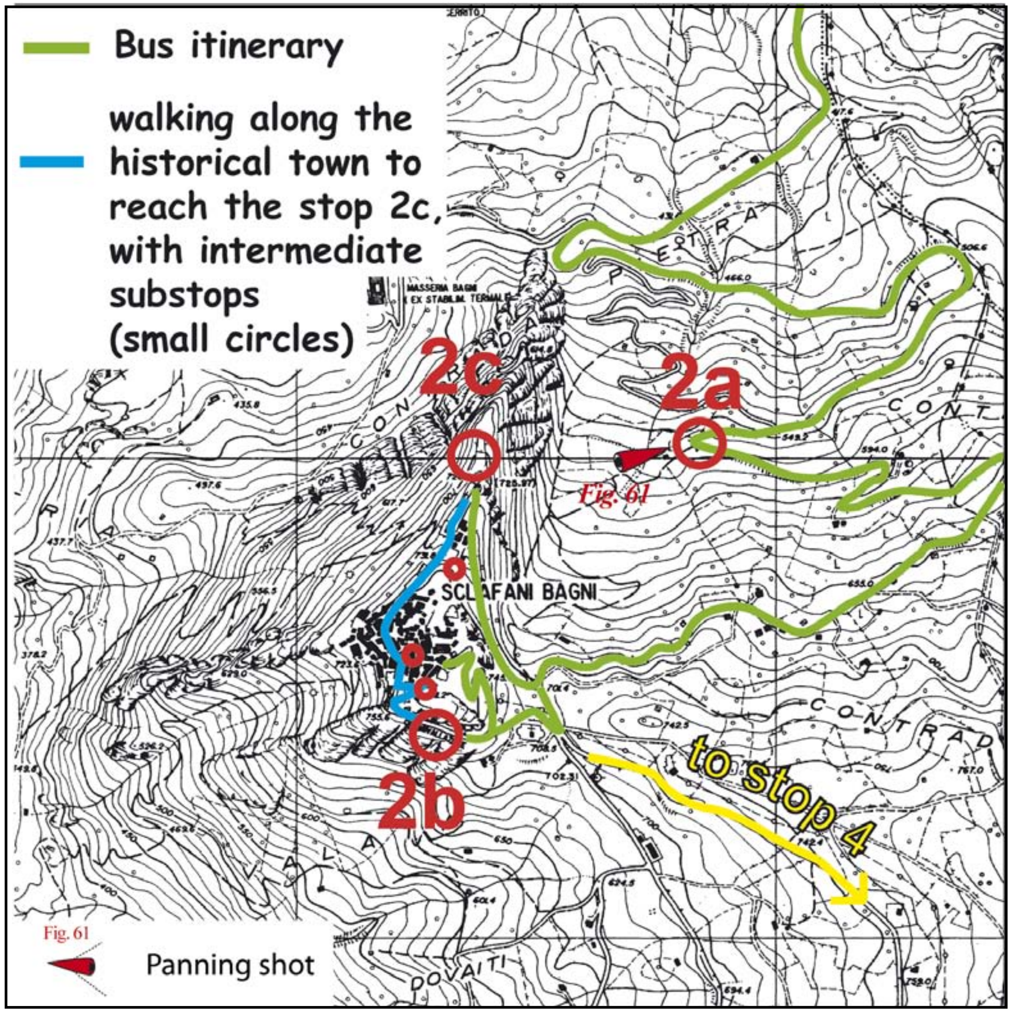

Fig. 59 - Index map of the Stops 2a, 2b, 2c.

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Imerese pelagic succession (see description in Basilone, this guidebook, pp. 102-110) is dominated by spectacular gravity-flow deposits that include: **a)** breccias, megabreccias and megaconglomerates, **b)** bioclastic turbidites, **c)** laminated fine-grained limestones (diluted turbidites).
The strata displays a carbonate platform margin, characterized by resedimented facies with progradational stacking patterns.
The well preserved outcrop of the Sclafani Bagni section provides a complete overview of the Mesozoic succession of the Imerese units.

Stop 2a. Panoramic view of the Sclafani Bagni natural section (Fig. 61): identification of the main lithotypes and submarine erosional surfaces of the Imerese succession

Starting from the bottom, the succession consists of:
- Grey, thin-bedded, cherty limestones and dolostones (see b in Fig. 60 and Fig. 61), 100 m-thick, including laminated mudstone-wackestones and marls (Scillato fm). The fossil content (radiolarians, sponge spiculae, conodonts, ostracods and rare bivalves, as *Halobia styriaca* Mojsisovics, *Halobia norica* Mojsisovics), suggests a Late Carnian-Rhaetian age.

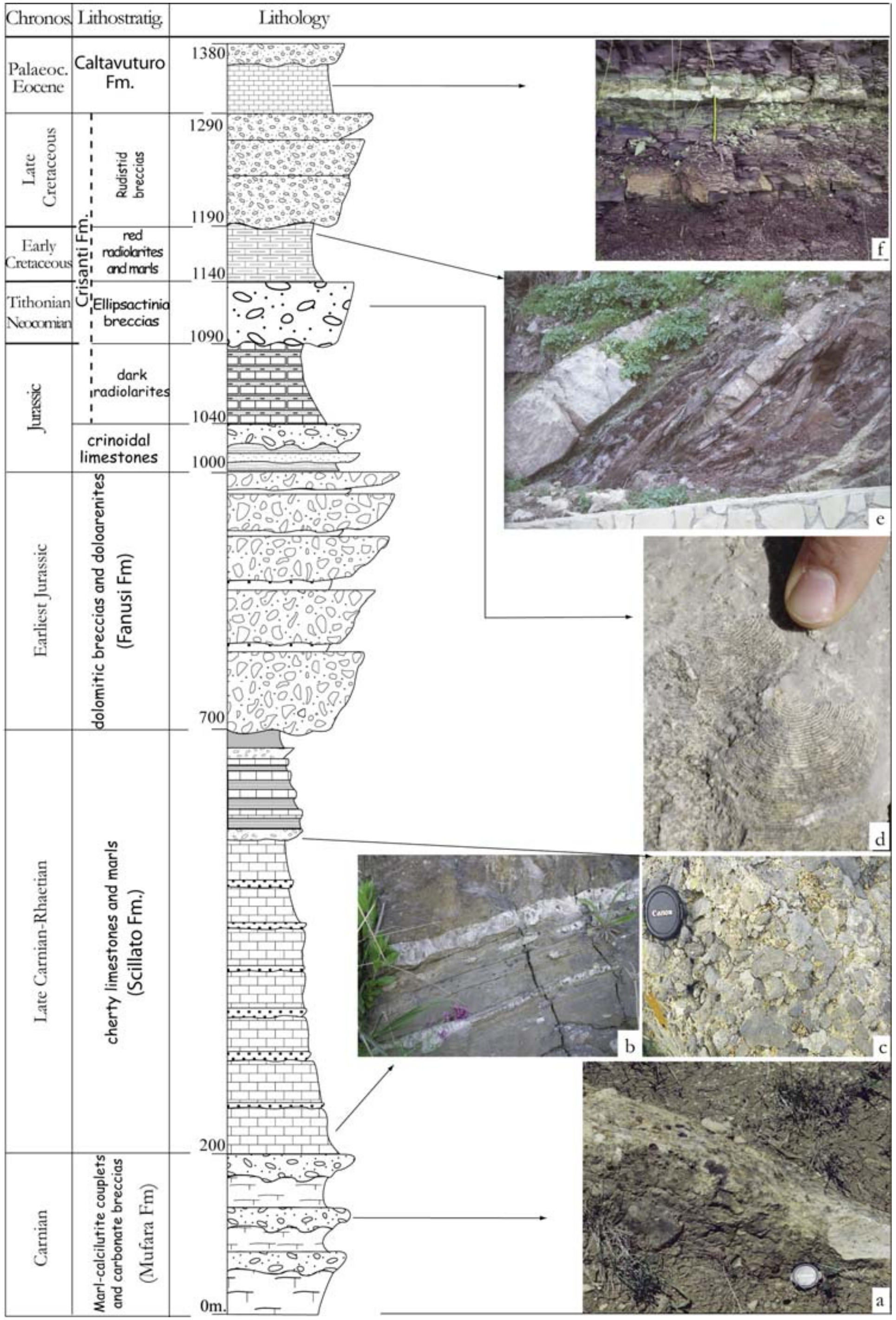

Fig. 60 - Imerese type section.

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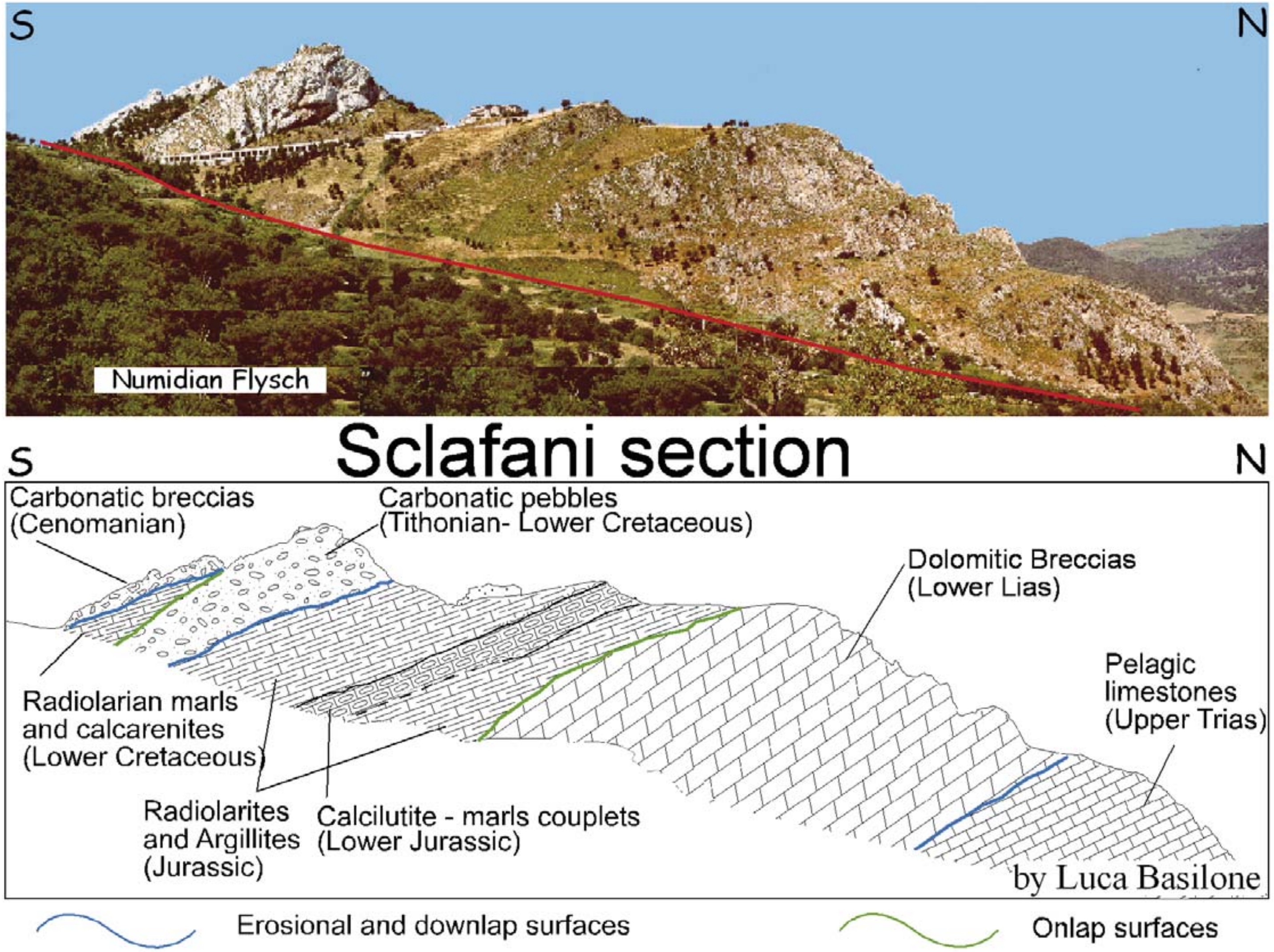

Fig. 61 - Panoramic view of the Sclafani Bagni Mesozoic natural section.

- White massive dolomites, coarse-grained decametric dolomite breccia beds, thin graded and laminated doloarenites (Fanusi fm), 150m thick, with erosion and downlap, unconformably follow (Fig. 61). Pervasive dolomitization has obliterated fossils and organic traces and a Lower Liassic time is commonly indicated on the basis of its stratigraphic position, encompassed between Rhaetian cherty limestones and the Middle-Upper Liassic crinoidal limestones. Several coarsening and upwards thickening facies units, showing intraformational erosional surfaces, channel filling geometries and progradational geometries, are cyclically repeated.

- Bioclastic and oolitic packstone-to-grainstone, with crinoids and benthic foraminifers, alternating with red and green marls (crinoidal limestones), unconformably follow, with onlap. The upper part of the unit is characterized by thin bedded white-grayish cherty limestones. Brachiopods and nannofossils, dates these beds to the Pliensbachian-Toarcian time interval.

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- Cretaceous-Jurassic mudstone-wackestone with radiolarians and sponge spiculae, radiolarites and bedded cherts with episodic intercalations of calcareous breccias with carbonate platform-derived elements (Crisanti fm) unconformably follow (Fig. 61). The formation can be subdivided into four members, well exposed along the Sclafani Bagni section. These lithological intervals, bounded among themselves by unconformity and erosional surfaces (Basilone, 2009a), consist of:

- Thin-bedded blackish radiolarites (see Fig. 67), bedded cherts, clays and siliceous mudstone with parallel lamination and bioturbations (radiolaritic mb). A Middle-Late Jurassic age is generally indicated.
- Calcareous breccias and conglomerates (rudstone-floatstone), bioclastic packstone and oolitic grainstone, (*Ellipsactinia* breccia mb), 50-60 m-thick, with an erosional lower boundary, follow. The breccia elements consist of reef margin-derived fragments with *Ellipsactinia* sp. (d in Fig. 60), corals, gastropods (*Nerinea* sp.), algae, calpionellids and microproblematics. A Tithonian-Neocomian age is indicated.
- Red radiolarites, bedded cherts, grey and green mudstone and red marl alternations (Fig. 65, spongolithic mb), 50m thick, rich in sponge spiculae, radiolarians, planktonic foraminifers of Lower Cretaceous, follow upwards with an onlap boundary. Packstone-grainstone with benthic foraminifers and rudistid fragments, are interbedded in the upper portion of the succession (Fig. 66).
- Rudstone and grainstone-packstone, 80-100m thick, with shallow- and deep-water lithoclasts (Fig. 63), rudistid fragments and benthic foraminifers (*Orbitolina* sp.) of Late Cretaceous age (rudistid breccias mb). The resedimented graded and laminated beds, with lower erosional surfaces, are organized in several coarsening-upward facies units, showing progradational geometries. The lower boundary is an erosional and downlap surface with the Lower Cretaceous radiolarites and radiolarian marls.
- Red, white and greenish wackestone-mudstone and marls (Caltavuturo fm, f in Fig. 60) 20 to 200m thick; slump structures, parallel lamination and bioclastic grainstone-packstone intercalations with large benthic foraminifers (*Nummulites partschi*, *Nummulites prelucasi*), colonial coral fragments, bryozoans, are common. The fossil content (planktonic foraminifers and calcareous nannofossils) points to a Paleocene-Lower Oligocene time interval. The lower boundary is a transgressive surface above the Crisanti fm (Fig. 64), with onlap geometry and with a hardground crust with phosphatic nodules.
The Mesozoic carbonate succession is unconformably covered by the Oligocene-Miocene clays and turbiditic quartz-sandstones of the Numidian flysch (see Stop 4 for further details).

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Stop 2b. Paleogene-Cretaceous succession (Fig. 62)

Upper Cretaceous carbonates

Upper Cretaceous (mostly Cenomanian) carbonate breccias and turbiditic calcarenites (rudistid breccias mb of the Crisanti fm) are easily observable along the above mentioned panoramic road (Fig. 59). The elements of the clastic rock consist, mainly, of shallow-water and reef-derived fragments, with rudistid shells, colonial corals, gastropods and benthic foraminifers. Also, in the rock, several fragments of red, fine-grained carbonates and radiolarites, cherty lithoclasts and round-shaped elements of claystones greenish in colour, occur (Fig. 63). These elements derived from the dismantling and erosion of the deep-water Lower Cretaceous deposits below (spongolithic mb of the Crisanti fm). The lower boundary of the Upper Cretaceous resedimented carbonate body is a downlap surface characterized by widespread erosion.

The intraclastic calcite cements put in evidence the fact that the rudist shells are either preserved as dull brown luminescent calcite fragments that have undergone minor diagenetic alteration, or are characterized by the existence of a thin, dull brown micritized fringe, corresponding to the micrite coating that developed around the fragment, prior to the dissolution of the rudist shell. These molds are subsequently cemented by dull brown acicular cements, which are in fact the recrystallization products of marine cements. The molds are subsequently cemented by equant and blocky calcite.

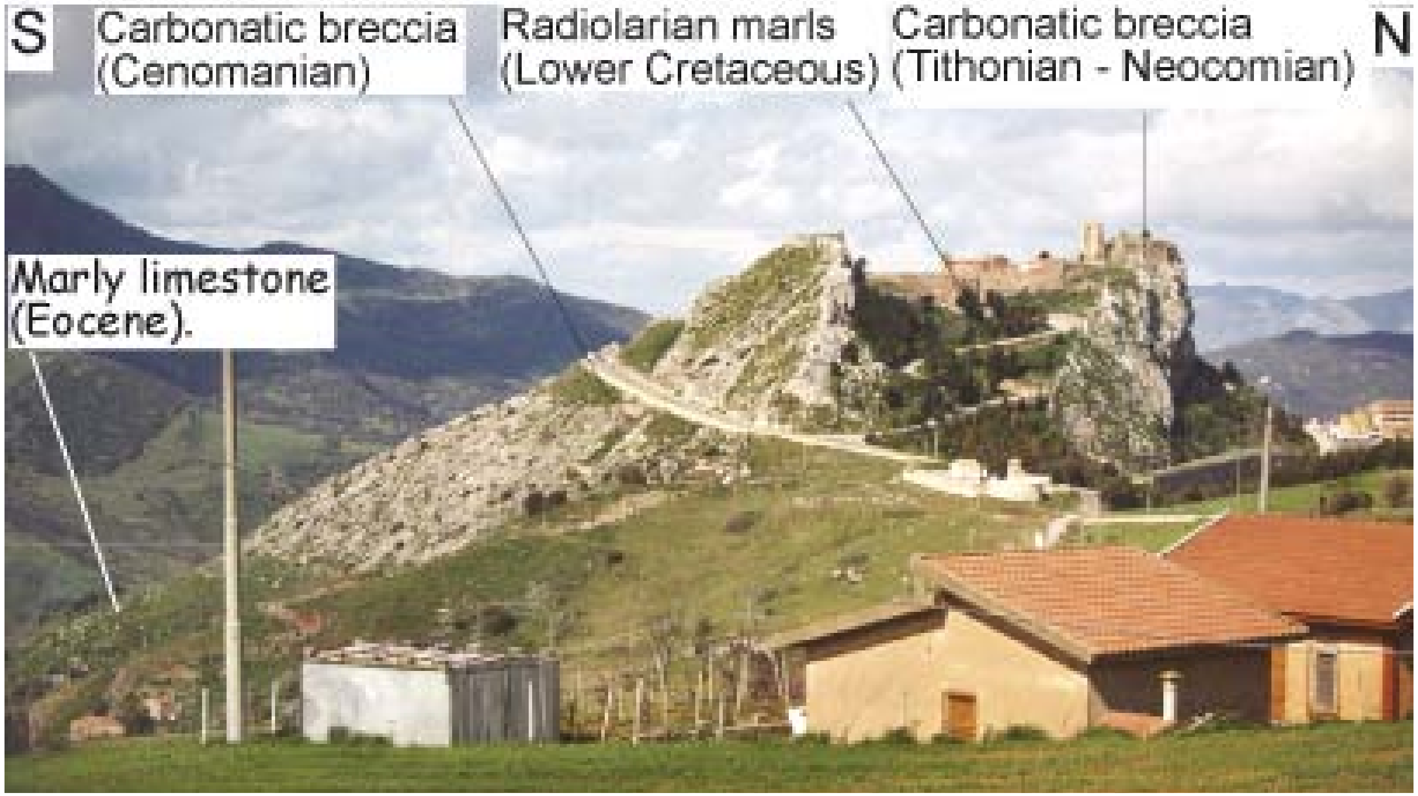

Fig. 62 - Rocca di Sclafani Bagni. The Cretaceous-Eocene section.

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Fig. 63 - Upper Cretaceous rudistid reworked limestone, consisting of reef-derived elements (rudistid fragments) and clasts derived from the underlying Lower Cretaceous radiolarite beds.

Roure & Swennen (2002) have suggested that the two cement generations can be interpreted in terms of a change in redox conditions evolving from an oxic over suboxic to a reduction during calcite cementation. The dull orange luminescent phase is the one which is best developed, whereby one can observe that the bioclasts are floating in the cement, pointing towards an early diagenetic cementation.
There are at least 2 other types of calcite veins, of which at least one post-dates burial stylolitization. The veins are respectively luminescent brown and orange brown. The alteration products of ferroan saddle dolomite crystals occur along the stylolite non-transparent dolomite phases. The blocky calcite crystals filling the rudist molds are also worthy of note as they display nice twinned cleavage planes visible in transmitted light microscopy. These twins testify a tectonic strain postdating cementation (Roure & Swennen, 2002).

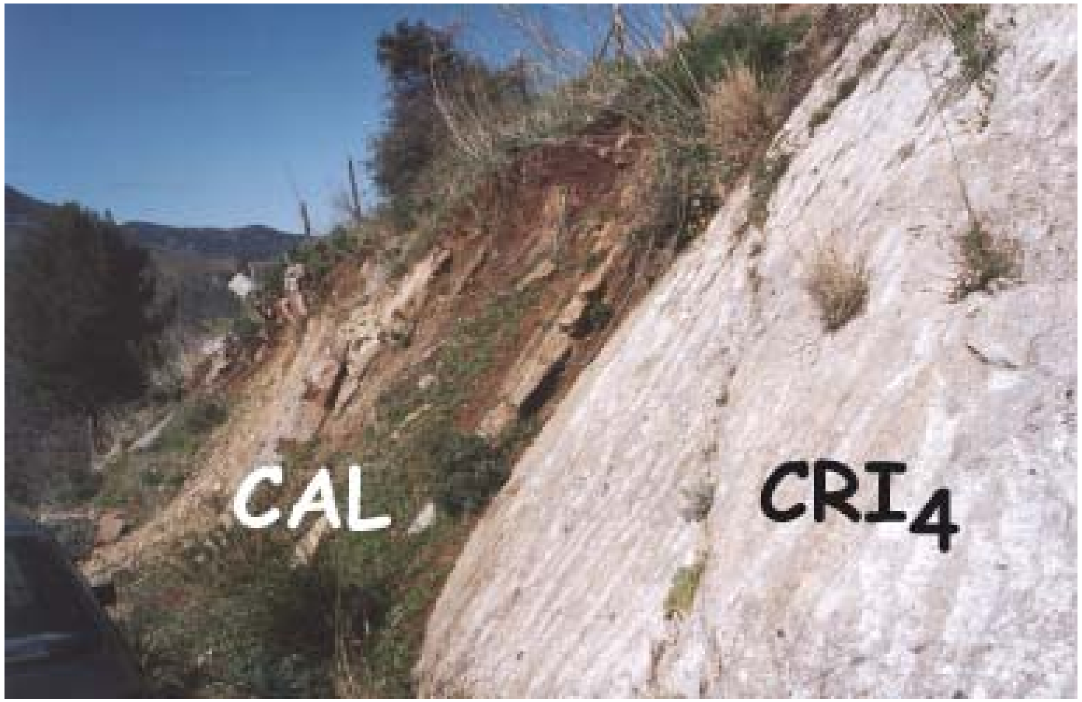

Fig. 64 - Abrupt boundary between Paleocene-Eocene pelagic marly limestone (Caltavuturo fm, CAL) and rudistid reworked limestones (CRI4).

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Lower Cretaceous pelagites

A 40 m thick layer of red siliceous limestones, radiolarites, marls and clays (Fig. 65, spongolithic mb of the Crisanti fm) crosses the ancient entrance of Sclafani Bagni. It consists of thin bedded wackestone rich in radiolarians, spongid spiculae and planktonic foraminifers, displaying lamination. Cherty nodules, bedded cherts and, mostly in the upper portion, dm-m thick beds of clastic carbonates with shallow-water derived fragments interlayered in the pelagic succession, occur; the reworked deposits display lenticular geometry and pinching-out terminations (Fig. 66).

Fig. 65 - Lower Cretaceous thin-bedded red radiolarites, bedded cherts and thin intercalations of reddish marls.

Fig. 66 - Grain flow deposits rich in rudistid fragments and benthic foraminifers with pinch-out geometries, interbedded in the Lower Cretaceous thin-bedded red radiolarites.

Along the road, it is also possible to observe the lower unconformity boundary of the unit, that consists of an onlap surface with the underlying Tithonian-Neocomian calcareous *Ellipsactinia* breccias (visited at a later stage).

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Stop 2c: Jurassic deposits

Crossing the town center, we will reach the remnants of the XII century town Castle (erected by the Sclafani family), built above the Jurassic rocks.

Tithonian-Neocomian *Ellipsactinia* breccias

The texture features of the calcareous breccias body (*Ellipsactinia* breccias mb of the Crisanti fm) will be discussed. The rocks consist of conglomerates and calcirudites with large and thick reef-derived elements of colonial corals, mollusc shells and sponges (*Ellipsactinia* sp., d in Fig. 60). Locally, within the intrareef micrite elements benthic foraminifers and intrabiolithitic cavities bordered by rim cements, occur.
Leaving the Castle we will meet:

Jurassic radiolarian cherts and Liassic calcilutites, crinodal calcarenites and marls

The thin-bedded dark radiolarites and bedded cherts (Fig. 67) consist of a monotonous pelagic succession, where planar laminations and bioturbations are frequently present.
Roure & Swennen (2002) reveal that the sponge spiculae are dominantly cemented by a dull and locally luminescent bright yellow calcite phase while the micritic matrix is luminescent orange brown. The cherts are often rich in dolomite, and are dominantly non luminescent but, locally, some brown luminescent chalcedony phases correspond to cemented bioclasts and there the dolomite is luminescent bright yellow. Relict textures of radiolarians often occur within the chert.

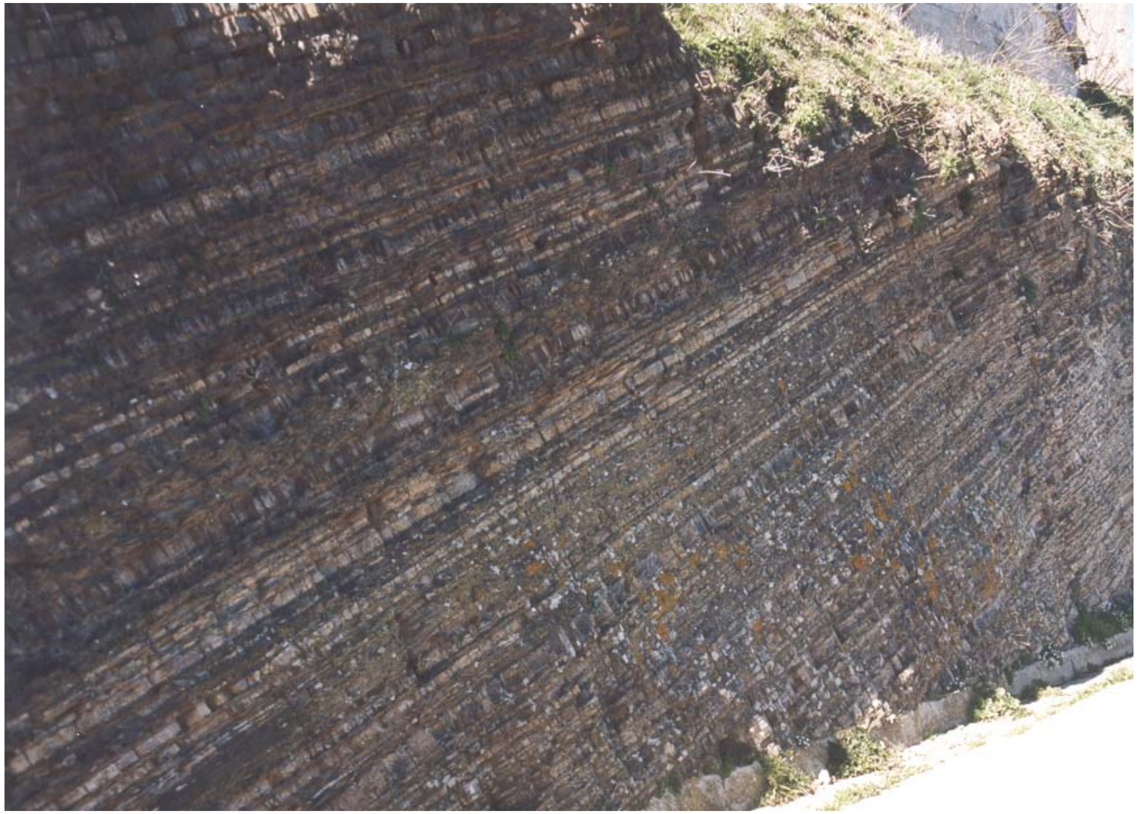

Fig. 67 – Jurassic dark radiolarites and bedded cherts.

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Immediately below the dark radiolarites a rather sharp transition occurs with white coloured, thin-bedded pelagic limestone with darkish chert nodules. The bright luminescent nature of the calcite cements, in these otherwise, silica-rich lithologies, most likely reflect calcite redistribution, possibly of early diagenetic origin. Below the chert interval, the transitional facies consists of bioclastic wackestone and marls rich in crinoidal fragments, sponge spiculae and radiolaria. Some foraminifers also occurs dispersed within this lithology.

Lower Liassic dolomite (sedimentology, diagenesis and dolomitization processes)

Within the Sclafani outcrop, the sequence exposed gives a good overview of the carbonate platform collapse at the end of the Triassic-Lower Jurassic (see also Basilone, this guidebook, pp. 102-110). In the lower part of the outcrop, massive Lower Liassic dolomites dominate. The dolomitization of the rock is largely pervasive but the original texture is often recognizable. Here, the typical feature is that these dolomites are intensively fractured giving rise to a cataclastic fabric. In these fractures, chalcedony and quartz cements have been recognized (Roure & Swennen, 2002), while locally, some coarse, crystalline dolomite developed. However, porosity is low. Chemical analyses reveal that the $\delta^{18}O$ and $\delta^{13}C$ signatures of these dolomites and of the coarse dolomite cement varies, supporting a marine derived origin of these dolomites (Roure & Swennen, 2002). The cataclastic fracture development most likely links with the tectonic deformation in relationship with the collapse of the platform, while the silica cements most likely relate to the involvement of silica-rich fluids, derived from the overlying chert rich strata.

STOP 3 - Geological setting of the Madonie Mts and surrounding regions, panoramic view

Luca Basilone, Raimondo Catalano, Carlo Gugliotta, Maurizio Gasparo Morticelli, Vera Valenti

Main purpose

To observe the relationships between the Miocene silici-clastic succession of the Scillato basin and the adjacent regional structures with the main aim of describing: (1) the major tectonic structures affecting the Imerese units exposed along the Monte dei Cervi, Rocca di Sciara and Sclafani Bagni scarps; (2) the regional structural setting of the deformed substrate units comparing subsurface and field data.

Itinerary

Leaving the Imerese carbonate succession, we will stand on a panoramic site on the Northern Sclafani Bagni hill slope (Figs 50 and 59).

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Structural setting of deformed substrate, major structures and the syn-tectonic deposition in the Scillato basin

In a panoramic view, eastwards (Fig. 68), we can observe that the Late Miocene Scillato basin unconformable succession rests above the Sicilide nappe (Cretaceous to lower Oligocene varicoloured clays).

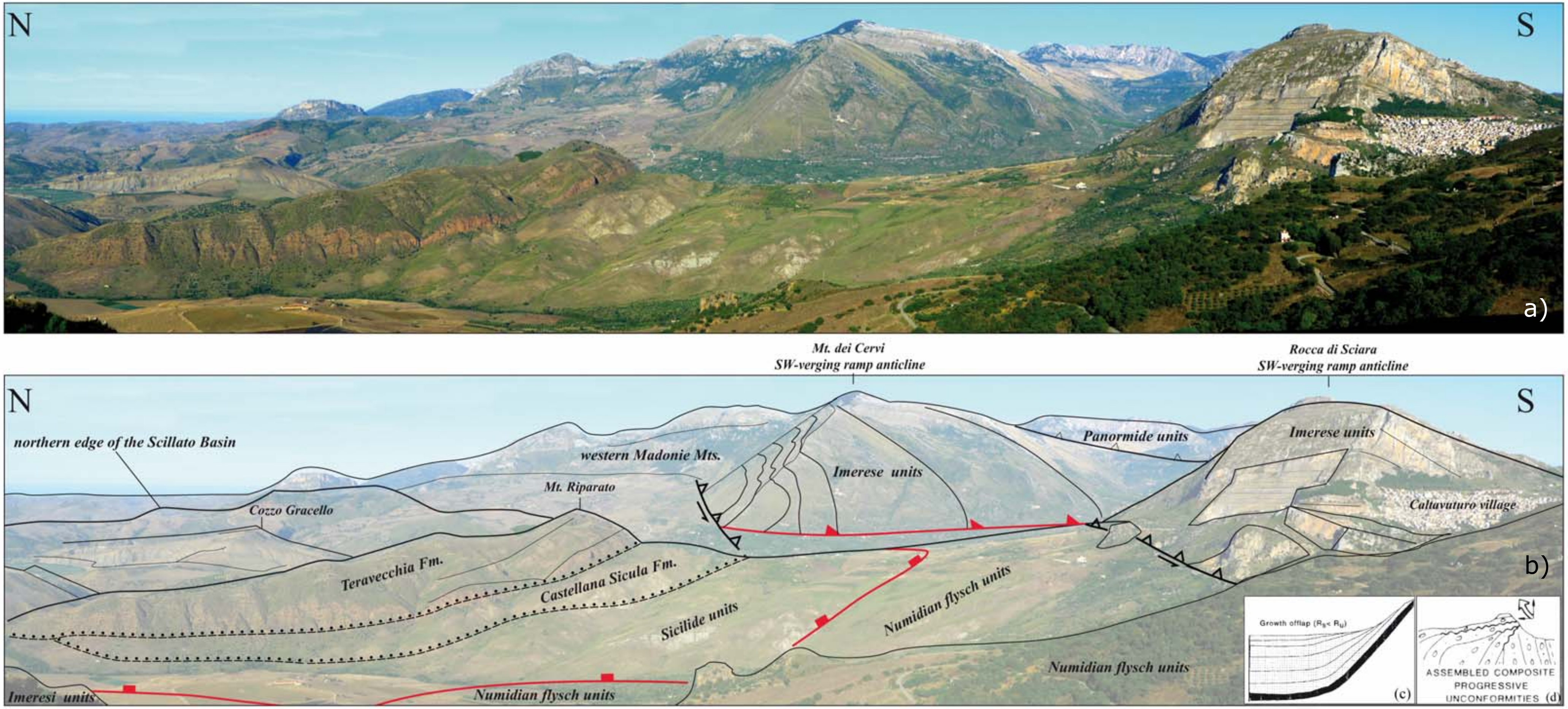

Fig. 68 - Panoramic view **(a)** and line drawing **(b)** of the western Madonie Mts and surrounding regions from “La Piazzetta”. **(c–d)** Conceptual models accounting for a growth offlap geometry (mod. from Hardy and Poblet, 1995 and Ford et al., 1997) and assembled, composite, progressive unconformity (after Anadon et al., 1986). The main stratigraphic and structural features of this wide region are reported. The main tectonic alignments are differentiated in: lower Miocene main thrusts (red lines with small squares), middle Miocene main thrusts (red lines with triangles), late Miocene-Pliocene transpressional faults (black lines).

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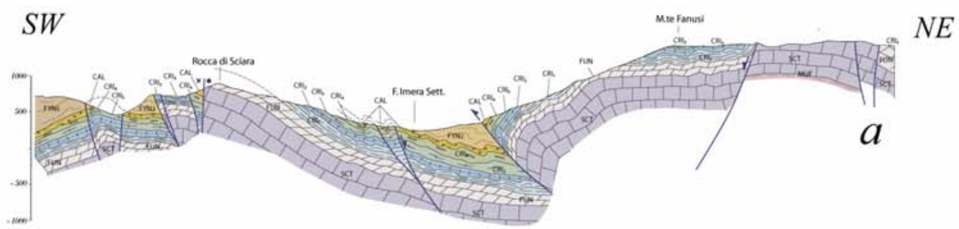
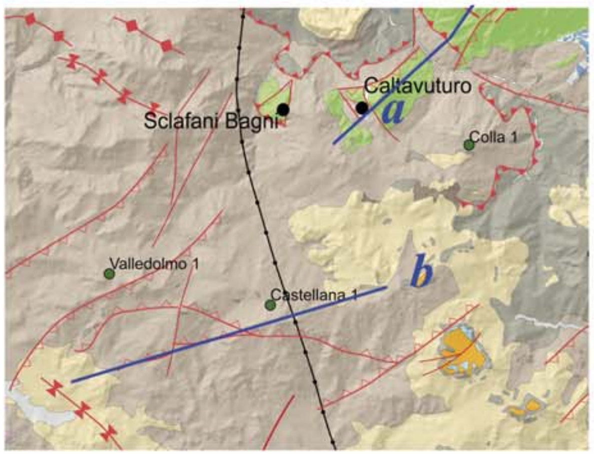
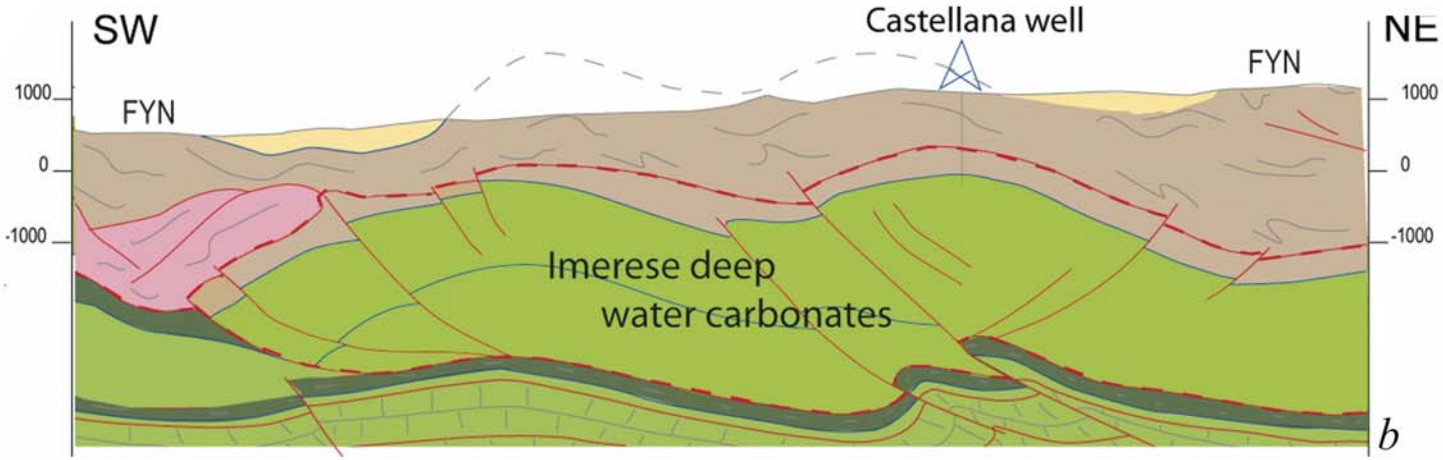
Moving southward, the latter, overthrust the Numidian flysch rock bodies (Upper Oligocene – Lower Miocene) along a roughly SW-ward verging main thrust. This tectonic emplacement occurred after the Langhian (see Catalano, this guidebook, pp. 13-50). The Numidian flysch units farther south, are abruptly juxtaposed to Mesozoic Imerese rock units, outcropping along the Rocca di Sciara and Sclafani Bagni highs. The Imerese units are exposed, characterizing NW-SE-trending major ramp anticlines (Fig. 69, for details see also Gugliotta & Gasparo Morticelli, this guidebook, pp. 89-101), developed in association with main SW-verging thrusts, Middle Miocene in age. These SW-ward verging structures are widespread in this sector of the chain, as imaged in the subsurface of the adjacent Velledolmo region (Fig. 69).







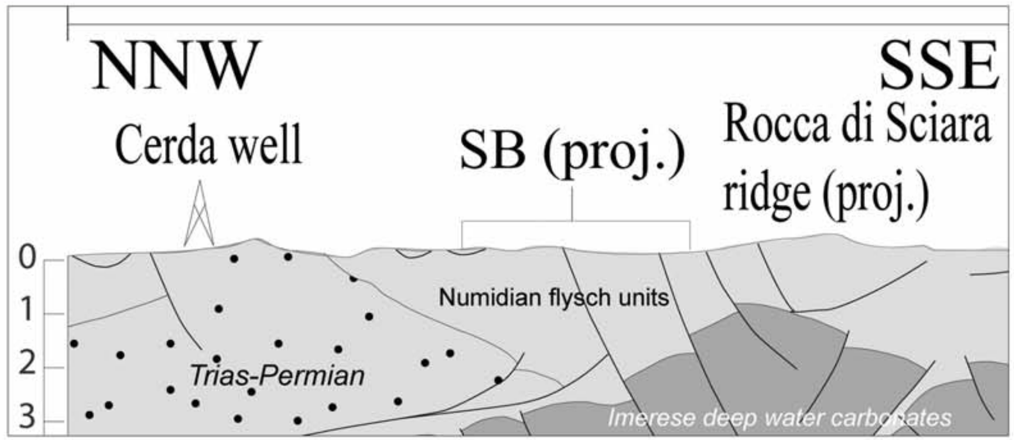


Fig. 69 - The gelogical sections (a-b) crossing the Western Madonie Mts and the Valledolmo area show how the outcropping and buried thrust sheets correlate in the facies stratigraphy, thrust geometry and the same south west vergency. The interpreted northern transect of the crustal seismic reflection profile (SI.RI.PRO. in right) shows the structural setting of the tectonic units buried in the Scillato basin area (mod. after Catalano et al., 2010c).

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The Imerese thrust units are strongly uplifted along NE-SW-trending, SE-dipping, transpressive, left-lateral faults (Fig. 68) superimposed on the older SW-verging structures. Kinematic data about these faults are summarized in Gugliotta & Gasparo Morticelli, this guidebook, pp. 89-101.
In the panoramic view (Fig. 68), moving from Mt Riparato to Cozzo Gracello, (uppersection in the Scillato basin succession) a progressive decrease in the mean tilting value of the strata can be observed.
An approximate 40° discordance can be traced between the lower portion of the Terravecchia fm (about 70° of strata attitude at Mt Riparato) and its upper portion (about 15° of strata attitude at Cozzo Gracello). This peculiar feature accounts for a partially preserved growth offlap (Fig. 68c; Ford et al., 1997) coherent with the development of a progressive unconformity (Fig. 68d; Riba, 1976; Hardy and Poblet, 1995; Ford et al., 1997). The growth geometry suggests the N-and NW-ward tilting of the eastern and south-eastern limbs of the basin, plausibly in response to the development of these transpressional faults. These faults may have been active at least during the late Tortonian, driving the Scillato basin infill and later during its post-depositional deformation. A comparison between field and subsurface data (northern sector of the SI.RI.PRO. profile, Fig. 69) suggests that the outcropping transpressional faults could represent the analogue of major deep-seated, S-dipping high angle faults which generate large scale backthrusts in the buried carbonate units.
Normal faults, superimposed on the pre-existing compressional structures are also observed in the area and related to the Pleistocene extensional/transtensional structures found in the Northern Sicily coastline, originated by the southern Tyrrhenian Arc opening.

Panoramic view of the Madonie Mts: nappe anticline and tectonic features. Relationships between the Panormide platform and the Imerese basinal thrust units

The panoramic view from Sclafani Bagni, towards the Madonie Mountains, provides a good image of a complex nappe anticline structure that involves the Panormide and Imerese units.
The large carbonate thrust pile, consisting of Meso-Cenozoic carbonate platform Panormide and deep-water Imerese thrust units now outcropping as a complex nappe anticline (Fig. 51) where the Panormide units appear to be the highest units. The core of the nappe anticline, formed by Monte dei Cervi, Caltavuturo and Sclafani Bagni outcrops, is made up of Mesozoic basinal sequences of the Imerese domain which are overlain by Late Oligocene to Miocene Numidian flysch deposits. A Mesozoic carbonate shelf structure (Carbonara Mount), one of the main culminations of the Panormide Meso-Cenozoic shelf carbonate structural unit is visible from the sky. Farther to the east the wide nappe anticlinal is overthrusted by the Sicilide allochtonous units (see Basilone et al., this guidebook, pp. 61-78).

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In this complex structure the occurrence of the Panormide units is variously interpreted: a) one tectonic interpretation describes the overriding of the Panormide carbonate platform above the basinal Imerese units, that is believed to have taken place during the Early Miocene (Ogniben, 1960, Grasso et al., 1978, Abate et al., 1982, Bianchi et al., 1989, Renda et al., 1999); b) an alternative interpretation of the local structural setting suggested by (Catalano et al., 2004, 2011b), envisages a juxtaposition of the two main thrust units along a NNE-SSW-striking, high-angle, reverse fault dipping to the NE and formed after the Miocene with a breaching mechanism (or thrust envelopment). This long lived contrast could be solved looking at a larger regional geological setting. The new results of the crustal SI.RI.PRO. interpretation suggest that the carbonate structures encountered just beneath the Late Neogene Scillato basin, pertain to the Imerese deformed domain thus indicating the absence of a Panormide shallow carbonate thrust at the top. As a consequence our data point out that the present day structural setting of the Panormide units is a tectonic feature formed after the emplacement of the Imerese units above the underlying carbonate platform units present in the subsurface.
Accordingly, the giant fault scarp that limits the lateral continuity of the Monte dei Cervi former nappe anticline to the west, hides a complex kinematic evolution already explained; the last step suggests the occurrence of a normal fault. Although no direct dating of the fault can be proposed, it clearly post-dates the nappe anticline and is thus assumed to be Late Pliocene or even Quaternary. This is in agreement with the occurrence of most normal faults around the Tyrrhenian Sea that developed within the upper crust as a result of the back-arc extension.

STOP 4 - Road to Valledolmo: the Numidian flysch. Lithology and sedimentological characteristics

Luca Basilone

Main Purpose
To observe quartzarenites interlayered with Lower Miocene clays and argillites and discuss the main sedimentary and paleogeographic implications.

Itinerary
Taking the road leaving Sclafani Bagni (Fig. 59) towards Valledolmo across a Numidian large outcrop area.

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Geological background

As mentioned before, the uppermost Oligocene-lower Miocene terrigenous deposits (marly shales, turbiditic sandstones and quartzarenites) are the foreland basin infill, unconformably deposited above the older mostly carbonate substrata of the progressively deforming African continental margin (Ogniben, 1960, 1963; Wezel, 1970, Broquet, 1968, Duèe, 1969, Giunta, 1985 and many others).

The Numidian basin is believed to have developed above both an inherited oceanic crust (Tethys) and a continental one (African margin). Some Authors have differentiated internal and external Numidian flysch (Caire et al., 1960; Broquet et al., 1966), according to their substrate, Sicilide paleo-oceanic realm or Imerese-Panormide carbonate successions developing along the African continental margin.

The early Miocene rock-interval, the Numidian flysch s.s. (target of the present stop) is assumed to account for oil and gas in the Sicilian belt, both offshore (Nilde field) and onshore (Gagliano field).

Description of the outcrops

At Cont.da Brignoli, several m-thick of eastwards dipping sandstone beds occur (Fig. 70).

The rocks consist of arenaceous and local conglomerates with well rounded and irregular shaped quartz grains as the main component (Fig. 71).

The Numidian sandstones are very porous and lack any clear carbonate cement. Sorting is normally

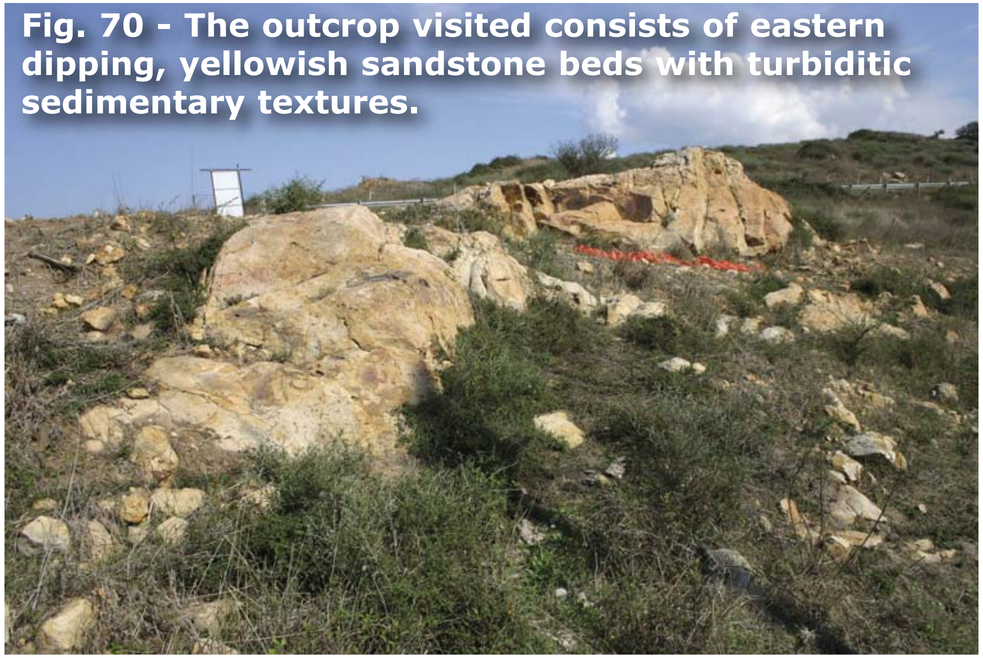

Fig. 70 - The outcrop visited consists of eastern dipping, yellowish sandstone beds with turbiditic sedimentary textures.

Fig. 71 - Well rounded quartz grains. This facies is frequently recognized at the base of the arenaceous beds.

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moderate to weak. Large green-brown and small green coloured glauconitic grains are dispersed within the sandstones and testify the marine origin of these strata. Porosity is mainly interparticular. Frequently, iron oxide nodules and crusts characterized the sandstone strata. They may represent an important component of the porosity of the rock.

Bouma's turbiditic, more or less complete sequence, is the main sedimentary structure found in the sandstones (Figs 72, 73 and 74).

Fig. 72 - Sandstone bed showing the typical turbiditic sedimentary structures. (Ta-Tc of Bouma's sequence).

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Fig. 73 - Turbiditic facies sequence in a sandstone bed of the Numidian flysch deposits outcropping near the visited outcrop.

From a tectonic point of view the Numidian flysch has two main settings: it is found to be involved in the deformation together with its carbonate substrate or as a nappe wedge composed of several thrust sheets reaching, generally, thicknesses of about 3000 m.
In our region, mostly the Numidian flysch rock bodies pertain to the previously mentioned nappe wedge.

Fig. 74 - The laminated layer of Fig. 73, where parallel laminations exhibit ripples and convolute laminae.

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SECOND DAY

Central Sicily. The region of the Eastern Sicanian Mountains

Giuseppe Avellone, Luca Basilone, Raimondo Catalano, Maurizio Gasparo Morticelli, Vera Valenti

Main Purpose

To demonstrate that the exhumed carbonate thrust sheets (visited at Monte Cammarata and Montagnola) and the structures recognized in the subsurface further east along the SI.RI.PRO. seismic profile are comparable. To discuss relationships among tectonics, sedimentation and eustatism, at Monte Capodarso, a Pleistocene thrust-top basin located in the Caltanissetta region.

Field Itinerary

Accordingly, we will visit the outcropping Imerese and Sicanian successions showing their tectonic relationships (Fig. 75a).

Moving towards Monte Cammarata, we will reach the Montagnola (**Stop 1**) where the section displays the stratigraphic characteristics of the Imerese succession (similar to the one previously visited in Sclafani Bagni outcrop).

The **2nd Stop** will deal with lithostratigraphy of the Sicanian succession at Monte Cammarata. Facies differences between the Imerese and Sicanian deep-water domains will be discussed.

The **3rd Stop** will show the main setting of the Sicanian units and their tectonic relationships with the Imerese units focusing on the subsurface regional structure. On the basis of a panoramic view, the **4th Stop** will display the deformational style of the Neogene sequence, represented by marls and sandstones, evaporites and overlying pelagic marly carbonates (Trubi) at Cozzo Tre Monaci.

As we cross Central Sicily, we will reach (after a long way) **Stop 5**, the last one, in Monte Capodarso area (Fig. 75b). There, both the sequence stratigraphy and the evolution of a Pleistocene thrust-top basin, will be discussed.

Basics. Eastern Sicani Mts and their subsurface extension

A recent, available stratigraphy of the area, summarized in the Stratigraphy notes (Basilone et al., this guidebook, 61-78), illustrates the main lithostratigraphic units that are referred to the shallow- and deep-water palaeogeographic domains. Imerese and Sicanian units are the Meso-Cenozoic deep-water domains; the

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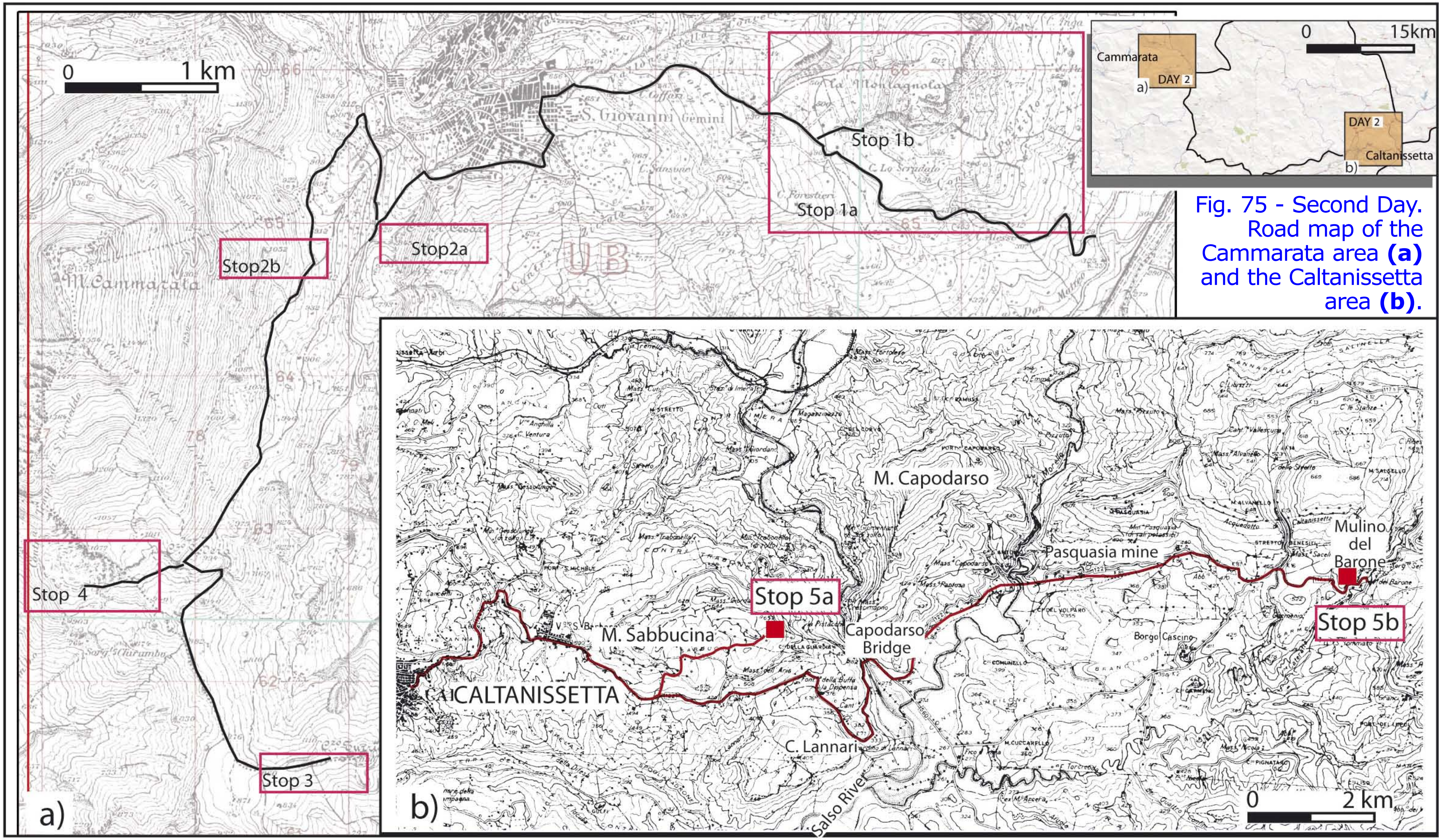

Fig. 75 - Second Day. Road map of the Cammarata area **(a)** and the Caltanissetta area **(b)**.

Trapanese-Saccense units represent the Meso-Cenozoic carbonate platform domains, as well as the Iblean unit that is the foreland of the chain (Catalano & D'Argenio, 1978). These lithologies were reached by deep wells, located in the neighbourhood of the study area (see Basilone et al., this guidebook, pp. 61-78).

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The new stratigraphy and the mesostructural analyses accomplished in the last years in the frame of the CARG Project (Catalano et al., 2010a, b; 2011a, b), support the joint interpretation of the confidential seismic lines acquired by ENI (Catalano et al., 2008, 2009) with field data (Avellone et al., 2010). The latter are now calibrated by a crustal profile (SI.RI.PRO. Project) recently acquired across Sicily from the Tyrrhenian coast to the Sicily Channel.

Due to the poorly known structural and stratigraphic characters of the study area some questions have arisen:
- Is there a thrust pile structurally comparable with the Western and Eastern Sicily tectonic wedges?
- Are there carbonate platform units involved in the thrust stack and what is their depth?
- Are these units a local prolongation of the Iblean carbonate plunging foreland or a more internal carbonate platform thrust unit?
- Is the clastic and evaporitic Neogene sedimentary wedge filling the Caltanissetta trough thin ? enough to be crossed by oil research boreholes?

Regional geological framework of the Sicanian thrusts system

The study area extends southwards from the westernmost side of the Madonie Mts to the impressive NE-SW tertiary clastic evaporitic range, north of the Caltanissetta trough; the area covers the eastern side of the Sicani Mts (Fig. 76). The region is located in an area where some of the deep-water carbonate thrust systems (Imerese and Sicanian) disappear beneath a wedge of deformed Neogene deposits. The latter are known to be some thousand of meters thick (Caltanissetta trough, Fig. 76).

Two main sectors can be differentiated in the study area (Fig. 76): 1) the southeastern sector shows the Tortonian-Messinian foredeep deposits filling a flat depression; it is locally interrupted by NE-SW, tectonically controlled ridge associated to SE-ward verging folds; 2) the northwest sector, where both the Numidian flysch and the Permo-Triassic Sicanian deposits outcrop, displays NW-SE trending ridges (e.g. M. Cammarata, Castronovo, Serra del Leone, Fig. 76). Some of them appear progressively rotated into ENE-WSW alignments (e.g. Serra Quisquina-Serra della Venere, Fig. 77b). These ridges are tectonically controlled as they correspond to the stiff lithologies (upper Triassic cherty limestones) at the core of the map scale anticlines. A set of SW-ward imbricated units characterizes the area (Broquet et al., 1966; Catalano et al., 2000a; Avellone et al., 2010), involving the whole 1.200-1.700 m thick Sicanian succession from the Triassic cherty limestones to the upper Miocene marls (Monte Cammarata).

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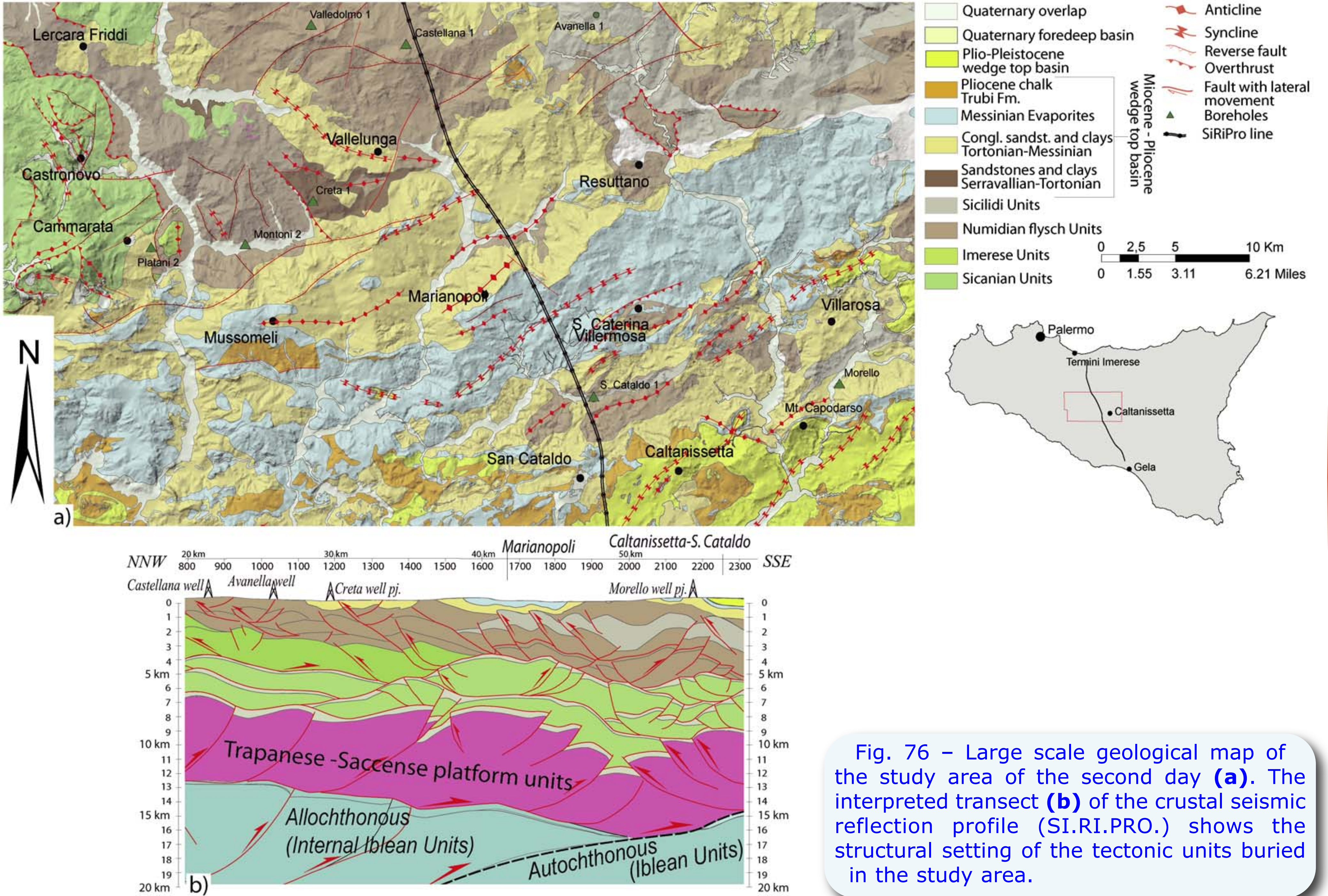

Fig. 76 – Large scale geological map of the study area of the second day **(a)**. The interpreted transect **(b)** of the crustal seismic reflection profile (SI.RI.PRO.) shows the structural setting of the tectonic units buried in the study area.

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Imbrication has repeatedly involved the whole Sicanian succession (Fig. 77). NW-SE to NS trending folds and related thrusts display a W and SW vergence with local back thrusting (early tectonic event with shallow seated structures). The flat thrusts, originally bounding the Sicanian units, appear today strongly folded and faulted along NNW–SSE (dextral) and WSW–ENE (sinistral) transpressive faults (later event with deep-seated structures). During this event, deep-seated thrusts generated double-verging, relatively narrow anticlines, with steep axial surfaces (Avellone et al. 2010).

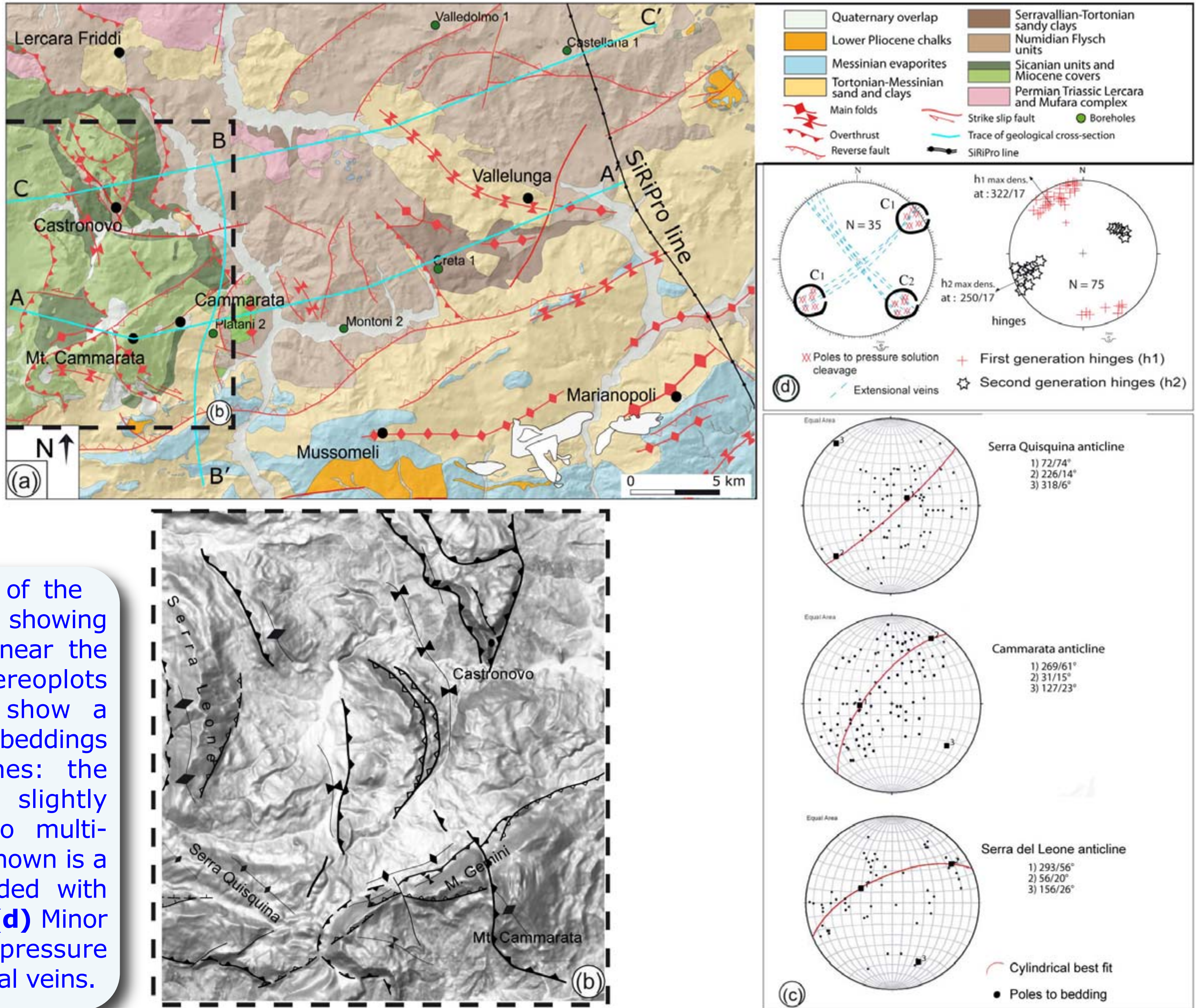

Fig. 77 - **(a)** Geological map of the Sicani Mts area. **(b)** Shaded relief, showing the main morphotectonic units near the Cammarata area. **(c)** Stereoplots (Schmidt, lower hemisphere) show a cylindrical best fit of poles to beddings surveyed along major anticlines: the bedding attitudes display a slightly dispersed distribution related to multi-phase fold¬ing (the great circle shown is a computer best-fit solution provided with StereoWin, Allmendinger 2002). **(d)** Minor fold hinges with associated pressure solution cleavages and extensional veins.

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The axial trend of the folds is variable as multiphase folding occurred (Fig. 77c, d). The latter produced a characteristic interference pattern, reflecting continuous variations of the apparent transport direction during the emplacement (i.e. clockwise rotation of the allochthonous thrust sheets, Catalano et al., 1976; Channel et al., 1990) calibrated by field mesostructural analyses (Oldow et al., 1990).
The outcropping Sicanian and Imerese units disappear southwards and eastward of Monte Cammarata, covered by Tertiary deformed rocks (Fig. 77).

Previous papers, describing the main structural pattern of the region have neglected to mention the occurrence of carbonate platform rock bodies at depth and their tectonic relationships with the carbonate foreland and the overlying, deep-water, carbonate thrust systems.
The SI.RI.PRO. seismic profile crossing the area, farther east, shows how these carbonate units occur as buried structures, that appear continuous in a large region reaching south of the subsurface region of the Butera basin (GFT Map).

STOP 1 – La Montagnola section: a slope facies of the Imerese Mesozoic basinal domain

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Main purpose
To illustrate the stratigraphic characteristics of the section outcropping at La Montagnola.
The facies analysis reveals how the main characteristics are quite similar to those identified at the Sclafani Bagni section visited on the first day, at Stop 2. When the two successions are compared, they display a common facies sequence and paleogeographic setting. As a consequence, here the Montagnola section is believed to pertain to the Imerese domain.

Field Itinerary
Leaving our Hotel, and taking the SS 624, we reach the slope that leads us down towards San Giovanni Gemini. In short, we will reach the basal beds of La Montagnola hill where, the whole section involving the Jurassic – Lower Miocene rocks will be visited in different outcrops.

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Geological framework

Structure: Observing the outcropping N-S anticline from the South, it displays a westward vergence and appears to overthrust the Tortonian clays (Fig. 78).

Stratigraphy: From the outcropping lowermost deposits, the succession (Fig. 79) consists of:

a) black radiolarites interlayered with clays, bedded cherts and brown siliceous mudstones (Fig. 80) with few intercalations of gray calcareous breccias; outcropping thickness, about 60 m. The lower boundary is not outcropping. The unit is correlated here to the radiolarites mb of the Crisanti fm, seen at the Sclafani Bagni section (First day, Stop 2c);

b) carbonate breccias Upper Tithonian-Lower Cretaceous with reef-derived fragments (*Ellipsactinia* sp., Fig. 81) and reworked calcarenites (packstone-grainstone). The unit is correlatable to the *Ellipsactinia* breccias mb of the Crisanti fm pertaining to the Imerese domain seen at the Sclafani Bagni section (First day, Stop 2c);

c) greenish siliceous mudstone, cherty nodules, clay marls with radiolarian and sponge spiculae (Fig. 82), 10-15 m-thick, dated as Lower Cretaceous. They could correspond to the spongolithic mb of the Crisanti fm of the Imerese section seen in Sclafani Bagni (First day, Stop 2b);

d) breccias, conglomerates and reworked calcarenites with rudistid fragments and benthic foraminifers (Figs 83, 84), Cretaceous in age, up to 80 m thick. The unit visited is similar, even if thicker, to the Rudistid breccias mb of the Crisanti fm, seen in the Sclafani Bagni section (First day, Stop 2b);

e) greenish and reddish Scaglia-type pelagic limestones, marly limestones and marls with planktonic foraminifers and nannofossils, Paleogene in age, several metres thick (Fig. 85); calcareous breccias and calcarenites rich in large benthic foraminifers (nummulitids), follow upwards. The unit is quite similar to the Caltavuturo fm deposits outcropping along the Sclafani Bagni section (First day, Stop 2b);

The Paleogene-Mesozoic carbonate succession exposed here, lacks the Triassic pelagic carbonates of the Scillato fm and dolomitic breccias of the Fanusi fm, seen at the Sclafani Bagni section. These underlying rocks are expected to be buried in the subsurface as suggested by nearby boreholes and seismic lines.

f) Brown clays and argillites with quartz sandstone intercalations (Numidian flysch), follow upwards with a paraconformity surface. The lower boundary, at places, is a mechanical (tectonic) contact.

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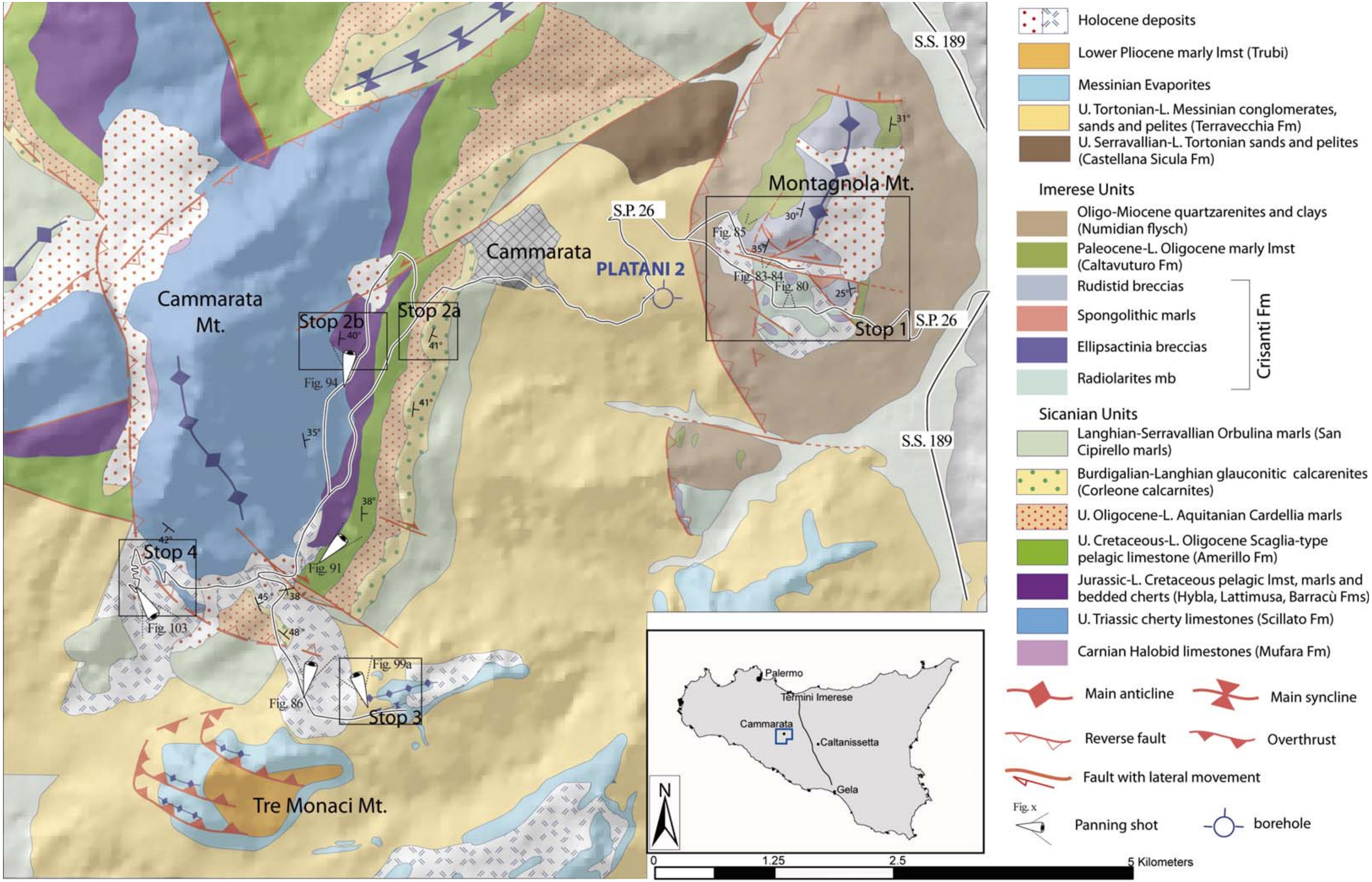

Fig. 78 - Geological map of the visited area (Stops 1-4).

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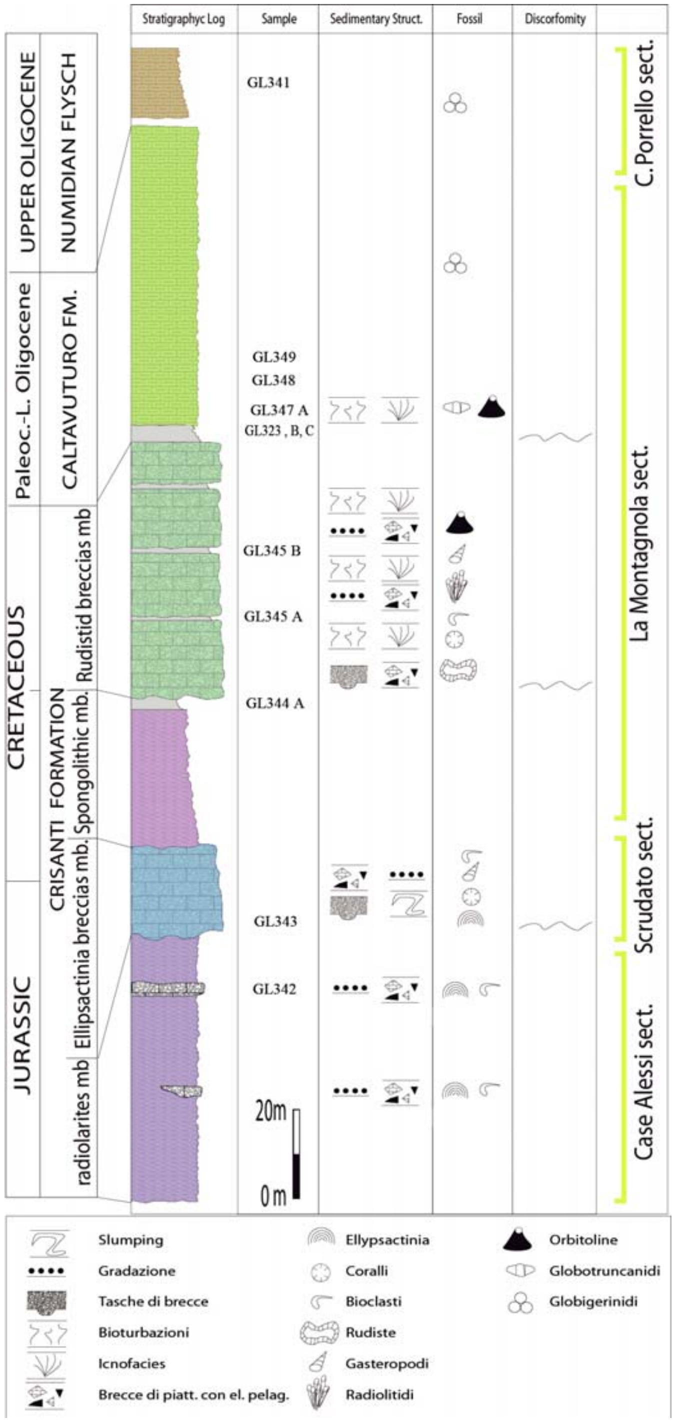

Fig. 79 - Composite stratigraphic column of the La Montagnola outcropping section.

Stop 1a. Dark Jurassic radiolarites and *Ellipsactinia* breccias

Along the road, thin bedded darkish radiolarites and brown clay intercalations, with bedded cherts, can be seen (Fig. 80). The dm-thick regular beds are rich in radiolarians and sponge spiculae and display planar laminations and bioturbations. Locally, gray siliceous limestones with cherty nodules are interlayered.

These beds are referred to the Upper Liassic-Malm time interval (Broquet, 1968).

Fig. 80 - Black radiolarites and bedded cherts.

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Carbonate breccias follow upwards, covering the dark radiolarites along an erosional unconformity surface. The unit consists of calcirudites, graded and laminated calcarenites and local conglomerates and breccias with large platform-derived elements that contain a shallow-water rich association of bryozoans, corals, calcareous sponges (*Ellipsactinia* sp. Fig. 81), molluscs and microproblematics.
According to the fossil content the age is referred to the Upper Tithonian-Neocomian time interval.

Fig. 81 - Bioclastic fragments of *Ellipsactinia* sp. found in the Tithonian-Neocomian carbonate breccias.

Stop 1b. Cretaceous deposits

Yellowish and greenish marly clays, cherty limestones, bedded cherts and siliceous limestones (Fig. 82), rich in radiolarians, sponge spiculae and planktonic foraminifers.
Their lower boundary is an unconformity surface (locally with onlap geometries) with the *Ellipsactinia* breccias mb. The upper boundary is an erosional surface with the Rudistid breccias (Fig. 83). Rare planktonic foraminifers point to an Aptian-Albian age.
Breccias, conglomerates, graded calcirudites, laminated calcarenites with rudistid fragments, benthic foraminifers (*Orbitolina* sp.), crinoids, corals, calcareous algae follow upwards, with erosional unconformity (Figs 83, 84). Frequently, pyrite green bearing marls with planktonic foraminifers in cm-to-m thick layers are

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Fig. 82 - Deformed Lower Cretaceous greenish cherty limestones, radiolarites and spongolithic marl member of the Crisanti fm.

intercalated. Locally, bluish microbreccias and calcarenites with pyroxene crystal and igneous clasts are present. Ichnofacies occur at the top of the beds. The fossil content suggests an Upper Cretaceous (Cenomanian) age. The lithology shows the characteristics known in the rudistid breccias mb of the Crisanti fm outcropping in the Sclafani Bagni Imerese succession.

At the top, well-bedded varicoloured marly limestones (Fig. 85) follow: They appear as mudstone-wackestones with planktonic foraminifers and intercalation of graded calcareous breccias with large benthic foraminifers (Alveolinids and Nummulitids). Marls and clays prevail upwards. These rocks pertain to the Caltavuturo fm whose age spans from Paleocene to Early Oligocene.

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Fig. 83 - Erosional relationships between the greenish spongolithic marls mb and the Rudistid breccias mb of the Crisanti fm).

Fig. 84 - Upper Cretaceous calcareous breccias with shallow-water derived, elements consisting, mainly, of rudistid reef limestones.

Fig. 85 - Yellow and greyish marly clays and mudstone of the Caltavuturo fm.

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STOP 2 – Sicanian basinal stratigraphy at Monte Cammarata

Luca Basilone

Main purpose

This Stop will deal with the lithostratigraphy of the Sicanian deep-water succession whose well exposed outcrops will be visited along the Monte Cammarata slope. Facies similarities and differences between the pelagic succession of Monte Cammarata and the Imerese section, visited previously at La Montagnola and Sclafani Bagni sections, will be shown and discussed (see also Basilone et al., this guidebook, pp. 61-78).

Field Itinerary

Leaving la Montagnola, we will reach the slope of Monte Cammarata (on which the towns of Cammarata and San Giovanni Gemini grew and expanded) where we will visit well preserved outcrops.

Main frame

The eastern flank of Monte Cammarata appears, at first glance, as an eastward dipping regular monocline (Fig. 78). When compared to the outcrop and the nearby well stratigraphy (see Figs 99 and 26), these rocks display the characteristics recognized elsewhere in the Sicanian Domain succession (Fig. 86).

Facies comparison between Sicanian and Imerese deep-water rocks (see Basilone et al., this guidebook, pp. 61-78) point out how both Imerese and Sicanian successions have the same basal lithofacies consisting of Middle-Upper Triassic marls and cherty limestones (Mufara and Scillato fms); but the Sicanian succession clearly differs, as it lacks the Jurassic-Eocene redeposited shallow-water carbonates and the Upper Oligocene-Lower Miocene Numidian strata that are typical lithologies of the Imerese sequence.

Stratigraphy of the Sicanian succession

The Monte Cammarata succession (Fig. 86), 1200–1700 m thick, consists, from the bottom, of:

a) thin-bedded mudstones, marly calcilutites and clays (Mufara fm) of Carnian age. As evidenced in the Platani 2 well and in other outcrops of the Sicanian Mts, they rest unconformably above the underlying Permian-Middle Triassic (Ladinian) terrigenous and clastic carbonate deposits of the Lercara complex (see also Basilone et al., this guidebook);

b) thin-bedded cherty limestones (Scillato fm, Fig. 87) with radiolarians, conodonts and pelagic bivalves (*Halobia* sp. and *Daonella* sp.), conformably follow. These deposits are quite similar to those of the Imerese succession (see Sclafani Bagni Stop 2, First day);

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c) oolitic and crinoidal calcarenites (Fig. 88), belemnitic calcareous breccias and greenish marls of Liassic age, follow upwards, with onlap of the lower boundary;

d) Jurassic thin-bedded radiolarites, mostly reddish in colour, bedded cherts and siliceous limestones, rich in radiolarians and sponge spiculae (Barracù fm, Fig. 89);

e) white calpionellid limestones (Lattimusa) of Tithonian-Neocomian age conformably follow (Fig. 90);

f) Aptian-Albian greenish calcareous marls and greyish limestones with planktonic foraminifers (Hybla Fm.);

g) reddish and white limestones and marly limestones with planktonic foraminifers and ichnofacies (Figs 91 and 92) of Late Cretaceous-Lower Oligocene age (Amerillo fm), 200 m-thick, follow;

h) marls, marly clays and intercalations of reworked calcarenites with large benthic foraminifers (*Lepidocyclina* spp.), 80-150 m-thick (Cardellia marls);

i) glauconitic calcarenites (Corleone calcarenites), unconformably follow and pass upwards to;

j) grey-bluish marls with pelagic fossil content (S. Cipirello marls).

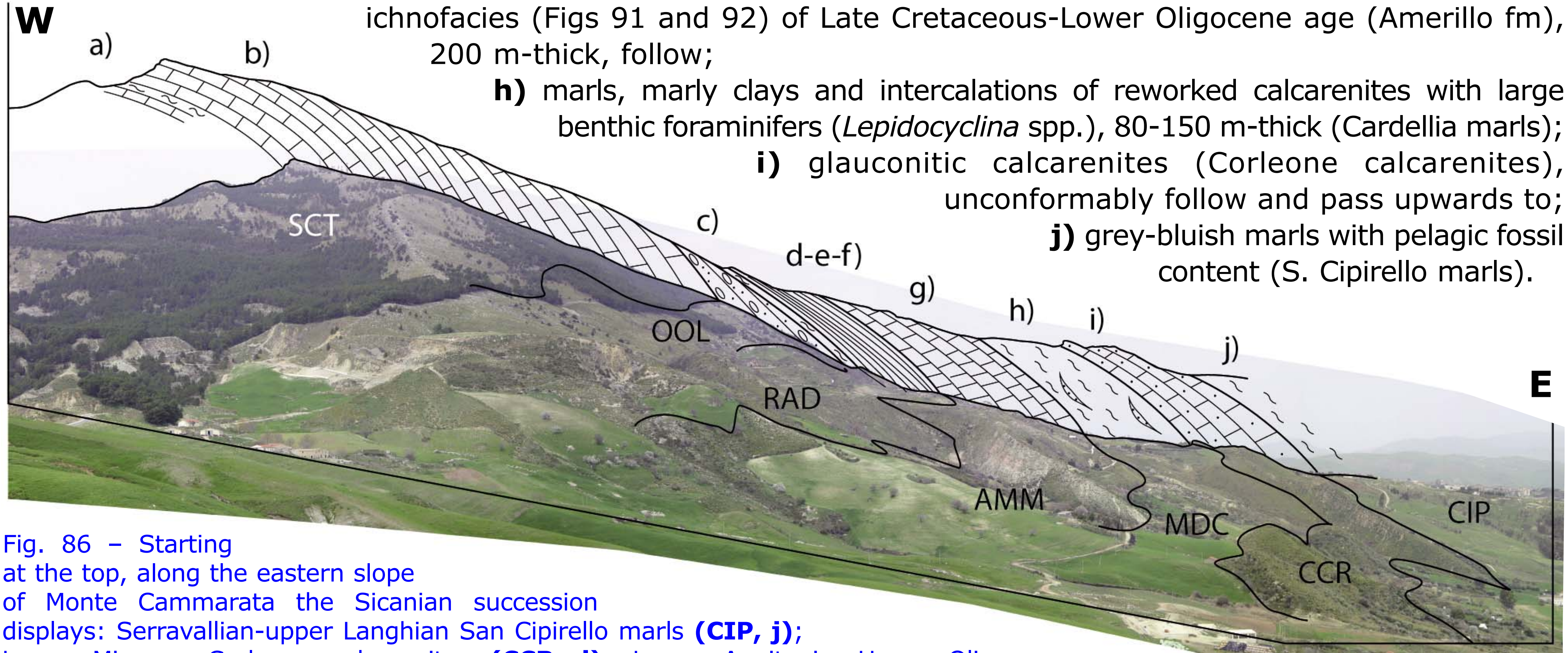

Fig. 86 – Starting at the top, along the eastern slope of Monte Cammarata the Sicanian succession displays: Serravallian-upper Langhian San Cipirello marls **(CIP, j)**; Lower Miocene Corleone calcarenites **(CCR, i)**; Lower Aquitanian-Upper Oligocene Cardellia marls **(MDC, h)**; Lower Oligocene-Upper Cretaceous Scaglia-type pelagic limestones of Amerillo fm **(AMM, g)**; Jurassic-Lower Cretaceous pelagic deposits **(RAD)**: Lower Cretaceous Aptyhcus marly limestones (**Hybla Fm.**, **f**); Tithonian-Neocomian calpionellid limestones **(Lattimusa, e)**; radiolarites, siliceous limestones and marls **(Barracù fm, d)**; Lower Liassic oolitic and crinoidal calcarenites, conglomerates with belemnites and varicoloured marls **(OOL, c)**; Upper Triassic cherty limestones of Scillato fm **(SCT, b)**; Carnian marls and pelecypods limestones of Mufara fm **(a)**.

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Fig. 87 - Upper Triassic cherty limestones of the Scillato fm with nodular textures due to the thin marl intercalations.

Fig. 88 - Fragment of thick bed of the Lower Liassic oolitic and crinoidal calcarenites.

Fig. 89 - Middle Jurassic white siliceous limestones, gray clays and red radiolarites (Barracù fm).

Fig. 90 - Tithonian-Neocomian white calpionellid limestone (Lattimusa).

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Fig. 91 - Upper Cretaceous-Eocene red and white Scaglia-type limestones with planktonic foraminifers of the Amerillo fm.

Fig. 92 - Lower Oligocene Scaglia-type limestones (Amerillo fm) with *Cancellophycus* isp. ichnofacies.

Stop 2a: Cozzo Cesare, Lower Miocene glauconitic calcarenites (Corleone calcarenites)

At Cozzo Cesare a dipping succession of yellowish glauconitic and thin marl intercalations of the Corleone calcarenites formation, outcrops. The beds rest unconformably above the underlying Cardellia marls, with erosional surface.

The calcarenite beds, consisting of bioclastic grainstone-packstone, are rich in glauconitic grains, shallow-water intraclasts, large benthic foraminifers (*Miogypsina* spp.), teeth fish (*Charcarodon* sp.) fragments, red algae, crinoid, echinoid and bivalve fragments (Fig. 93).

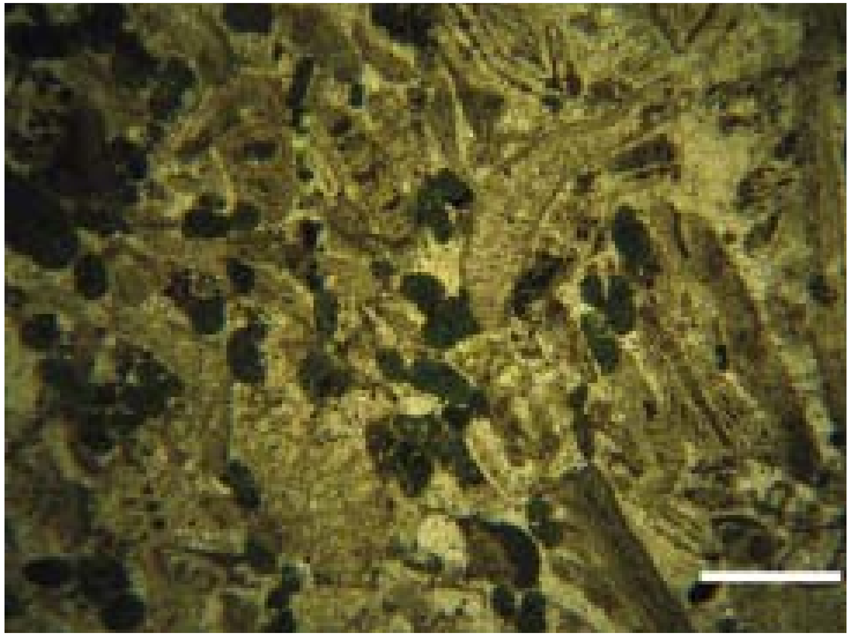

Fig. 93 - The Corleone calcarenites consist of packstone-grainstone with large benthic foraminifers, glauconites and intraclasts (scale bar 1 mm).

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Stop 2b: Monte Cammarata eastern slope, Jurassic-Lowermost Cretaceous pelagic deposits of the Sicanian succession

The Stop will display the Jurassic-Lower Cretaceous rock interval of the sicanian M. Cammarata section (Fig. 94). When observed in detail the section (Fig. 95) shows, from the top:

a) white to grey thin bedded (10-15 cm-thick) limestones with cherty nodules and bedded cherts (Fig. 90); downwards thin layers, are interbedded with red to yellow marls. The limestones display a tabular and pseudonodular texture, planar lamination and bioturbations; they are mudstone/wackestone rich in calpionellids and radiolarians and, locally, *Aptychus* sp. On the whole the rock body has a thinning upwards facies sequence trend.

b) Reddish limestones and marly limestones with belemnites; downwards, reddish to whitish marly clays are interlayered. The planar beds, 20 cm-thick on average, are wackestone with radiolarians and calpionellids and show pseudonodular texture and undulating boundaries; the lithological interval, 3.10 m-thick, displays upwards thickening facies sequences.

These intervals, Tithonian-Valanginian in age, correspond to the lithostratigraphic unit, locally known as Lattimusa.

c) White-pinkish thin bedded (3-5 cm-thick) limestones, alternated with bedded cherts (3.80 m-thick); the tabular limestone beds display a nodular texture and planar lamination and are rich in ichnofacies (tracks).

Fig. 94 - Panoramic view of the visited east dipping Jurassic succession.

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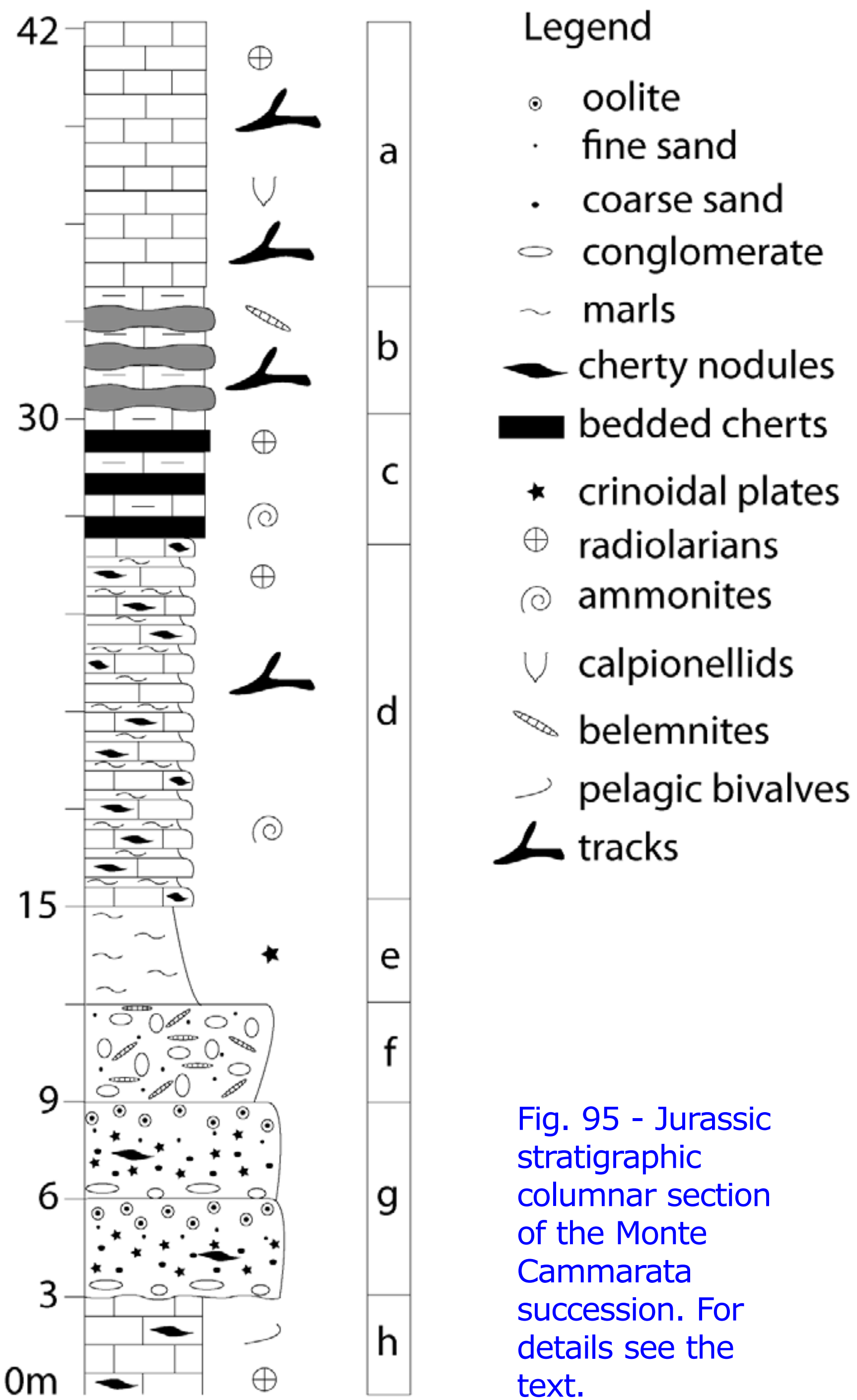

Fig. 95 - Jurassic stratigraphic columnar section of the Monte Cammarata succession. For details see the text.

d) White and pinkish marly limestones, bedded cherts and siliceous mudstones (Fig. 89), with darkness Mn-oxide encrustations alternated with red clayey marls in cm-thick layers. These two rock units pertain to the middle-upper Jurassic Barracù fm. This unit, 15 m-thick, passes downwards to;

e) greenish and greyish marls (Fig. 96), Pliensbachian in age (Broquet, 1968), that are partly covered by vegetation.

The marls, onlap the Lower Liassic resedimented oolitic and crinoidal calcarenites (g) and, locally, the Upper Triassic Scillato fm cherty limestones. Locally, as observable along the road at Cozzo Ledera (Stop 3) these marls lie above a conglomerate whose matrix is rich in belemnites **(f)**. The elements derive mostly from the erosion of the stratigraphically underlying Upper Triassic cherty limestone strata.

Fig. 96 - Middle Liassic greyish marls, with belemnites (e) and Jurassic siliceous limestone (d).

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Fig. 97 - Lower Liassic crinoidal and oolite limestones.

g) White oolitic limestones with extraclasts, intraclasts and crinoidal fragments; cherty nodules are also present. Each bed (0.8-1.5 m-thick) displays an erosional lower boundary, gradation and channallized geometry. In detail it consists, from base-to-top of: i) breccias and pebbly conglomerates whose major axis element shows the transport direction, ii) graded crinoidal grainstone (Fig. 88) and iii) reworked oolitic grainstone to packstone (Fig. 98).

The unit, Lower Liassic in age, WNW dipping, with a 45 degree inclination (Fig. 97), lies unconformably, above the 500 m-thick Upper Triassic cherty limestones of the Scillato fm **(h)**.

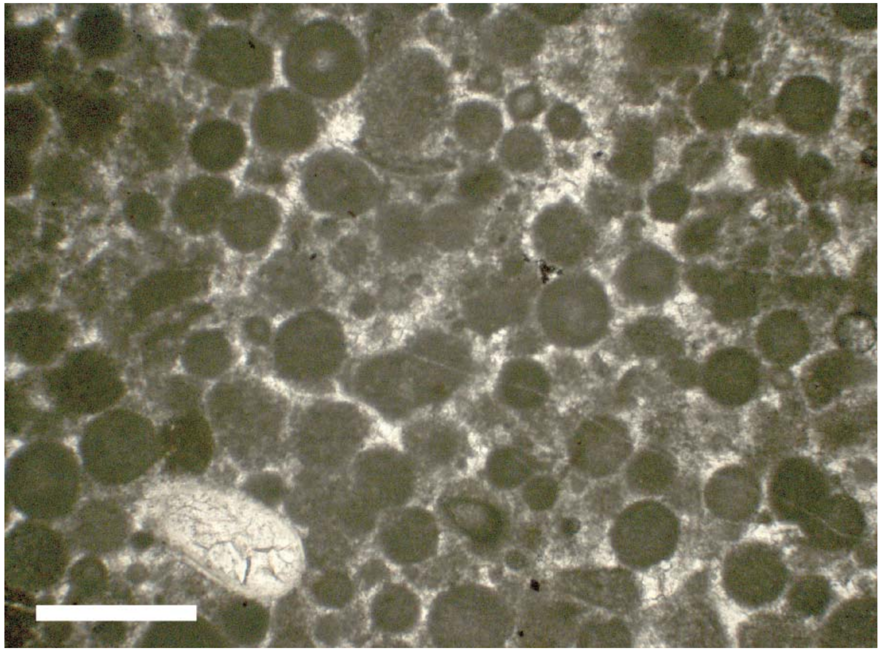

Fig. 98 - Lower Liassic oolitic grainstone (Platani 2 well, cutting, 1691-1694m, scale bar 0,5 mm).

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STOP 3 - Comparison of surface and subsurface structures

Giuseppe Avellone, Raimondo Catalano, Vera Valenti, Maurizio Gasparo Morticelli

Main Purpose

To show the main setting of the Sicanian units and their tectonic relationships with the Imerese ones. The focus is on the subsurface regional structures.

Itinerary

Leaving the outcrops along the eastern slope of Monte Cammarata, visited earlier, we will reach the place where we will have a panoramic overview of the eastward dipping Cammarata tectonic unit (see Fig. 78).

Geological framework

The Cammarata unit is the highest in the Sicanian thrust system. The structural analyses performed in the last years (Avellone et al., 2010 and references therein) support the SW or W-ward tectonic transport of the whole thrust stack.

Fig. 99 shows the panoramic view of the eastward dipping Monte Cammarata monocline and the Platani 2 borehole (Fig. 100), seated at the foot of the slope; farther to the east the Montagnola asymmetric anticline appears to overly the Miocene clastic rocks.

The eastward extension of the Sicanian rock units and their relationships with the underlying buried rocks will be illustrated based on subsurface information.

Correlation between the Monte Cammarata section and the Platani borehole succession, calibrated by seismic reflection data, suggest how the subsurface elongation of the Cammarata unit underthrusts the Montagnola unit (Figs 99, 100).

When seen at map scale, the previously shown and visited monocline, is the backlimb of the NW-SE trending Monte Cammarata anticline displaying a Triassic cherty limestone core (Figs 99a,b).

Fig. 99 - Panoramic view of the Cammarata unit **(a)**. Location of the Platani 2 well (map) is shown in the line drawing **(b)**. Geological section linking the Cammarata structure, the Platani 2 borehole, the Montagnola unit and the Creta1 well area **(c)**.

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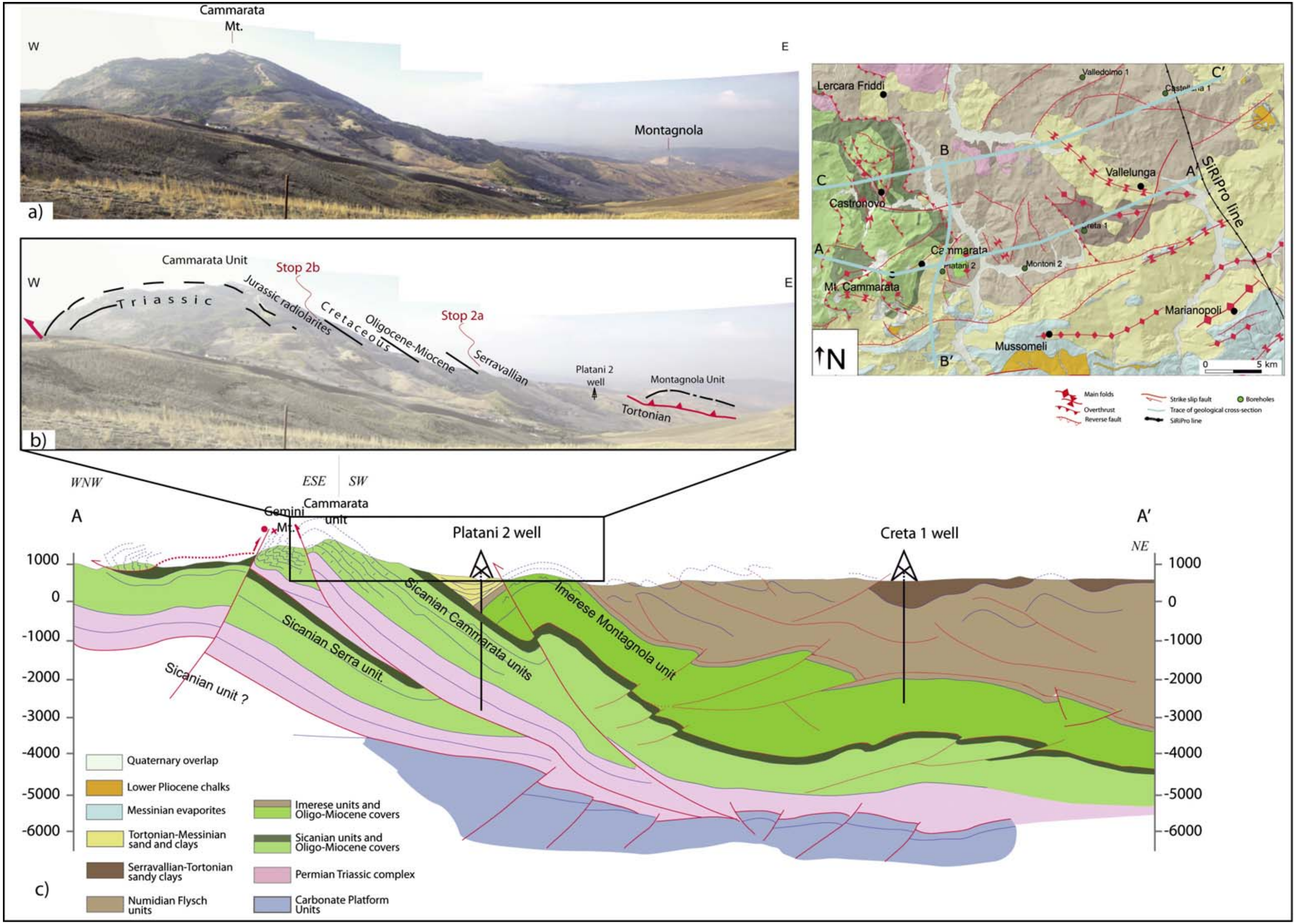

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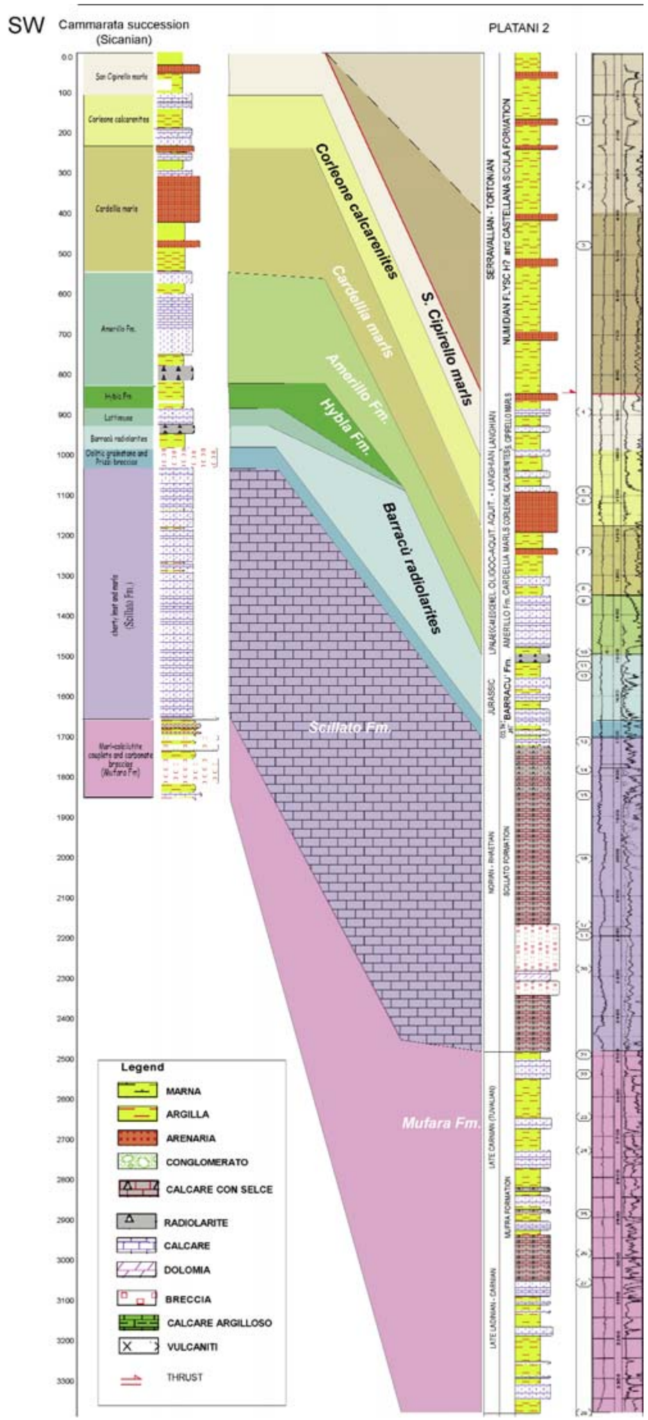

The structure is associated to a SW-vergent thrust (Fig. 99b,c) that is well imaged in the WSW-ENE trending cross-section (Fig. 99c) where the Sicanian units appear overthrusted by a 1200 m thick rock body (Montagnola). The section confirms the previously described stacking pattern between the Imerese (above) and Sicanian units (see Fig. 99c). The western side of the cross-section shows how the Sicanian body is arranged in two tectonic slices (Cammarata unit and Serra unit, Fig. 99c).

The Montagnola unit extends in south (seismic profile evidence in Fig. 101) and eastwards, respect to the site of he Creta 1 well (see Fig. 99c). Based on seismic profile interpretation, the deepwater carbonate thrust sheets appear to overlie interpreted platform carbonate units, at a depth that varies approximately between 4 and 6 km.

Platform carbonate structures have been commonly found in the Western Sicanian chain beneath the deep-water carbonate thrust wedge (Catalano et al., 2000a; Finetti et al., 2005). The SI.RI.PRO. profile, crossing farther east of the area, supports this structural setting.

Along the several geological cross-sections performed in the area, the deep-water carbonate thrust pile appears overthrusted by a stack of Permian-Triassic Lercara complex, Numidian flysch nappe and its overlying Tertiary rocks (Figs 99c, 101b). The Numidian flysch nappe, 2,5 km thick in place, appears (see Fig. 99c) as a deformed fold and related thrust system with a SW-ward vergence (see also field data on the map). This nappe is seen, in place, to overlie the Permian-Triassic Lercara complex (Fig. 101b).

Fig. 100 - Correlation between Cammarata deep-water carbonates and succession drilled by the Platani 2 well (Basilone et al., this guidebook, pp. 61-78).

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A unexpected support comes from a geological cross-section, located to the north of the study area, between the Castronovo village and the Castellana 1 well (Fig. 101a). The section, calibrated by outcrops and by the Castellana 1 borehole, through the trace section trend, shows the early generation of the Sicanian main thrusts (NW-SE oriented).

The geological section (Fig. 101b) crossing the transect described above, along a N-S trend, highlights the latter generation of compressional structures (NE-SW trending, double-verging, mostly duplex structures).

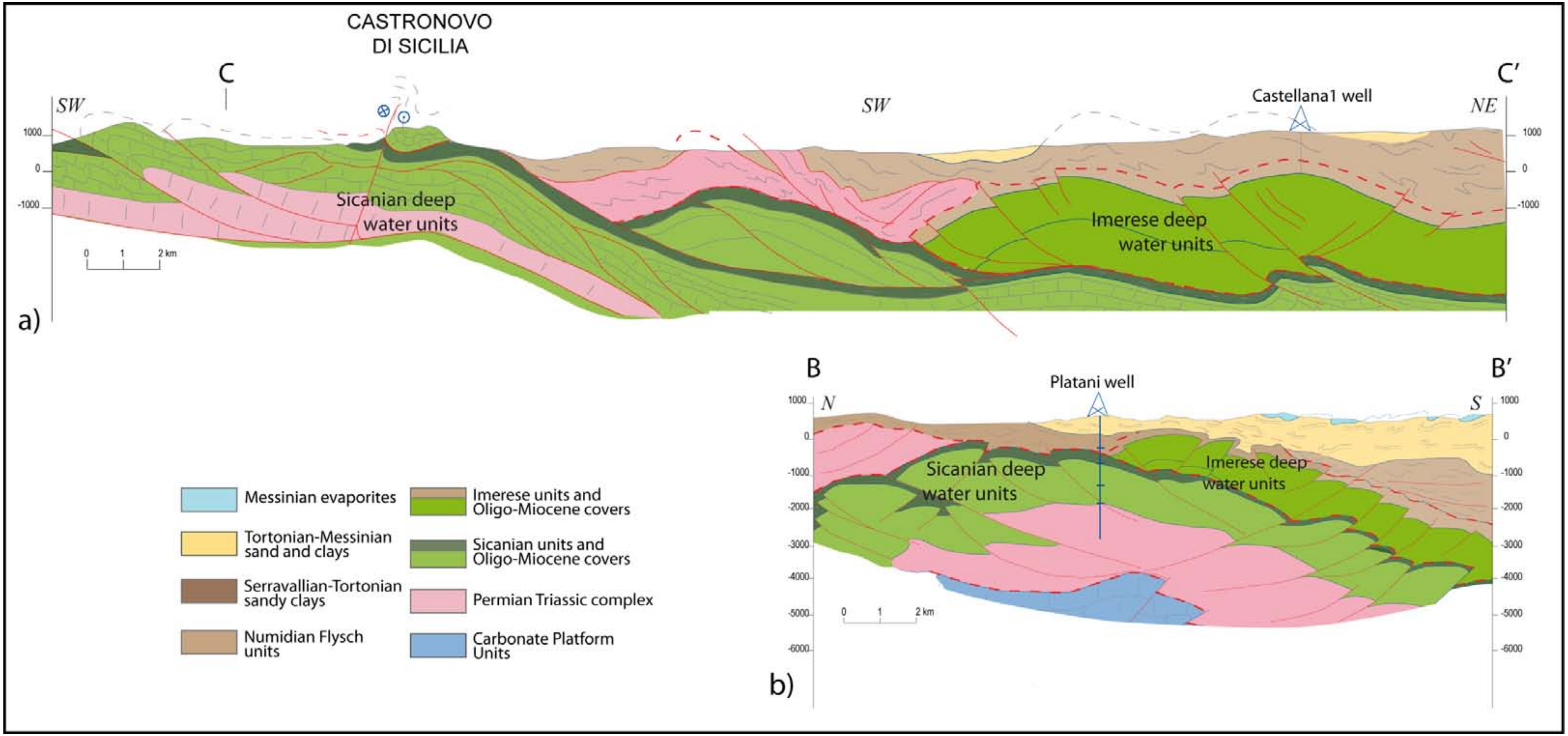

Fig. 101 - Geological cross-section (see traces in the map of Fig. 99).

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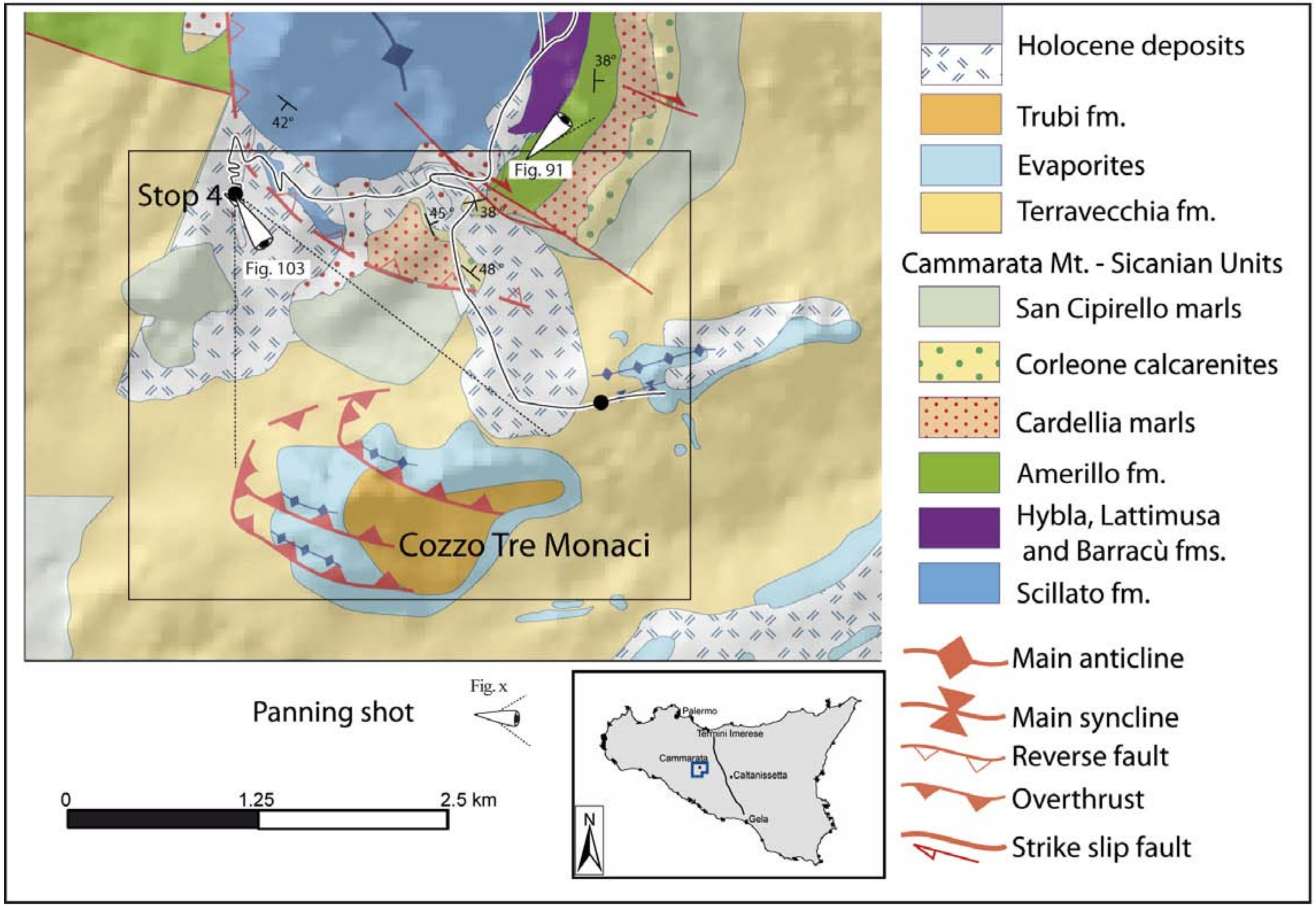
STOP 4 - Neogene thrust systems: Cozzo tre Monaci field example

Giuseppe Avellone

A well exposed, impressive Tertiary succession shows an embricate thrust system and related folds involving Messinian evaporites and Lower Pliocene chalks (Fig. 102).
The splays highlighted on the photo, showing ramp and flat geometries, merge at depth in a sole thrust located in the Tortonian clays (Fig. 103).



The post-early-Pliocene shallow structures have a SW-ward vergency documented by the axial fold setting and by the striated fault plains orientation (see stereographic projection of Fig. 103).

Fig. 102 - Geological map of the study area of Stop. 4.

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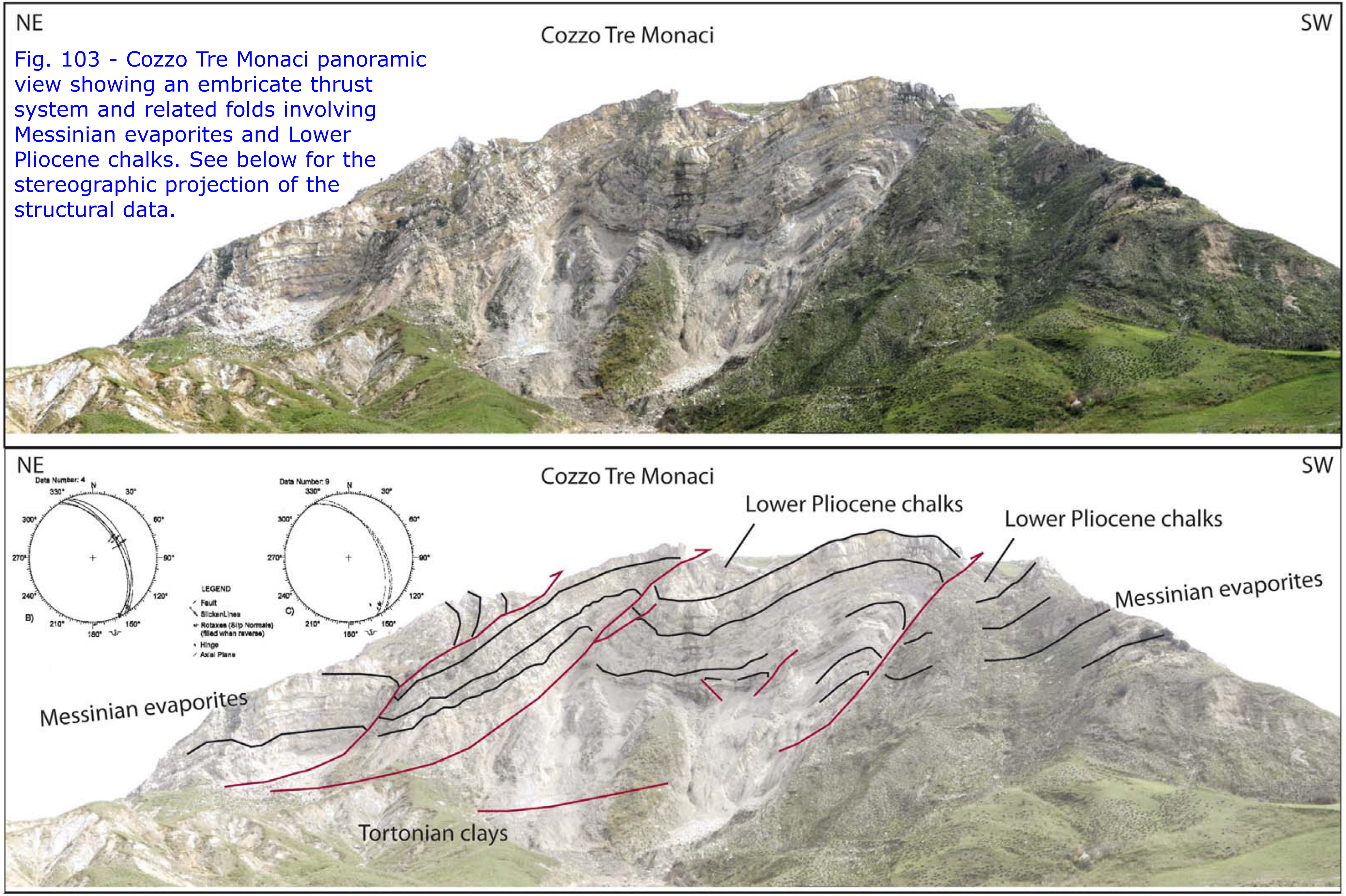

Fig. 103 - Cozzo Tre Monaci panoramic view showing an embricate thrust system and related folds involving Messinian evaporites and Lower Pliocene chalks. See below for the stereographic projection of the structural data.

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STOP 5 - Sedimentation within Pleistocene syn-tectonic basins in the Capodarso region

Mauro Agate, Carlo Gugliotta, Vera Valenti

Main purpose

In the Capodarso basin two stops will be devoted to: 1) showing one of the most spectacular Plio-Pleistocene wedge-top basins in Central Sicily; 2) illustrating the lithofacies assemblage and the stratal pattern of the Lower Pleistocene syn-tectonic succession; 3) discussing the relationships among tectonics, eustatism, sediment accommodation and facies staking pattern of the clastic carbonatic succession.

Itinerary

From Cammarata (AG) along a side street in the direction of Caltanissetta to San Cataldo village. Then, we will pass the town of Caltanissetta reaching the Capodarso Bridge, and from there, along the SP 122, we will reach the first of the two planned stops located in the Mount Sabbucina area (Fig. 75).

Geological framework and background concepts

- Plio-Pleistocene wedge-top basins, outcropping in Central Sicily, provide several examples of coarse-grained, bioclastic, coastal lithosomes sandwiched in offshore deposits which record changes of relative sea level and the evolution of the tectonic structures (Butler & Grasso, 1993; Catalano et al., 1993a, b; 1998 and references therein; Vitale, 1998). The Capodarso Antiformal Ridge is located in the central part of Sicily, near the town of Caltanissetta; its westward prolongation is crossed by the SI.RI.PRO. profile (Fig. 76) that has encountered Neogene to Pleistocene deposits (Fig. 104) partly relatable to the deformed sedimentary fill of a syn-tectonic basin system. This system goes back to the late Pliocene - early Pleistocene age as it was formed during the Gela Thrust Wedge development (Gela Nappe of Ogniben, 1969; Catalano et al., 1993a; Lickorish et al., 1999).
- The Gela Nappe is a geologically complex sector of the Sicilian thrust belt (see third day of this GFT) where the progressive activation of thrusts and backthrusts occurred from the end of the Pliocene. Beside its tectonic stacking, large scale (thousands of meters wavelength) structural depressions, enclosed between growing structural highs, developed. The syn-depositional growth of such structures is recorded in the Plio-Quaternary stratigraphic succession (Catalano et al., 1993b) which develops in a typical syn-tectonic stratal pattern (Vitale, 1996).
- Monte Capodarso provides a spectacular exposition of the Pleistocene basins stacking pattern, showing at the same time the underlying deformed and uplifted Late Neogene substrates. A point of stratigraphic interest

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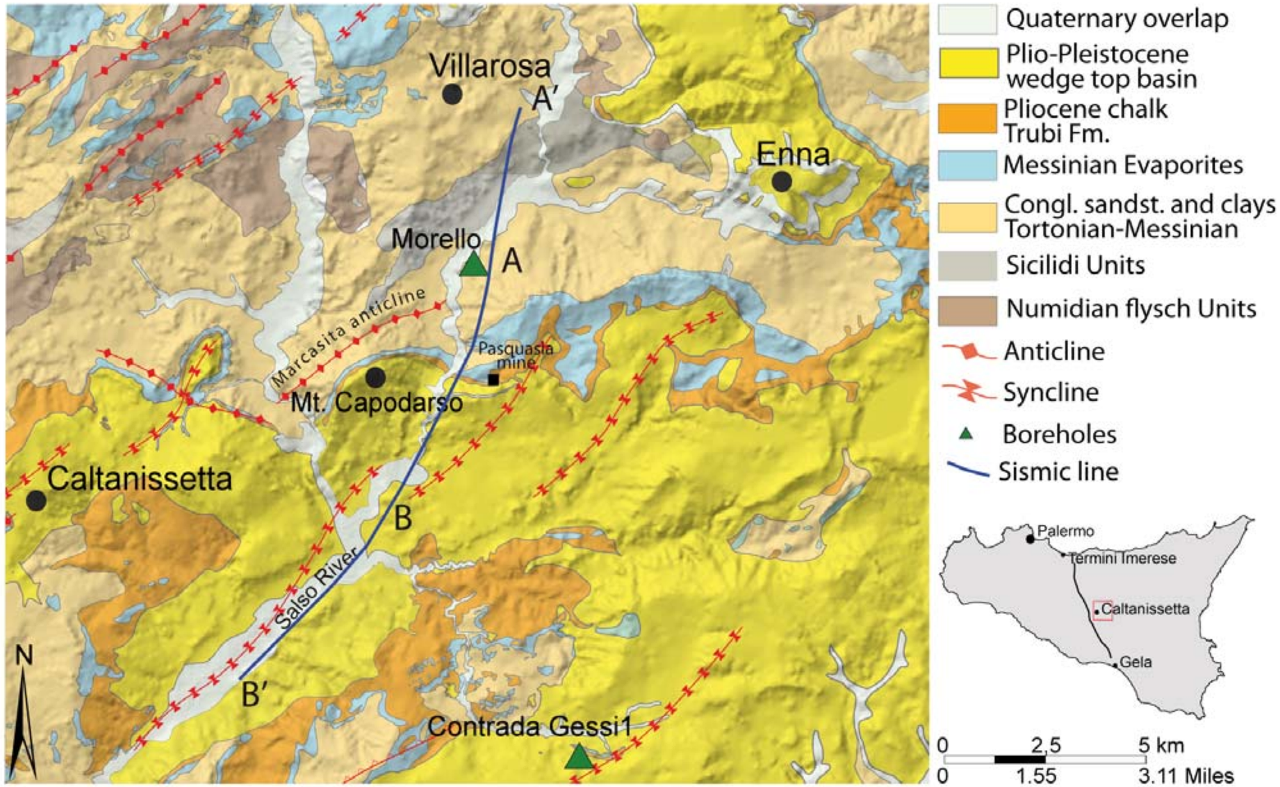
Fig. 104 - Simplified geological map of the area of interest showing the location of the trace of seismic section (blue line) shown in Figs 105a, b. Inset map shows the location of the SI.RI.PRO. profile.



is a sharp lithological boundary along the exposed succession that highlights the new chronostratigraphic boundary between Tertiary and Quaternary systems (Pliocene and Pleistocene series; Gibbard et al, 2010).

The subsurface structural setting of the area has been outlined by analyzing high-medium resolution seismic reflection profiles, calibrated by field surface and borehole data (Catalano et al., 2010).

A detailed seismostratigraphic analysis allowed us to reconstruct, as reported in Fig. 105a, a set of subsurface data, that discriminates the top of the following rock intervals: Geracello's marls, Capodarso's calcarenites, Enna marls, Trubi Fm. limestones, Gessoso–Solfifera group deposits, Tripoli Fm., upper Miocene marly-argillaceous clastic deposits (Terravecchia fm). Some of them can be recognized in the detailed geological map (Figs 104 and 105d).

Conversion from time to depth of the main horizons (Fig. 105b) was obtained by applying the average velocities deriving from well-velocity surveys. The analyzed section is also correlated with two geological cross-sections constructed on the basis of several potassic salt exploration wells (Fig. 105c). The following stratigraphic and structural features can be highlighted.

The Terravecchia fm appears offset by thrust faults together with its overlying Messinian evaporite and Trubi deposits (Figs 105a,b).

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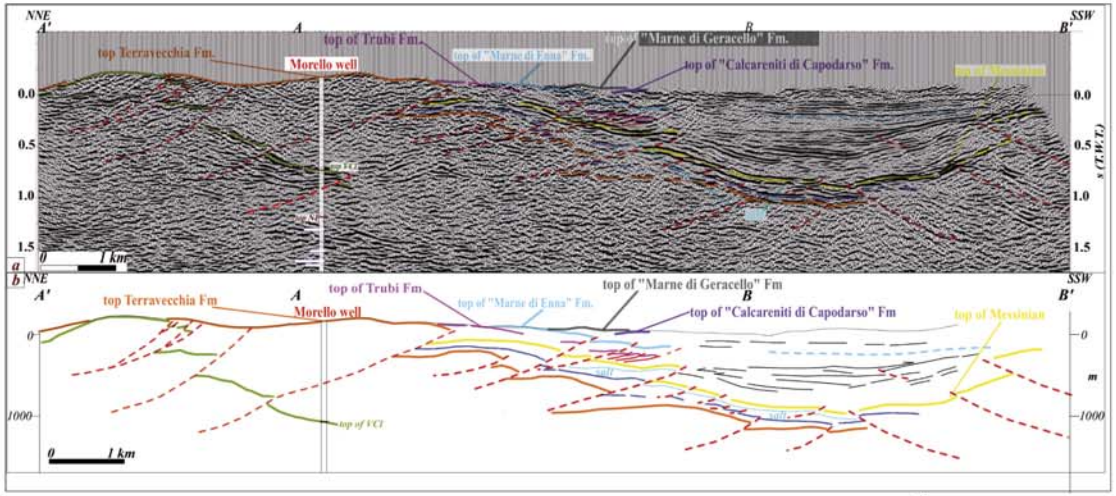
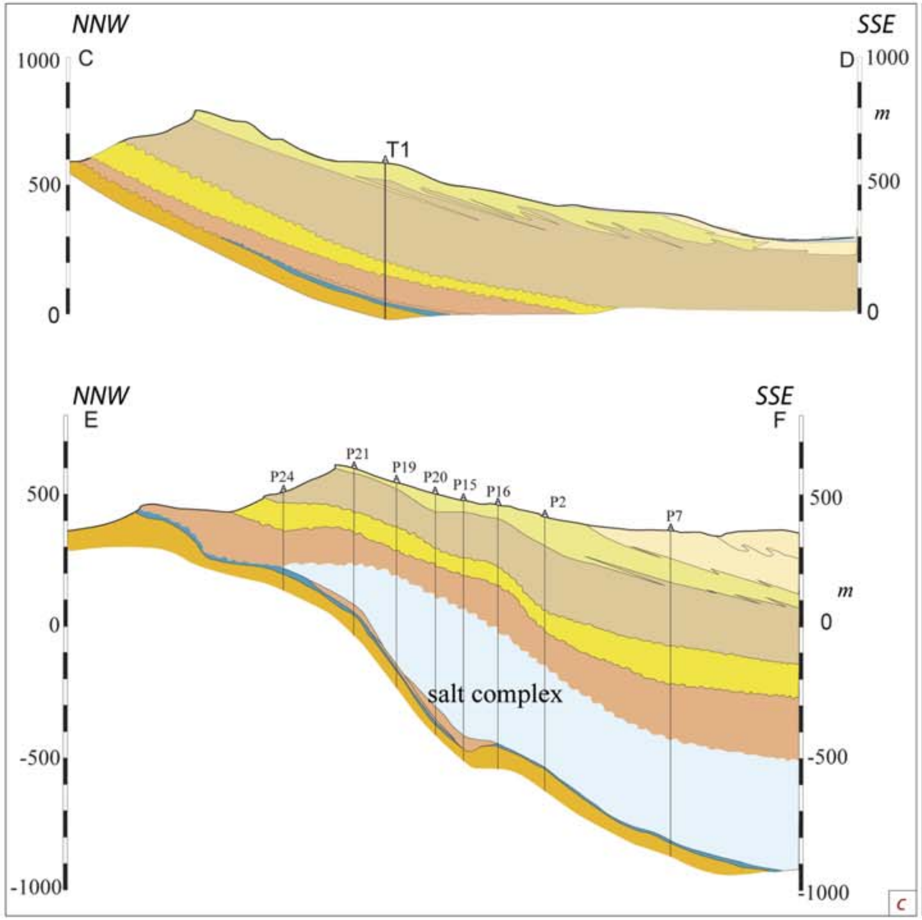
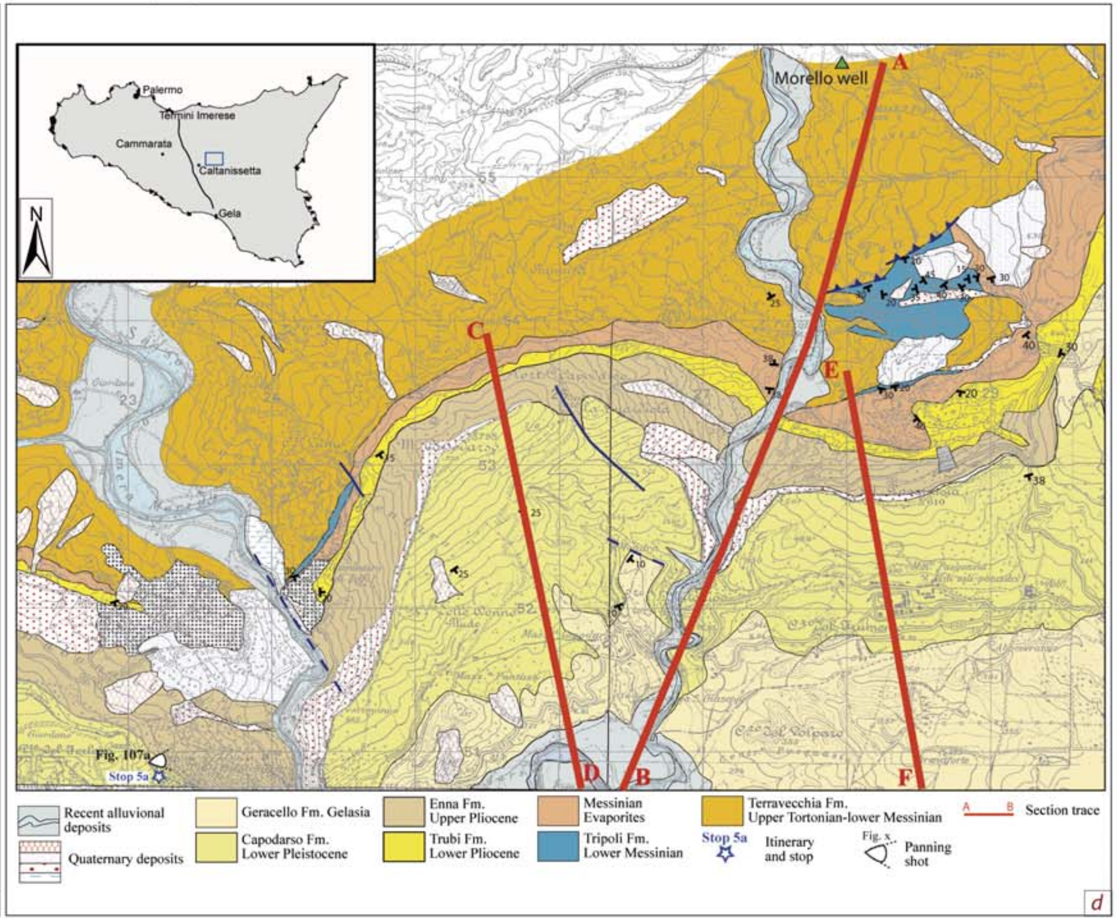


Fig. 105 - **a)** geoseismic section across the Mt Capodarso region and **b)** its schematic depth conversion (VCl: Varicoloured Clays, Late Cretaceous); **c)** geological cross-sections of Monte Capodarso ridge controlled by drill holes from the Pasquasia mine; **d)** geological map sheet of the Monte Capodarso area (mod. after Catalano et al., 2010a), depicting the traces of seismic and geological sections shown in a and c (red line).





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A well-developed basin of Plio-Pleistocene deposits (Catalano et al., 1998; Vitale, 1996) is shown along the analyzed NNE-trending profile. The Plio-Pleistocene sedimentary infill reaches a maximum thickness of about 1000 m in the depocentre; it thins toward the SSW and NNE flanks to form a roughly symmetrical "U"-shaped geometry. A prominent unconformity separates a higher, less deformed, sedimentary unit from a lower, folded and faulted unit. The older layers of the upper unit, located just above the unconformity, display NE-ward and SW-ward onlap terminations. The depocentre appears to have migrated SSW-ward suggesting a shift in sedimentation as sedimentary accretion proceeds. A SW-wards wedging out pattern and slow growth of sedimentary structures occurs implying a syn-tectonic sedimentation and reflects interaction between a tectonic uplift of the underlying thrust sheet and sedimentary supply and subsidence. The most recent, sub-horizontal reflectors could be correlated to the Lannari fm calcarenites and sands (see Fig. 106) that is the most recently known outcropping unit.

The morphology and infilling pattern strongly relate to the characteristics suggested by Zapata & Allmendinger (1996) and Ori & Friend (1984) to define their "thrust-top basins".

The formation of these basins is due to the development of deep-seated thrusts with related foreland and hinterland verging structures. The onset of the syntectonic latest Pliocene-Pleistocene wedge top basins, rapidly subsiding, took place after the deposition of the marly carbonate Trubi (end of early Pliocene). The age of this event is fixed at about 2.6 Ma.

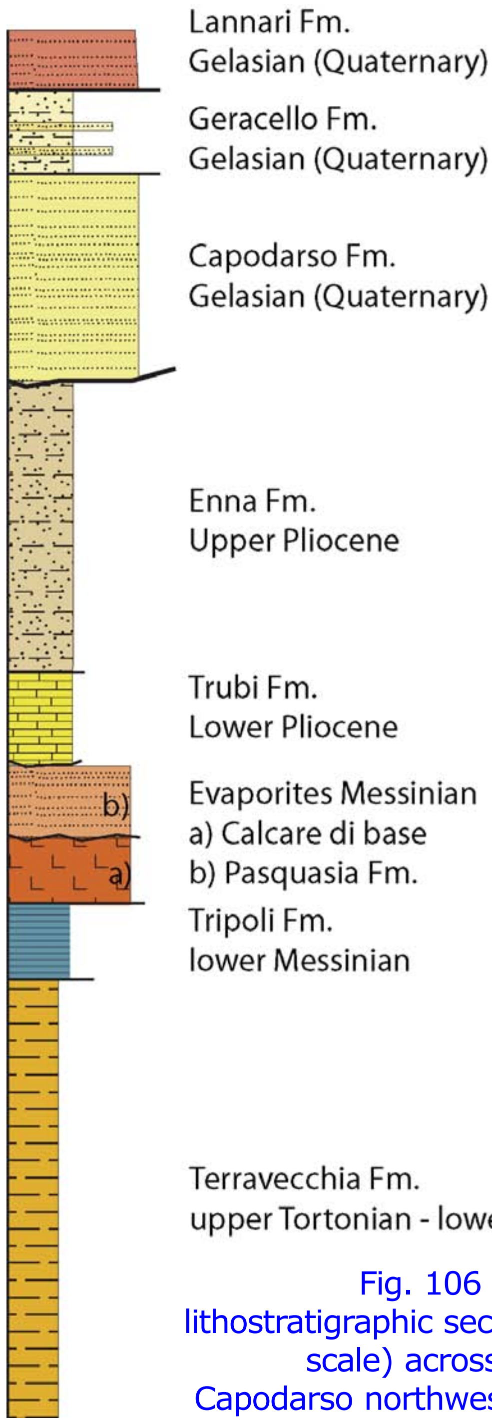

Fig. 106 - Columnar lithostratigraphic section (not to scale) across the Monte Capodarso northwestern slope.

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Stop 5a: Panoramic view of the Plio-Quaternary sedimentary succession from Pizzo del Ferlaro (Monte Sabbucina)

Main purpose

We will illustrate the sequence stratigraphic pattern of the Capodarso formation and its boundary features. We will also discuss the stacking pattern of the seven siliciclastic-carbonate cycles and the tectonic vs. eustatic control on the sedimentary processes during the early Pleistocene deposition.

Itinerary

Leaving the SS122 and walking for about 15 minutes, we will reach "Cozzo Ferlaro" on top of Monte Sabbucina (Fig. 75). A panoramic view of the northwestern side of Monte Capodarso will display the stratigraphic relationships between the underlying and overlying sedimentary units and the Capodarso fm.

Stratigraphy of the Mt Capodarso region

If we turn our attention to the northwestern escarpement of the Mt Capodarso, we can identify the local stratigraphic succession (Fig. 106) consisting, from the bottom, of uppermost Miocene, fine terrigenous deposits (Terravecchia fm), bituminous laminites (Tripoli Fm.), evaporites (Gessoso-Solfifera Group) that form a slight buttress along the escarpment profile, lower Pliocene deep-water pelagic chalks (Trubi Fm.), hemipelagic (slope to shelf margin) silty marls of the Enna fm (upper Pliocene), unconformably followed by Pleistocene deposits. The latter consist of (Fig. 107): i) a stack of seven siliciclastic-carbonate cycles pertaining to the Capodarso fm (Gelasian); ii) offshore marly and silty mudstones with thin calcarenitic layers of the Geracello fm (Gelasian); iii) calcarenites and siltstones (Gelasian) locally called Lannari fm.

Capodarso formation: internal arrangement

The Capodarso lithostratigraphic unit consists of greyish siltstones, interbedded with yellowish biocalcarenitic layers (Fig. 107). In the well-exposed sections, its internal facies arrangement is characterized by the cyclic alternation of seven siltite-calcarenite wedges showing, in turn, a progradational stratal pattern with distinct clinoforms. Clinoforms might be up to 25-27 m high and 1-2 km long in the direction of the progradation. Sediments are mainly bioclastic packstone and grainstone. Abundant fossil content (molluscs, echinoderms and "rodolithes"), several sedimentary and biological structures (ichnological suites) demonstrate a shallow-water

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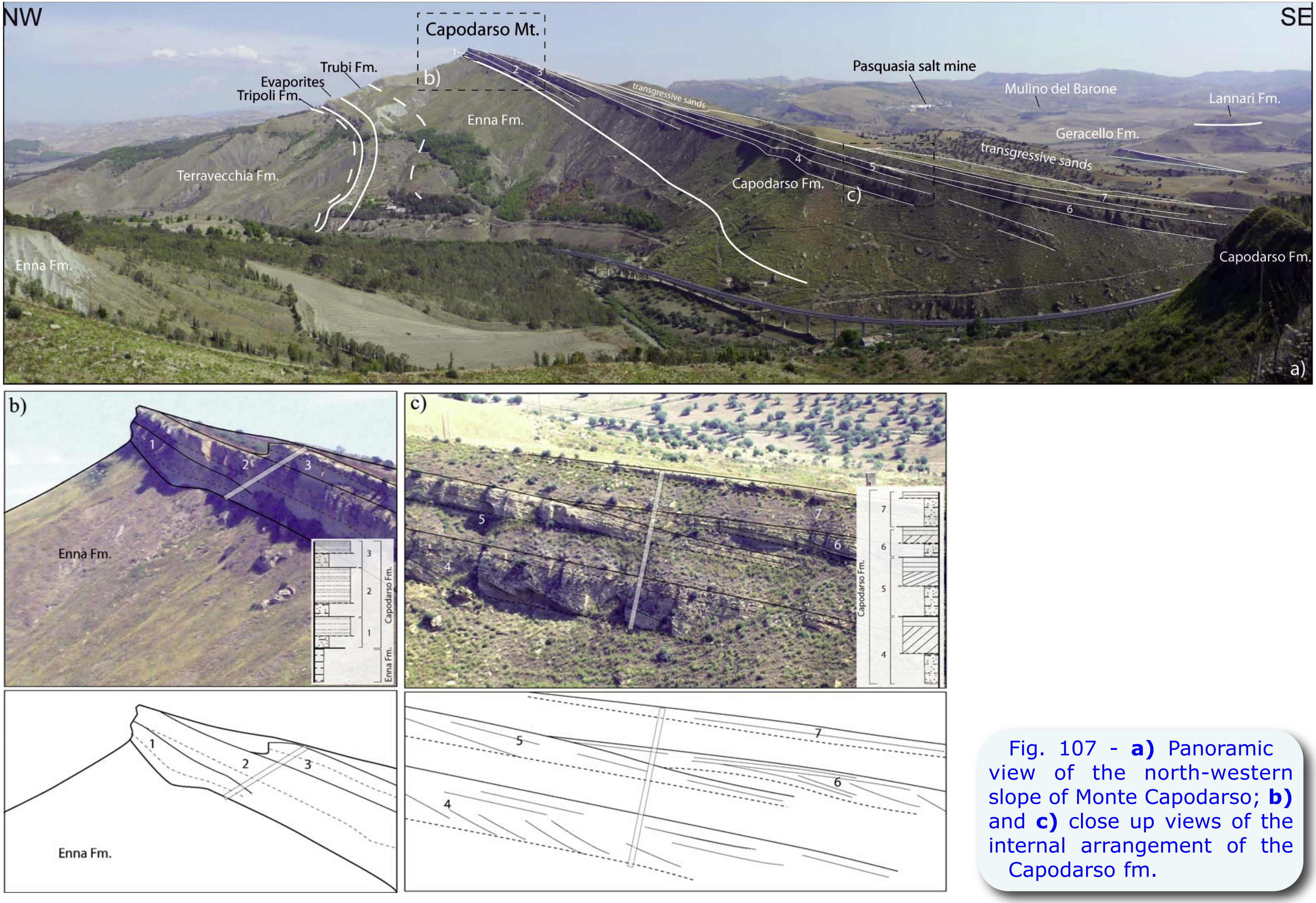

Fig. 107 - **a)** Panoramic view of the north-western slope of Monte Capodarso; **b)** and **c)** close up views of the internal arrangement of the Capodarso fm.

sedimentary environment where the deposition of the calcarenitic wedges took place. The calcarenitic bodies show lateral continuity for several kilometres; by occurring in a constant number over the whole area, they support possible relationships with a high frequency, astronomical (Milankovitch) cyclicity. Integration of high resolution biochronological data with the correlation and numbering of siliciclastic-carbonate cycles, suggests that the cyclicity of the Capodarso fm turns out to be mainly forced by the orbital obliquity changes (Catalano et al., 1998), that is each siliciclastic-carbonate cycle had been deposited during a time span of about 41.000 years.

Sequence stratigraphy

This sedimentary cyclicity clearly indicates subsequent, periodical, accommodation space changes related to the sea level fluctuations. More information regarding the stratigraphic and sedimentary evolution was obtained from a sequence stratigraphy analysis performed by Catalano et al. (1993, 1998) and Vitale (1996, 1998). In a sequence stratigraphic interpretation, the Gelasian succession, including the Capodarso and Geracello fms, better describes a complete IV order depositional sequence (*sensu* Vail et al., 1991), named here Capodarso Sequence (Fig. 108), spanning about 400.000 years.

The lower boundary of the Capodarso Sequence is an impressive unconformity (age dated to about 2.5 Ma by Vitale, 1996) corresponding to an abrupt, erosional surface between the shelfal carbonate sandstones and the underlying hemipelagic shales of the Enna fm (Figs 106 and 107). At the top, the Capodarso Sequence is truncated by an unconformity (age dated to about 2.1 Ma by

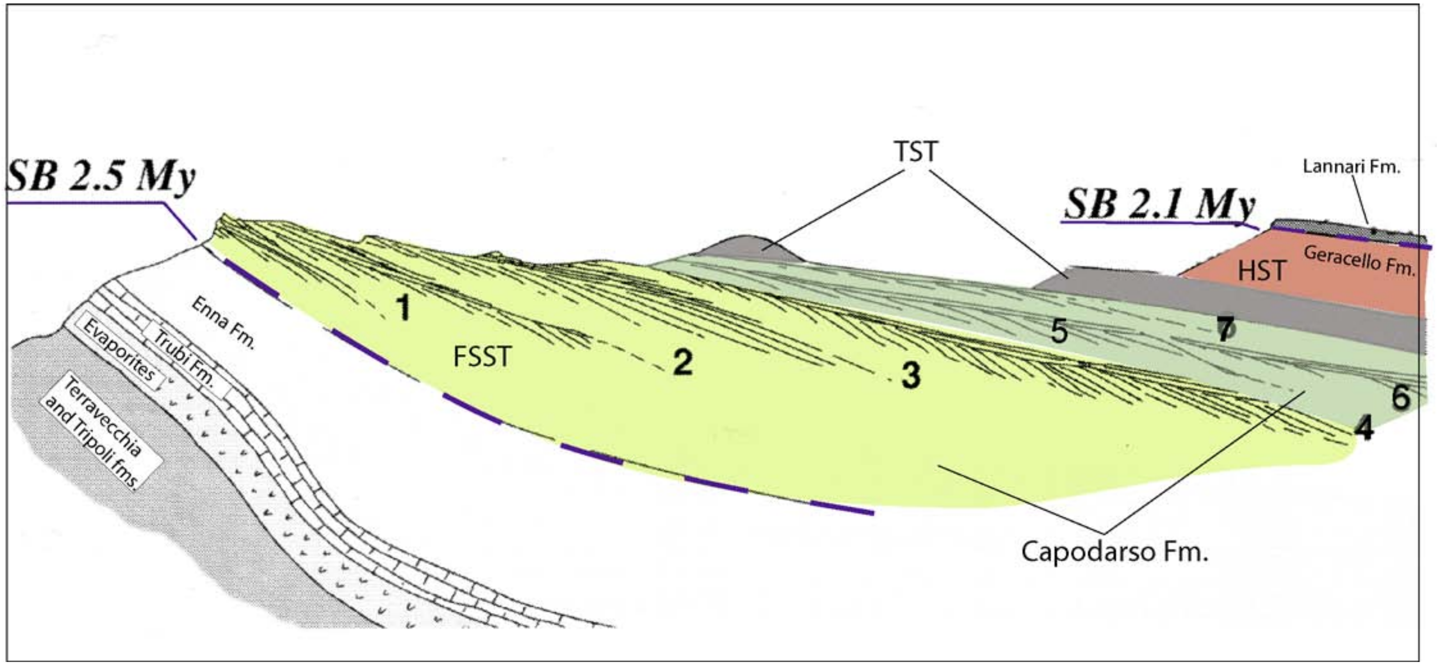

Fig. 108 - Scheme showing the internal organization in the systems tract of the Capodarso Sequence (mod. from Catalano et al., 1993a).

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Catalano et al., 1993a) which corresponds to the sharp lithologic boundary separating the calcarenites of the Lannari fm (above) from the silty mudstones of the Geracello fm (below).
On the basis of the integrated biochronological data (Vitale, 1996 and Catalano et al., 1998), the lowermost carbonate wedge has been correlated to the isotopic stage 100 (Raymo et al., 1989); therefore, the base of the Capodarso Sequence is nearly relatable to the new Pliocene-Quaternary boundary (base of Gelasian stage, corresponding to Marine Isotope Stage 103 and to an absolute age of 2.58 Ma; Tab. 4; Gibbard et al., 2010).
The stacking pattern of the siliciclastic-carbonate couplets allowed us to distinguish the following system tracts inside the Capodarso Sequence (Fig. 108):
- the cycles 1 to 6 exhibit an offlapping stacking pattern characterized by an enhanced downward shift of the up-dip termination of the sedimentary wedges; therefore, this cycle set, deposited in a context of forced regression, corresponds to the Falling Stage Systems Tract (Plint and Nummedal, 2000);
- the up-dip termination of the cycle 7 indicates a coastal encroachment (with respect to the underlying cycle 6) followed by deposition of more distal fine sands in the uppermost portion of the Capodarso fm; therefore, we can assign the 7th cycle, with the overlaying fine sands, to the Transgressive Systems Tract;
- upwards, the marly- and silty-mudstones with shelfal sandy layers (Geracello fm) could represent the Highstand Systems Tract.

Each siliclastic-carbonate couplet pertaining to the Capodarso Sequence does not represent a classic parasequence (Van Wagoner et al., 1987), but is a simple sequence (*sensu* Vail et al., 1991), generated in response to higher-order sea level changes, as expected during a forced regression (Plint and Nummedal, 2000).
Detailed sequence stratigraphic interpretation of the seven biocalcarenitic wedges will be discussed at Stop 5b.

The syn-tectonic stratal pattern

In the Monte Capodarso region, Pliocene strata overlaying the upper Miocene deformed sedimentary units, were deposited widely in wedge-top basins during active compression (Figs 105, 108; Catalano et al. 1993). The syn-sedimentary tectonics that occurred during the deposition of the Capodarso fm are primarily proven by the growth stacking pattern, coherent with the development of a progressive syn-tectonic unconformity which accounts for an about 15°-25° discordance between the lower portion of the filling Capodarso unit and the overlying Lannari Calcarenites (Fig. 108). The up-dip termination of the individual calcarenitic wedge migrated along the syncline limb, generating a slightly divergent fan, with an upsection decrease of the dip of the carbonate wedge. Strata, younger than 2 Ma (post-Gelasian), appear unfolded or less deformed.

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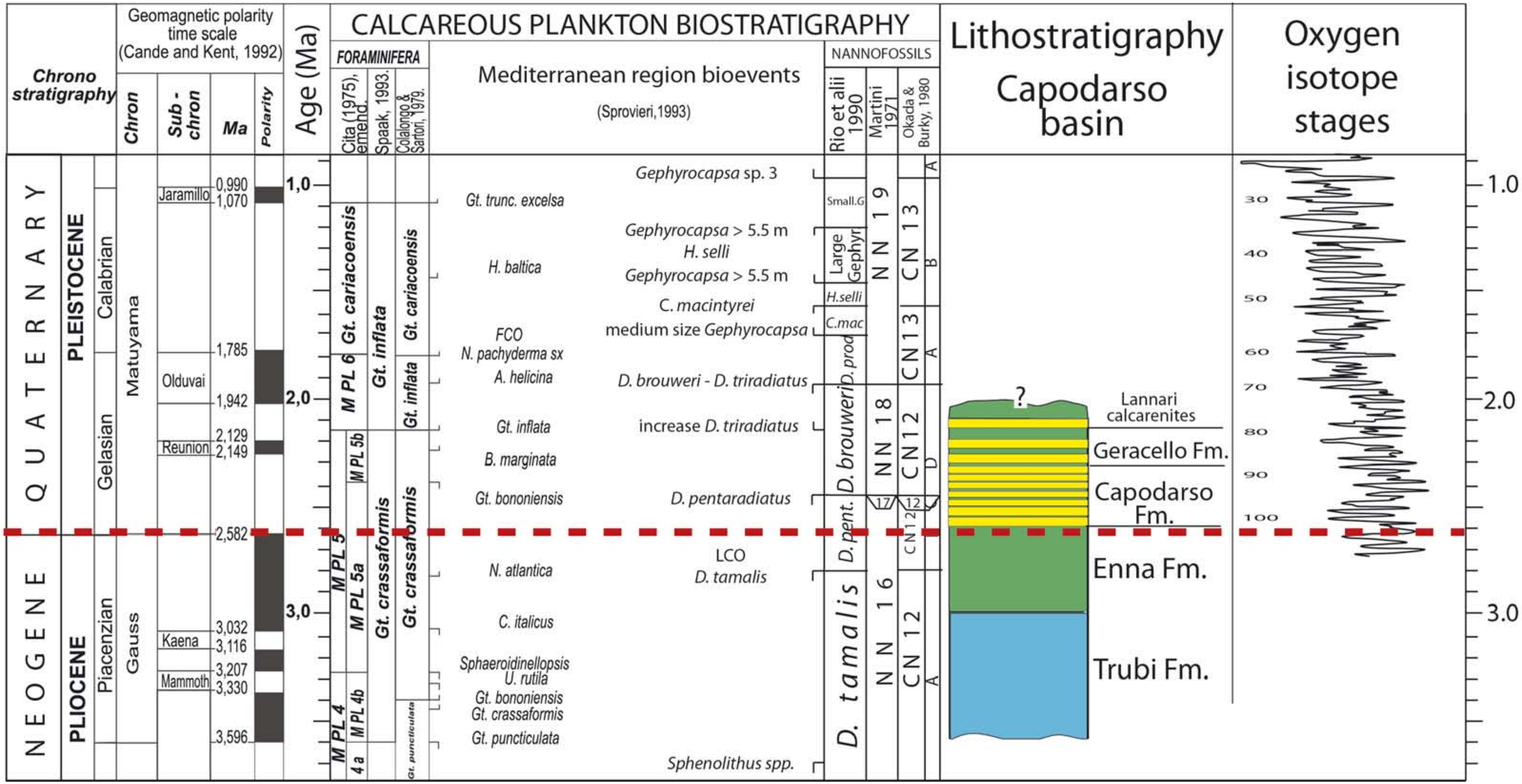
Tab. 4 - Integrated chrono-, magneto-, isotope- and bio-stratigraphic scheme supporting the stratigraphic analysis of the Mount Capodarso Pliocene – Lower Pleistocene sedimentary succession. The siliciclastic-carbonate wedges of the Capodarso fm have been correlated to the Oxygen isotope stages. The red dashed line highlights the Neogene – Quaternary boundary.



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These peculiar features have been related to the syn-depositional growth of a fault-related anticline that involved the Late Miocene-Early Pleistocene substrate (Fig. 105). The occurrence of local erosional truncations associated with the folds growth (Fig. 109) represent more evidence of syn-depositional tectonics.
The tectonic uplift rate may have exceeded the eustatic rate, generating local unconformities or considerable stratal expansions. Almost in the expanded successions, significant pulses in the syn-sedimentary growth of tectonic structures occur in very short time spans: tectonic features, having the amplitude of tens of meters, have been generated within the duration of Milankovitch cycles (average rate: 1.5 m/ky; Vitale, 1996; 1998).

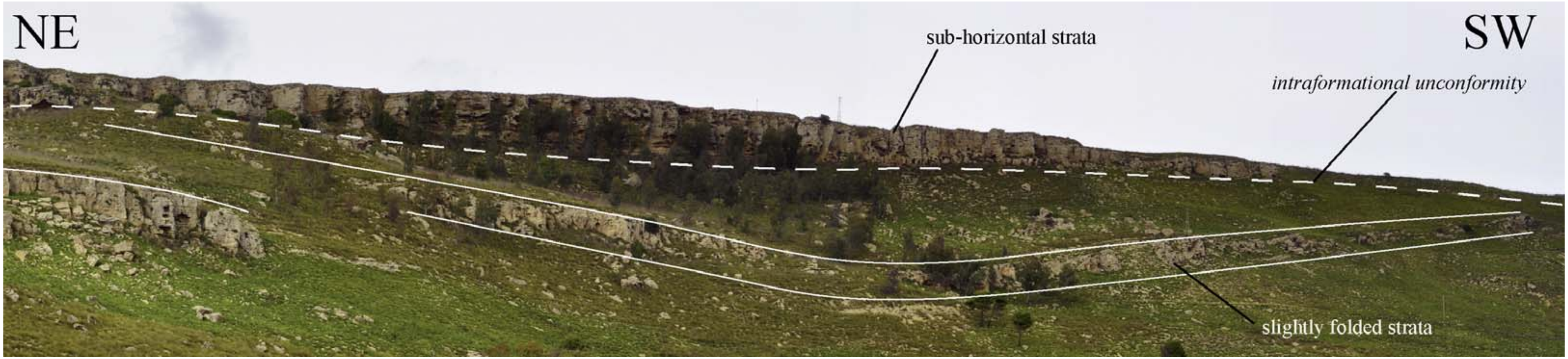

Fig. 109 - Local tectonic unconformity developed within the Capodarso fm strata (southeastern escarpment of Monte Carangiaro).

Stop 5b: Close-up of the Capodarso fm "sequences" at Mulino del Barone: sequence stratigraphy interpretation of the carbonate-siliciclastic cycles

Main purpose

The good quality of the outcrops and their lateral continuity allow us to give a detailed description of lithofacies and bounding surfaces as well as to formulate some hypotheses about their sequence stratigraphic significance.

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Itinerary

Moving from Stop 5a towards the Capodarso bridge, we will proceed along the SP 122 road towards the town of Enna. After about two kilometres from the Pasquasia mine, turn right into a secondary road where we are going to closely observe the calcarenite-siltite cycles representative of the Capodarso fm while going through its curves (Fig. 110).

Clastic-carbonate cycles

Sedimentology and facies

Each cycle consists of a mudstone unit and a carbonatic wedge. Two units can be separated to better identify the vertical profile of each wedge (Fig. 111a): (a) a clinoform unit and (b) a capping, sheet-like, sub-horizontal unit (Vitale, 1996, 1998; Massari and Chiocci, 2006):

a) the wedge-shaped clinoformed unit displays spectacular, large, oblique and sigmoid clinoforms dipping seawards at angles of up to 19°. The biocalcarenites are grainstones, rudstones, and packstones, mainly composed of generally well-sorted, heterozoan skeletal particles. Foreset beds pass downdip to seaward-thinning and gradually pinching-out bottomset beds, that alternate with siliciclastic mudstones. A proximal segment, corresponding to a brief initial phase of the development of the sedimentary body, displays an aggradational stratal pattern, passing upwards to low-angle climbing, prograding horizons (Fig. 111b).

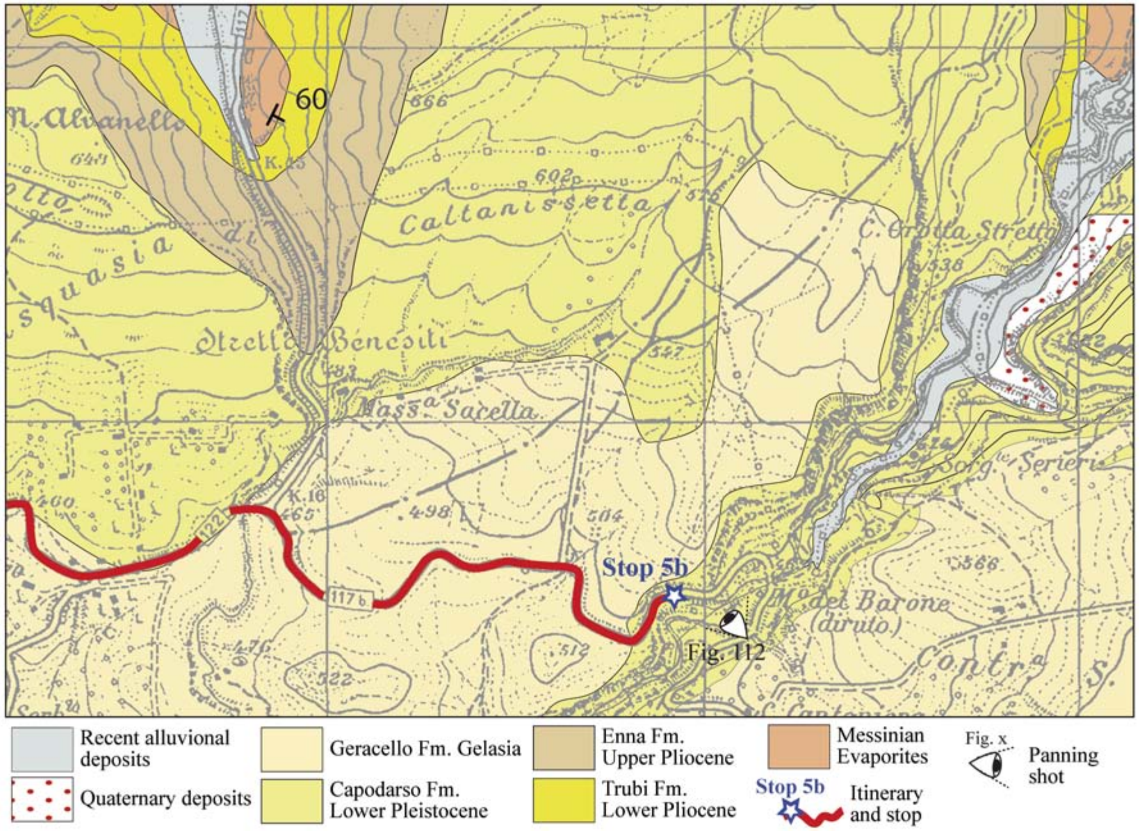

Fig. 110 - Geological map showing the location of Stop 5b.

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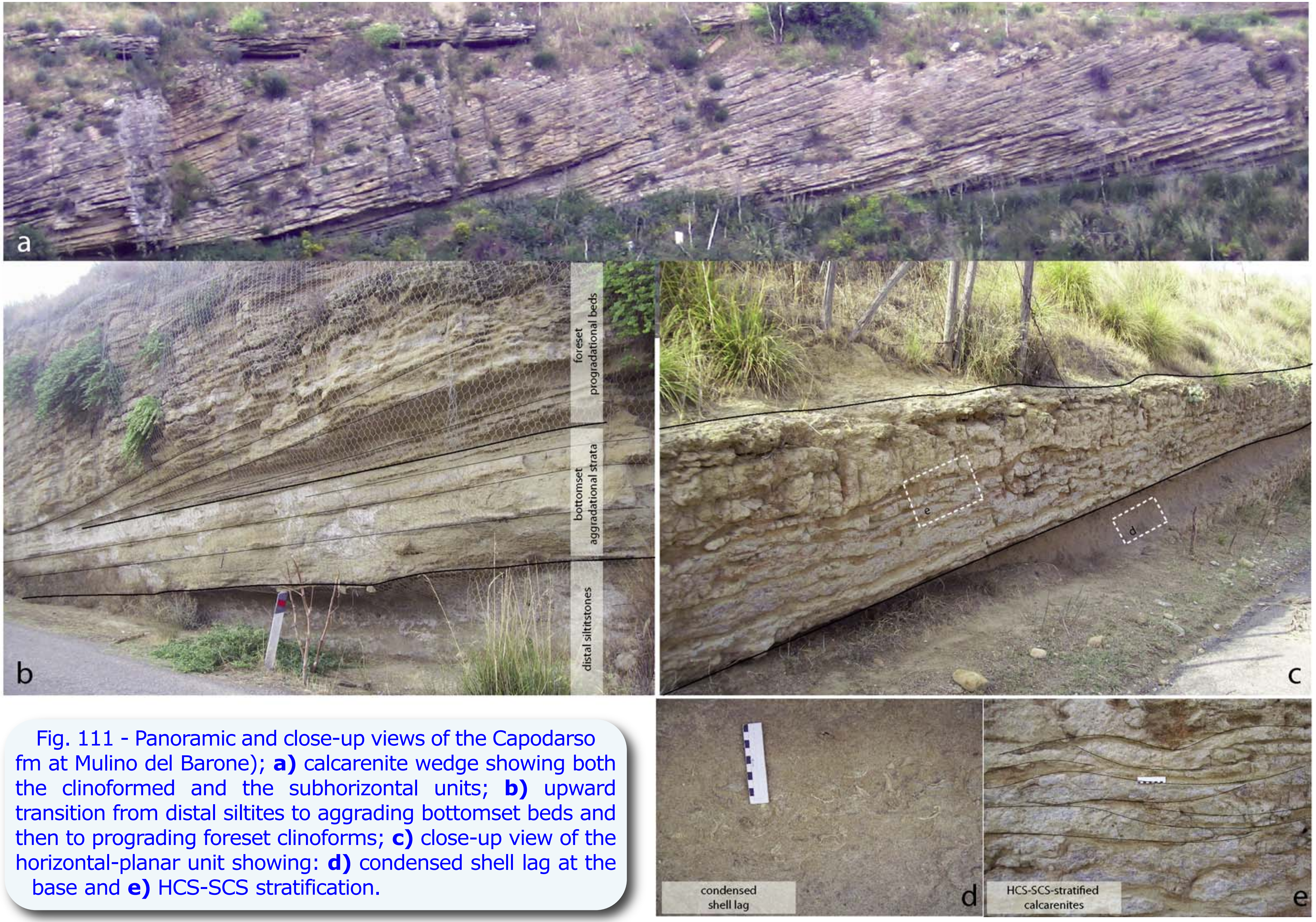

Fig. 111 - Panoramic and close-up views of the Capodarso fm at Mulino del Barone); **a)** calcarenite wedge showing both the clinoformed and the subhorizontal units; **b)** upward transition from distal siltites to aggrading bottomset beds and then to prograding foreset clinoforms; **c)** close-up view of the horizontal-planar unit showing: **d)** condensed shell lag at the base and **e)** HCS-SCS stratification.

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Facies, within the foresets, include a few decimetre-thick couplets formed by a basal massive or normally grading packstone layer and an upper silty layer with bioclastic sandstones, often laminated. These beds may have been deposited by high-concentration, suspended clouds (Colella & Vitale, 1998).
b) a sheet-like, sub-horizontal unit, commonly capping the clinoform units (Fig. 111c). Two intervals can be differentiated (Massari and D'Alessandro, 2009): (1) a locally observable poorly cemented, silty, highly fossiliferous condensed band (50–70 cm-thick, Fig. 111d) and (2) a biocalcarenitic bed package 2.5m-thick (gradual to erosional basal contact, hummocky and swaley cross-stratification, and local pavements of large bivalve shells like oysters and pectinids, Fig. 111e). The landward-onlapping termination of this bed package occurs updip of the landward pinch-out of the fossiliferous band.
The planar surface at the top of the clinoformed units records the progradation abandonment stage.
Lack of fresh-water cement and subaerial elaboration of the surface suggests the clinoformed wedges did not undergo subaerial exposure. Due to the gentle erosion at the expense of still soft sediment, the sharp surface at the top of the clinoformed unit can be regarded as a flooding "transgressive" surface (Massari & D'Alessandro, 2009). It marks an abrupt deepening of the sedimentary facies from shoreface to offshore/transition.

Depositional environment and processes

Foreset deposits have been mainly emplaced by gravity flow, triggered by storm-driven currents that re-sedimented down the slope the sediments mainly produced in the upper shoreface (Colella & Vitale, 1998). Deposition of carbonate wedges presumably occurred on a wave- and storm-dominated microtidal margin with long fetch; they are thought to be the sedimentary expression of a grain—producing, cool-water carbonate factory (Massari & D'Alessandro, 2009), occurring as distally steepened prograding ramps (Massari & Chiocci, 2006).

Sequence stratigraphic significance of high-frequency cyclicity

Each mudstone-carbonate cycle is interpreted as representing a high-frequency (maybe 5th order) depositional sequence constituted by (Fig. 112): i) an early and late Highstand Systems Tract (uppermost part of the mudstone unit and the "proximal" segment of the clinoformed wedge); ii) a Falling Stage Systems Tract (main bulk of the prograding carbonate wedge); iii) a TST (sub-horizontal unit) bounded at the base by a

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flooding "trangressive" surface and at the top by a marine flooding surface; iv) a TST to HST (lower mudstone unit). No LST deposits outcrop in the study section probably because they were removed or because they are preserved south of the stop area.

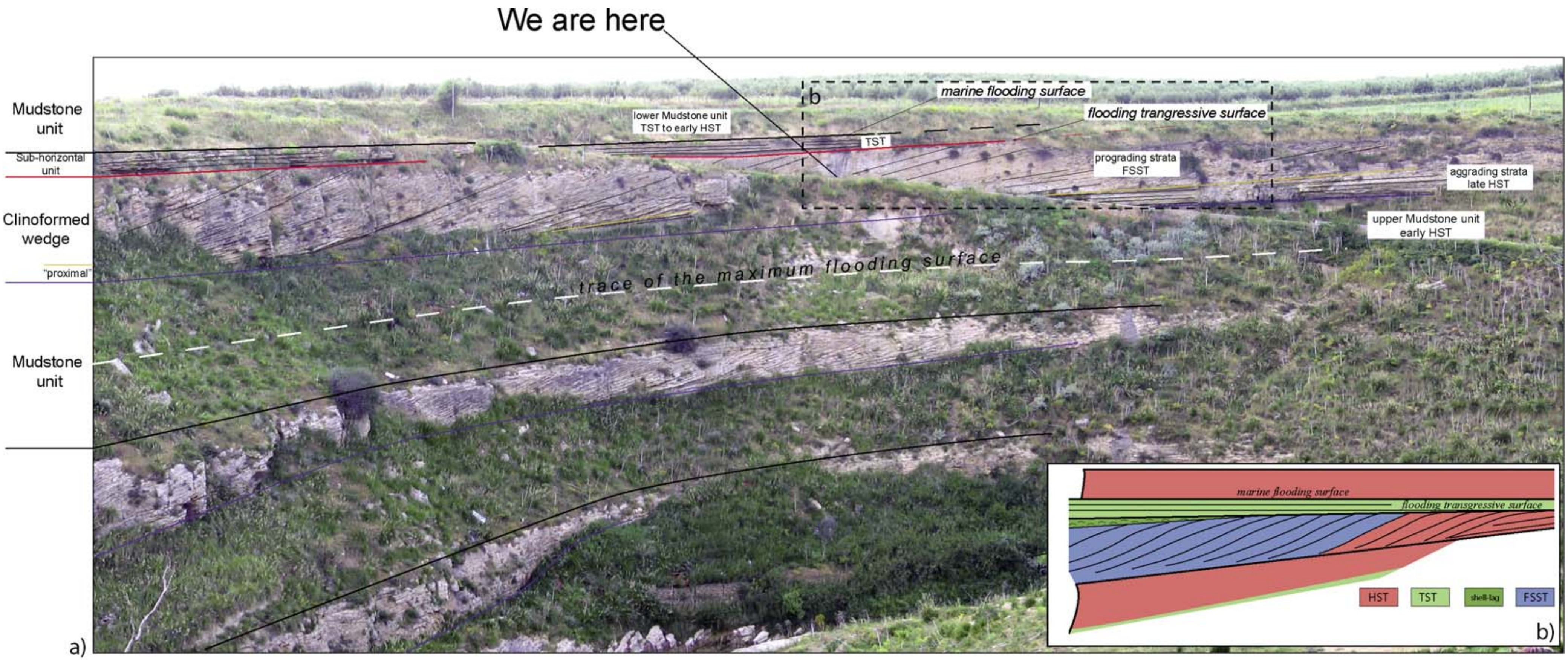

Fig. 112 - Panoramic view and line drawing **(a)** showing a tentative sequence stratigraphic interpretation **(b)** of the Capodarso Sequence's cycles outcropping at Mulino del Barone.

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THIRD DAY

The Gela Thrust System and the Iblean foreland. Syntectonic and foredeep Pleistocene basins

Mauro Agate, Cinzia Albanese, Giuseppe Avellone, Raimondo Catalano, Maurizio Gasparo Morticelli, Attilio Sulli, Vera Valenti

Main Purpose

Main aim of the day is to illustrate the geological setting of the Gela Thrust System both along the outcropping Settefarine thrust and in subsurface, buried in the Gela Plain, and to show the geological setting of the Gela foredeep and Iblean foreland.

Itinerary

Leaving Pergusa we will go southward, crossing for a long way a region where deformed Messinian evaporites outcrop (Fig. 113).

Along the road to Gela we will reach the **Stop 1** at the Castelluccio hill, at the northern edge of the Gela plain. There we could observe the outcropping Iblean foreland facing the frontal thrust wedge. Subsurface setting of the Gela Thrust System will be shown with the help of some geoseismic sections calibrated by several drill holes (see Sulli, this guidebook, pp. 111-116).

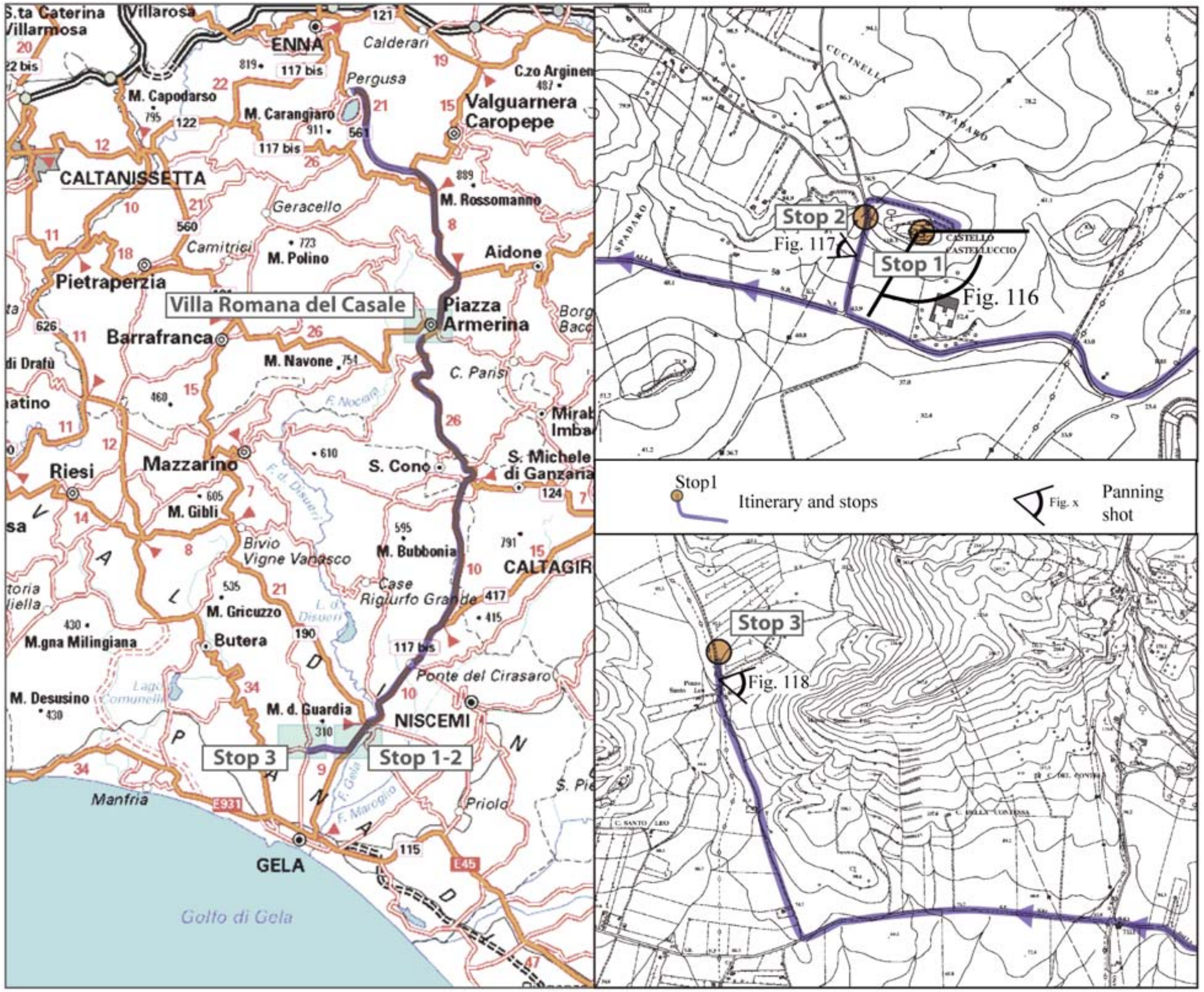

Fig. 113 - Road map of the third day itinerary.

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Stop 2 will be dedicated to the illustration of the tectonic setting of the high angle Settefarine thrust.
Stop 3 will be worked out at the starting point of the SI.RI.PRO. Profile (see also Catalano et al., this guidebook, pp. 13-50) to have a direct knowledge of the plunging carbonate foreland and its structural relationships with the frontal part of the Gela Thrust System and its overlying different types of syntectonic basins.

Forewords. The Gela Thrust System and the Iblean foreland

The Gela Thrust System is a tectonic wedge of incompetent sedimentary rocks (late Mesozoic-early Pleistocene) partly known as the "Gela Nappe" (Ogniben, 1960; Roure et al., 1990; Grasso & Butler, 1991). We use the term "Gela Thrust System" extensively to indicate an accretionary wedge (Figs 114, 115) of a) polyphasally deformed carbonates and terrigenous cover deposited in more internal domains (Mesozoic-Cenozoic Sicilide succession and Oligocene-Miocene flysch); b) Lower Tortonian to lower Pleistocene migrating foreland basin deposits. Centred in the Gela region of southern Sicily, the wedge occurs predominantly in east-central and southern Sicily from Catania to Sciacca, where it reaches up to 3 km in thickness, and along the NE-SW border of the Iblean plateau. It thins towards the submerged thrust front in the southern Sicily offshore.
The main transport direction was toward the SE; widespread backthrust features are exposed in the Southwestern Sicily rim (Catalano et al., 1993a) as well as further east (Grasso & Butler, 1991).
The southerly displacement of the wedge is related to Late Pliocene transpressional tectonics in the structural hinterland. It was active up to middle Pleistocene in the most external thrust fronts (Trincardi & Argnani, 1990; Catalano et al., 1993b). Wedge-top and foreland basins, growing on the structural edifice, are briefly illustrated in Sulli, this guidebook, pp. 111-116.

STOP 1 - Castelluccio hill. Panoramic view of the Gela plain

The panoramic view of the Gela plain allows to illustrate the geological setting of the frontal area of the Sicilian-Maghrebian chain. From NW to SE we can observe (Fig. 116):
1) the outcrop of the Gela Nappe, through the Settefarine thrust. This anticline represents the more advanced outcrop of the Gela thrust wedge. Subsurface data show at depth the tectonic body which can be continued more southeastward, where it is buried in the Gela plain, in the area between Gela and Dirillo river. This sector was progressively shortened during the late Miocene-Pleistocene (Fig. 115). The dominant structures are represented by NE-SW and locally E-W trending folds relatable to N-dipping both blind and outcropping thrust faults (Fig. 114).

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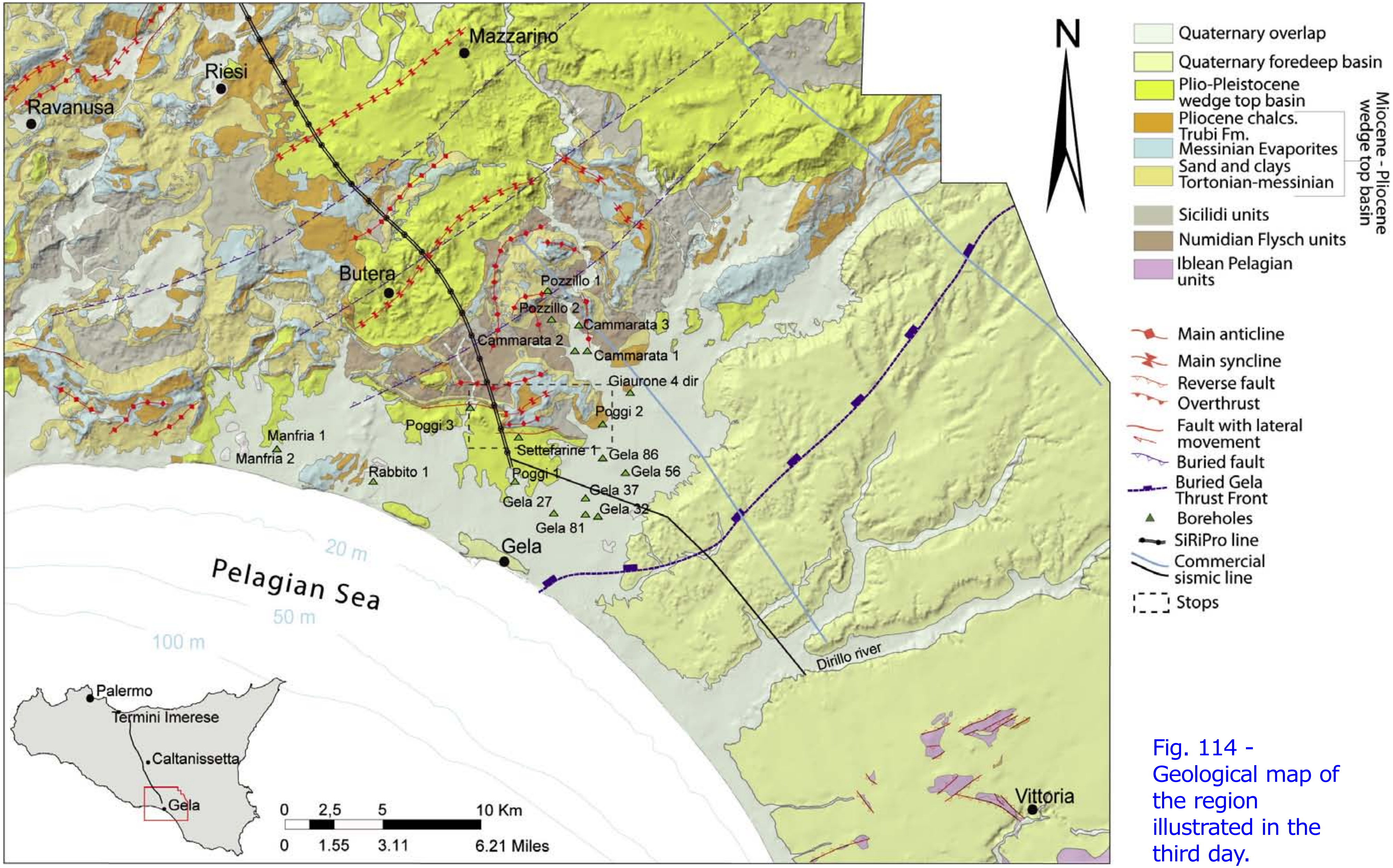

Fig. 114 - Geological map of the region illustrated in the third day.

In the Settefarine well, located south of the Castelluccio hill, Plio-Pleistocene deposits appear to be redoubled by thrust planes. In this area the outcropping Oligocene-Gelasian successions are involved in compressional deformation, mainly E-W trending (Figs 114, 115). The asymmetric E-W trending fold systems, recognized

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near the Poggi 3 well, rotate to NE-SW directions towards the Giaurone well. Axial culminations and depressions characterize the outcropping folds.

2) The Gela Plain, covered by Pleistocene deposits, which hide a complex setting, well revealed by subsurface data. In detail, between the Gela and Dirillo rivers the syntectonic deposits of the Settefarine wedge-top basin rest on the frontal units of the Gela thrust wedge. Between the Dirillo river and Vittoria town the Gela foredeep basin develops (Fig. 114); its deposits rest both on the thrust sheets and on the Iblean foreland successions; 3) the Vittoria salient, consisting of Oligocene-Miocene calcarenites and marls of the Ragusa formation. The structural setting of this unit, which appears deformed and faulted in outcrop (see Sulli, this guidebook, Fig. 49), is well imaged in subsurface, where it can be correlated to the pop-up structures characterizing the Iblean foreland successions (see Sulli, this guidebook, Fig. 48a, b).

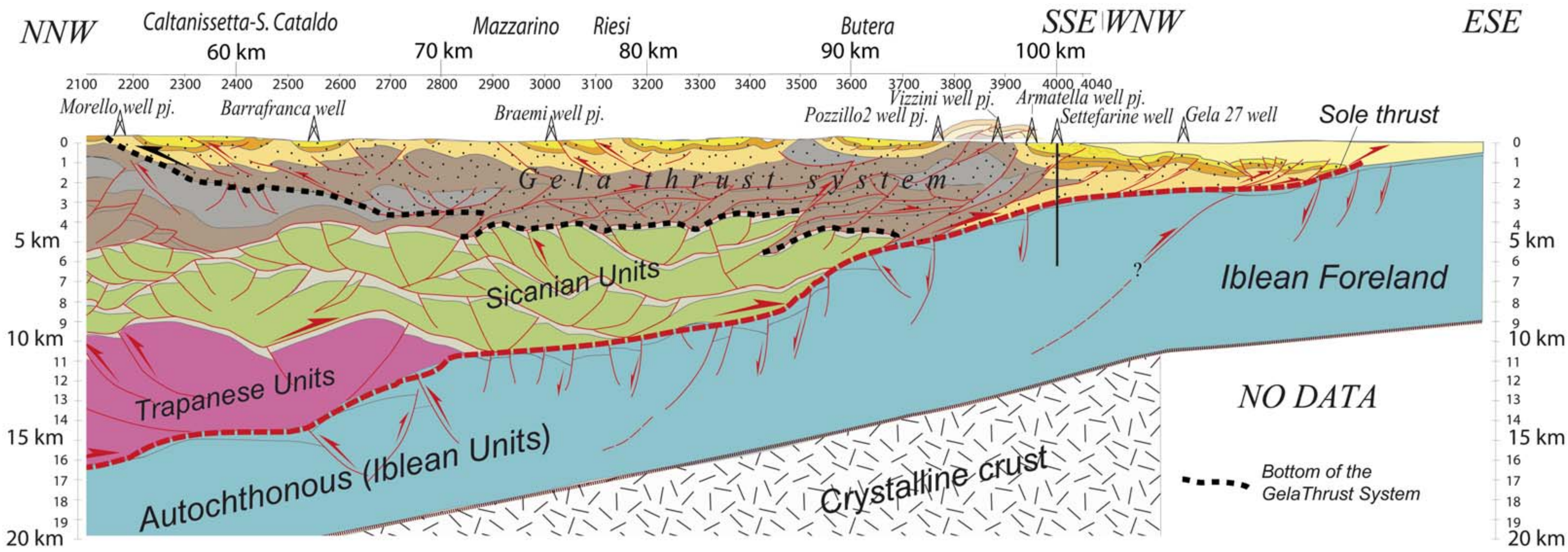

Fig. 115 - The southern sector of the interpreted SI.RI.PRO. seismic profile (see trace in Fig. 114). It clearly shows the main characters of the Gela Thrust System.

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Fig. 116 - Panoramic overview of the outcropping Iblean foreland (farther southwards) and the flat Gela plain.

STOP 2 - The Settefarine thrust. Tectonic setting

Near the Settefarine well an E-W trending thrust (Fig. 117) dissects the top of the Messinian evaporites and lower Pliocene limestones (Trubi) and the base of the Gelasian sandy clays (Lickorish et al., 1999). Mesostructural analysis of the thrust surface suggests a SSE-directed tectonic transport.

The Gela Nappe shows in this area three main thrust wedges, whose progressive deformation is outlined by the involvement of rocks progressively younger going towards the present-day foredeep. The reverse fault here observed is part of this complex embricate fan, but it doesn't represent the present-day front of the nappe (see Sulli, this guidebook, Fig. 48a).

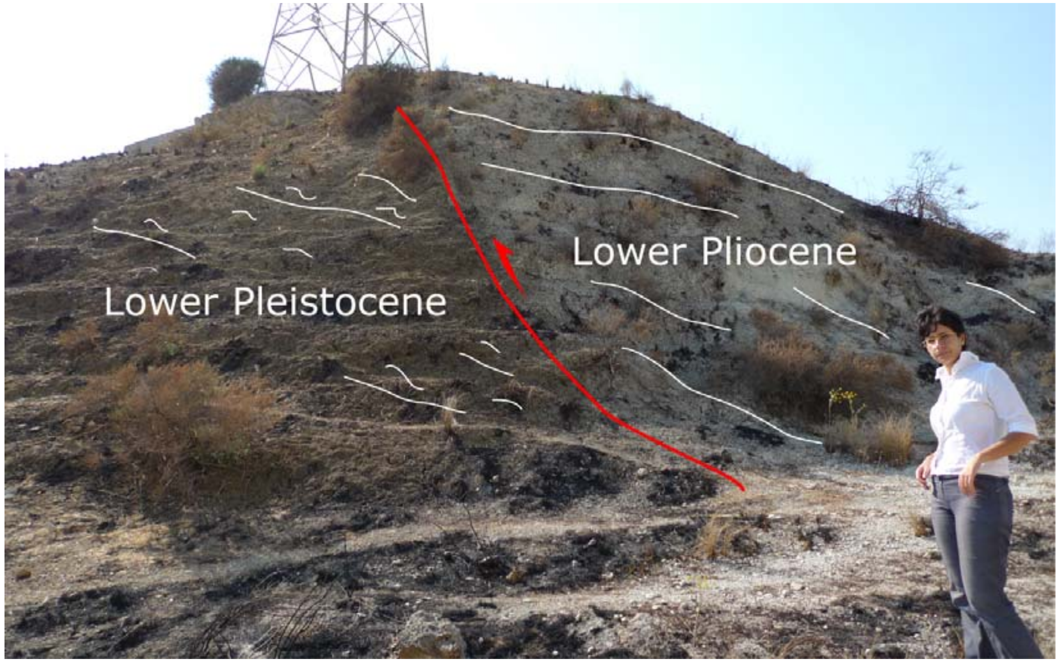

Fig. 117 - The high angle reverse fault (Settefarine thrust) along which the Messianian-lower Pliocene evaporites, limestones and marls overthrust the lower Pleistocene clays (Castelluccio hill area).

STOP 3 - The SE-ward plunging Iblean foreland and the Butera thrust-top basin

Along the Settefarine thrust, evidenced by a sharp morphological gradient at the base of the hill alignment (Fig. 118), we can observe Messinian-lower Pliocene evaporites, limestones and marls overthrusting the lower Pleistocene clays.

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At the starting point of the SI.RI.PRO. Profile we'll illustrate, by means of the geological interpretation of the crustal seismic line, the characteristics of the Iblean carbonate foreland and the structural relationships with the Gela Thrust System and overlying basins (wedge-top and foredeep basins).

Fig. 118 - The Settefarine thrust outcropping at the base of Castelluccio hill alignment.

The Iblean crust

The buried Iblean foreland units form a steep regional monocline, believed to be deformed by NW-dipping normal faults, locally reactivated by successive compressional tectonics (Bello et al., 2000). At the southern edge of the profile, the crystalline basement is at around 5.5 s/twt and the Moho at about 9–10 s/twt, corresponding approximately to 25 km depth, with 15–16 km of not sedimentary crust (Chironi et al., 2000; Catalano et al., 2000a). The Iblean crust deepens and thins towards the Caltanissetta depression, where the Moho quickly reaches 12 s/twt (5 s below the Iblean carbonate platform) at the depression centre. Then, it deeps gently northwards, attaining about 14 s/twt beneath the Tyrrhenian coastline. A complex interaction between the northern thickened crystalline crust and southern Sicilian crust occurs in correspondence of the Caltanissetta depression with a strong flexure and a pronounced thinning of the foreland crust.

In the southern sector the SI.RI.PRO. profile images the Gela Nappe, the outermost and youngest wedge of the Sicilian FTB (Catalano et al., 1993b; Lickorish et al., 1999; Ghisetti et al., 2009) overthrusting the NW-dipping Iblean foreland.

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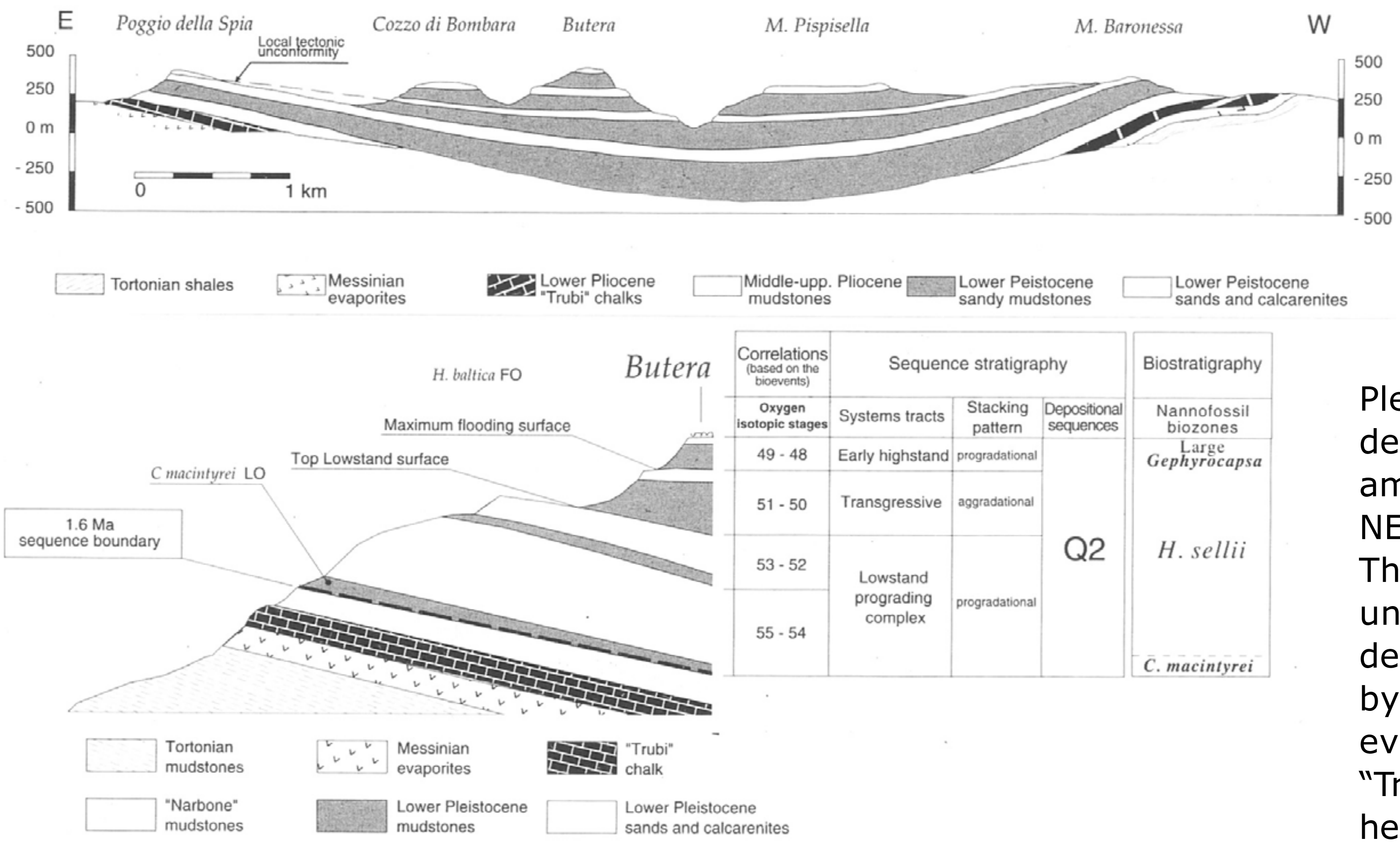

Fig. 119 - Geological cross-section and stratigraphic column of the Plio-Pleistocene Butera basin infill.

The Plio-Pleistocene evolution of the Butera basin

The Butera basin fill outcrops close to Gela in southeastern Sicily more than 10 km northward of Gela (Fig. 119). Here the Pleistocene succession was deposited in a growing low-amplitude, large–wavelength NE-SW trending syncline.

The Butera succession unconformably covers a deformed substrate formed by: Miocene shales and evaporites; lower Pliocene “Trubi” chalks; upper Pliocene hemipelagic shales.

The exposed Calabrian age (Early Quaternary, Fig. 119) succession lies above an unconformity that has been dated 1.58 Ma by Catalano et al. (1998). The sedimentary succession consists of 500 m thick alternation of yellowish shallow marine sandstones, fossiliferous calcarenitic bars, sandy and silty grey shales with bioturbation. This succession is interpreted (Catalano et al., 1998) as deposited in a coastal to open shelf environment with a deltaic influx.

The stratal pattern documents a set of four major coarsening-upward cycles. Each cycle consists of thick sandstones bodies prograding toward south-southeast over offshore mudstones (Fig. 119).

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On the basis of sequence stratigraphy and integrated biostratigraphy analyses, Catalano et al. (1998) conclude that: a) the post 1.6 Ma facies cycles of Butera basin succession formed in response to high-frequency global sea level fluctuations; b) these oscillations can be correlated to the high-amplitude and low-period climatic changes, linked to the 41 ky component of the orbital obliquity.
Each cycle, on average 100 m thick near the depocenter of the basin, thins down to 20-30 m toward the margin, where minor erosional surfaces are found. These latter are clearly linked to the growth of the underlying tectonic structures. Repeated episodes of slumping directed toward the depocenter also testify to a syn-sedimentary tilting of the basin margins (see also Sulli, this guidebook, Fig. 48a, b).
Concluding, the syn-tectonic Pleistocene strata of the Butera basin fill a low-amplitude growth syncline (Fig. 119), representing a wedge-top basin developed above the Gela Thrust Wedge.

Aknowledgements
The leaders are indebted to a group of mostly younger collegues Mauro Agate, Giuseppe Avellone, Luca Basilone, Maurizio Gasparo Morticelli, Carlo Gugliotta, Vera Valenti and Carmelo Gibilaro, Salvatore Pierini.
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The whole of the above work was carried out at the Department of Earth and Marine Sciences in Palermo.

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Villa Romana del Casale

Brief Description

Roman exploitation of the countryside is symbolized by the Villa Romana del Casale (in Sicily), the centre of the large estate upon which the rural economy of the Western Empire was based. The villa is one of the most luxurious of its kind. It is especially noteworthy for the richness and quality of the mosaics which decorate almost every room; they are the finest mosaics in situ anywhere in the Roman world.

Justification for Inscription

The Committee decided to inscribe this property on the basis of criteria (i), (ii) and (iii), considering that the Villa del Casale at Piazza Armerina is the supreme example of a luxury Roman villa, which graphically illustrates the predominant social and economic structure of its age. The mosaics that decorate it are exceptional for their artistic quality and invention as well as their extent.

Long Description

Villa del Casale at Piazza Armerina is the supreme example of a luxury Roman villa, graphically illustrating the predominant social and economic structure of its age. Its decorative mosaics are exceptional for their artistic quality and invention as well as their extent.

An earlier rural settlement generally thought to have been a farm, although on slender evidence, existed on the site where the late Roman villa was built. Its orientation was the same as that of the baths of the villa, and its foundations were discovered beneath parts of the villa. The existence of baths in the earliest phase of the site suggests that it was the residence of a rich tenant or the steward of a rich landowner. Two portraits were discovered dating from the Flavian period (late 1st century AD) that may represent members of the owner's family. The stratigraphy of this earlier house provides a chronology from the 1st century AD to the Tetrarchy at the end of the 3rd century. There are indications that the earlier house was destroyed by an earthquake in the first decade of the 4th century, by which time it was probably owned by Marcus Aurelius Maximinianus, a Pannonian who had risen from the ranks of the Roman army to become a general, and then was raised to the status of Augustus by Diocletian. On the violent death of Maximinianus in 310 it would have

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passed to his son and imperial colleague Maxentius, killed at the battle of Milvian Bridge in Rome in 312. The grandeur and lavishness of the structure that arose on the ruins of the house suggests that it was built on the orders, if not of a Roman ruler, then by a rich and powerful landowner, between 310 and 340. It was occupied until the Arab invasion of the 9th century, although in a state of increasing degradation. The final act of destruction was the work of the Norman ruler of Sicily, William I the Bad, around 1155.

This building, which merits the title of 'palace' rather than villa, is designed in the tradition of the Roman villa but on a scale and to a level of luxury with no parallels in the Roman Empire. The area that has been excavated, which is only part of the full establishment and covers about 4,000 m2 , may be divided into four zones or groups of rooms, all of them decorated with floor mosaics of superlative quality.

The villa is built on a series of terraces. The first is the monumental entrance, which opens into a courtyard, on to which faces the elaborate baths complex. The oval palaestra gives access to an impressive octagonal frigidarium (cold room) and thence through the tepidari um (warm room) out of which open three caldaria (hot baths). Next comes the impressive main peristyle with its monumental fountain in the centre, and the rooms opening off it. There is a small apsidal shrine to one side. To the south is the third group, around the elliptical peristyle. The spacious triclinium has apses on three sides and is decorated with mythological scenes, notably the Labours of Hercules. The fourth group lies to the east of the main peristyle, linked by the long Corridor of the Great Hunting Scene.

This monumental area contains one of the finest and deservedly most famous mosaic pavements, depicting the capture of wild animals in Africa, with the master and his assistants directing the activities in the centre. This group also includes the basilica, a large hall for receptions, which is paved in marble rather than mosaics. Most of the small private rooms in this part of the complex contain mosaic floors depicting more peaceful anddomestic activities. Particularly well known is the group of young women wearing costumes remarkably similar to modern bikinis, engaged in sporting activities. The mosaics are the glory of the Villa del Casale. They date from the most advanced period of mosaic art and were in all probability the work of artists from North Africa, judging by both the quality of the work and the scenes they depict. On stylistic grounds it is believed that at least two master-mosaicists worked on the villa, one working in a more classical style on principally mythological scenes and the other using a more realistic approach for scenes of contemporary life. The range of subject matter is vast: mythology, hunting scenes, flora and fauna, domestic scenes and much more. The columns and walls of the villa were also decorated, with painted plaster, both inside and out, and much of this survives.

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Historical Description

An earlier rural settlement, generally thought to have been a farm, although on slender evidence, existed on the site where the Late Roman villa was built. Its orientation was the same as that of the baths of the villa, and its foundations were discovered beneath parts of the villa.

The existence of baths in the earliest phase of the site suggests that it was the residence of a rich tenant or the steward of a rich landowner. Two portraits were discovered dating from the Flavian period (late 1st century AD) that may represent members of the owner's family. The stratigraphy of this earlier house provides a chronology from the 1st century AD to the Tetrarchy at the end of the 3rd century. This is an obscure period of Sicilian history, when the traditional latifundia system using slave labour underwent considerable changes. There are indications that the earlier house was destroyed by an earthquake in the first decade of the 4th century, by which time it was probably owned by Marcus Aurelius Maximinianus, a Pannonian who had risen from the ranks of the Roman army to become a general. and then was raised to the status of Augustus by Diocletian.

On the violent death of Maximinianus in 3 10 it would have passed to his son and Imperial colleague Maxentius, who lost his life at the hands of Constantine the Great at the Battle of the Milvian Bridge in Rome in 312.

The grandeur and lavishness of the new structure that arose on the ruins of the earlier country house suggests that it was built on the orders, if not of one of these Roman rulers, then of a rich and powerful landowner, some time between 310 and 340. It continued to be occupied up to the Arab invasion of the 9th century, though in a state of increasing degradation. It seems that the final act of destruction was the work of the Norman ruler of Sicily, William I the Bad, around 1155.

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