Neogene tectono-sedimentary interaction between the Calabrian Accretionary Wedge and the Apulian Foreland in the northern Ionian Sea

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ABSTRACT

The structural setting of the northern Ionian Sea is the result of the collision between the Calabrian Accretionary Wedge (CAW) and the adjacent foreland, i.e. the Apulian Carbonate Platform. The CAW represents a sector of the Apennine accretionary system extending in the Ionian Sea, bounded to the west by the Malta Escarpment and to the east by the Apulia Escarpment. This work presents the results of the interpretation of new seismic and bathymetric data acquired on the north-eastern edge of the CAW, in the N-Ionian Sea. The data interpretation has identified four main structural domains from NE to SW: 1. The Apulian carbonate Platform consisting of foreland shelf and transitional Mesozoic-Cenozoic carbonate deposits; 2. A narrow foredeep basin, filled by a very thick Plio-Quaternary succession; 3. A deformed domain, at the front of the CAW, incorporating thrusted foredeep sequences and a carbonate block of the Apulian Platform (Transpressed Apulian Block, TAB); 4. A highly deformed pre-Pliocene accretionary wedge. A mid-Pliocene unconformity interpreted on both the CAW and Apulian Foreland suggests that a regional tectonic event occurred at that time, related to the evolution of Calabrian Arc, moving on the subducting oceanic Ionian slab before the collision. This event would correspond to a main tilting and faulting phase of the Apulian Foreland during the diachronous oblique collision with the CAW. The collision and the presence of a remnant of Ionian foreland at the southern front of the accretionary prism, caused a gradual transition to a transpressional tectonics which produced the uplift of the TAB. The TAB would be the south-east continuation of the Amendolara ridge transpressed structure, which forms the offshore extension of the Pollino range. This transpressed shear zone involving the Apulian Foreland developed above the transition between the Adriatic continental crust and the subducting Ionian oceanic crust.

1. Introduction

The Calabrian Accretionary Complex, in the Central Mediterranean region, is an independent arcuate block that connects the NW-trending Apennine chain to the E-trending Sicilian Maghrebides, and separates the Ionian from Tyrrhenian basins. In the Ionian Sea, contractional tectonics controlled the Neogene interaction of the Calabrian Accretionary Complex with a foredeep-foreland system, connected to the north-western subduction of the Ionian slab (Malinverno and Ryan, 1986; Gueguen et al., 1997; Faccenna et al., 2001). The external part of the CA is a submerged accretionary wedge, the Calabrian Accretionary Wedge (CAW), consisting of SE-verging thrust sheets composed of deformed Mesozoic and Cenozoic sediments scraped from the descending Ionian slab (Rossi and Sartori, 1981; Finetti, 1982; Cernobori et al., 1996; Minelli and Faccenna, 2010). The Ionian lithosphere is laterally confined by two major structural features, the Malta escarpment to the southwest and the Apulia escarpment to the northeast; its abyssal plain and the Apulian and Pelagian continental blocks constitute the foreland of the chain. Several studies analysed, mainly through the interpretation of reflection multichannel and single-channel seismic profiles, the structural setting of the central and south-western sectors of the CAW and tried to reconstruct its tectonic evolution (Finetti, 1982; Del Ben et al., 2008; Argnani, 2009; Polonia et al., 2011, 2016b; Gallais et al., 2013; Gutscher

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et al., 2015). The NE portion of the wedge, i.e. the stratigraphy and its tectonic interaction with the Apulian Foreland, still remains less explored and defined. The lack of offshore exploration wells to calibrate seismic data makes the seismo-stratigraphic and structural interpretation of this area a critical issue.

The multichannel seismic and bathymetric datasets recently acquired in the northern Ionian Sea (Salento offshore), integrated with the existing data, cover with a higher detail this collisional area which involved different paleogeographic domains. A particularly focused analysis has been dedicated to the presence of a semi-transparent seismic facies below the Messinian unconformity in the outer sector of the CAW. Butler (2009), using two seismic lines crossing the same study area, hypothesized that this semi-transparent body would correspond to the Messinian evaporites expelled during gravitational collapse of the accretionary wedge. We have supplemented this interpretation by means of seismic velocities and attribute analysis to consider also alternative origins for the uncalibrated seismic facies. Also, an accurate interpretation of an unconformity generally presents in the Pliocene sequence along all the seismic profiles, brought new details on the tectonic evolution of the area. A wide transpressional zone has been recognized in the external portion of the CAW, strongly influenced by the inherited Mesozoic paleogeography of the southern Adria plate.

2. Geological setting

The study area is located in the Northern Ionian Sea at the convergence between the NE sector of the CAW and the western margin of the Apulian Carbonate platform or Apulian Swell (Catalano et al., 2001) (Fig. 1). The CAW is part of the Calabrian accretionary complex that extends for nearly 300 km in the Ionian offshore at a water depth of 4000 m. It was generated, together with the back-arc basins in the Tyrrhenian area, through episodic Neogene NW-dipping subducting and progressive SE-retreating of the Ionian oceanic slab (e.g. Catalano et al., 2001) in the context of the convergence between African and Eurasian plates (Rehault et al., 1984; Malinverno and Ryan, 1986; Dewey et al., 1989; Sartori, 1990; Gueguen et al., 1997; Faccenna et al., 2001, 2004; Rosenbaum and Lister, 2004; Guillaume et al., 2010). Tomographic images (Wortel and Spakman, 2000; Faccenna et al., 2007; Neri et al., 2009; Neri et al., 2012) and intermediate to deep seismicity (Selvaggi and Chiarabba, 1995; Frepoli et al., 1996) show the presence of a narrow and continuous Ionian slab with about 70° NW dipping Benioff-Wadati zone descending into the mantle beneath the south-eastern Tyrrhenian Sea. In addition, geodetic measurements testify the outward motion of Calabria relative to Apulia (GPS rate of 2 mm/yr, D'Agostino and Selvaggi, 2008) with shortening accommodated in the CAW (Polonia et al., 2011). The

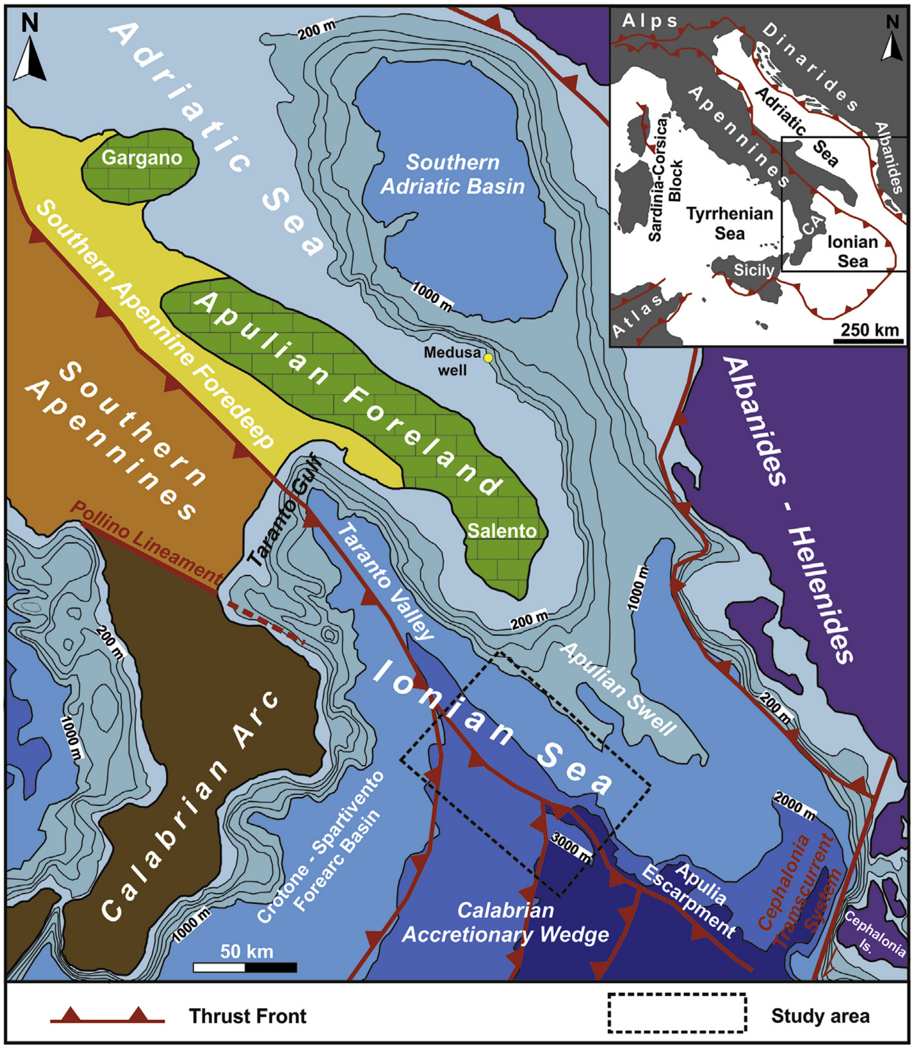

Fig. 1. Sketch map of the southern Italy with the main tectonic domains and the offshore region where is located the study area.

progressive retreating of the Ionian slab was accompanied by the development of vertical lithospheric tear faults or STEP (Subduction Tear Edge Propagator, sensu Govers and Wortel, 2005) along its lateral edges with the Apulian and Hyblean Foreland areas to the northeast and to the southwest, respectively. Simultaneously, strike-slip faults developed in the overriding plate. In the south-western side of the Ionian sea, an active NNW-SSE right-lateral strike-slip fault, located to the east of the Malta escarpment (Finetti, 2005; Western Ionian Tear Fault in Del Ben et al., 2008; Argnani, 2006; Alfeo-Etna fault in Polonia et al., 2011; Gallais et al., 2013; Gutscher et al., 2015) crossing also the NE Sicily (Barreca et al., 2016), has been ascribed to the lithospheric fault separating the Ionian slab from the Hyblean Foreland.

The north-western boundary of the Ionian lithosphere is represented by the NW-trending Pollino Fault Zone (Van Dijk and Scheepers, 1995) and by its offshore continuation (Del Ben et al., 2008; Ferranti et al., 2009, 2014), separating the CAW from the southern Apennines. This NW-SE trending fault may correspond to a lithospheric tear fault separating the Adria Foreland into the continental Apulian crust and the subducting Ionian crust (Apulian-Ionian Tear Fault, Del Ben et al., 2008). The position of this structure seems to be controlled by an inherited mechanical discontinuity between the thick Apulian and the thin Ionian crusts (Ferranti et al., 2014). This mechanical discontinuity controlled the location of the north-eastern boundary of the CAW along which a major left lateral fault zone developed as the CAW propagated south-eastward.

In the study area, CAW and Apulian Swell are separated by the Taranto Valley, which hosts the submerged part of the Apenninic foredeep basin (Senatore et al., 1988) (Fig. 1). The Apulian Swell is a NW-SE elongated ridge culminating onshore in the Salento peninsula and extending to the Ionian Islands (Fig. 1). Its Meso-Cenozoic shallow-water carbonate succession, about 8 km thick, consists of Paleogene transgressive clastic carbonate deposits, Cretaceous limestones, Jurassic dolostones, and late Triassic anhydrite-dolomites (Anidriti di Burano Formation) resting unconformably on more than 1000 m of Early Triassic-Permian terrigenous deposits ("Verrucano") (Ricchetti et al., 1988; Puglia-1 well, ViDEPI, 2009) (Fig. 2). This succession is locally interrupted by pelagic sequences that attest the existence of intra platform basins (Nicolai and Gambini, 2007; Del Ben et al., 2015). The CAW has been generally subdivided in two main sectors: the outer domain (Minelli and Faccenna, 2010) which approximately coincides with the frontal salt-bearing post-Messinian accretionary wedge (Polonia et al., 2011), made of Messinian evaporites overlain by Plio-Quaternary hemipelagites and turbidites; the inner domain (Minelli and Faccenna, 2010), whose north-eastern border is investigated in this paper, consists of a deformed nappe stack of pre-Messinian units, composed of Tertiary and Mesozoic clastic sediments (Fig. 2). Starting from Pliocene times, the Apulian Foreland has undergone a flexural process beneath the CAW, generating at the foot of the frontal thrust belt the deep and narrow Pliocene-Quaternary foredeep basin. This would be emphasized by a reactivation of Mesozoic normal faults, producing the peculiar high slope gradients at the seafloor (Volpi et al., 2011).

3. Materials and methods

We discuss the results of acquisition, processing and interpretation of a geophysical dataset acquired in the Salento offshore by the research vessel OGS/Explora, consisting of 5 multichannel seismic reflection profiles and a morpho-bathymetric survey (Fig. 3).

3.1. *Multibeam seafloor bathymetry*

Bathymetric data were acquired during three geophysical surveys in the years 2003, 2005 and 2010 covering a total area of 10.700 km^2 in a depth range from 630 to 3450 m below the sea-level (Fig. 3). Their processing consisted of: 1) calibration of data to correct the errors introduced by sensors (time, pitch, roll and yaw); 2) correction of depth measurements using sound velocity profile through the sea water applied at different locations; 3) manual editing to remove both errors in the navigation positions and residual spikes induced by lateral anomaly reflections from the seafloor.

3.2. *Seismic dataset*

The OFS_10 seismic dataset consists of five multichannel seismic profiles, four of which are NE-SW oriented, therefore perpendicular to the main tectonic structures of the study area. These lines were acquired in 2010 for a total length of ~570 km (Fig. 3).

Part of the multichannel seismic line CROP (CROsta Profonda project) M5 (Fig. 3), made available by the Ministry of the Economic Development in the framework of the project "Visibility of Petroleum Exploration Data in Italy (ViDEPI)" (http://www.videpi.com), has been considered to integrate the interpretation for the northern part of the investigated area (Fig. 3).

The acquisition parameters of the OFS_10 dataset were chosen in order to obtain a good compromise between resolving power and penetration. The result is a high quality image of the upper part of the sedimentary sequence and gradually poorer information of the deeper portion.

The data were acquired using a 1500 m long Sercel digital streamer with 120 channels spaced 12.5 m apart, corresponding to an effective horizontal sampling of 6.25 m in the stacked section. The seismic source consisted of two expanded volume 355 cu.in. (8 L) GI guns organized in a 2 m long linear array and fired in harmonic mode, in order to provide a good quality signature by reducing the bubble effect, while preserving a sufficient amount of emitted acoustic energy. The source was towed at a depth of 4 m, the streamer at 5 m, with the first ghost effect related frequency notch occurring at around 150 Hz. The shot point interval was 25 m, with a resulting fold coverage of 30 traces for each investigated common depth point. The acquisition parameters are summarized in Table 1.

A standard processing was adopted to improve the signal to noise ratio and better define the main targets: the Plio-Quaternary sequence, the top of Miocene M-reflector and the deeper structures of the CAW and Apulian platform, generally above 4 s TWT, where often the first seafloor multiple is evident. The processing consisted in the following steps: data reformatting from SEGD field format to Vista processing package internal format, trace editing, amplitude recovery, sort from shot point to common depth point domain, velocity analysis every 400 CMPs (around 2500 m), Normal Move Out correction, stack and time migration.

After a first evaluation of the preliminary results, specific velocity analysis (based on velocity spectra and Common Velocity Stack) were later conducted on selected locations to improve the velocity model along the profiles and better assist the interpretation. Velocity analysis often represents a useful tool to clarify some uncertainties regarding the seismo-stratigraphy in particular when well data are not available, as will be described in the following chapters.

4. Seismo-stratigraphic interpretation

The four NE-SW oriented seismic profiles cross orthogonally the

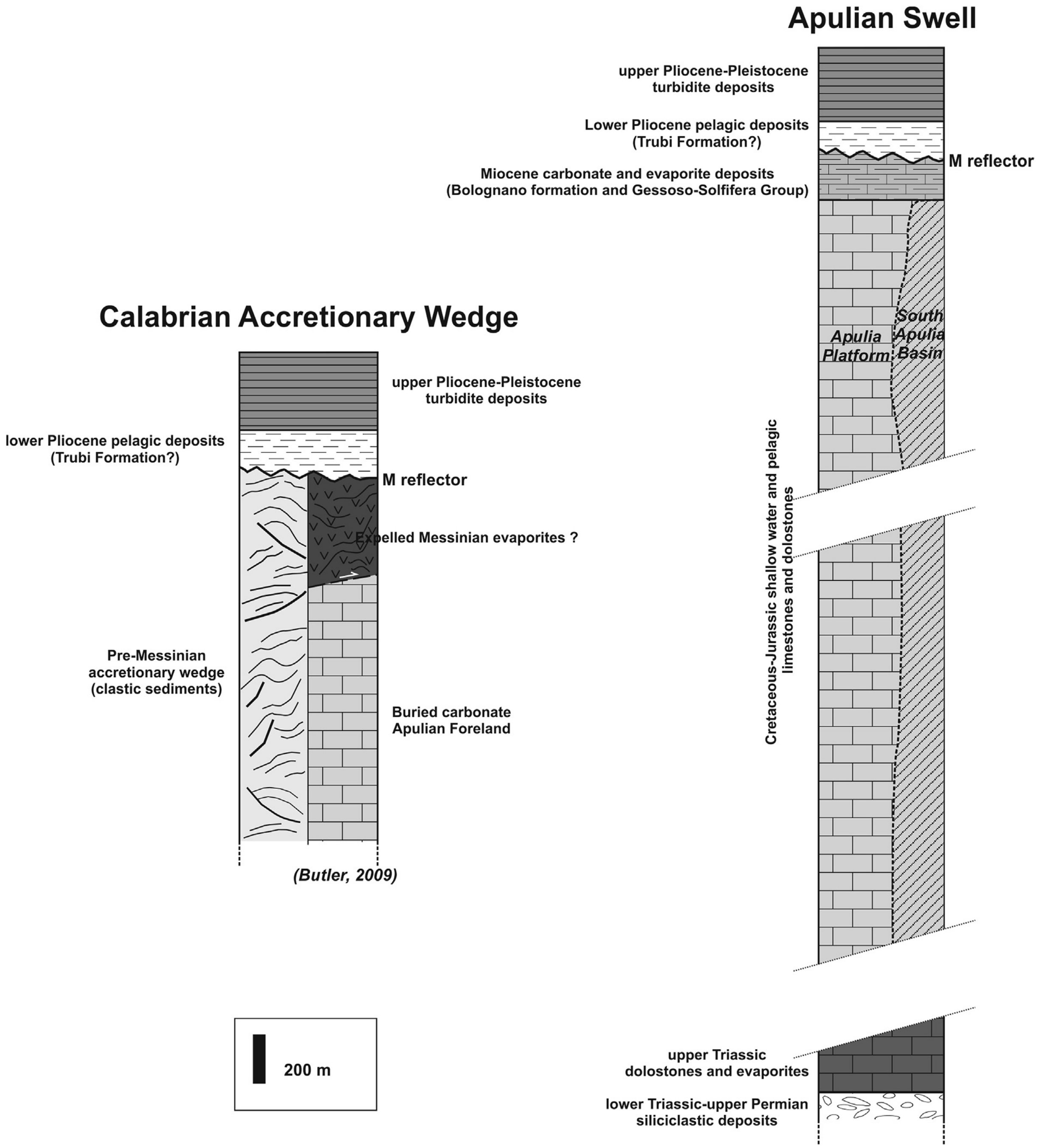

Fig. 2. Schematic stratigraphic columns of the external Calabrian Arc (on the left) and of the Apulian swell (on the right), reconstructed on the base of the available literature (Catalano et al., 2001; Patacca et al., 2008; Butler, 2009; Minelli and Faccenna, 2010; Del Ben et al., 2015).

convergence zone between the CAW and the Apulian Foreland, marked by a sharp foredeep basin (Fig. 4). The Pliocene-Quaternary succession shows a variable thickness ranging from 100 to 150 ms TWT on the foreland (Fig. 5A) to 500 ms TWT in the more internal sector of the accretionary wedge (Fig. 5B), reaching up to 1600 ms TWT in the foredeep basin (Fig. 5C). The upper part of the Pliocene-Quaternary succession consists of high amplitude continuous and sub-parallel reflectors, interpreted as clastic turbiditic deposits according to Rossi and Borsetti (1974), Rossi et al. (1983), Minelli and Faccenna (2010), Polonia et al. (2012; 2016a; 2016c). The lower portion of this succession shows a typical semi-transparent seismic facies (Fig. 5A and B) ascribed to the lower Pliocene rhythmically bedded pelagic deposits of the Trubi Formation (Cita and Gartner, 1973), sampled by Rossi and Borsetti (1974) in the same area. The low contrast of acoustic impedance within the lower Pliocene sequence induces a semi-transparent seismic response on the amplitude section (Fig. 6A), but a clear stratification is highlighted by the instantaneous phase seismic attribute (Fig. 6B).

The base of the Plio-Quaternary sequence is generally clearly recognized as a prominent seismic reflector characterized by high amplitude and considerable lateral continuity interpreted as the Messinian unconformity (M-reflector after Ryan and Cita, 1978) (Fig. 5).

Seismic data have highlighted some important and often

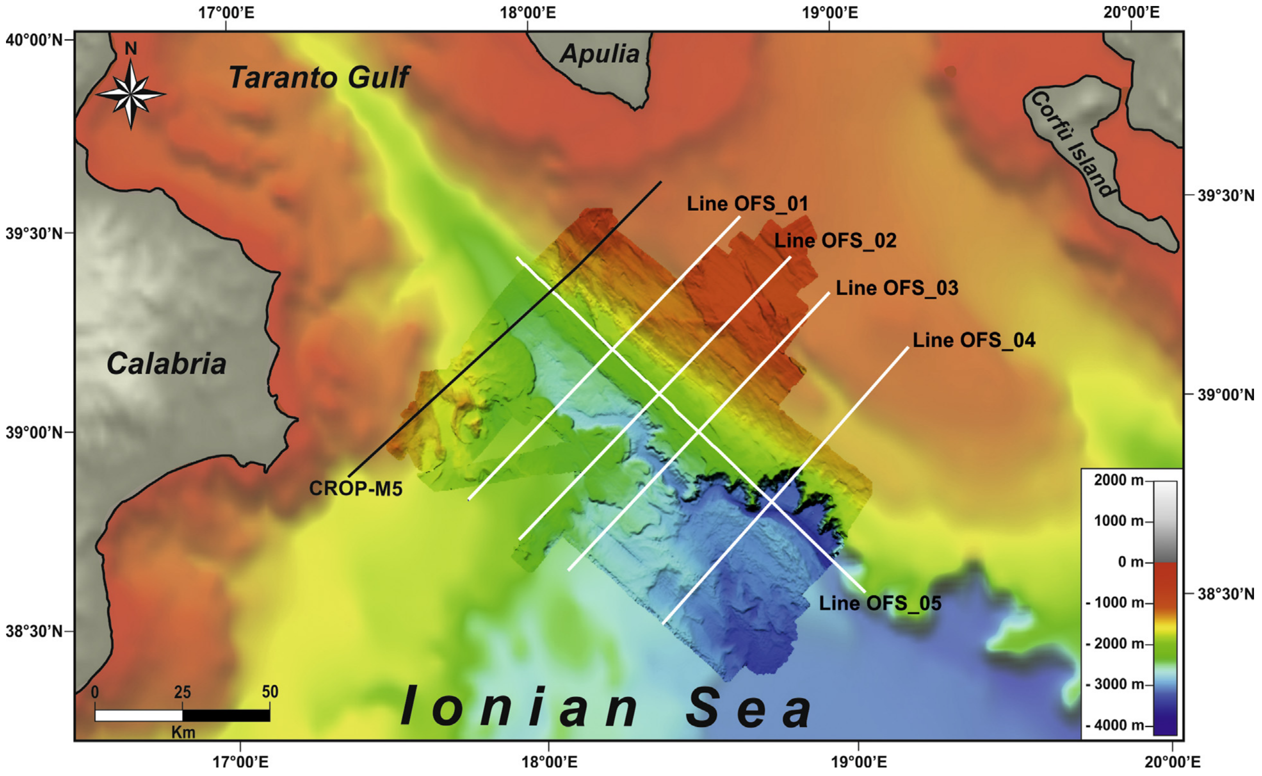

Fig. 3. Bathymetric map of the northern Ionian Sea showing the location of the OFS_10 seismic dataset, the multibeam bathymetry and the CROP M5 profile analysed in this paper.

Table 1
Acquisition parameters of the OFS dataset, interpreted in the present paper.

Acquisition parameters					
Source		Streamer		Recorder	
Model	GI-GUN Sercel	Model	Sercel Seal	Model	Sercel Seal
Array	2 × 355 cu.in. (7.6 l)	Length	1500 m	Samp. Rate	1.0 ms
Gun mode	250 Gen.+105l Inj.	Ch. No.	120	Rec. length	8 s
Shot Interval	25 m	Ch. Dist.	12.5 m	LC filters	3 Hz (LC);
Depth	4 m ± 0.5 m	Depth	5 m ± 0.5 m	HC filters	Antialias
Pressure	140 atm.	Fold	30 tr/CDP	Aux. ch.	12

peculiar characteristics in the seismo-stratigraphy of the two main tectonic domains of the study area (Apulian Foreland/Swell and CAW) separated by the foredeep basin.

4.1. Apulian Swell

Below the M-reflector, a thin seismic unit (up to ~50 ms TWT) is generally observed, composed of discontinuous and high amplitude reflectors (Fig. 5A). Considering the stratigraphic data reported in Catalano et al. (2001), Patacca et al. (2008) and in the available exploration well Medusa (Fig. 1), this seismic unit could include the evaporitic deposits of the Messinian Gessoso-Solfifera Group and the Bolognano Formation. The base of this unit is generally marked by a high amplitude reflector (Top Apulian Carbonate Platform in Fig. 5), probably representing the top of the Mesozoic carbonate succession. The upper part of this succession is generally characterized by sub-parallel and low amplitude reflectors tentatively assigned to the shallow water Cretaceous carbonates; the base of this unit is not always clearly recognizable.

The remaining part of the carbonate foreland succession shows three different seismic facies (Fig. 7):

- reflection-free seismic facies, probably related to a massive carbonate platform succession (Massive Apulian Carbonate Platform in Fig. 7A);
- seismic facies characterized by discontinuous and low to moderate amplitude reflectors (Fig. 7B) interpreted as a transitional facies;
- layered seismic facies (Fig. 7C) related to the intra-platform South Apulian Basin, developed since Jurassic time (Del Ben et al., 2015).

The base of the carbonate platform succession is not identifiable on the OFS_10 dataset; however, its thickness has been interpreted to be about 3000 ms TWT (more than 8 km with an average P-velocity of 5,5 km/s) along the CROP-M5 section in the Apulian Swell (Finetti, 2005).

The Apulian Foreland is affected by flexural bending toward the accretionary wedge which produces several north-eastward and south-westward dipping normal faults (Fig. 7). Syn-tectonic wedges in the Plio-Qauternary succession resting above the semi-transparent and isopach lower Pliocene deposits are associated with the normal faults (Fig. 8): this suggests a generic mid-Pliocene

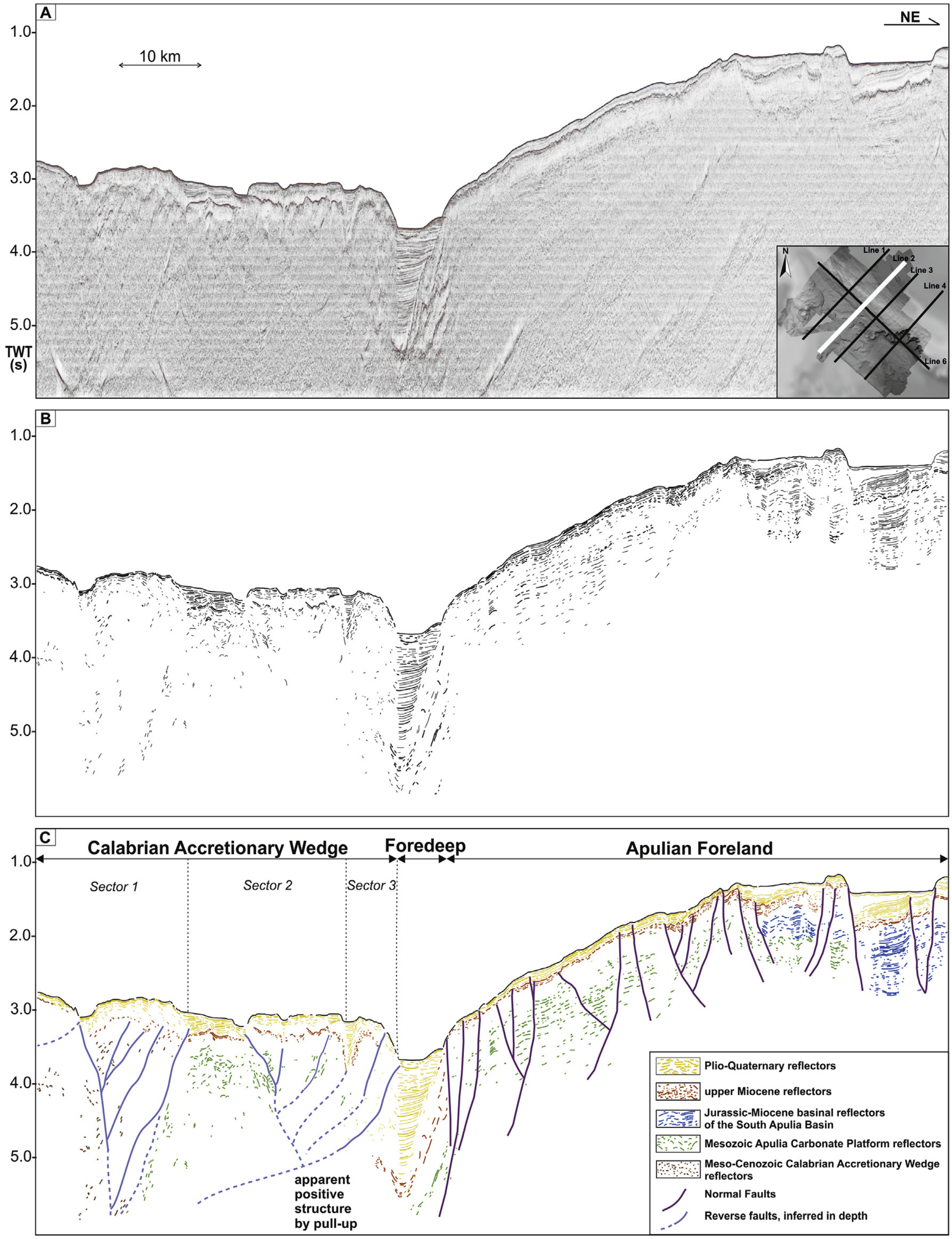

Fig. 4. Seismic line OFS_02 showing the main structural features, discussed in the text, of the CAW and the western Apulia platform margin: A) seismic data; B) line drawing; C) interpretation.

important tilting phase of the foreland. The normal faults can reach the sea bottom, especially where the upper Pliocene/Pleistocene succession is absent (Fig. 8) likely due to erosion, mass wasting processes and/or non-deposition. Furthermore, these faults are less developed inner the massive carbonate blocks (Fig. 8B), which seem to be more resistant to fracturing.

The westward tilted carbonate succession of the foreland extends to the north of the investigated area below the foredeep basin and the external sector of the accretionary wedge, as evidenced along the CROP-M5 profile (Finetti, 2005).

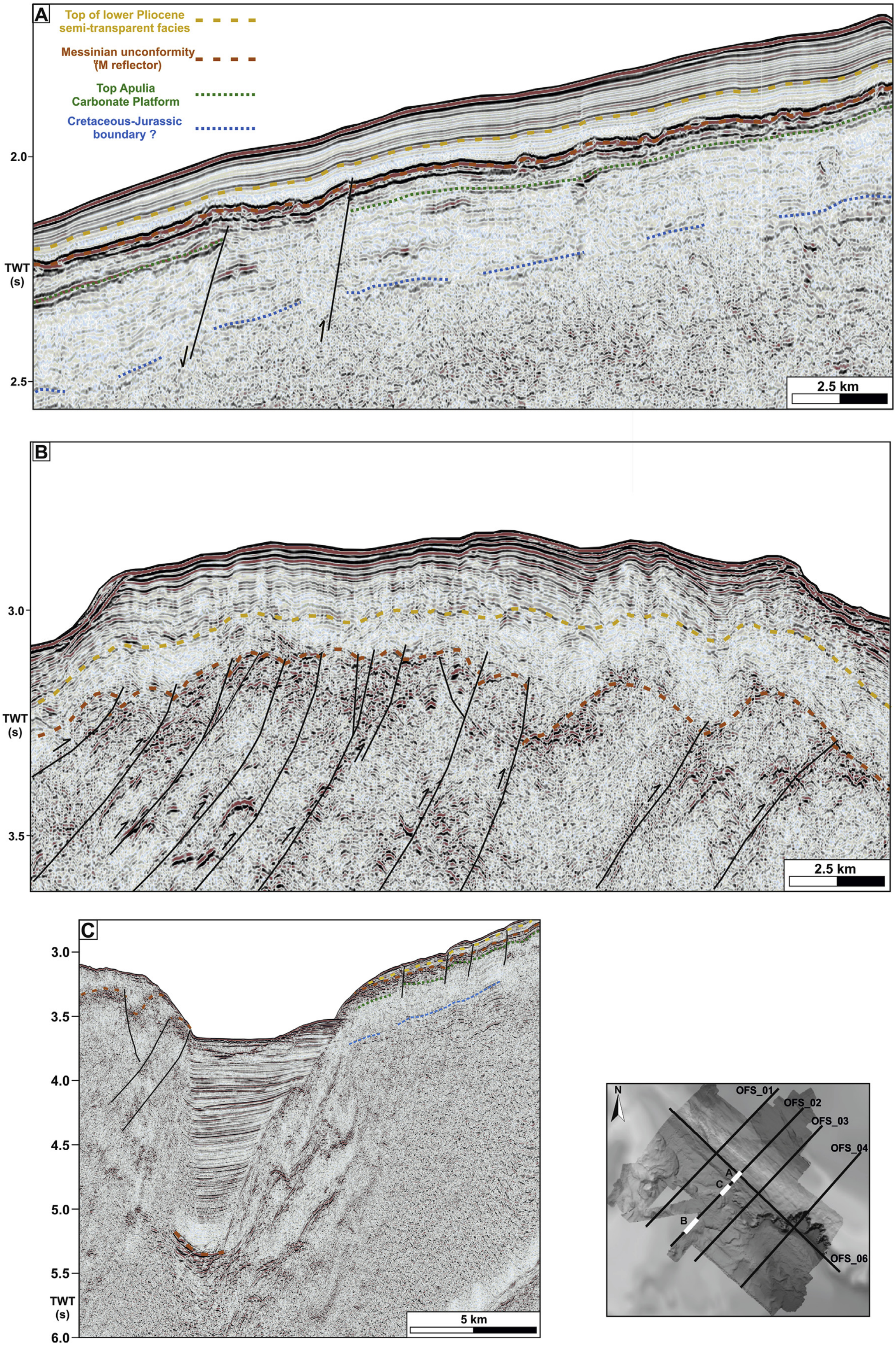

Fig. 5. Details of line OFS_02 evidence the seismic-stratigraphic facies across A) the foreland (Apulian Carbonate Platform), B) the external front of the Calabrian Accretionary Wedge and C) the foredeep basin. The presented seismic profiles are oriented with the SW on the left.

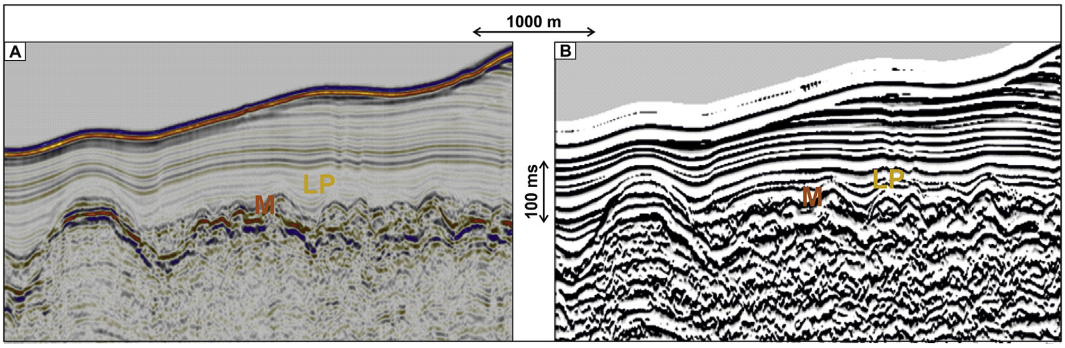

Fig. 6. Details of line OFS_01 showing the seismic response of the Plio-Quaternary sequence: A) Amplitude B) Instantaneous phase. M = Messinian unconformity; LP = lower Pliocene.

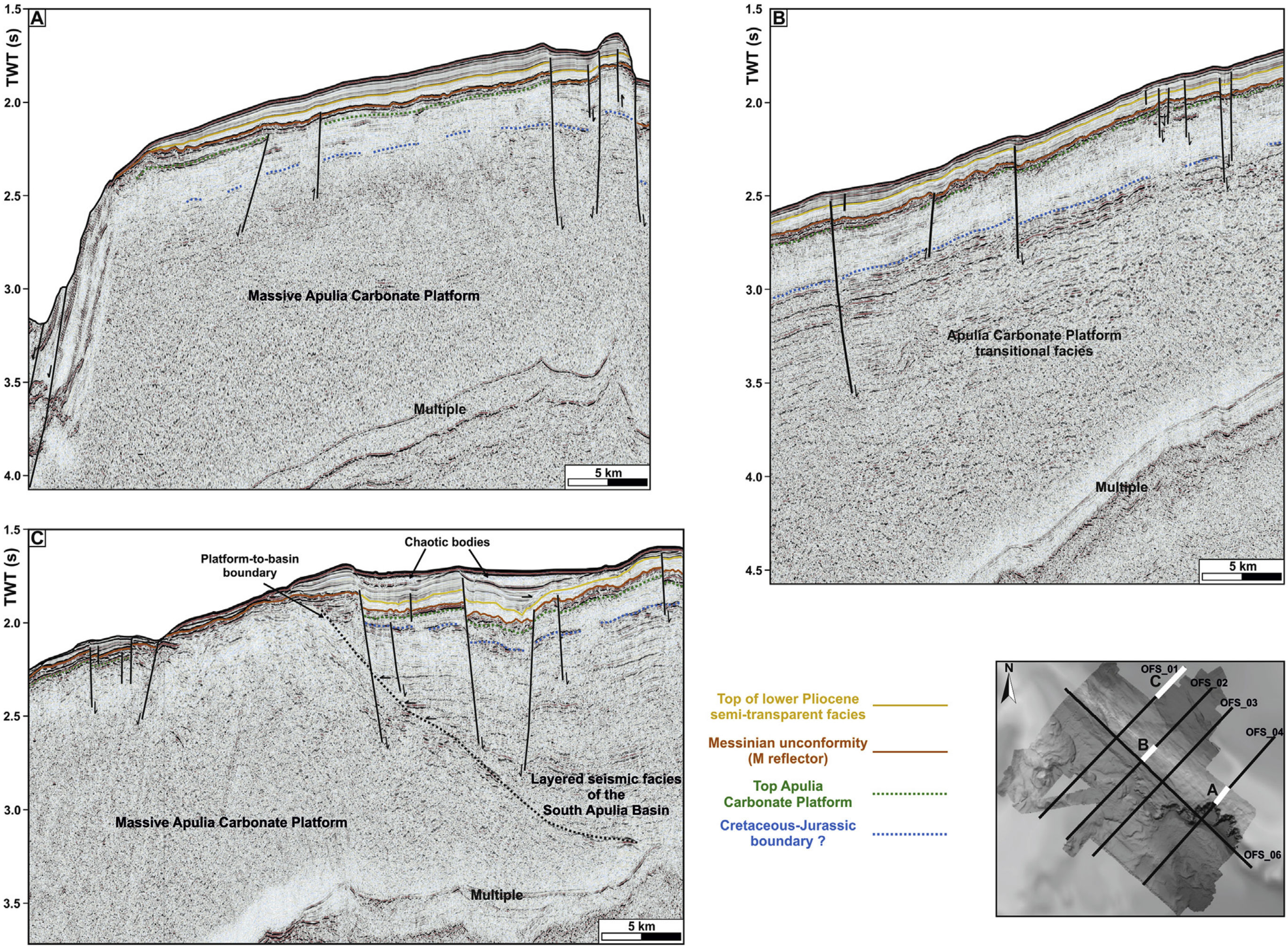

Fig. 7. Different seismic facies identified on the Apulian Foreland have been ascribed to different sedimentary domains: A) reflection-free to a massive carbonate platform; B) variable reflectivity to a transitional platform; C) stratified facies to the intra-platform pelagic deposition of the South Apulia Basin. The presented seismic profiles are oriented with the SW on the left.

4.2. *Foredeep basin*

The foredeep basin, whose morphology is well depicted by the multibeam bathymetry (Fig. 3), is about 4–7 km wide along the lines OFS_02 and 03, while along the northernmost line OFS_01 reaches 15 km (Fig. 8). It shows very steep flanks and a seafloor depth ranging between 2600 and 2800 m. It is filled by an undeformed thick Plio-Quaternary succession, up to 1700 m thick, considering a maximum thickness of 1700 ms TWT (Fig. 8B) and an interval velocity of 2000 m/s. The foredeep infill consists of parallel, sub-horizontal, high frequency, low to high amplitude continuous reflectors onlapping some chaotic bodies likely originated by gravitational sliding observable along the lines OFS_02 and 03. Along the line OFS_01, the foredeep deposits cover directly an abrupt slope where westward normal faults disrupted the M-reflector of the western margin of the Apulian Foreland (Fig. 8) with considerable displacement. This suggests that these faults, which probably represent the northern continuation of some of the normal faults present along the Apulia Escarpment, and the chaotic bodies were likely produced during the Pliocene diachronic collision between the CAW and the thick Apulian Foreland. The pre-Pliocene foreland succession dips below the CAW, as evidenced by some deep reflector below the frontal thrust affected by pull-up velocity (Fig. 8A, C).

At about 4.2 s TWT along the line OFS_01 (Fig. 8A), the occurrence of a growth wedge inner the foredeep succession is likely related to a compressional phase affecting the chain. This tectonics was probably coeval to the mid-Pliocene normal faults described in the Apulian Swell (Figs. 8 and 9A) which cut a thin lower Pliocene conformably resting over a clear M-reflector. A comparison of CROP-M5 and Line OFS_01 highlights the geometry of the thrust zone between the CAW front and the tilted Apulian Foreland in the north and southern part of the investigated area (Fig. 9). The thick foredeep evidenced on all the NE-SW profiles of the OFS_10 dataset seems to become thinner to the northern sector (CROP-M5 profile, Fig. 9A) which is not affected by Mesozoic normal faults.

At the sea bottom a characteristic sedimentary body is present at the foot of the compressional front, with a typical chaotic seismic facies (Fig. 8). It is particularly evident along the northern profile (Fig. 8A) with a decreasing size towards south-east (Fig. 8B and C). Its base is well depicted by an erosional surface that cuts the previous horizontal stratification and is likely originated by turbidity currents with a transport direction perpendicular to the orientation of the seismic profiles.

4.3. *Calabrian Accretionary Wedge*

The OFS_10 profiles cross the north-western part of the Calabrian Accretionary Wedge (Fig. 3). The deformed Messinian unconformity is generally identified at the top of a chaotic assemblage, consisting of discontinuous and often disrupted reflectors generated by a complex system of imbricated thrusts and backthrusts (Figs. 5B and 10). The overlying lower Pliocene semi-transparent seismic unit (Fig. 5B) seems also to be affected by compressional tectonics.

The profile OFS_03 (Fig. 10) shows the structural setting of the accretionary wedge in the investigated area. From west to east we have identified:

Sector 1: the western part of the wedge shows a thick Pliocene-Quaternary succession, up to 500 ms TWT. The thickness of the lower Pliocene seismic unit is variable in this sector and is clearly affected by compressional deformations. This tectonic event produced an angular unconformity probably mid-Pliocene in age marked by the onlap of the Upper Pliocene/Quaternary succession (Fig. 10). The Messinian unconformity is discontinuous and not always easily recognizable. This sector consists of the chaotic units of the accretionary prism deformed mainly during pre-Pliocene time. Several NE-verging thrust faults and back-thrusts locally generate pop-up and flower structures, also involving the lower part of the Pliocene-Quaternary succession (Fig. 4). According to previous papers (Del Ben et al., 2008; Ferranti et al., 2014) these structures were generated by an important strike-slip component which was active since pre-Pliocene times, with a migration of the CAW toward the Ionian oceanic domain. The occurrence of a contractional-transpressional mid-Pliocene phase (late Zanclean to early Piacenzian) is well documented in the Calabrian Arc basins and in the southern Apennines leading to uplift and basin closure (Van Dijk, 1994; Consolaro et al., 2013; Massari and Prosser, 2013; Zecchin et al., 2012, 2015).

Sector 2: this sector, located further to the north-east towards the external front of the CAW, shows a thinner Pliocene-Quaternary cover that seems to be predominantly composed of lower Pliocene deformed deposits. The top of this unit is marked by the interpreted mid-Pliocene angular unconformity, shown by arrows in Fig. 10, and its base corresponds to the M-reflector. A reflection-free seismic facies, about 300 ms TWT thick, is present below the M-reflector and overlies a deeper package composed of high amplitude reflectors. This seismic character has been observed along all the NE-SW profiles of the OFS_10 dataset and is not present laterally in the adjacent sectors of the accretionary wedge. This transparent character could be attributed to the diffuse presence of (diapiric) salt as described by Finetti and Morelli (1973) in the nearby deep Ionian basin. Butler (2009), with the same kind of hypothesis, proposed a possible lateral expulsion of salt, producing imbricated Messinian evaporites and carbonates. Instead, considering the close analogy of the seismic facies of this unit of the CAW with the facies in the Apulian Foreland (Fig. 11), we suggest that this unit could correspond to Cretaceous carbonates. This hypothesis is strengthened by a comparison of the velocity profiles inferred by velocity spectra originated in three different points along section OFS_03 (Fig. 12): A) in the Apulian Foreland, B) in the external thrust of the chain (sector 2 in section OFS_03), C) in the highly deformed accretionary prism (sector 1 in section OFS_03). Our aim was to obtain the P-wave velocity trend with depth, more than the velocity absolute values, whose reliability are not univocal considering the stacking velocity. The pre-Pliocene chaotic units in Fig. 12C show an unclear velocity trend, essentially due to diffraction produced by frequent cut-offs of reflectors and by thrust faults. Fig. 12A and B shows similar trends: in both of them the velocity analysis show three main sharp increases of the interval velocity: at the top Miocene reflector, at the base of the semi-transparent Cretaceous unit and in correspondence of the deeper stratified unit. Moreover, we observed that the velocity profile of Fig. 12B does not show any velocity inversion that generally occurs at the base of the salt layer. Finally, we noted that the semi-transparent unit is only gently deformed, while a considerable diapiric effect should be expected in this collisional area for a so thick salt layer (approximately 800 m considering a TWT thickness of 400 ms and an interval velocity of 4000 m/s). On the base of all these observations, we assume that this sector of the CAW would represent an Apulian carbonate block (Transpressed Apulian Block) that was involved in the outer compressional deformation of the accretionary prism. We then infer that the uplift of this structure would be due to a transpressional regime that affected this region after the diachronic collision of the external front of the accretionary wedge with the Apulian Foreland.

Sector 3: it represents the most external sector of the accretionary wedge, characterized by a complex sea-bed morphology and by a strongly scattered internal seismic signals (Fig. 10) related to highly folded and fractured sequences. They originated from a pre-existing middle-Pliocene foredeep separating the Apulian block from the rest of the Apulian Platform; after the diachronous collision of the Calabrian Arc with the thick Apulian Platform, in post-lower Pleistocene, the foredeep sequences and the Apulian block were involved in compressional/transpressional deformation.

5. Discussion

A critical issue for the study area is the complete lack of wells to calibrate the sequences of the CAW and of the foreland. For this reason a special focus has been dedicated to the analysis of seismic facies, also supported by the interval velocities and by seismic attributes obtained from the seismic data processing. Adopting this approach, the OFS_10 seismic dataset has allowed us to depict the

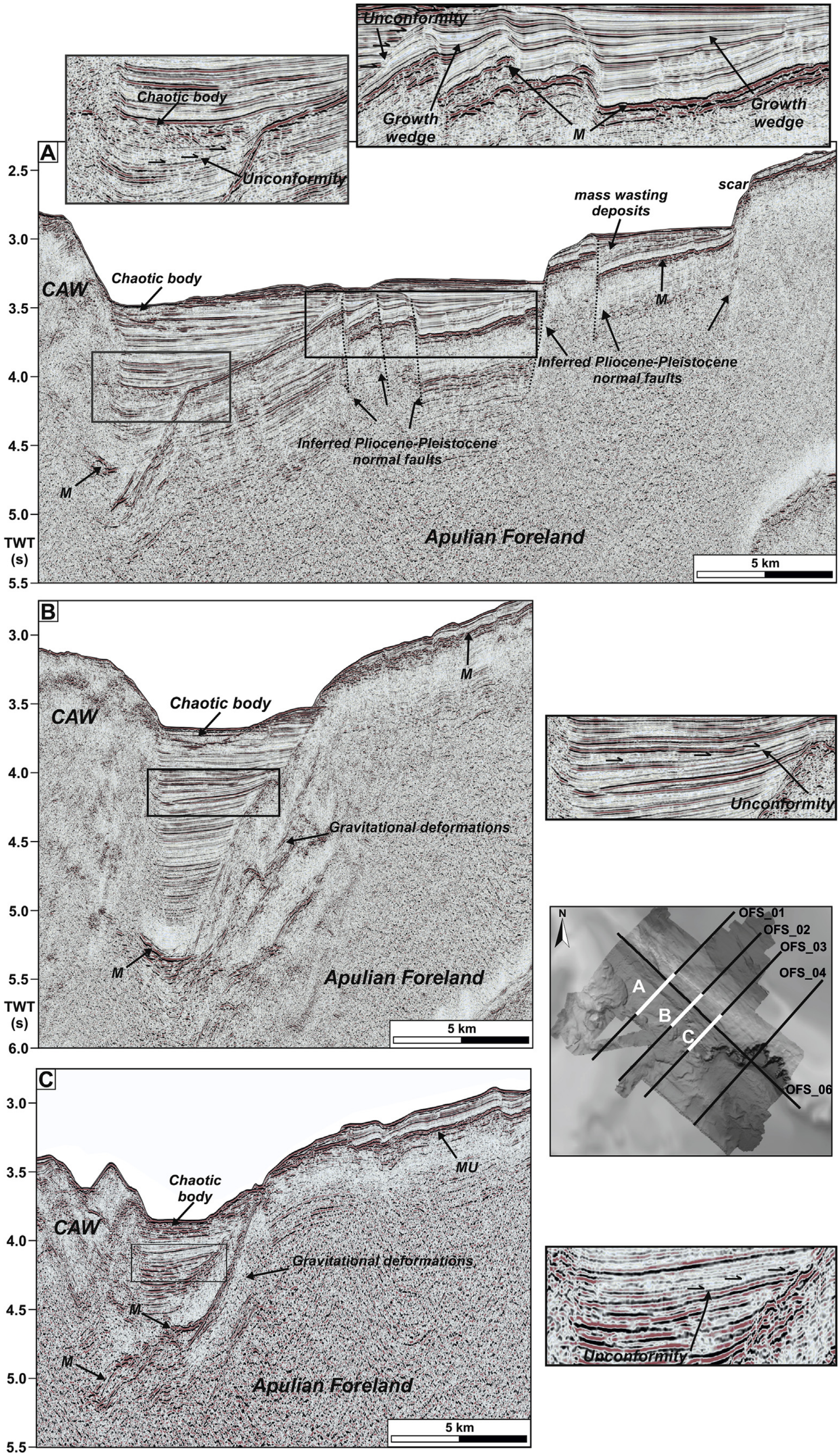

Fig. 8. The foredeep basin across the CAW/Apulian margin. A) the northernmost profile OFS_01, shows the tilted Apulian Foreland fragmented in large blocks bounded by normal faults; the detail on the right evidences the parallel layers and the constant thickness of the lower Pliocene; mid-Pliocene growth stratum would date the faults related to the coeval tilting of the foreland; B) profile OFS_02, shows a narrower and deeper foredeep basin and with the growth stratum still evident within the Plio-Quaternary succession. C) the southern profile OFS_03 shows a thinner Plio-Quaternary sequence holding again the mid-Pliocene growth stratum. M-reflector: top Miocene. The presented seismic profiles are oriented with the SW on the left.

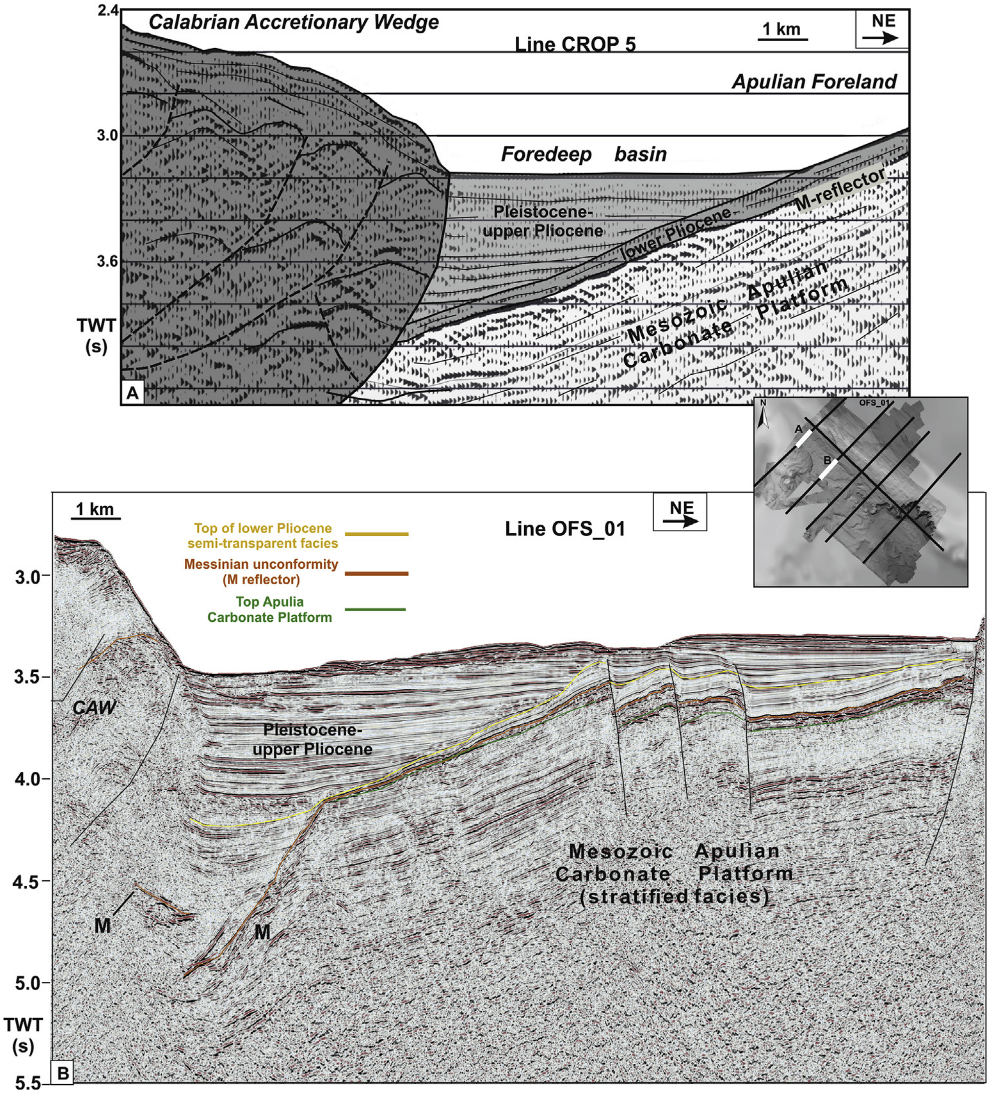

Fig. 9. Comparison of **A)** CROP-M5 and **B)** OFS_01 lines across the foredeep basin (see Fig. 3 for location) highlights the collision between the CAW front and the tilted block of the Apulian Foreland in the northern and further southern sectors of the investigated area. On the CROP-M5 the tilted Apulian Foreland shows the M-reflector covered by a thin conformable lower Pliocene sequence onlapped by the sediments filling the foredeep.

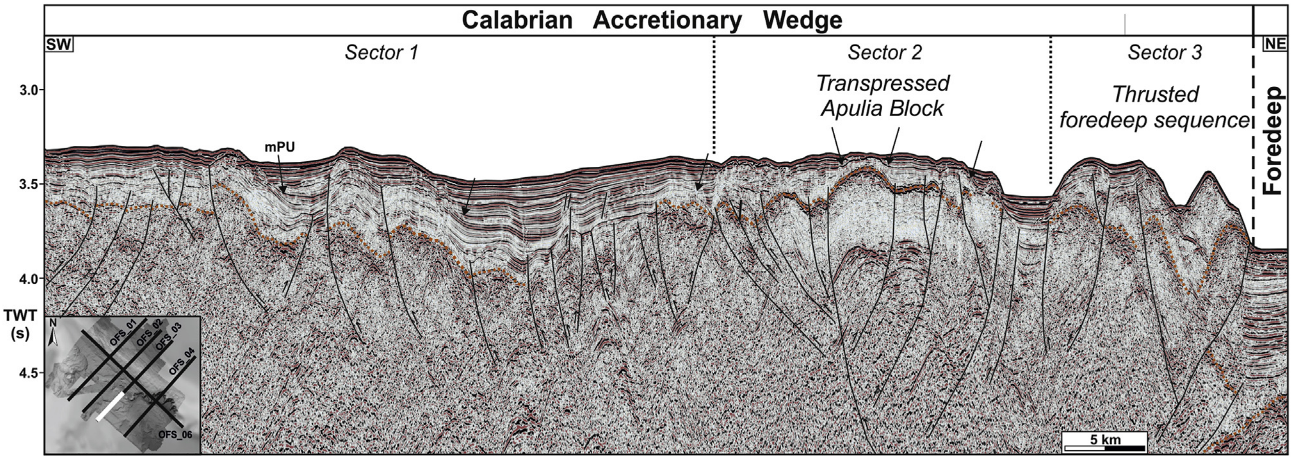

Fig. 10. Calabrian accretionary wedge (CAW) along the seismic line OFS_03. Black arrows mark the interpreted mid-Pliocene unconformity (mPU), which separates the semi-transparent facies ascribed to the lower Pliocene unit from the overlying well-stratified succession. Three different sectors, discussed in the text, have been identified.

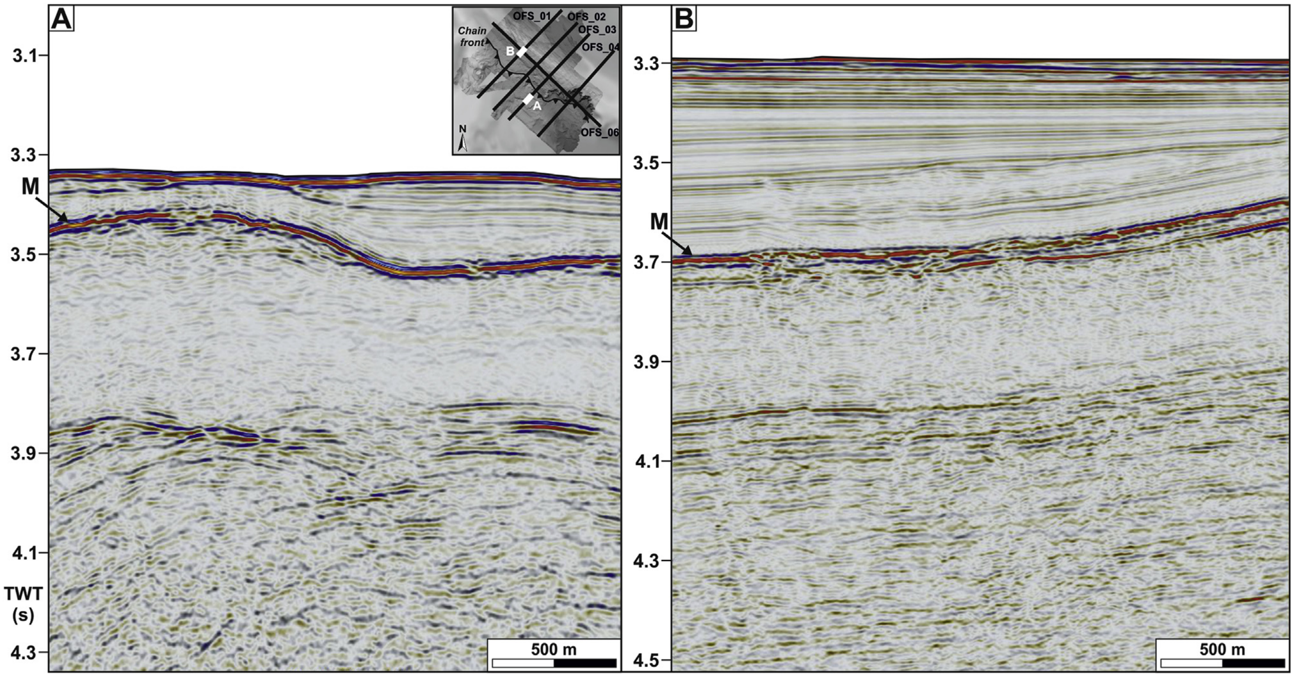

Fig. 11. Comparison of the semi-transparent seismic facies below the M-reflector on the opposite sides of the current foredeep basin: A) along the interpreted *sector 2* of the external CAW; B) along the Apulian Foreland. Note their close analogy of thickness and seismic facies.

peculiar geological setting resulted from the collisional system between the CAW and the Apulian Foreland, as shown in Fig. 13 and described below.

The *pre-Pliocene accretionary wedge* (the interpreted *sector 1*) would represent the easternmost extension of the Calabrian Accretionary Wedge deformed mainly in pre-collisional time.

The oblique collision with the thick carbonate Apulian Foreland caused a strong resistance for the chain, which started to migrate along the Apulian margin. Collision involved also the western Apulian Foreland in compressional deformation and induced the development of a foredeep which is evidenced along the southern profiles (Fig. 8); gravitational bodies present on the eastern slope of the foreland, facing the frontal chain, can be referred to the same event (Fig. 8B and C). In the northern sector of the study area the foredeep was less developed, likely buried and deformed by the CAW (Fig. 9). At the end of the lower Pliocene the front direction changed from W-E to WNW-ESE (Del Ben et al., 2008) and the mainly compressional tectonics changed to a prevailing transpressional regime. This change, recorded by the mid-Pliocene unconformity observed in the CAW and by syn-tectonic wedges recognized in the foredeep basin and in the foreland, was probably associated with a general re-organization of the plate motions in the central Mediterranean (Mantovani et al., 2014). We interpret this event as a last attempt of the eastward migration of the chain, before the lateral front would align to the margin of the thick Apulian Foreland. Argnani et al. (2001) and Argnani (2006) interpreted the normal faults affecting the foreland as the product of the bending of the lithosphere induced by the double loading of the subducted slab by CAW on the west and the Hellenides to the east. They proposed a general Plio-Quaternary time for this flexure and the related normal faults; whereas Butler (2009) provided an upper Miocene-lower Pliocene age for the same features. In our interpretation the normal faults would be strictly joined to the orogenward tilting of the foreland, which developed in a very short time after the deposition of the lower Pliocene semi-transparent layer covering the M-reflector. In the upper portion of the foredeep basin the horizontal stratification suggests an overall stop of the main front migration after the last compressive phase marked by the growth wedge observed at 4.2 s TWT. It has been laterally correlated to the syn-tectonic wedges recognized on the foreland. After the middle Pleistocene transpressional tectonic affected the collisional area in the Taranto Gulf (Del Ben et al., 2008; Ferranti et al., 2009), and also deformed the western sector of the foredeep sequences (*Thrusted Foredeep Succession*, the interpreted *sector 3*).

The involvement of the thick western margin of the Apulian Foreland by compression produced the original deformed structure of the *Transpressed Apulian Block* (*TAB*, the interpreted *sector 2*) which is characterized by a little horizontal throw, suggesting its “semi-autochthonous” nature (Figs. 4 and 13*)*. The existence of this block would mark a new position of the more recent foredeep basin developed on the Apulian Platform domains and consequently a jump to the NE of external front of the CAW. The seismic facies of the outer thrust of the CAW is characterized by a high amplitude reflector at the top of a semi-transparent facies toward NW as can be seen on one of the profile interpreted by Butler and on the CROP-M5 profile (Fig. 9). It extends on a narrow NW-SE oriented belt parallel to the collisional front. We assume that it could not be an evaporitic structure considering that: i) the transpression on a so wide area should have produced a halokinetic deformation that is not evident in the analysed profiles. On the contrary, in the study area, the transparent sequence involved in the outer thrust seems rather a solid block only weakly folded and fractured; ii) P-wave velocity trends deduced by velocity spectra do not show any velocity inversion as expected in presence of salt, as discussed in Chapter 4.3; iii) the close analogy of the seismic facies recognized in the main part of the Apulian Foreland, characterized by high reflectivity at the top and an internal transparent upper thickness (2–300 ms TWT) covering a medium/high amplitude sequence (4–500 ms TWT and more). Integration of these different data supports the affinity of TAB to the Apulian carbonate platform. Finally, the TAB would be the southern continuation of the Amendolara Ridge, identified further to the north in the Taranto

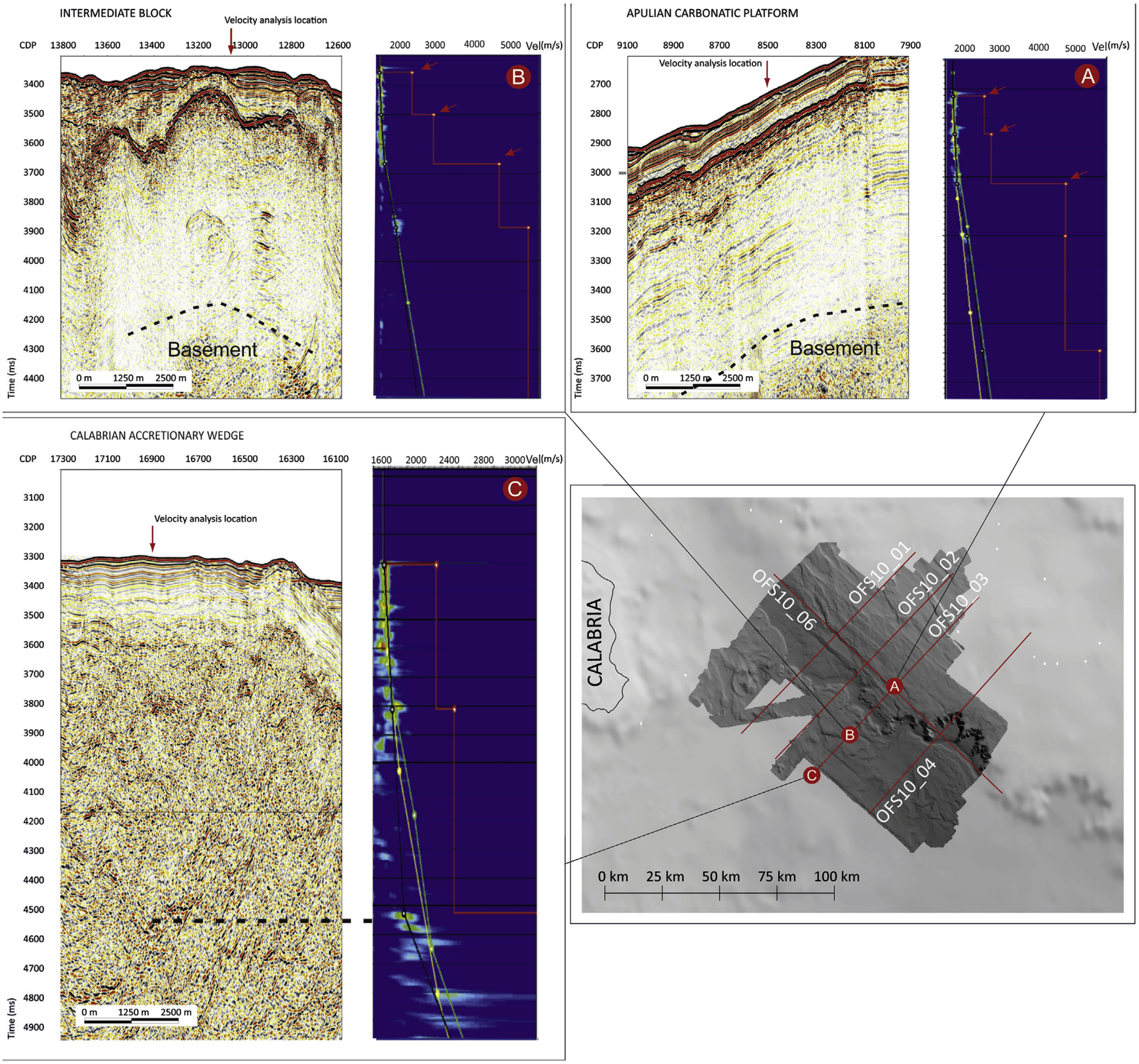

Fig. 12. Velocity spectra used for generating seismic stacking velocities.

Gulf (Ferranti et al., 2009, 2014). They together would represent the result of a middle-upper Pleistocene transpressional tectonics (Del Ben et al., 2008; Ferranti et al., 2009) that has affected the margin of the thick Apulian Foreland. In the Apulian Foreland, the predominant stratified deep seismic facies, also evidenced in the TAB, could be due to Mesozoic temporary drowning of the platform, with the development of transitional sequences (ViDEPI, 2009; Permits D.R67.FI and F.R26.AG). This facies laterally changes to a reflection free seismic facies that can be ascribed to competent carbonate formations. Along the OFS_10 profiles this massive facies identifies a block more or less 10 km large, representing the central part of the Apulian Swell (Fig. 13). It is bordered by the westward onlapping reflectors that characterize the Jurassic intraplatform pelagic domain of the *buried South Apulian Basin* (Fig. 7C), located at the eastern side of the swell (Fig. 4). As already defined by Del Ben et al. (2015) this basin is probably a western continuation of the Ionian basin which is largely deformed in the Corfù Island. Thanks to the high quality of the OFS_10 dataset, it shows to be more extensive than what defined by Cazzini et al. (2015) and occupies a large part of the south Salento offshore (Fig. 13).

6. Conclusions

This work is an attempt to reconstruct the structural tectonic setting and the Neogene tectonic evolution of the northern Ionian Sea starting from a careful seismo-stratigraphic analysis of the new OFS_10 seismic dataset, in an area where no well data are available. The study area includes the northeastern CAW/Apulian Foreland collisional system.

On the basis of seismic facies, also supported by interval

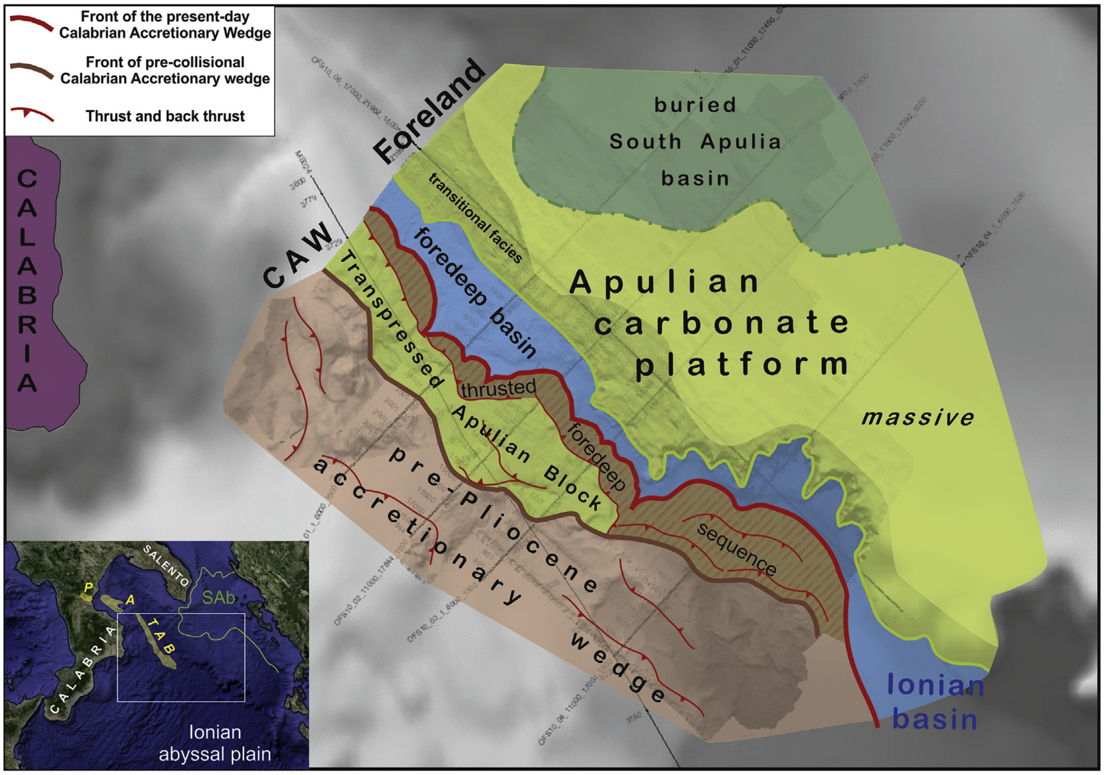

Fig. 13. Summary map of the main tectonic domains identified in the investigated area. The inset map shows the location of the *Transpressed Apulian Block* (TAB), the two major tectonic fault zones of Pollino (P) and Amendolara (A) and the South Apulia basin (SAb).

velocities and seismic attributes analysis obtained from data processing, three different sectors have been recognized in the front area of the CAW: a more external deformed domain, composed of thrusted foredeep sequences; a carbonate block belonging to Apulian Foreland (Transpressed Apulian Block, TAB) involved in the wedge; a highly tectonized, predominantly pre-Pliocene accretionary wedge. A reflection free seismic facies characterizes the massive carbonate succession of the Apulian Platform, which extends toward the east up to the South Apulia basin, in the SE-Salento offshore. The platform massive facies turns westward in a transitional stratified seismic facies which includes the present-day foredeep-foreland margin. This prominent basin, filled by a thick sub-horizontal Plio-Quaternary succession, was originated by the Pliocene oblique collision between the CAW and the thick Apulian Foreland. In particular, the westernmost Apulian margin was affected by a compressional deformation which borders the foredeep to the west. Subsequently, a mid-Pliocene tectonic event, showed by the presence of a regional angular unconformity, and probably related to a general re-organization of the plate motions in the central Mediterranean area, produced the main tilting phase of the Apulian Foreland, generating SW-flexuring and normal faulting. Afterwards, the oblique and diachronous collision between the CAW and the thick and rigid Apulian Foreland and the presence at the southern front of a remnant Ionian basin, produced a re-orientation of the direction of the CAW migration toward the SE. This induced a tectonic re-organization characterized by a predominant strike-slip regime in the study area. In this tectonic context, the TAB is interpreted as a structural high generated by a Pleistocene transpressional tectonics. Position, orientation and tectonics of the TAB suggest that this high could be the south-east continuation of the Amendolara Ridge, which forms the offshore extension of the Pollino range. It was interpreted as the result of a transpressional deformation along a deep-seated tear fault, which gradually developed toward the SE, separating the continental foreland crust of the Apulian Platform from the thin subducted Ionian crust.

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