

Accepted Manuscript

Distinguishing tectonically- and gravity-driven synsedimentary deformation structures along the Apulian platform margin (Gargano promontory, southern Italy)

Irina Korneva, Emanuele Tondi, Danica Jablonska, Claudio Di Celma, Ian Alsop, Fabrizio Agosta



PII: S0264-8172(15)30157-4

DOI: [10.1016/j.marpetgeo.2015.12.009](https://doi.org/10.1016/j.marpetgeo.2015.12.009)

Reference: JMPG 2417

To appear in: *Marine and Petroleum Geology*

Received Date: 24 June 2015

Revised Date: 30 November 2015

Accepted Date: 15 December 2015

Please cite this article as: Korneva, I., Tondi, E., Jablonska, D., Di Celma, C., Alsop, I., Agosta, F., Distinguishing tectonically- and gravity-driven synsedimentary deformation structures along the Apulian platform margin (Gargano promontory, southern Italy), *Marine and Petroleum Geology* (2016), doi: 10.1016/j.marpetgeo.2015.12.009.

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

DISTINGUISHING TECTONICALLY- AND GRAVITY-DRIVEN SYNSEDIMENTARY DEFORMATION STRUCTURES ALONG THE APULIAN PLATFORM MARGIN (GARGANO PROMONTORY, SOUTHERN ITALY)

¹Irina Korneva, ¹Emanuele Tondi, ¹Danica Jablonska, ¹Claudio Di Celma, ²Ian Alsop, ³Fabrizio Agosta.

¹ Geology Division, School of Science and Technology, University of Camerino, Italy
Via Gentile III da Varano, Camerino (MC) 62032, Italy.
Email: irina.korneva@unicam.it (corresponding author)

²Department of Geology and Petroleum Geology, School of Geosciences, University of Aberdeen, U.K.
King's College, Aberdeen AB24 3FX, United Kingdom.
Email: ian.alsop@abdn.ac.uk

³Department of Sciences, University of Basilicata, Italy.
Via Nazario Sauro, 85, Potenza 85100, Italy.
Email: fabrizio.agosta@unibas.it

Abstract

The assessment of deformation types within the slope of a carbonate platform can be complicated by the possible interaction of rooted (tectonically-induced) and superficial (gravity-driven) structures. An ideal case study to document and distinguish tectonically- and gravity-driven structures is provided by the Cretaceous slope-to-basin carbonates exposed in the Gargano Promontory, southern Italy. These carbonates formed adjacent to the Apulian platform margin, which was oriented approximately NE-SW to NW-SE along the southern and northern edges of the promontory, respectively. Slump-related folds are characterised by axial planes typically oriented either sub-parallel or at small angles to the strike of the inferred paleoslope. In fact, the strike of folds is roughly NE-SW in the southern portion of the study area, whereas it is NW-SE in the northern part. Correspondingly, gravity-driven normal and reverse faults strike sub-parallel and at acute angles to the adjacent Apulian paleoslope. Cretaceous tectonic faults in the slope-to-basin carbonates form two principal sets striking NW-SE and WNW-ESE. The former set is made up of normal faults and the latter one includes mainly oblique-slip normal

faults. Neither normal nor oblique-slip normal faults show any relationship with the geometry of the paleoslope. The results obtained from this study may help the interpretation of subsurface data in those geological contexts in which the interplay of gravitational and tectonic processes is responsible for deformation.

Key Words: Apulian platform; Maiolica Formation; synsedimentary faults; slumps; mass-transport deposits.

1. Introduction

Sediments deposited along the slope-to-basin margin of carbonate platforms represent important hydrocarbons reservoirs worldwide (e.g. Casabianca *et al.*, 2002). These rocks are commonly affected by multiple stages and types of deformation (Antonellini *et al.* 2008; Hairabian *et al.*, 2015, and references therein; Pickering, 1987; Santantonio *et al.*, 2012) governed by both, gravitational and tectonic processes. This results in carbonate reservoirs being affected by a wide range of different permeability structures and petrophysical properties of associated fault rocks (Agosta *et al.*, 2009; Agosta *et al.*, 2010; Balsamo & Storti, 2010; Guerriero *et al.*, 2013).

The oldest deformation structures are often contemporaneous with the platform growth (Bourrouilh *et al.*, 1998; Kosa & Hunt, 2005; Rusciadelli *et al.*, 2003) and could be formed due to either gravity-driven re-sedimentation processes (Drzewiecki & Simo, 2002; Hairabian *et al.*, 2015; Jablonská *et al.*, in press; Strachan & Alsop, 2006) or tectonically-triggered synsedimentary deformation (Rosales, 2001; Wiedl *et al.*, 2012).

The presence of rooted (tectonically-induced) and superficial (gravity-driven) structures in a carbonate reservoir may strongly affect migration and storage of geofluids. Tectonic faults can form efficient pathways for upward fluid flow from depth (Faulkner & Rutter, 2001;

Rotevatn & Bastesen, 2014), whereas gravity-driven structures are generally confined within the reservoir without any connection to deep fluids (Alsop & Marco, 2011; Roberts *et al.*, 2002 and references therein). This results in rooted and superficial structures having different roles in the diagenetic evolution of sediments (e.g., hydrothermal and/or epigenetic dolomitisation phenomenon) and in the flow of prospective hydrocarbons from source to reservoir rocks.

Distinguishing structures triggered by gravity, tectonics or any combination thereof, along passive continental margins may not be straightforward. In fact, gravitational forces acting on slopes can produce a large component of differential stress within a tectonically-controlled stress field. Soft-sediment deformation driven by rooted tectonic processes was previously documented at many plate boundaries (Bievre & Quesne, 2004; Bourrouilh *et al.*, 1998; Pochat & Van Den Driessche, 2007).

A distinction between different types of deformation structures was proposed by Waldron & Gagnon (2011). According to these authors, 'superficial' deformation occurs above a basal detachment linked to the surface in both the up-slope and down-slope directions. Conversely, 'rooted' deformation is connected to a shear zone propagating at depth. The authors distinguished four different types of deformation based upon the physical state of rock (i.e., lithified or unlithified) and type of deformation (i.e., superficial or rooted). Superficial deformation of unlithified sediments produces structures such as slumps, whereas rooted deformation of similar sediments consists of folds and growth faults connected to a shear zone propagating at depth. Superficial deformation of lithified rocks allows down-slope rock sliding, while rooted deformation of the same material produces brittle and ductile structures of classic rock deformation environments.

As noted above, soft sediment deformation within carbonate-dominated continental margins can therefore be related either to gravitational processes or tectonic activity. The former depends on parameters such as sedimentation rate, compositional and textural features of

sediments and depositional architecture (Hance, 2003; Le Goff *et al.*, 2015; Okada *et al.*, 2014). All these parameters can help overcome the angle of internal friction of carbonate sediments to create instability on the slope and generate down-slope mass transport with related deformation. Tectonics affecting the slope may also be the triggering mechanism for slumping due to the earthquake-induced reduction in the shear strength of sediment, slope steepening due to faulting, and tsunami-induced deformation (Alsop & Marco, 2012a, Mastrogiacomo *et al.*, 2012; Spalluto *et al.*, 2007; Alsop & Marco, 2012b).

The Gargano Promontory, southern Italy, represents an ideal place to document and distinguish tectonically- and gravity-driven deformation structures within slope-to-basin carbonates. There, Cretaceous tectonic structures and their interaction with the sedimentation processes along the margin of the Apulian platform have been widely documented (Borgomano, 2000; Graziano, 2000, 2001, 2013; Hairabian *et al.*, 2015 and references therein; Santantonio *et al.*, 2012). However, there remains a lack of a detailed description of exposed deformation structures, as well as distinction of their triggering mechanisms.

The present work focuses on deformation structures within the Late Jurassic to Early Cretaceous basinal Maiolica Formation exposed immediately to the east of the Apulian platform margin in the eastern part of the Gargano Promontory (Fig. 1, 2). Field structural data, collected from synsedimentary tectonic faults and slump-related structures, are discussed in terms of paleogeography of the Apulian margin, Cretaceous tectonic activity of the study area and significance for subsurface fluid flow. The detailed description of rooted and superficial structures, provided in this study, can be a helpful guide for their recognition from subsurface data in similar carbonate reservoirs.

2. Geological framework

The Gargano Promontory is part of the Apulian Mesozoic carbonate shelf that formed along a passive margin of the Tethys Ocean (Fig. 1; Bosellini *et al.*, 1999; Graziano, 2000; Turco *et al.*, 2012). It also represents the foreland of both the Apennine and Dinaride thrust-and-fold belts (Billi & Salvini, 2003; Doglioni, 1994). Along the Italian eastern shoreline, the Apulian Mesozoic shelf also crops out at Majella Mountain in central Italy, where the transition from platform to slope/ramp facies is well exposed (Accarie *et al.*, 1986; Casabianca *et al.*, 2002; Eberli *et al.*, 2004; Morsilli *et al.*, 2002). Coarse deposits and mass-transport deposits (MTDs) largely constitute the Apulian paleoslope, being re-deposited during the Upper Albian - Cenomanian due to tectonic instabilities at the shelf margin (Le Goff *et al.*, 2015). Based on field evidence (Bosellini *et al.*, 1999) and seismic data (Santantonio *et al.*, 2012) the paleoslope of the Apulian platform is characterised by the following orientations (Fig. 1): NE-SW in the north (Abruzzo region and Adriatic offshore), NW-SE in the central portion (Adriatic offshore and most of the Gargano Promontory), and NE-SW in the south (southern portion of the Gargano Promontory and the Murge Plateau).

The whole Gargano succession is approximately 4000 m-thick, and comprises Upper Jurassic to Eocene limestones and dolomites (Bosellini *et al.* 1993b; Martinis & Pavan 1967; Masse & Luperto Sinni 1989). Both the western and central portions of the Gargano Promontory expose Apulian platform carbonates, whereas slope to basinal carbonates crop out only along its eastern side (Figs. 1, 2; Bosellini *et al.*, 1993b, 1999; Martinis & Pavan 1967). Several authors have documented a strong interaction between tectonic and sedimentary processes along the margin of the Apulian carbonate platform (Borgomano, 2000; Graziano, 2000, 2001, 2013; Hairabian *et al.*, 2015 and references therein; Santantonio *et al.*, 2012). In fact, some of these authors have also proposed that formation of megabreccia bodies was triggered by Cretaceous tectonics (Borgomano, 2000; Graziano, 2000, 2001; Masse & Borgomano, 1987). In particular, Hairabian *et al.* (2015) documented two main types of calciclastic lithologies characterised by

differences in the nature and source of material: (1) breccias related to the erosion of lithified limestones, and (2) loose bioclastic sands and gravels directly exported from the neritic “carbonate factory”. These breccia types are located along two different portions of the Apulian margin characterised by two different slopes: a gentle one and a steep, fault-controlled slope.

From a structural point of view, the Gargano Promontory is composed of a WNW-ESE trending anticline crosscut by several E-W, NE-SW and NW-SE trending steep to sub-vertical normal and strike-slip faults. The Mattinata Fault System (MAFS) is the most prominent structural element of the Gargano Promontory onshore (Fig. 2 A). As shown by seismic profiles, MAFS extends offshore for a few tens of kilometres and merges into the Gondola Line (De Dominicis & Mazzoldi, 1989). MAFS has been characterised by right-lateral kinematics since Middle to Late Pleistocene times, which was superimposed onto earlier left-lateral kinematics (Fiore, 2013; Tondi *et al.*, 2005).

This study focuses on the well-known Late Jurassic to Early Cretaceous basinal Maiolica Formation, which consists of whitish thin-bedded micritic limestone with cherts, affected by a large number of syn-depositional slumps featuring intraformational folds and faults, and truncation surfaces (Bosellini *et al.*, 1999; Jablonska *et al.*, in press; Morsilli & Moretti 2011).

3. Field analysis

The present study aims to distinguish and characterise rooted (tectonic) and superficial (gravitational) synsedimentary deformation structures along the Apulian margin. The studied outcrops of the Maiolica Formation consist of natural cliffs and road cuts located along the eastern coast of the Gargano Promontory, specifically between the towns of Mattinata and Vieste (Fig. 2, 3). The present-day bedding attitude, statistically measured through the whole study area, is sub-parallel to the Apulian palaeoslope (Santantonio *et al.*, 2012). Therefore, from Mattinata to Pugnochiuso, the established paleoslope orientation is NE-SW, and from Pugnochiuso to

Vieste it is NW-SE (Figs 1, 3). Field observations focus on slumps and faults within the slope-to-basin succession. Data on spatial and dimensional characteristics of folds (fold hinge plunge, vergence, inter-limb angle, amplitude and wavelength) were acquired from within slump sheets. Faults were studied by considering their orientation, kinematics and internal structure. Dips of faults were measured with reference to the horizontal surface. Particular attention was paid to documenting possible relationships between MTDs and fault-related structures. Slump décollements and overlying sediment caps have been identified, and faults located within slump bodies have been described in detail. Bedding of undeformed layers below MTDs was also measured in order to provide a reference frame.

Field data gathered from the southern (from Mattinata to Pugnochiuso) and northern (Pugnochiuso to Vieste) portions of the study area are reported separately below.

3.1. Southern portion of the study area (from Mattinata to Pugnochiuso)

Within the slope-to-basin succession exposed in the southern portion of the study area, slump-related folds verging both downslope (to the SE and E) and upslope (to the NW and WNW) were documented. Folds verging down-slope are the most abundant, and comprise inclined-to-overtuned tight folds with interlimb angles ranging between 30 and 60° (Fig. 4 A). They are characterised by bedding being thicker in the fold hinges relative to the fold limbs, and define similar folds (*sensu* Ramsay, 1967). Commonly, fold hinges plunge at low angles to either the NE or SW. The fold wavelengths range from tens of centimetres to few metres and amplitude is up to several metres. Folds verging up-slope consist of inclined, open to tight up to isoclinal folds. They are characterised by thickening of chert in the hinge with respect to the fold limbs and are classified as similar folds (*sensu* Ramsay, 1967). The fold wavelengths range from a metre to a few metres and amplitude is up to several metres (Fig. 4 B, E, F). The upper boundary of deformed slumped units is generally flat and is overlain by undeformed beds.

Four main sets of faults are present in the southern portion of the study area (Fig. 5). Set 1 includes low-angle NE-SW striking reverse faults that are located within slump sheets (Fig. 4 B) and are characterised by fault cores represented by a single surfaces and no visible damage zones (see definition of fault core and damage zone in Caine *et al.*, 1996). Set 2 is comprised of NE-SW striking normal faults located within deformed beds and is characterised by dip angles varying within individual faults (Fig. 6). These faults generally have a few centimetres to tens of centimetres offset. In the hanging wall, beds are characterised by dip angles gradually decreasing upward which is an indicator of synsedimentary fault activity. The damage zones of these faults cannot be observed in the field and the fault core is represented by a single surface. Set 3 is made up of NW-SE striking normal faults forming conjugate systems dipping at 65-80° either towards the NE or SW (Fig. 7). In Fig. 7, the growth syncline above the upper tip of the NE-dipping normal fault is consistent with 45 cm of throw and a ~ 20 cm increase in bed thickness in the hanging wall of the fault. The fault cores of the two structures are made up of discontinuous slip surfaces bounding a 1-to-10 cm-thick fault gouge (Fig. 7 B), and up to 20 cm-thick uncemented breccia in extensional jogs of the fault. The damage zones of these faults consist of joints and sheared joints striking E-W and NW-SE and dipping to the S and SW respectively. Set 4 consists of high-angle WNW-ESE striking oblique-slip normal faults (Fig. 8) crosscutting undeformed beds. These faults are characterised by fault cores constituted by discontinuous slip surfaces bounding chert lenses (Fig. 8 B). The damage zones are mostly located at fault tips and linkage zones and are made up of fractured limestone rocks. The main slip surface is usually discontinuous with its distinct segments abutting against chert beds.

3.2. Northern portion of the study area (from Pugnochiuso to Vieste)

Along the northern portion of the study area, where the most intensely deformed units occur, slump-related folds are characterised by axial planes orientated either sub-parallel or at

small angles to the inferred strike of the paleoslope (Santantonio *et al.*, 2012). Folds verge either up- or down-slope, and are characterised by hinges plunging predominantly at low angles to the NW or SE (Figs. 9, 10). Folds verging down-slope are open to tight (up to isoclinal), inclined to recumbent structures with wavelengths of several metres and amplitudes of tens of metres. The folds limbs are characterised by smaller scale open folds (inter-limb angle 120°) with wavelengths of 1 m and amplitudes up-to 40 cm (Fig. 9 B, C). A significant increase in thickness of beds is observed at the fold hinges relative to the limbs. The upper contact with undeformed beds is flat and it is commonly represented by a chert layer. Folds verging up-slope are characterised by hinges plunging at low angles either to the NW, W or SE, E (Fig. 10). These folds are inclined and recumbent, up to several metres in amplitude and wavelength, with inter-limb angles ranging from ~ 8 to 60° . Some folds display beds of equal thickness in the hinge and the limbs and are parallel folds (*sensu* Ramsay, 1967)

Three main sets of faults have been recognised (Fig. 5). Set 1 is made up of low-angle NW-SE striking reverse faults dipping to the ENE and NE at $30-40^{\circ}$. These faults are located within individual slump sheets and are characterised by fault cores represented by single surfaces and no damage zones (Fig. 10 B). Set 2 consists of NW-SE striking normal faults dipping either towards the SW or NE, which show variable dip angles along individual slip planes. These faults are characterised by vertical offset up to several tens of centimetres. According to their relationships with slumps, set 2 faults have been arranged in two subsets: subset 2a faults located within individual slump sheets and subset 2b faults crosscutting undeformed beds. Based on field observations, faults of set 2a are characterised by the absence of recognisable damage zones and fault cores represented by a single surface. The faults shown in Figure 10 dip at 45° towards the NE and SW and form a conjugate system. They are characterised by listric geometries. These faults belong to set 2a and are mostly located within deformed beds of folded and brecciated limestone (Fig 11). The individual faults are made up of multiple slip surfaces with variable dip

angles. Limestone beds are often rotated across these faults. Set 2b faults are located within undeformed beds (outside of any MTDs). These faults dip towards the NE and SW and cut either flat-lying or tilted limestone beds, typically showing about 60° cut-off angles with present-day tilted bedding (Fig. 12 A). The upper fault tip is often characterised by a growth syncline with an increase in bed thickness in the hanging wall (Fig. 12 A). The fault cores are made up of discontinuous slip surfaces bounding chert incorporated in the fault and abutting against chert layers within the succession (Fig. 12 B). The measured fault throw is up to 50 cm. Set 3 comprises WNW-ESE striking oblique-slip normal faults which crosscut undeformed beds and dip at $50\text{-}65^\circ$ to either the SW or NE (Fig. 13). Fault planes typically comprise discontinuous segments and damage zones are commonly localized within linkage zones. Fault cores are represented by discontinuous slip surfaces. Some of these faults are characterised by rotation and downward steepening of bed-parallel stylolites in the hanging wall (Fig. 13 B). The measured fault throw is up to 40 cm.

4. Discussion

The geometry of the paleoslope and faults orientation, kinematics and spatial relationship with MTDs permits us to discriminate tectonically-driven faults from gravity-related faults exposed along the Apulian margin.

Within the southern portion of the study area, both set 1 and set 2 faults strike sub-parallel to the NE-SW oriented paleoslope (Figs. 4, 6). These faults are interpreted as gravity-driven structures because they are localised within slump deposits and are characterised by listric geometries. In fact, according to previous authors, who worked in the other areas, gravity-driven faults are rooted downwards into décollements located within MTDs (e.g. Roberts *et al.*, 2002 and references therein). The occurrence of gravity-driven faults oriented parallel to the strike of

palaeoslopes was previously documented in different locations, based on field observations and seismic reflection data (Posamentier & Martinsen, 2011; Strachan & Alsop, 2006; Xinong Xie *et al.*, 2008). Deformation structures characterised by reverse and normal kinematics were recognised within slumps by numerous authors (Martinsen & Bakken, 1990; Smith, 2000; Strachan, 2002). Critically, set 3 normal faults and set 4 oblique-slip normal faults are orthogonal to the strike direction of the Apulian paleoslope. These fault sets are interpreted as tectonically-driven Cretaceous structures because they have been documented through the whole study area and are located far from MTDs. Consistently, Aptian-Albian faulting has been reported from the Gargano area by Graziano (2001), while further south in the Murge area, along the NE edge of the Apulian carbonate platform, Cretaceous extensional tectonics has been proposed by Borgomano (2000), Festa (2005), Spalluto *et al.* (2007) and Korneva *et al.* (2014). Moreover, Cretaceous tectonic deformation affecting the Apulian margin exposed in the Majella area, to the north of the study area, has been documented by Casabianca *et al.* (2002), Morsilli *et al.* (2002), Rusciadelli (2005), Santantonio *et al.* (2012) and Abela (2012) who have also recognised NW-SE oriented Jurassic and Cretaceous normal faults based on offshore and onshore seismic data.

In the northern portion of the study area both set 1 and set 2 faults, strike NW-SE, sub-parallel to the Apulian paleoslope. The stress field affecting the Gargano during Cretaceous time was likely characterised by the maximum horizontal compressive stress axis being oriented NW-SE (Korneva *et al.*, 2014; Santantonio *et al.*, 2012). As set 1 reverse faults formed due to NE-SW compression and could not occur under this stress state, they are interpreted as gravity-driven faults. Since both, the paleoslope orientation and the strike of slump-related fold axial planes are NW-SE oriented, the formation of gravity-driven reverse and normal faults with sub-parallel orientations is justified (Martinsen & Bakken, 1990; Smith, 2000; Strachan, 2002). In fact, set 2a normal faults are located within deformed units formed by slumps and other MTDs and are oriented sub-parallel to the paleoslope; thus they are interpreted as gravity-driven faults.

Nevertheless, set 2b faults showing the same orientation (strike direction NW-SE) crosscut undeformed units and do not exhibit any relationship with MTDs; as such, they are interpreted as tectonic features. To conclude, in the northern portion of the Gargano Promontory, faults clearly related to slumps (gravity-driven) and faults without any correlation to slumps (tectonically-driven), display the same orientations. Set 3 is made up of NW-SE oriented oblique slip normal faults which correspond to set 4 faults in the southern portion of the Gargano Promontory which are already interpreted as tectonic features.

Set 1 and set 2 faults in the southern portion of the study area, and set 1 and set 2a faults in the northern part that have been interpreted as gravity-driven structures, share several structural characteristics. These include variable dip angles within individual faults, their listric geometry being associated with flattening of fault planes into décollements within the slump sheet, together with the absence of damage zones and fault cores represented by discontinuous slip surfaces. Conversely, set 3 and set 4 faults in the southern part of the study area, and set 2b and set 3 faults in the northern portion of the Gargano, that have been interpreted as tectonic structures, are generally characterised by poorly developed damage zones and discontinuous slip surfaces bounding chert which was dragged along the fault planes. Faults crosscutting carbonate successions interbedded with chert layers, and characterised by the presence of chert in the fault core have been previously documented across Western Europe and interpreted as early diagenetic structures (Clayton, 1986; Hibsich et al., 2003). Chert observed in the studied faults in the Gargano is deformed in a brittle manner, which means that it was already partially lithified during the fault activity related to Cretaceous tectonics. However, the observation that chert was incorporated and thinned along the fault plane, suggests that chert was partially mobile during the faulting.

To sum up, tectonic faults documented along the Apulian paleoslope exposed in the eastern Gargano are NW-SE oriented dip-slip normal and WNW-ESE oblique-slip normal faults. Gravity-driven folds and faults display variable orientations along the exposed Apulian paleoslope and typically strike sub-parallel to it (Fig. 14). The interaction of gravitational phenomena along the paleoslope, and Cretaceous tectonics acting in the study area, resulted in different structural architectures of the Apulian margin (Fig. 15).

The results presented in this work clearly show that the paleogeography and, in particular, the geometry of the paleoslope strongly controls the orientation of gravitational structures and represents a key factor for their recognition. Furthermore, gravity-related structures often are 'apparently' kinematically incompatible, as in the case of normal and reverse faults with the same orientation. Gravity-driven faults are systematically associated with slumps and MTDs with an elevated degree of heterogeneity in terms of both mechanical and petrophysical properties of the rock masses. On the contrary, tectonic structures are not affected by the paleogeography and show a persistent orientation and kinematics. In the southern portion of the Apulian margin exposed in the Gargano, gravity-driven and tectonic faults are orthogonal to each other, whereas in the northern part they are subparallel (Fig. 14). This means that in former case gravity-driven faults may form additional pathways for geofluids and play an important role in fault-related diagenesis of the rock due to their higher connectivity with tectonic faults. As shown by previous authors, syndepositional faults formed within the platform and its margin can be responsible for a significant diagenetic alteration and determine resultant hydraulic properties of a carbonate reservoir (Dewit *et al.*, 2012; Hollis & Juerges., 2011; Hunt *et al.*, 2002; Kosa & Hunt., 2006; Simon, 2014).

The outcomes of this study increase our knowledge regarding the different deformation processes that may affect slope-to-basin sedimentary rocks associated with the margins of

carbonate platforms. Improving our ability to distinguish structures triggered by gravity and tectonics is essential for the prediction of reservoir quality in similar systems in the subsurface.

5. Conclusions

The eastern Gargano slope-to-basin succession of the Apulian platform is affected by synsedimentary deformation generated by both tectonic and gravitational phenomena. NW-SE oriented dip-slip faults and WNW-ESE oriented oblique-slip normal faults have been interpreted as Cretaceous tectonic features. These structures are exposed throughout the whole study area and do not show any relationship with MTDs. Tectonic faults are generally characterised by chert dragged along the fault planes, and slightly fractured limestone in the tip damage zones. The orientations of slump-related folds and gravity-driven faults change in sympathy with the geometry of the Apulian paleoslope. Most of gravity-driven faults are normal or reverse, and are oriented sub-parallel to the strike of the paleoslope. These faults are characterised by variation in angles of dip of the fault planes within individual faults, and by the absence of visible deformation in fault cores and damage zones.

In synthesis, along the NE-SW-oriented Apulian margin, gravity-driven and tectonic faults are orthogonal to each other, whereas along the NW-SE oriented part of the margin they are sub-parallel. The resulting different structural architecture of the southern and northern part of the Apulian margin in the Gargano Promontory is the key factor for distinguishing structures triggered by gravity and tectonics. The orientation and distribution of these structures along the platform margin could control the pathways for migration of geofluids which, in turn, may affect the petrophysical properties of the rock due to fault-related diagenesis.

Acknowledgements

This work has been supported by Reservoir Characterisation Project (www.rechproject.com) and FAR Project 2014 "Characterisation and modelling of natural reservoirs of geofluids in fractured carbonate rocks", funded by the University of Camerino, coordinator Emanuele Tondi.

References

- ABLA, A. (2012) Subsurface characterisation of the Apulia carbonate platform in the foothills of the Apennines in Abruzzi Region (Central Italy). Master's thesis, University of Camerino.
- ACCARIE, H., BEAUDOIN, B., CUSSEY, R., JOSEPH, PH. & TRIBOULET, S. (1986) Dynamique sedimentaire et structural au passage plateforme/basin. Les facies carbonates cretaces du massif de la Maiella (Abruzzes, Italie). *Memorie della Societa Geologica Italiana*, 36, 217-231.
- AGOSTA, F., ALESSANDRONI, M., TONDI, E. & AYDIN, A. (2009) Oblique normal faulting along the northern edge of the Majella Anticline, central Italy: inferences on hydrocarbon migration and accumulation. *Journal of Structural Geology*, 31, 674-690.
- AGOSTA, F., ALESSANDRONI, M., ANTONELLINI, M., TONDI, E. & GIORGIONI, M. (2010) From fractures to flow: a field-based quantitative analysis of an outcropping carbonate reservoir. *Tectonophysics*, 490, 197-213.
- ALSOP, G. I. & MARCO, S. (2011) Soft-sediment deformation within seismogenic slumps of the Dead Sea Basin. *Journal of Structural Geology*, 33, 433-457.
- ALSOP, G.I. & MARCO, S. (2012a) A large-scale radial pattern of seismogenic slumping towards the Dead Sea Basin. *Journal of Geological Society London* 169, 99-110.
- ALSOP, G.I. & MARCO, S. (2012b) Tsunami and seiche-triggered deformation within offshore sediments. *Sedimentary Geology*, 261-262, 90-107.
- ALSOP, G.I. & MARCO, S. (2013) Seismogenic slump folds formed by gravity-driven tectonics down a negligible subaqueous slope. *Tectonophysics*, 605, 48-69.

- ANTONELLINI, M., TONDI, E., AGOSTA, F., AYDIN, A., AND CELLO, G. (2008). Failure modes in deep-water carbonates and their impact for fault development: Majella Mountain, Central Apennines, Italy. *Marine and Petroleum Geology*, 25 (10), 1074-1096.
- BALSAMO, F. & STORTI, F. (2010) Grain size and permeability evolution of soft-sediment extensional sub-seismic and seismic fault zones in high-porosity sediments from the Crotona basin, southern Apennines, Italy. *Marine and Petroleum Geology*, 27, 822-837.
- BIEVRE, G. & QUESNE, D. (2004) Synsedimentary collapse on a carbonate platform margin (Lower Barremian, southern Vercors, SE France). *Geodiversitas*, 26 (2), 169-184.
- BILLI, A. & SALVINI, F. (2003) Development of systematic joints in response to flexure-related fibre stress in flexed foreland plates: the Apulian forebulge case history, Italy. *Journal of Geodynamics*, 36, 523-536.
- BORGOMANO, J. R. F. (2000) The Upper Cretaceous carbonates of the Gargano-Murge region, southern Italy: a model of platform-to-basin transition. *AAPG Bulletin*, 84, 1561–1588.
- BOSELLINI, A., NERI, C. & LUCIANI, V. (1993b) Platform margin collapses and sequence stratigraphic organization of carbonate slopes: Cretaceous–Eocene, Gargano Promontory, southern Italy. *Terra Nova*, 5, 282–297.
- BOSELLINI, A., MORSILLI, M. & NERI, C. (1999) Long-term event stratigraphy of the Apulia Platform Margin (Upper Jurassic to Eocene, Gargano, Southern Italy). *Journal of Sedimentary Research*, 69, 1241–1252.
- BOURROUILH, R., BOURQUE, P.-A., DANSEREAU, P., BOURROUILH-LE JAN, F. & WEYANT, P. (1998) Synsedimentary tectonics, mud-mounds and sea-level changes on a Palaeozoic carbonate platform margin: a Devonian Montagne Noire example (France). *Sedimentary Geology*, 118, 95-118.
- CAINE, J.S., EVANS, J.P., FORSTER, C.B. (1996) Fault zone architecture and permeability structure. *Geology*, 24, 1025–1028.
- CASABIANCA, D., BOSENCE, D. & BECKETT, D. (2002) Reservoir potential of Cretaceous platform-margin breccias, central Italian Apennines. *Journal of Petroleum Geology*, 25, 179-202.
- CLAYTON, C.J. 1986. The chemical environment of flint formation in Upper Cretaceous Chalks. In: Sieveking G. De G. & Hart M.B. (eds) *The Scientific Study of Flint and Chert*. Cambridge University Press, Cambridge, 43-54.
- DE DOMINICIS, A. & MAZZOLDI, G. (1989) Interpretazione geologico-strutturale del margine orientale della piattaforma Apula. *Mem. Soc. Geol. It.*, 38 (1987), 163-176.

- DEWIT, J., HUYSMANS, M., MUCHEZ, PH., HUNT, W. W., THURMOND, J. B., VERGES, J., SAURA, E., FERNANDEZ, N., ROMAIRE, I., ESESTIME, P. & SWENNEN, R. (2012) Reservoir characteristics of fault-controlled hydrothermal dolomite bodies: Ramales Platform case study. In: *Advances in Carbonate Exploration and Reservoir Analysis* (Ed. by J. Garland, J. E. Neilson, S. E. Laubach and K. J. Whidden), Special Publication, Geological Society, 370, 83-109.
- DOGLIONI, C. (1994) The Puglia uplift (SE Italy): an anomaly in the foreland of the Apenninic subduction due to buckling of a thick continental lithosphere. *Tectonics*, 13, 1309-1321.
- DRZEWIECKI, P. A. & SIMO, J. A. (2002) Depositional processes, triggering mechanisms and sediment composition of carbonate gravity flow deposits: examples from the Late Cretaceous of the south-central Pyrenees, Spain. *Sedimentary Geology*, 146, 155-189.
- EBERLI, G. P., ANSELMETTI, F. S., BETZLER, C., VAN KONIJNENBURG, J.-H. & BERNOULLI, D. (2004) Carbonate platform to basin transitions on seismic data and in outcrops: Great Bahama Bank and the Maiella Platform margin, Italy. In: *Seismic imaging of carbonate reservoirs and systems*, AAPG Memoir, 81, 207– 250.
- FAULKNER, D. R. & RUTTER, E. H. (2001) Can the maintenance of overpressured fluids in large strike-slip fault zones explain their apparent weakness? *Journal of Geophysical Research*, 105, 16415-16426.
- FESTA, V. (2005) Cretaceous structural features of the Murge area (Apulian Foreland, Southern Italy). *Eclogae geol. Helv.*, 96, 11-22.
- FIORE, A. (2013) Evoluzione tardo-quadernaria dei sistemi deposizionali alluvionali e costieri del Gargano nord orientale (fra Mattinelle e San Menaio). *Ph.D. Thesis Dissertation*. Dipartimento di Scienze Geologiche, Dottorato di Ricerca in Scienze della Terra, XXIV ciclo, curriculum "Difesa dalle catastrofi idrogeologiche, monitoraggio e controllo delle risorse geologico-ambientali", Università degli Studi della Basilicata.
- GRAZIANO, R. (2000) The Aptian-Albian of the Apulia carbonate platform (Gargano Promontory, southern Italy): evidence of palaeoceanographic and tectonic controls on the stratigraphic architecture of the platform margin. *Cretaceous Research*, 21, 107-126.
- GRAZIANO, R. (2001) The Cretaceous megabreccias of the Gargano Promontory (Apulia, southern Italy): their stratigraphic and genetic meaning in the evolutionary framework of the Apulia carbonate platform. *Terra Nova*, 13, 110–116.

- GRAZIANO, R. (2013) Sedimentology, biostratigraphy and event stratigraphy of the Early Aptian Oceanic Anoxic Event (OAE1A) in the Apulia Carbonate Platform Margin – Ionian Basin System (Gargano Promontory, southern Italy). *Cretaceous Research*, 39, 78-111.
- GUERRIERO, V., MAZZOLI, S., IANNACE, A., VITALE, S., CARRAVETTA, A., STRAUSS, C. (2013) A permeability model for naturally fractured carbonate reservoirs. *Marine and Petroleum Geology*, 40, 115-134.
- HAIRABIAN, A., BORGOMANO, J., MESSE, J.-P., & NARDON, S. (2015) 3-D stratigraphic architecture, sedimentary processes and controlling factors of Cretaceous deep-water resedimented carbonates (Gargano Peninsula, SE Italy). *Sedimentary Geology*, 317, 116–136.
- HIBSCH C., CARTWRIGHT J., HANSEN D.M., GAVIGLIO P., ANDRE G. and CUSHING E.M. 2003. Normal faulting in chalk: tectonic stresses vs. Compaction-related polygonal faulting. Geological Society London Special Publications. 216(1):291-308.
- HOLLIS, C. & JUERGES, A. (2011). Fault-fracture diagenesis of Lower Carboniferous Platforms, UK-potential analogues for giant carbonate reservoirs of the Caspian Region? *Search and Discovery Article #30158*.
- HUNT, D. W., FITCHEN, W. M., KOSA, E. (2002) Syndepositional deformation of the Permian Capitan reef carbonate platform, Guadalupe Mountains, New Mexico, USA. *Sedimentary Geology*, 154, 89-126.
- JABLONSKA, D., DI CELMA, C., KORNEVA, I., TONDI, E., & ALSOP, I. Mass-transport deposits within basinal carbonates from southern Italy. *Italian Journal of Geosciences*. In press. DOI:10.3301/IJG.2014.51.
- KORNEVA, I., TONDI, E., AGOSTA, F., RUSTICHELLI, A., SPINA, V., BITONTE, R. & DI CUIA, R. (2014) Structural properties of fractured and faulted Cretaceous platform carbonates, Murge Plateau (southern Italy). *Marine and Petroleum Geology*, 57, 312-326.
- KOSA, E. & HUNT, D. W. (2005) Growth of syndepositional faults in carbonate strata: Upper Permian Capitan platform, New Mexico, USA. *Journal of Structural Geology*, 27, 1069-1094.
- KOSA, E. & HUNT D. W. (2006) The effect of syndepositional deformation within the Upper Permian Capitan Platform on the speleogenesis and geomorphology of the Guadalupe Mountains, New Mexico, USA. *Geomorphology*, 78, 279-308.
- LE GOFF, J., CEREPPI, A., SWENNEN, R., LOISY, C., CARON, M., MUSKA, K. & EL DESOUKY, H. (2015) Contribution to the understanding of the Ionian Basin sedimentary evolution along the eastern edge of Apulia during the Late Cretaceous in Albania. *Sedimentary Geology*, 317, 87-101.

- MARTINIS, B. & PAVAN, G. (1967) *Note illustrative della Carta Geologica d'Italia alla scala 1:100000*, Foglio 157, Monte Sant'Angelo. Servizio Geologico d'Italia, Roma, p.56.
- MARTINSEN, O. J. & BAKKEN, B. (1990) Extensional and compressional zones in slumps and slides in the Namurian of County Clare, Eire. *Geological Society of London*, 147, 153-164.
- MASSE, J. P. & BORGOMANO, J. (1987) Un modèle de transition plateforme-bassin carbonatés contrôlé par des phénomènes tectoniques: le Crétacé du Gargano (Italie Méridionale). *C. R. Acad. Sc. (Paris)* 304. Série II. 10, 521-526.
- MASSE, J. P. & LUPERTO SINNI, E. (1989) A platform to basin transitional model: the Lower Cretaceous carbonates of the Gargano Massif. *Mem. Soc. Geol. It.*, 40, 99-108.
- MASTROGIACOMO, G., MORETTI, M., OWEN, G. & SPALLUTO, L. (2012) Tectonic triggering of slump sheets in the Upper Cretaceous carbonate succession of the Porto Selvaggio area (Salento peninsula, southern Italy): Synsedimentary tectonics in the Apulian Carbonate Platform. *Sedimentary Geology*, 269-270, 15-27.
- MORSILLI, M. & MORETTI, M. (2011) Gli slumps del Gargano: paleofrane sottomarine del Cretaceo Inferiore, In: *Geoitalia Publications*, 47-51.
- MORSILLI, M., RUSCIADELLI, G. & BOSELLINI, A. (2002) Large-scale gravity-driven structures: control on margin architecture and related deposits of a Cretaceous Carbonate Platform (Montagna della Maiella, Central Apennines, Italy). *Bollettino Società Geologica Italiana*, 1, 619-628.
- OKADA, K., POGAČNIK, Ž., PINI, G.A., TUNIS, G., FESTA, A., CAMERLENGHI, A. & REBESCO, M. (2014) The carbonate MTDs of the Paleogene Friuli Basin (Italy/Slovenia): Internal anatomy and inferred genetic processes. *Marine Geology*, 356, 88–110.
- PICKERING, K.T. (1987) Wet-sediment deformation in the Upper Ordovician Point Leamington Formation: an active thrust-imbricate system during sedimentation, Notre Dame Bay, north-central Newfoundland. In: *Deformation of Sediments and Sedimentary Rocks* (Ed. by M.E. Jones and R.M.F. Preston), *Special Publication of the Geological Society London*, 29, 213-239. Oxford: Blackwell Scientific Publications.
- POCHAT, S. & VAN DEN DRIESSCHE, J. (2007) Impact of synsedimentary metre-scale normal fault scarps on sediment gravity flow dynamics: an example from the Gres d'Annot Formation, SE France. *Sedimentary Geology*, 202, 796-820.
- POSAMENTIER, H.W. & MARTINSEN, O.J. (2011) The character and genesis of submarine MTDs: insights from outcrop and 3D seismic data. *SEPM, special Publication*, 96, 7–38.
- RAMSAY, J.G. 1967. *Folding and Fracturing of Rocks*. McGraw-Hill, New York.

- ROBERTS, A.M., YIELDING, G. & FREEMAN, B. (2002) The geometry of normal faults. In: Seismic reflections from normal faults in the northern North Sea. *Special Publications The Geological Society of London*, 56, 61-78.
- ROSALES, I. (2001) Tectonic and environmental controls on platform geometry and facies architecture: the late Aptian-early Albian carbonate episode of the Castro Urdiales platform margin (Cantabria, northern Spain). *Geogaceta*, 30.
- ROTEVATN, A. & BASTESEN E. (2014) Fault linkage and damage zone architecture in tight carbonate rocks in the Suez Rift (Egypt): implications for permeability structure along segmented normal faults. In: Advances in the Study of Fractured Reservoirs (Ed. by Spence, G. H., Redfern, J., Aguilera, R., Bevan, T. G., Cosgrove, J. W., Couples, G. D., and Daniel, J.-M.), *Special Publications, Geological Society of London*, 374, 79-95.
- RUSCIADELLI, G., SCIARRA, N. & MANGIFESTA, M. (2003) 2D modelling of large-scale platform margin collapses along an ancient carbonate platform edge (Maiella Mt., Central Apennines, Italy): geological model and conceptual framework. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 200, 189–203.
- RUSCIADELLI, G. (2005) The Maiella escarpment (Apulia platform, Italy): geology and modeling of the Upper Cretaceous Scalloped Erosional Platform Margin. *Bollettino della Società Geologica Italiana*, 124, 661-673.
- SANTANTONIO, M., SCROCCA, D. & LIPPARINI, L. (2012) The Ombrina-Rospo Plateau (Apulian Platform): Evolution of a carbonate platform and its margins during the Jurassic and Cretaceous. In: The Geology of the Periadriatic Basin and of the Adriatic Sea. *Spec. Issue Marine and Petroleum Geology*, 42, 4 -29.
- SIMON, R. E. (2014) Syndepositional fault control on dolomitisation of a steep-walled carbonate platform margin, Yates Formation, Rattlesnake Canyon, New Mexico. Master's Thesis, University of Texas.
- SMITH, J. V. (2000) Flow pattern within a Permian submarine slump recorded by oblique folds and deformed fossils, Ulladulla, south-eastern Australia. *Sedimentology*, 47, 357-366.
- SPALLUTO, L., MORETTI, M., FESTA, V. & TROPEANO, M. (2007) Seismically-induced slumps in Lower-Maastrichtian peritidal carbonates of the Apulian Platform (southern Italy). *Sedimentary Geology*, 196, 81–98.
- SPALLUTO, L. & PIERI, P. (2008) Carta Geologica delle unità carbonatiche mesozoiche e cenozoiche del Gargano sud-occidentale: nuovi vincoli stratigrafici per l'evoluzione tettonica dell'area. *Mem. Descr. Carta Geol. d'It.*, LXXVII.

- STRACHAN, L. J. (2002) Slump-initiated and controlled syndepositional sandstone remobilization, an example from the Namurian of County Clare, Ireland. *Sedimentology*, 49, 25-41.
- STRACHAN, L.J. & ALSOP, G.I. (2006) Slump folds as estimators of palaeoslope: a case study from the Fisherstreet Slump of County Clare, Ireland. *Basin Research*, 18, 451-470.
- TONDI, E., PICCARDI, L., CACON, S., KONTNY, B. & CELLO, G. (2005) Structural and time constraints for dextral shear along the seismogenic Mattinata fault (Gargano, southern Italy). *Journal of Geodynamics*, 40, 134–152.
- TURCO, E., MACCHIAVELLI, C., MAZZOLI, S., SCHETTINO, A. & PIERANTONI, P. P. 2012. Kinematic evolution of Alpine Corsica in the framework of Mediterranean mountain belts. *Tectonophysics*, 579, 193-206.
- WALDRON, J. W. F. & GAGNON, J-F. (2011) Recognizing soft-sediment structures in deformed rocks of orogens. *Journal of Structural Geology*, 33, 271-279.
- WIEDL, T., HARZHAUSER, M. & PILLER, W. E. (2012) Facies and synsedimentary tectonics on a Badenian carbonate platform in the southern Vienna Basin (Austria, Central Paratethys). *Facies*, 58, 523.
- XINONG, X., MULLER, R. D., REN, J., JIANG, T. & ZHANG, C. (2008) Stratigraphic architecture and evolution of the continental slope system in offshore Hainan, northern South China Sea. *Marine Geology*, 247, 129-144.

Figure captions:

Fig. 1. Regional map showing the orientation of the paleoslope of the Apulian carbonate platform based on field and seismic data (modified after Santantonio *et al.*, 2012 and Bosellini *et al.*, 1999).

Fig. 2. A. Geo-structural scheme of the Gargano Promontory, the Mattinata Fault System is represented in red; Study area is marked by the black oval; B. Chronostratigraphic chart of the Gargano Promontory (after Bosellini *et al.*, 1999).

Fig. 3. A. Structural map of the study area (modified after Bosellini and Morsilli, 2001; Spalluto and Pieri, 2008), in which stereoplots show the bedding attitude (lower hemisphere, equal area projection) measured at several stations. B. Stratigraphic column of the study carbonate succession.

Fig. 4. Slump-related folds verging mostly to the SE, down-slope (A) and NW, up-slope (B, D) along the NE-SW oriented Apulian margin (station #1 in Fig. 3). Lower hemisphere, equal-

area stereographic projections of fold hinges verging either down, oblique to slope (red dots) or up slope (blue dots) (C). Black great circles represent bedding attitudes. Several reverse faults sub-parallel to bedding crosscut the few m-thick slump deposits (B). Yellow and purple lines indicate the lower (décollement) and upper (cap) boundaries of the slump deposit (A, B, D), respectively.

Fig. 5. Main fault sets documented within slope-to-basin succession adjacent to the NE-SW (A) and NW-SE (B) oriented Apulian paleoslope. A: black great circles show bedding attitudes, violet great circles represent attitudes of the set 1 faults, green great circles – set 2 faults, blue great circles – set 3 faults, orange great circles – set 4 faults; B: black great circles show bedding attitudes, violet great circles represent attitudes of the set 1 faults, blue great circles – set 2 faults, orange great circles – set 3 faults (lower hemisphere, equal-area projections).

Fig. 6. ENE-WSW normal faults recorded within MTDs exposed at station #7 (Fig. 3). Red lines highlight the fault traces. Lower hemisphere, equal-area stereographic projection displaying both bedding (black great circles) and fault attitude (red great circles).

Fig. 7. NW-SE oriented conjugate system of high-angle normal faults characterised by thickening of the beds within the hangingwall (from station 1, see Fig. 3) (A). B. Detailed photograph showing the fault core composed of un-cemented gouge. C. Stereographic projection showing bedding attitude with a black great circle and a fault with a red great circle (lower hemisphere, equal-area projection).

Fig. 8. A. WNW-ESE oriented transtensional fault with a maximum throw of 50 cm which gradually decreases upward (station 3 on the Fig. 3). B. Detailed photograph of the fault core composed of chert lenses. C. Stereographic projection showing bedding attitude with a black great circle and a fault with a red great circle (lower hemisphere, equal-area projection).

Fig. 9. Slump-related folds verging to N, NE (down-and oblique to slope) within several meter thick-slumps (A) along NW-SE oriented Apulian margin (station 6 on the Fig. 3). Limbs of larger inclined and recumbent folds are deformed with small inclined open folds (B, C). E. Stereographic projection showing bedding attitude with a black arc and folds hinges with red dots (lower hemisphere, equal-area projection).

Fig. 10. Gravity-driven deformation structures documented along NW-SE oriented part of the margin of the Apulian carbonate platform.

Fig. 11. WNW-ESE oriented conjugate normal faults crosscutting deformed units and the overlying cap. A. Outcrop photograph (station 5 on the Fig. 3). B. Line-drawing of WNW-ESE oriented normal faults crosscutting deformed unit and overlying cap. C. Lower

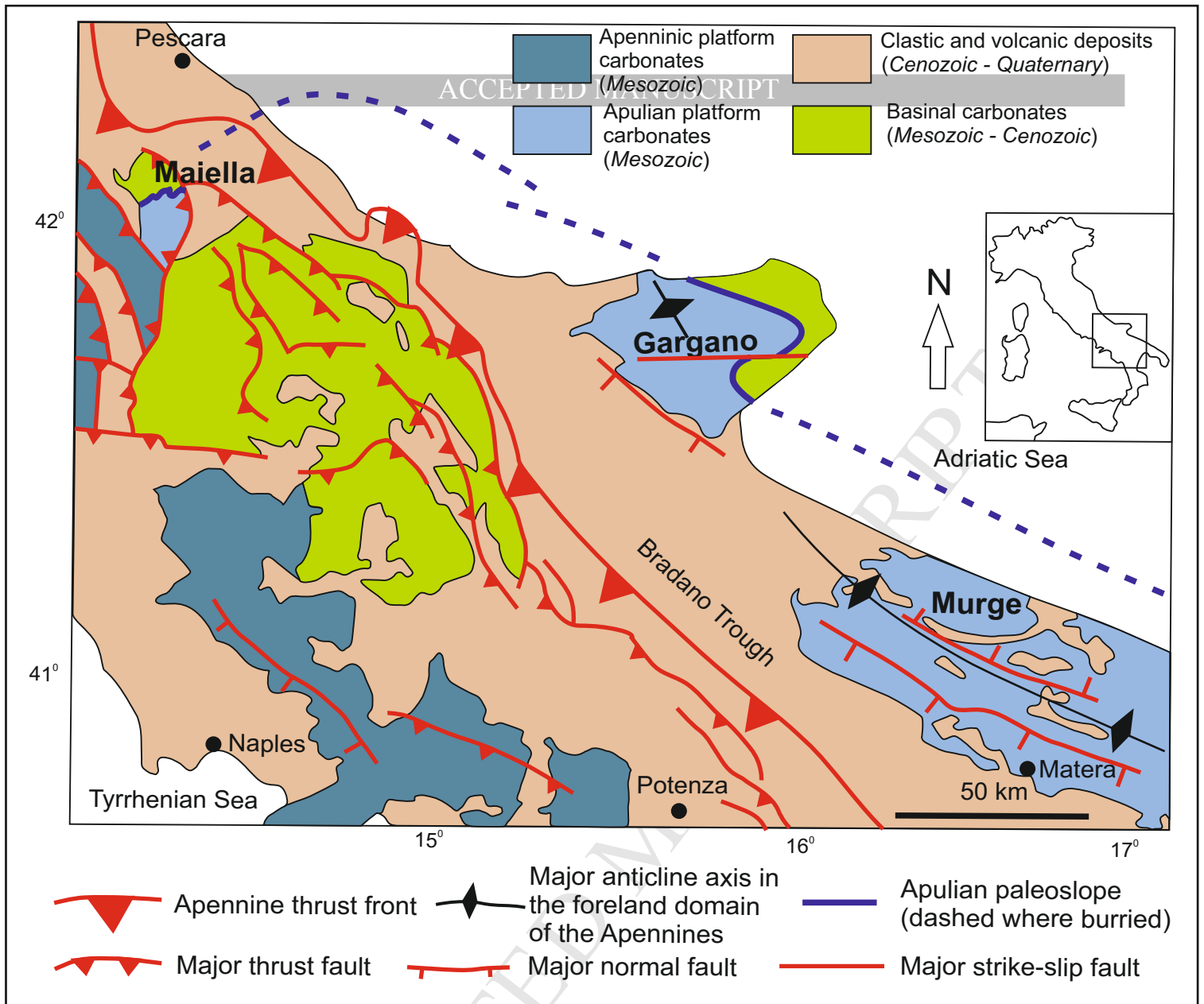
hemisphere, equal-area stereographic projection displaying bedding attitude (black great circle), faults (red great circles) and slump-related folds hinges (violet dots).

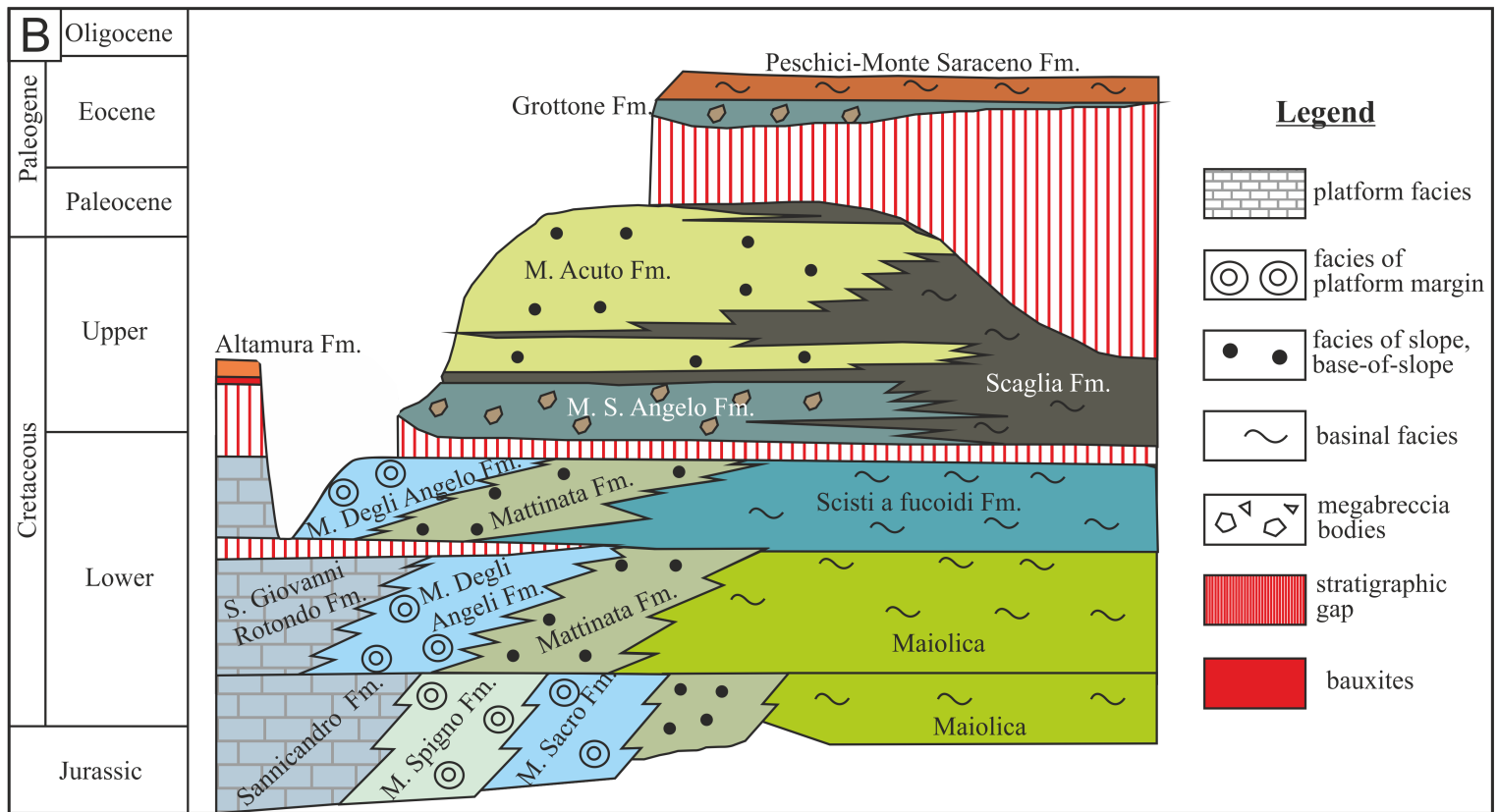
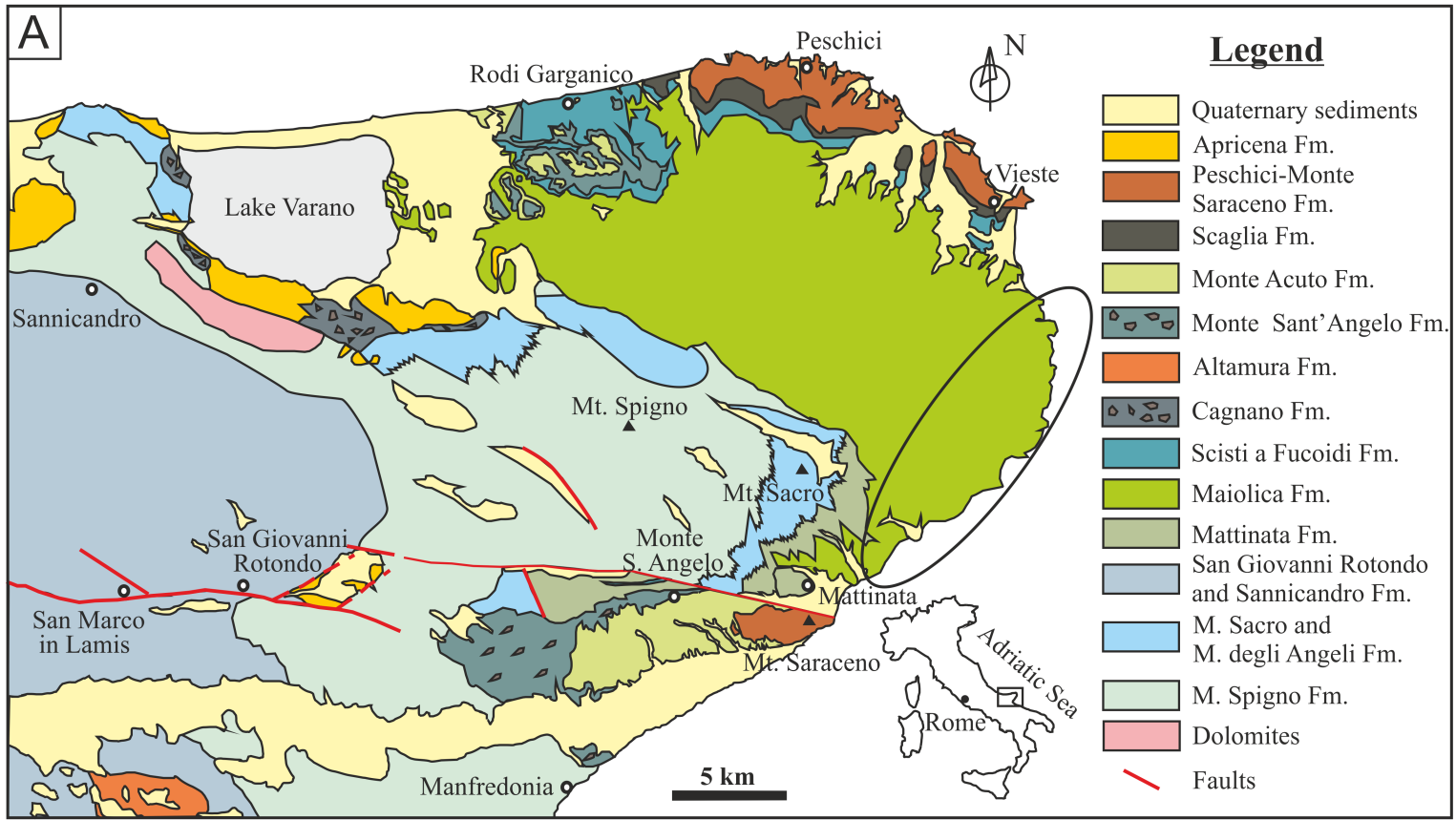
Fig. 12. A. NW-SE oriented normal fault including a fault core made up of chert dragged along the slip plane. The upper fault tip is characterised by a growth syncline, in which the bed thickness is greater in the fault hanging wall. B. Detailed picture of the fault core composed of chert dragged along the fault plane. Fault segments abut against the chert beds. C. Lower hemisphere, equal area stereographic projection showing NW-SE normal fault (red great circle) and bedding attitudes (black great circles).

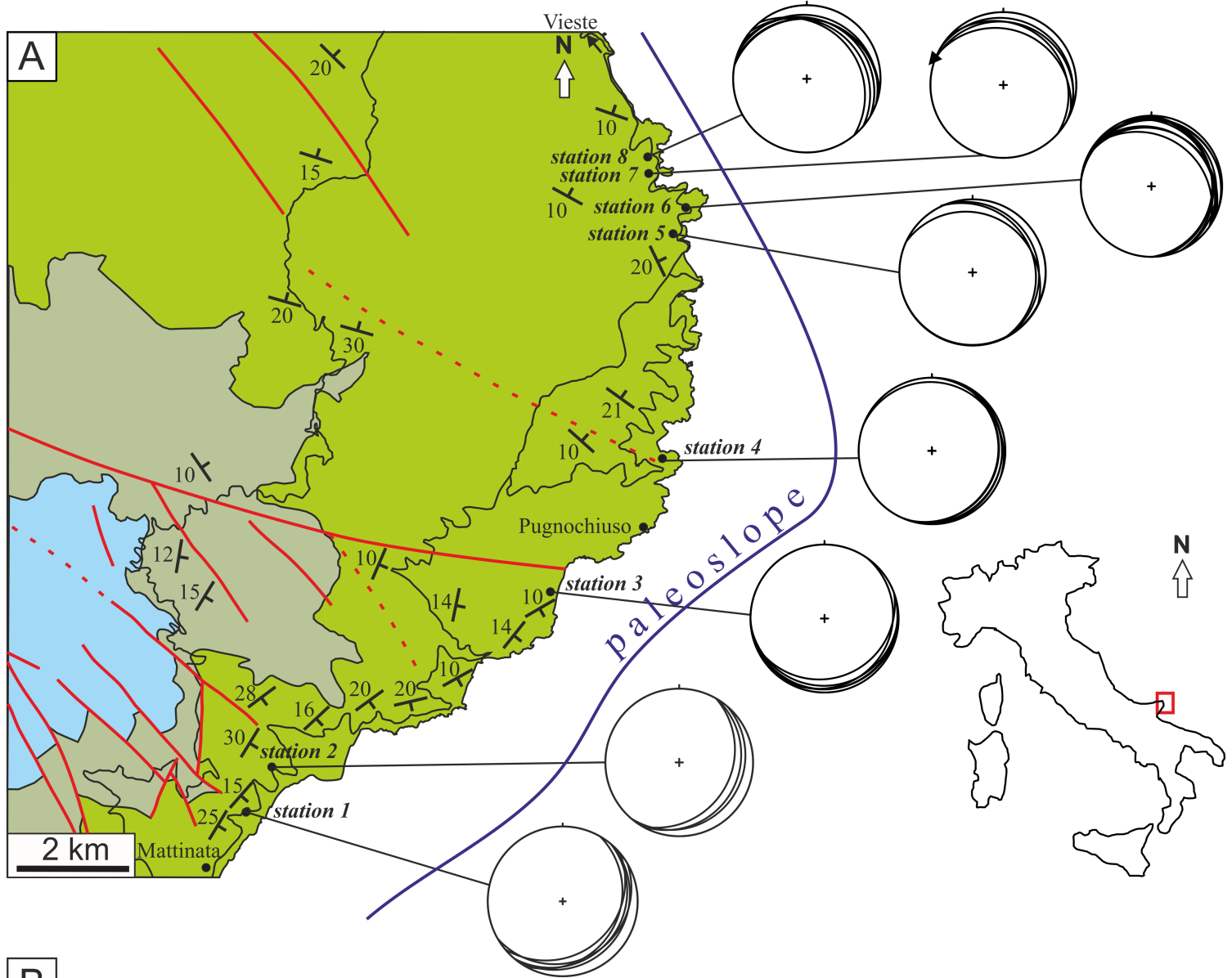
Fig. 13. WNW-ESE oriented normal fault with rotation of bed-parallel stylolites in its hanging wall (A). B. Close-up view of bedding-parallel stylolites gradually becoming more gentle upwards. C. Lower hemisphere, equal-area stereographic projection showing bedding (black great circle) and fault attitudes (red great circle).

Fig. 14. Stereographic projections displaying Cretaceous deformation structures within the slope-to-basin succession adjacent to NE-SW oriented paleoslope (A) and NW-SE oriented slope (B) (lower hemisphere, equal-area projection). Bedding attitude is shown with black great arcs, gravity-driven faults with green great arcs, tectonic faults with red great arcs and hinges of slump-related folds with violet dots.

Fig. 15. Rooted and superficial Cretaceous deformation structures within NE-SW and NW-SE oriented paleoslopes of the Apulian carbonate platform.







B

| | | | | |
|--------------|-------------|----------------------|-------------|------------|
| Barremian | S. Giovanni | Monte degli Angeli 1 | Mattinata 1 | Maiolica 2 |
| Hauterivian | | | | |
| Valanginian | | | | |
| Berriasian | | | | |
| Tithonian | Sannicandro | Monte Spigno | Monte Sacro | Varfone |
| Kimmeridgian | | | | Maiolica 1 |
| Oxfordian | | | | |
| Callovian | | | | |

Monte Sacro Fm. (Oxfordian-Valanginian)

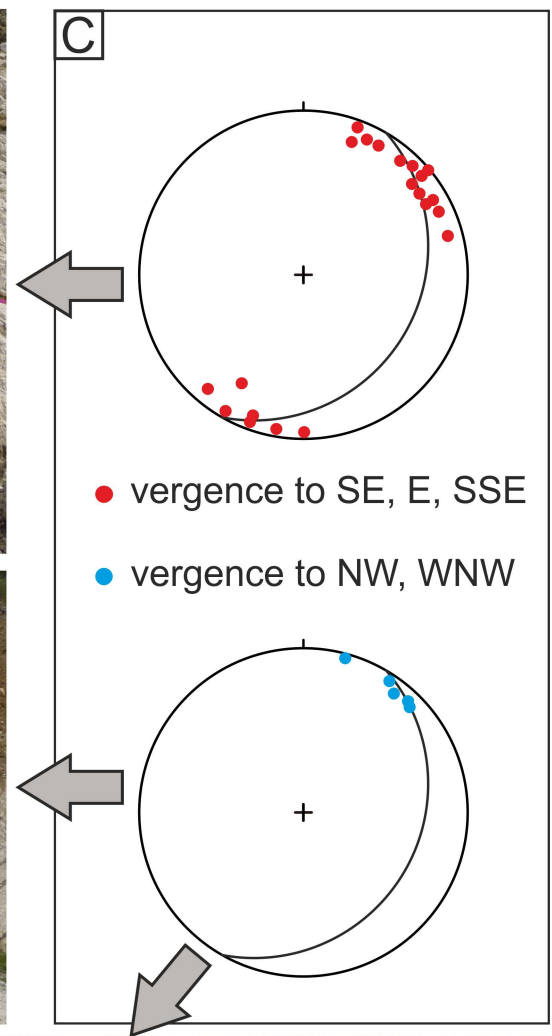
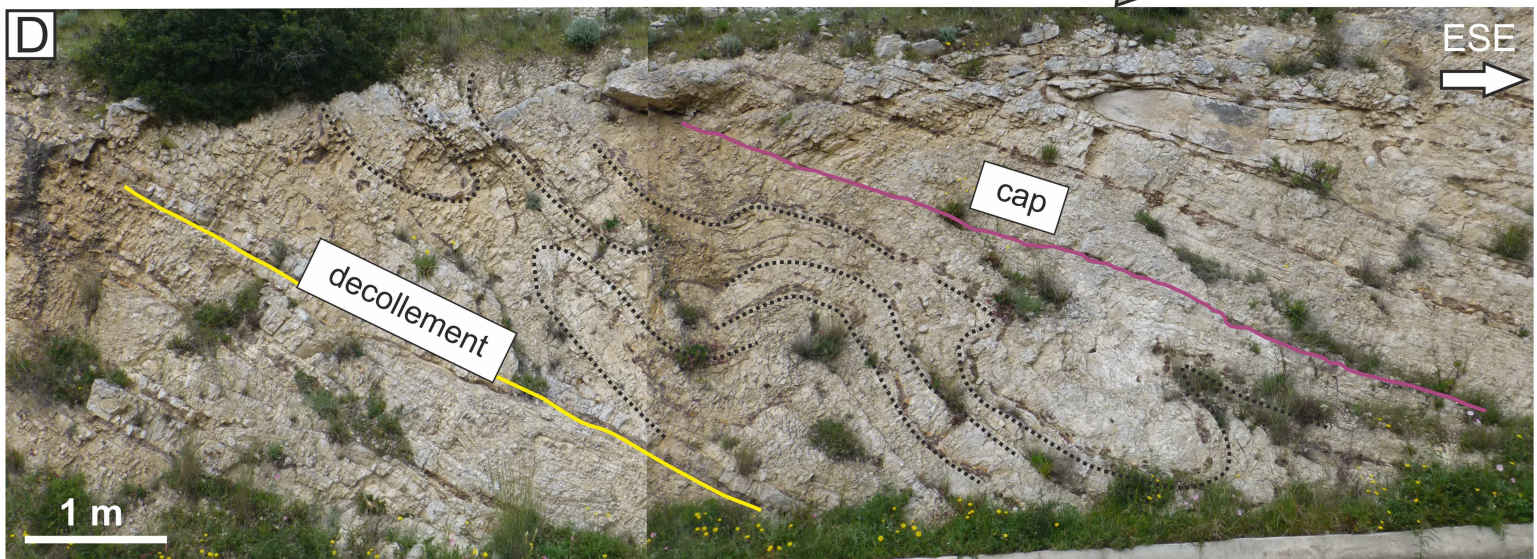
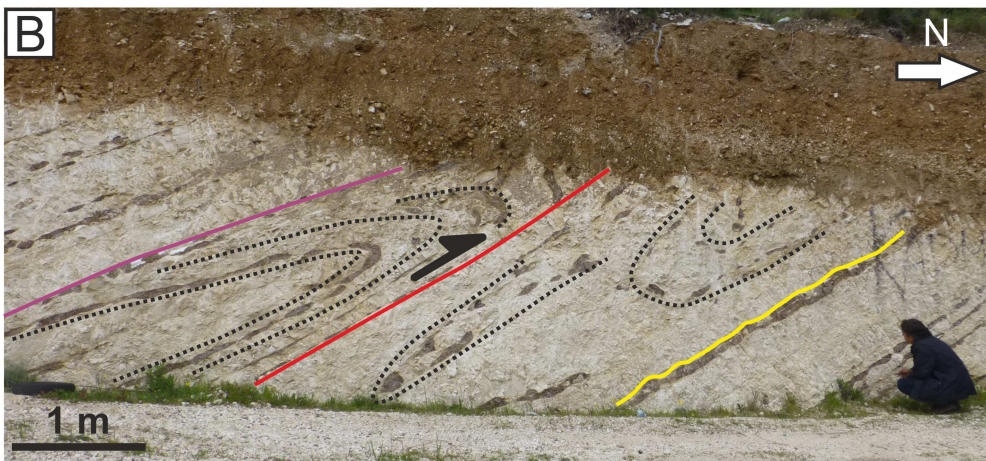
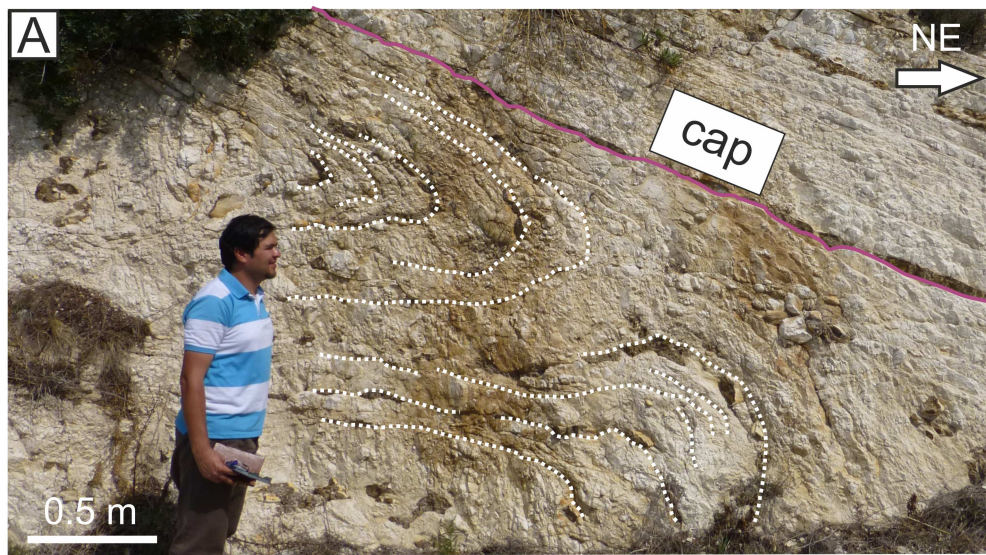
Massive wackestones with *Ellipsactinia*, *Sphaeractinnia*, *Tubiphytes* and stromatoporoids; **reef**.

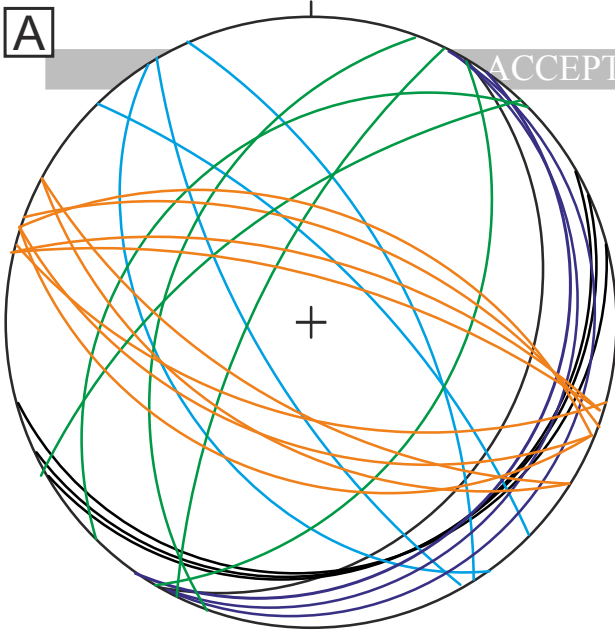
Casa Varfone Fm. (Tithonian-Valanginian)

Thick-bedded skeletal rudstone, stromatoporoid breccias, and graded beds of grainstone interfingering with cherty lime mudstones. Clasts are mainly fragments of *Ellipsactinia*, *Sphaeractinia*, stromatoporoids and brachiopods; **proximal-to-distal clinostratified slope**.

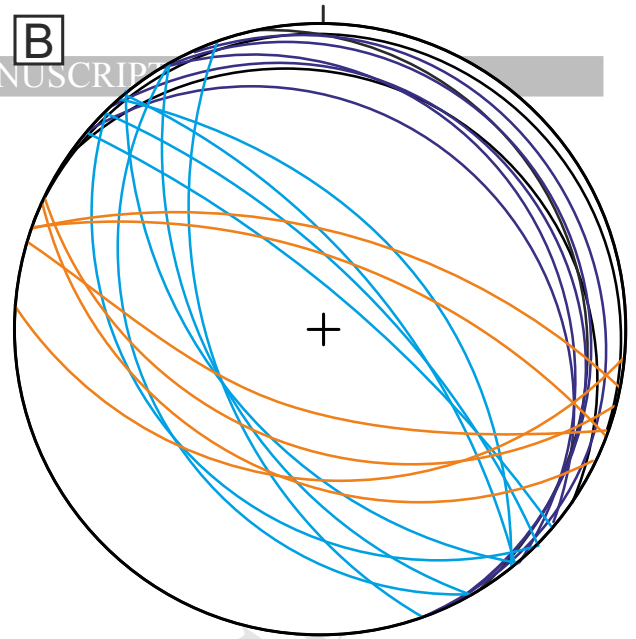
Maiolica 1 Fm. (Tithonian-Aptian)

White thin-bedded micritic limestone with abundant radiolaria and calpionellids; rich in intraformational truncation surfaces; white to black cherts are present in nodules and layers; **basinal**.



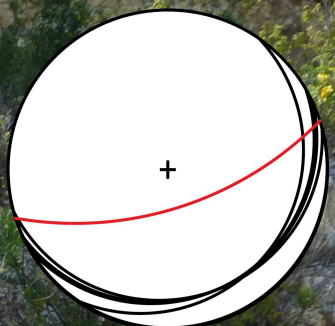
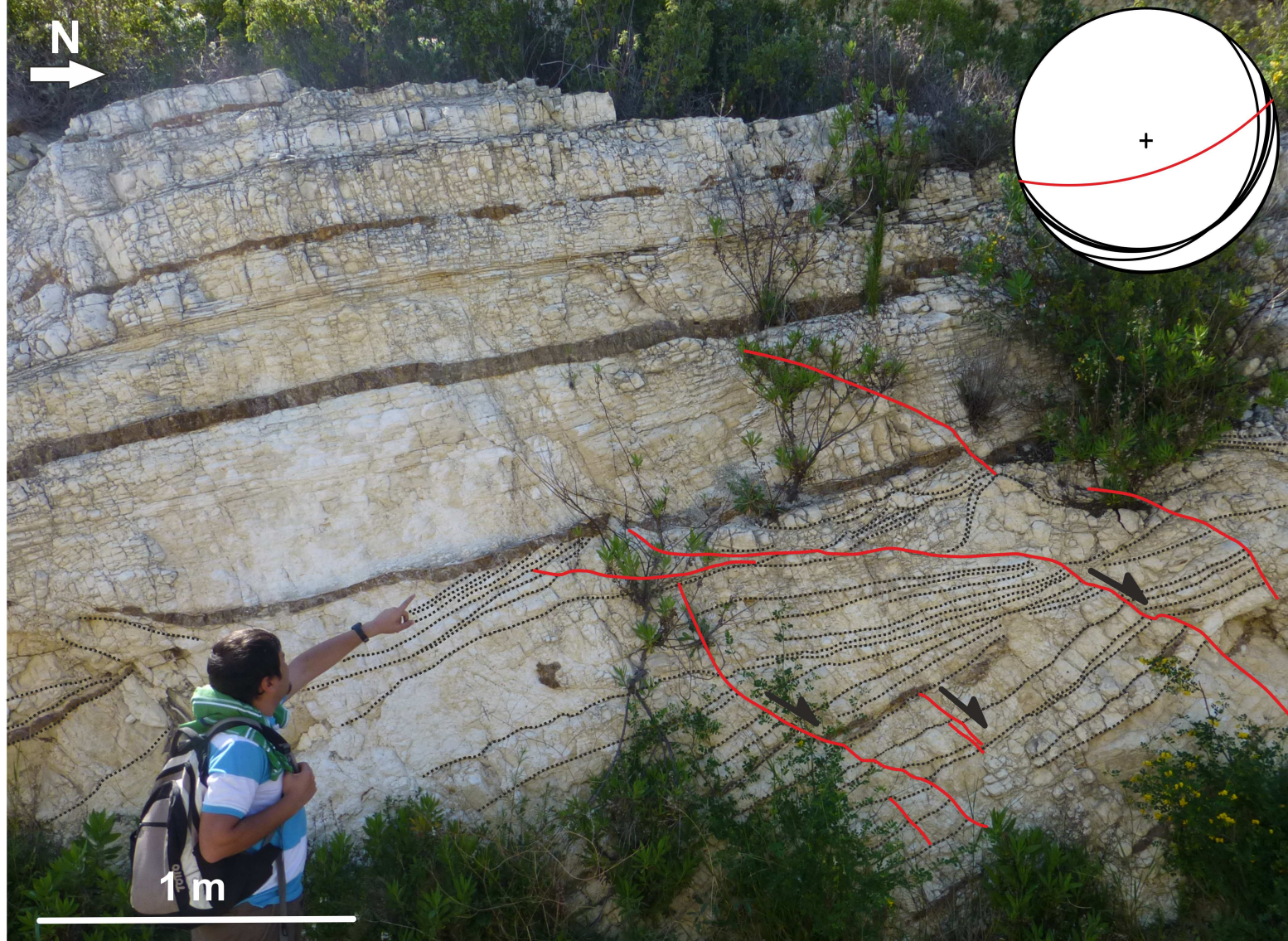


— set 1 — set 3
— set 2 — set 4

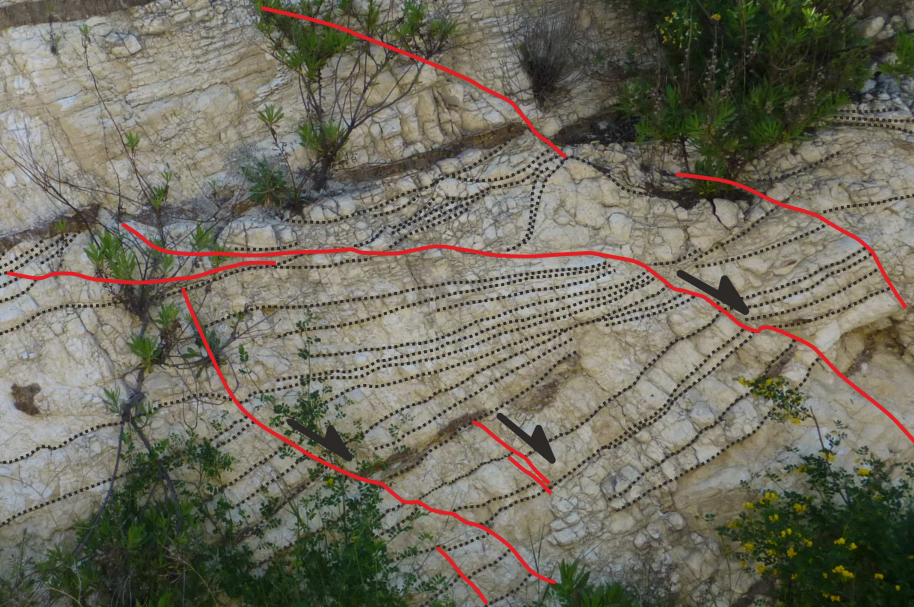


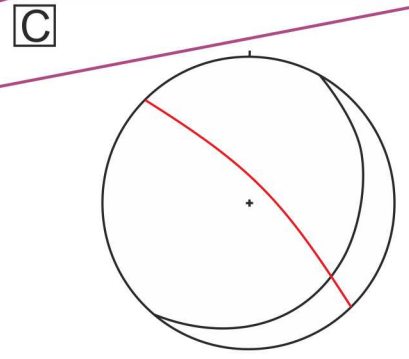
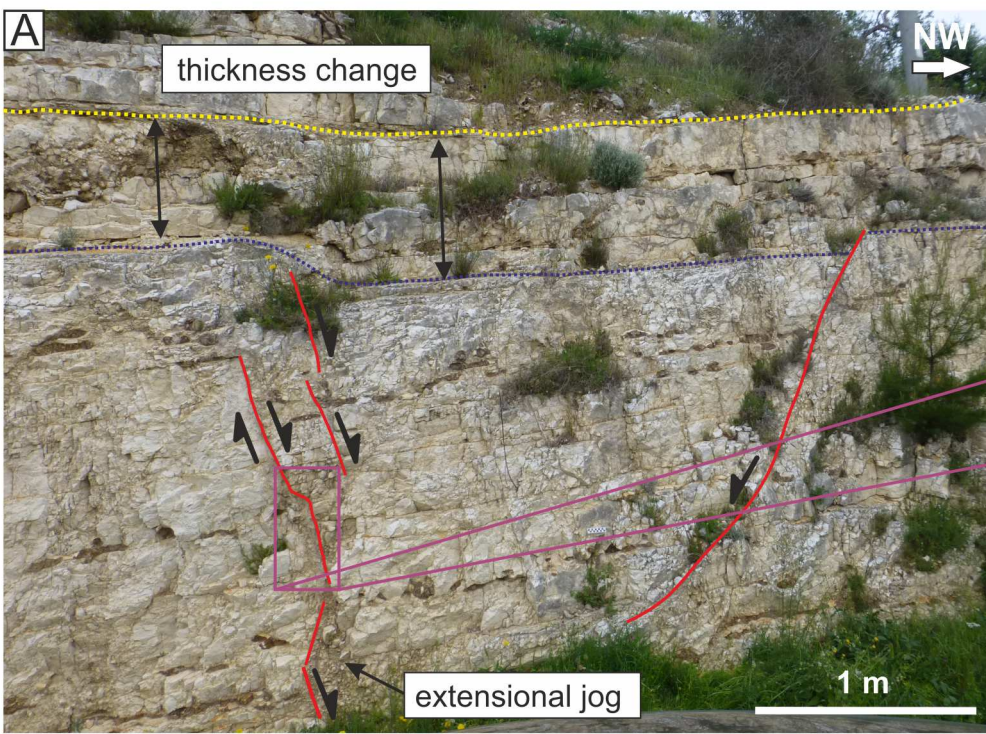
— set 1 — set 3
— set 2

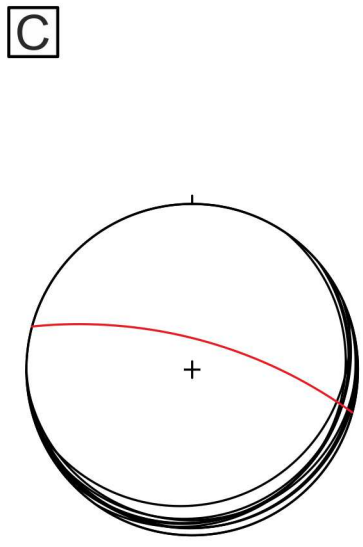
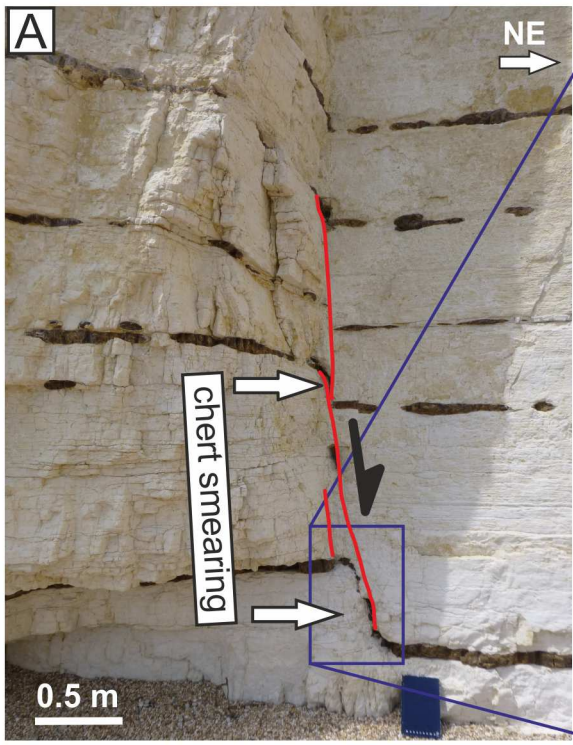
ACCEPTED MANUSCRIPT

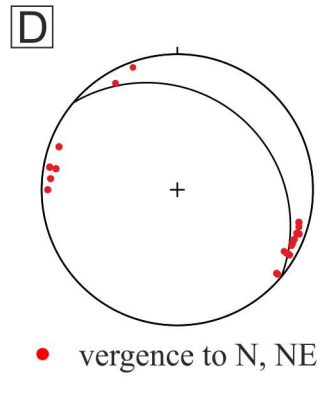
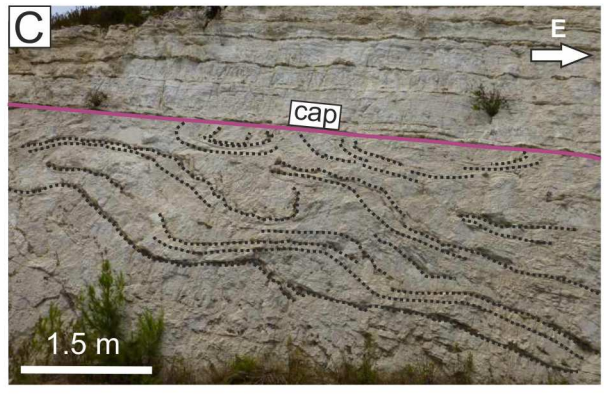
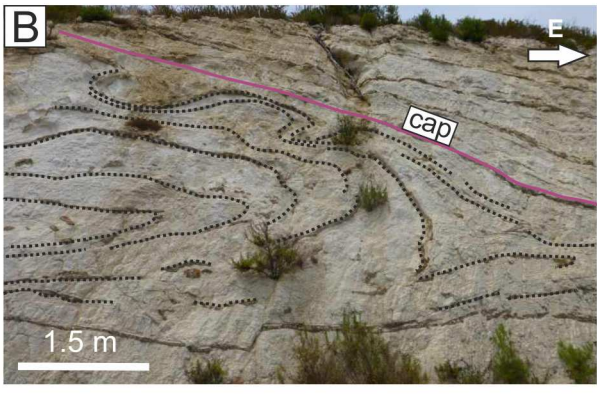
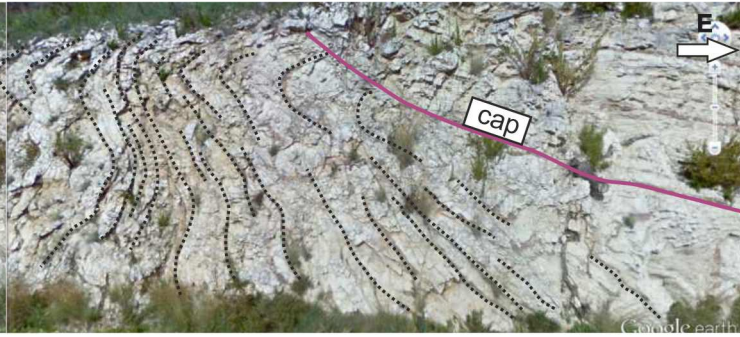


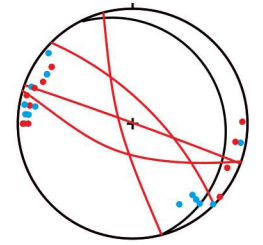
1m



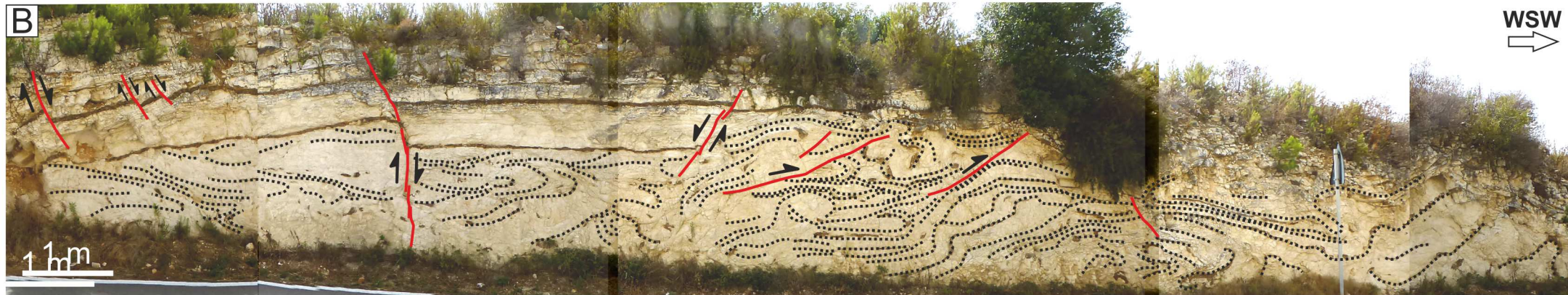


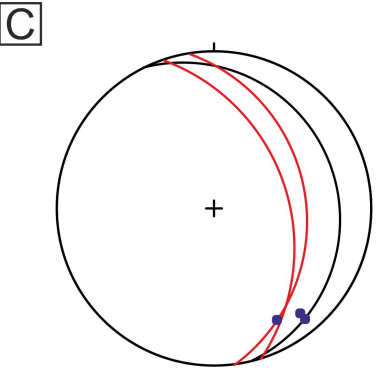
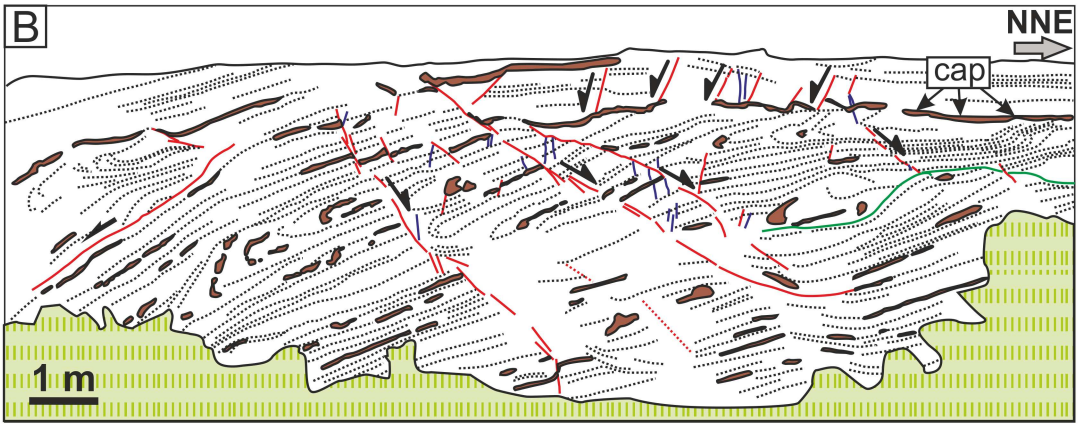










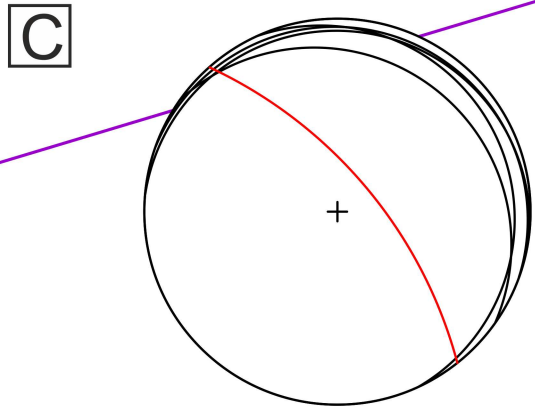
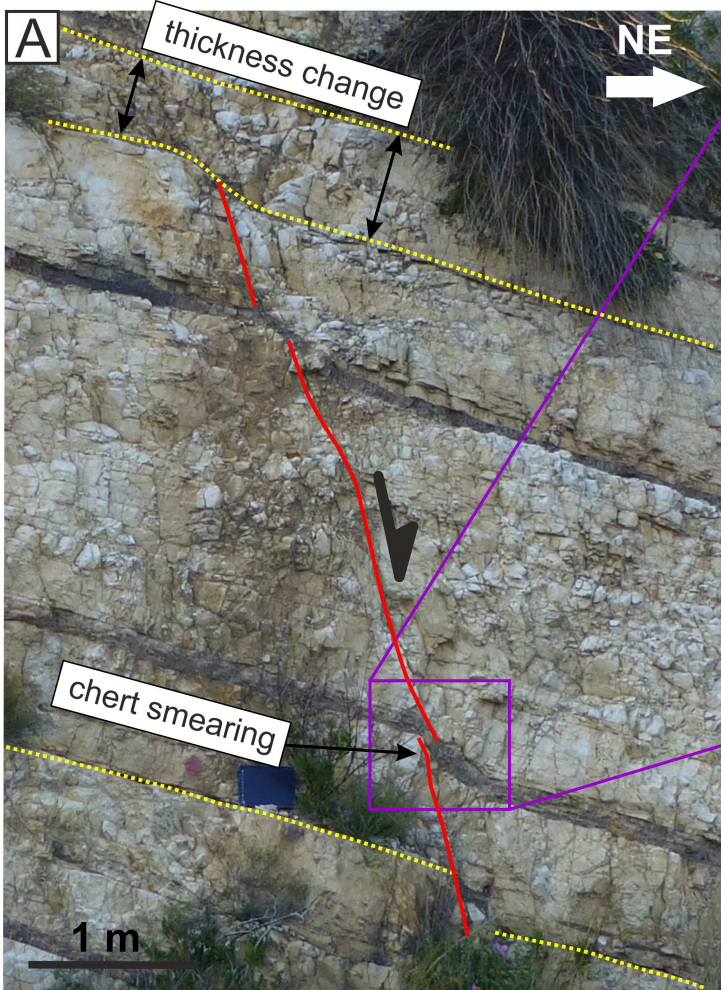


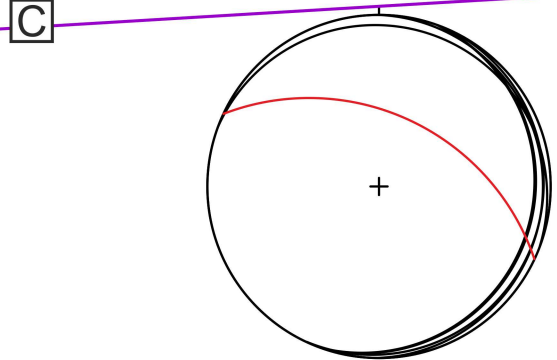
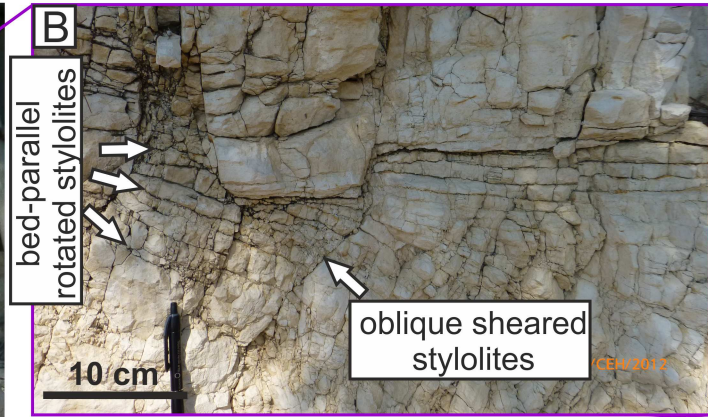
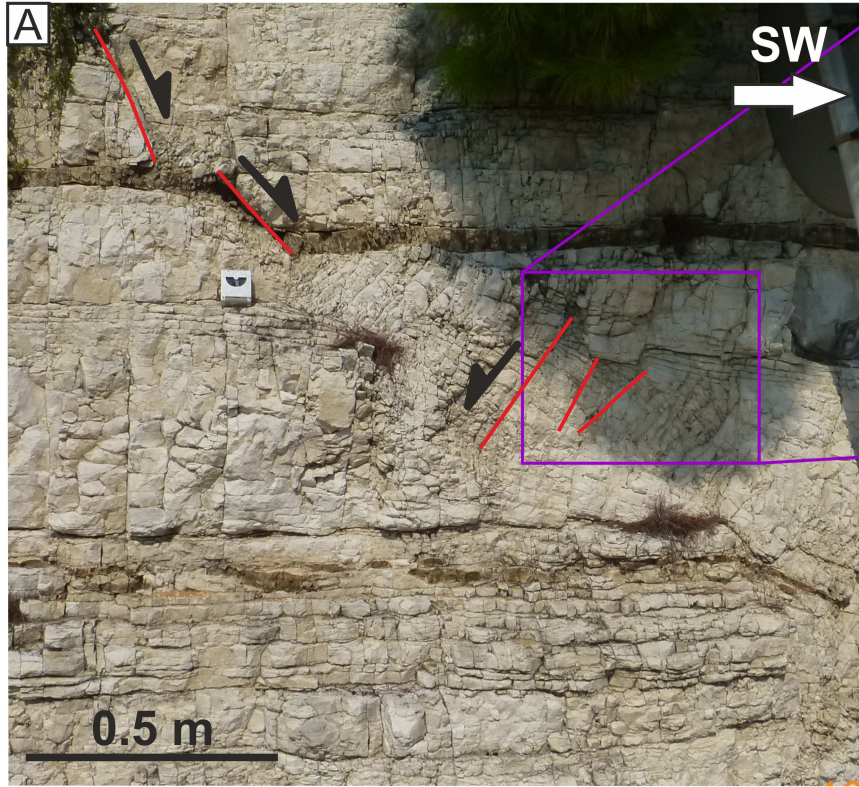
- vergence to N, NE
- vergence to SW



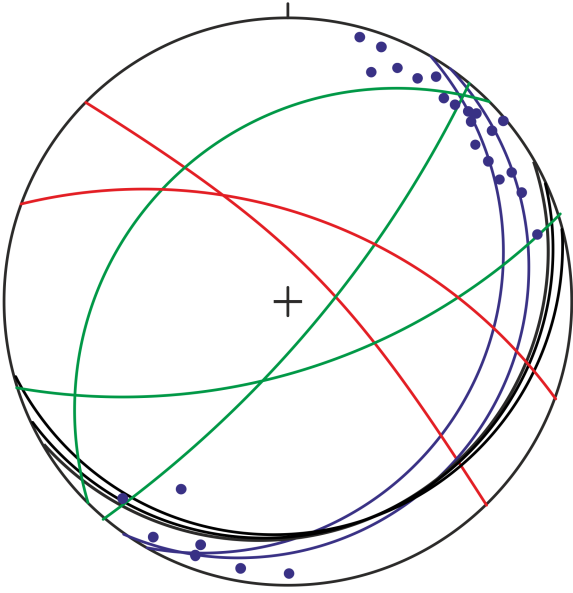


-  bedding
-  erosional surface
-  chert
-  fault
-  splays
-  cover

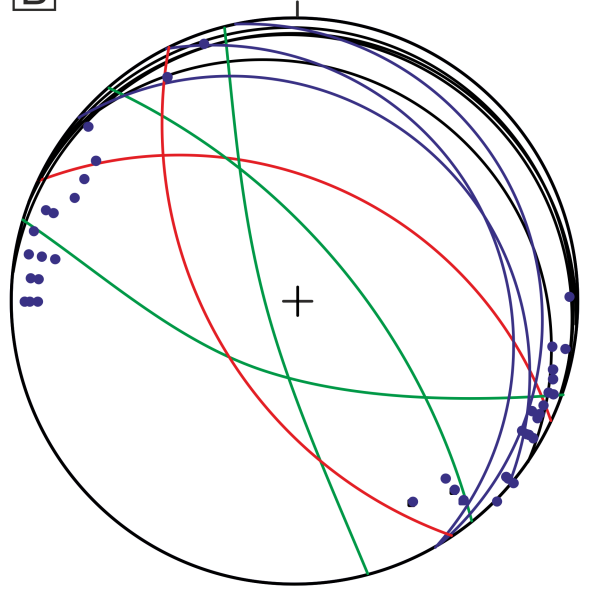




A



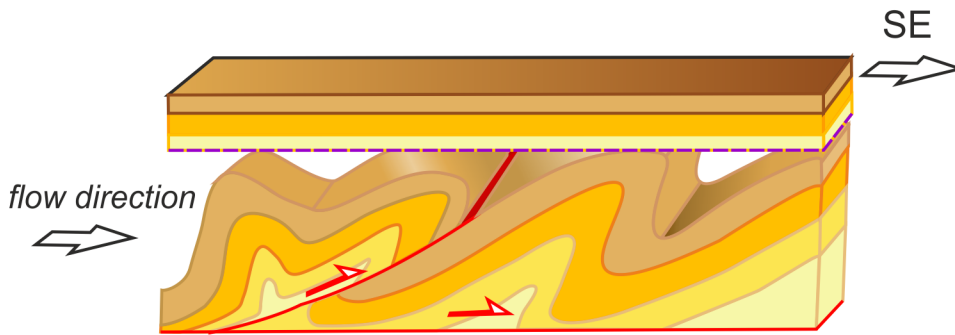
B



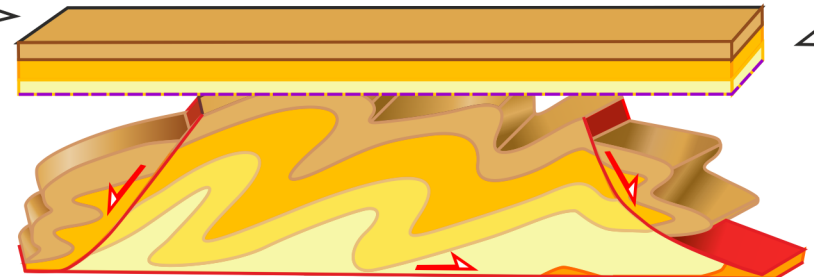
NE-SW oriented margin

NW-SE oriented margin

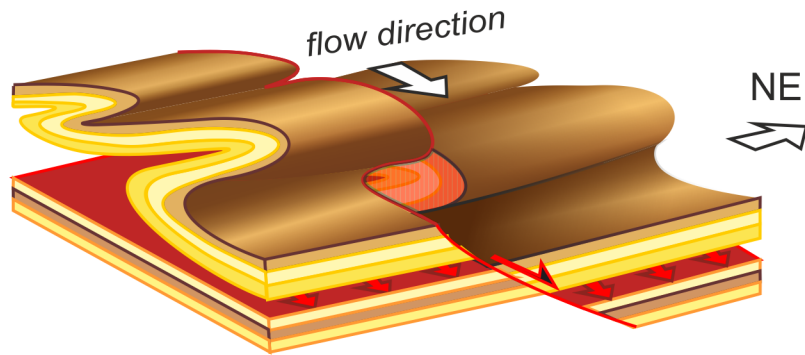
superficial faults



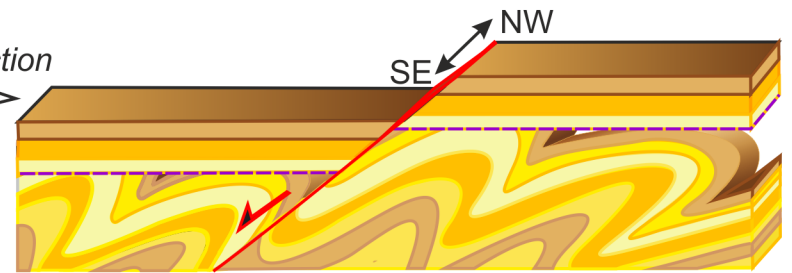
flow direction



rooted faults



flow direction



Synsedimentary faults along the Apulian margin are gravitational and tectonic.

Gravity-driven and tectonic faults are orthogonal to each other along NE-SW margin.

Gravity-driven and tectonic faults are sub-parallel along NW-SE margin.

Different structural architecture of the margins helps to recognise origin of faults.

The orientation and distribution of faults influence the migration of geofluids.

ACCEPTED MANUSCRIPT