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Late Quaternary deformation of the southern Adriatic foreland (southern Apulia) from mesostructural data: preliminary results

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ABSTRACT

Southern Apulia (Adriatic foreland, Italy), has long been considered a “stable area” lying in between two active orogens, but in fact its tectonic framework is poorly known. To learn more about this topic, we carried out an original structural analysis on Pleistocene deposits. The results indicate that southern Apulia has been affected by mild but discernible brittle deformation throughout the Middle and Late Pleistocene. Joints prevail, whereas faults are rare and all characterized by small displacement. Horizontal extension dominates throughout the entire study area; the SW-NE to SSW-NNE direction is the most widespread. WNW-ESE extension prevails in the Adriatic side portion of the study area, but the dispersion of the measured plane directions is high, suggesting that the local strain field is not characterized by a strongly predominant trend. A Middle and Late Pleistocene, SW-NE to SSW-NNE–oriented maximum extension is not surprising for the study area, as it is compatible with most of the available geodynamic models, whereas the different state of deformation affecting the Adriatic side of the study area requires further investigations. We tentatively interpreted this anomaly as reflecting some regional variation of the general geodynamic frame, for instance as the farthest evidence of ongoing compressional deformation across the W-verging Albanide-Hellenide fold-and-thrust belt.

KEY WORDS: *active tectonics, brittle deformation, Pleistocene, Salento.*

RIASSUNTO

Deformazione tardo-quaternaria dell’avampaese Adriatico meridionale (Puglia meridionale) da dati mesostrutturali: risultati preliminari.

La Puglia meridionale, parte dell'avampaese Adriatico emerso, è stata a lungo considerata un'area tettonicamente e sismicamente "stabile", collocata tra due orogeni sismicamente attivi come la catena Appenninica e quella Albanide-Ellenide. In realtà, l'attività tettonica recente di questa parte di avampaese è scarsamente conosciuta e mancano dati mesostrutturali a riguardo. Per acquisire maggiori conoscenze su questo tema, abbiamo condotto un'analisi strutturale alla mesoscala su depositi di età a partire dal tardo Pleistocene Inferiore. I primi risultati indicano che la Puglia meridionale è stata interessata da una deformazione fragile, debole ma riconoscibile, durante il Pleistocene Medio e Superiore. Le fratture estensionali, molto spesso organizzate in sistemi, prevalgono nella quasi totalità dei siti investigati, mentre le faglie sono rare e tutte caratterizzate da piccole entità di rigetto. L'estensione risulta dominante in tutta l'area di studio, sebbene con direzione variabile. La direzione di estensione SW-NE to SSW-NNE è la più diffusa; caratterizza siti che di solito mostrano sistemi di fratture ben organizzati e definiti, con un basso grado di dispersione rispetto alla direzione dominante. Nel lato prospiciente la costa Adriatica, invece, l'estensione si presenta con un diverso stile deformativo. Qui, infatti, prevale una direzione di estensione WNW-ESE, ma in questo caso la dispersione delle direzioni dei piani misurati è maggiore che nel caso precedente e suggerisce un campo di deformazione locale non caratterizzato da un netto andamento predominante.

Da un punto di vista regionale, una direzione di estensione orientata SSW-NNE, riferita al Pleistocene Medio e Superiore, non appare sorprendente per l'area di studio, essendo largamente compatibile con i modelli geodinamici disponibili in letteratura. La possibilità che più eventi deformativi siano occorsi nel periodo di tempo considerato, come anche il quadro leggermente diverso emerso per il lato Adriatico, richiedono invece ulteriori indagini. Nell'ambito dell'estensione

generalizzata dell’intera regione, quest’ultimo è stato preliminarmente interpretato come possibile espressione di una variazione locale all’interno del quadro geodinamico generale, ad esempio come evidenza remota della deformazione compressionale attiva nella catena per pieghe e accavallamenti W-vergenti delle Albanidi-Ellenidi.

TERMINI CHIAVE: *tettonica attiva, deformazione fragile, Pleistocene, Salento.*

INTRODUCTION

The foreland of the Apennine fold-and-thrust belt (Italy) corresponds essentially with the Adriatic Sea and has long been considered a tectonically and seismically “stable” area. Only in its central part (figs. 1 and 2), this foreland is characterized by significant historical and instrumental seismicity (BOSCHI *et alii*, 2000; GRUPPO DI LAVORO CPTI, 2004; CASTELLO *et alii*, 2005), both off-shore (active Mesoadriatic strip; CONSOLE *et alii*, 1993) and on shore (Gargano promontory), and some seismogenic faults have already been identified (DISS WORKING GROUP, 2007, and references therein).

The Adriatic foreland of the Apennines is exposed on shore only in the easternmost part of the Italian peninsula, *i.e.* in the Apulia region (from Gargano to Salento; fig. 1). Northern Apulia is the locus of rare but destructive historical earthquakes (GRUPPO DI LAVORO CPTI, 2004), occasionally associated with surface faulting (PICCARDI, 2005) and possibly with coseismic uplift of the coastline (MASTRONUZZI & SANSÒ, 2002). The coastline referred to the MIS 5.5 (~125 ka) is variously displaced along the Ionian and Adriatic sides of the region, indicating inhomogeneous tectonic behavior during the Upper Pleistocene-Holocene (BORDONI & VALENSISE, 1998; FERRANTI *et alii*, 2006; MASTRONUZZI *et alii*, 2007b). In addition, seismites have been recognized in Tyrrhenian age (~125 ka) deposits along the central and southern Adriatic coasts, testifying to the occurrence of strong ground shaking, that has been related to Upper Pleistocene earthquakes located within ca. 40 km (TROPEANO *et alii*, 1997). In contrast, only one moderate historical earthquake occurred in Southern Apulia (1826 Manduria earthquake, Imax=VI-VII, M=5.3; GRUPPO DI LAVORO CPTI, 2004; fig. 2). In 1743, the southern portion of the Adriatic foreland was also hit by a severe earthquake sequence (Imax=IX-X, M=6.9; GRUPPO DI LAVORO CPTI, 2004; fig. 2), but these events have been positively located off-shore

(GUIDOBONI & FERRARI, 2004). The sequence also triggered a large tsunami (MASTRONUZZI & SANSÒ, 2004; TINTI *et alii*, 2004; MASTRONUZZI *et alii*, 2007a).

All these clues suggest that southern Apulia is in need of a detailed analysis that may help outline its present tectonic setting. The recent deformation of this region has been neglected from a mesostructural point of view. Therefore, we conducted a structural analysis of Quaternary outcrops, aimed at (i) providing a first definition of the brittle deformation that has affected the area since the Middle Pleistocene, and (ii) testing the applicability of the mesostructural analysis to understand the active tectonics and seismotectonic implications of a foreland area. In this paper we present the preliminary results of the structural analysis carried out in southern Apulia with this purpose.

GEOLOGICAL AND SEISMOTECTONIC SETTING

The Apennine fold-and-thrust belt of peninsular Italy is a late Cenozoic accretionary wedge, that forms part of the Africa-verging mountain system in the Alpine-Mediterranean area. The Southern Apennines (fig. 1) formed by east-to-northeast verging thrust sheets deriving from paleogeographic domains of alternating carbonate platforms and pelagic basins (e.g. PATACCA & SCANDONE, 1989; MOSTARDINI & MERLINI, 1986). The most external of these domains is represented by the Apulia Platform, a ~6 km-thick succession of shallow-water Mesozoic carbonates (RICCHETTI, 1980). The Apulia Platform and underlying basement are partly involved in the orogenic wedge (MENARDI NOGUERA & REA, 2000; BUTLER *et alii*, 2004), partly form the foreland inflected below the outer front of the Apennines (MOSTARDINI & MERLINI, 1986), and partly form the Adriatic foreland *sensu stricto*, both on and off-shore (Gargano, Puglia and Southern Adriatic Sea; fig. 1).

Thrusting of the Southern Apennines progressed toward the Adriatic foreland up to the beginning of the Middle Pleistocene, when the motion of the wedge front is reported to have ceased (PATACCA & SCANDONE, 2004). Meanwhile, the foreland was affected by flexural tectonics and dissected by faults and vertical joints striking parallel to the NW-SE-trending flexure hinge (ROYDEN & KARNER, 1984; ROYDEN *et alii*, 1987; BILLI & SALVINI, 2003).

Since the Middle Pleistocene, SW-NE extension became dominant over the core of the Apennines causing normal fault development and interaction (ROBERTS & MICHETTI, 2004; PAPANIKOLAOU & ROBERTS, 2007). This extension has been interpreted as the result of a geodynamic change that took place around 800 ka (PANTOSTI & VALENSISE, 1990; CINQUE *et alii*, 1993; GALADINI, 1999; D'AGOSTINO *et alii*, 2001). It is worthwhile noting that Mt. Vulture, the only volcano located within the Apennines, is Middle Pleistocene in age (from 730 to 140 ka; BENEDUCE & GIANO, 1996, with references; fig. 1). This tectonic regime is still active, as demonstrated by breakout and seismicity data (MONTONE *et alii*, 2004), and accounts for large earthquakes generated by NW-SE–striking normal faults straddling the topographic divide of the Southern Apennines (GRUPPO DI LAVORO CPTI, 2004; DISS WORKING GROUP, 2007, with references). In contrast, recent instrumental evidence shows that to the northeast of the Apennines axis the SW-NE extension is associated with widespread NW-SE horizontal compression (VANNUCCI & GASPERINI, 2004; DEL GAUDIO *et alii*, 2007). For instance, the unusual 2002 Molise earthquakes (figs. 1 and 2) supplied new evidence that, in the frontal part of the chain, large upper crustal NW-SE normal faults give way to deeper E-W, right-lateral, seismogenic faults. These extend for tens of kilometers below the outer front of the Southern Apennines orogenic wedge (see, for instance, the 1990-91 Potenza earthquake sequence; BONCIO *et alii*, 2007; fig. 2) and, toward the east, below the foredeep deposits up to the foreland. Their present-day activity is interpreted as due to reactivation of inherited zones of weakness. Major E-W–oriented shear zones have been described in literature roughly between the latitudes 40°30’N and 42°30’N, both on shore and off-shore (DI BUCCI & MAZZOLI, 2003; VALENSISE *et alii*, 2004, with references). Among them, the best constrained is referred to as Molise-Gondola shear zone, that has a clear geologic and seismogenic signature (MGsz; DI BUCCI *et alii*, 2006, with references; fig. 1). Further south, another regional E-W lineament extending between Potenza and Taranto has been recently interpreted as active and seismogenic (DISS WORKING GROUP, 2007), as it includes the source area of a series of M5+ earthquakes that were caused by right-lateral slip on E-W planes at 15-25 km depth in 1990-1991 (Potenza earthquakes: fig. 2).

Assessing whether the southernmost portion of Apulia (figs. 1 and 2) is tectonically active is made more difficult by the following circumstances: (1) seismicity is moderate, scattered and essentially trendless (fig. 2); (2) no information on the active strain is available from breakout data; (3) geomorphological studies indicate that the southernmost sector of the study area underwent uplift during the Middle Pleistocene, followed by stability during the past 330 ka (MASTRONUZZI *et alii*, 2007b), while the Taranto area has been uplifted at ~0.20 m/ka since the Upper Pleistocene (BORDONI & VALENSISE, 1998; FERRANTI *et alii*, 2006).

STRUCTURAL ANALYSIS

A detailed structural study (figs. 3 and 4) reveals the joint and fault networks dissecting late Lower Pleistocene marine calcarenites (Gravina Fm.; fig. 5), Middle and Upper Pleistocene marine deposits (figs. 6 and 7), and Upper Pleistocene and Holocene cemented coastal dune deposits (fig. 8). The observed brittle deformation is generally poorly developed and mainly formed by joints (figs. 9 and 10). This is seen especially in Upper Pleistocene rocks, that is, very recent deposits. The joint density ranges between 0.13 and 0.34 cm^{-1} (DAVIS & REYNOLDS, 1996; BILLI *et alii*, 2007).

In most of the sites, the vertical propagation of individual joints and faults does not appear confined within the layers, and the fractures cut through the entire outcrop, even in case of tens of meters-high walls (fig. 11). In some cases, it is only partially confined and controlled by lithological layering. For instance, where a ~0.5 m-thick bed of colluvial clays is interposed between the Gravina Fm. and the Upper Pleistocene dune (figs. 8 and 11), only some of the faults and joints propagate from the calcarenites into the overlying dune deposits. The lateral extent of individual joints and faults exposed on bedding surfaces does not appear to be lithologically confined at the naked-eye. The reduced overburden (few meters maximum), and the regular distribution of the fracture pattern over wide areas and for tens of meters thickness (exposed on marine abrasion surfaces and on the high walls of large quarries; e.g., sites Sal011 and Sal034, respectively) suggest that we are not simply dealing with compaction features.

Faults and joints alike exhibit spacing in the order of a few meters, are usually millimeters to centimeters in aperture, and are sometimes filled by travertine locally incorporating sigmoidal lithons (fig. 8). Occasionally, fissures affecting the Gravina Fm. are filled by cemented sand containing reworked minerals (melanitic garnet, augite and hornblende) from the Vulture volcano, located 150-200 km NW of Southern Apulia (site Sal011, loc. Torre S. Giovanni; figs. 3 and 4A). This constrains their opening as being contemporary or younger than the first major phases of volcanic activity (730 to 600 ka; BENEDUCE & GIANO, 1996, with references; GIANNANDREA *et alii*, 2006). An even younger age is suggested by these minerals being largely reworked. In particular, they never exceed the sand grain size, are subspherical, well rounded and similar to the Vulture minerals reworked in the Upper Pleistocene dune deposits, which crop out in the study area. At very few sites (e.g., Sal027, Sal028, fig. 4B) brittle deformation is accompanied by gentle folds ranging in wavelength from meters to decameters. The latter folds are gentle, with an interlimb angle larger than 120°; a non-tectonic genetic component could be present too (differential compaction, karst, drape to underlying topography).

In many cases, the joint sets affect very large outcrops and are rectilinear, meters- to tens of meters-long and regularly spaced. Based on the literature (e.g., COSGROVE & ENGELDER eds., 2004; CAPUTO, 2005), they should have formed in response to the tectonic component of the stress field rather than to other local causes (landslides, rock-falls along the coastline, compaction, etc.). Indeed, they coherently accompany faults.

On the faults, we observed displacement values in the order of millimeters to very few centimeters (fig. 7). Only in a few cases we did find vertical displacements in the order of decimeters (fig. 5) or meters (fig. 6). Fault kinematics were defined based on layer or marker displacement, dragging along fault planes, releasing and restraining bends, striae and calcite fibers. Middle Pleistocene-Holocene faults are very rare in the study area; therefore, it was generally impossible to recognize mutual relationships between faults, but few cases characterized by conjugate faults (e.g., fig. 6).

Dilational joints are occasionally organized into two orthogonal sets of pervasive fractures (Sal011; figs. 4A and 9). In these cases, we observe mutual abutting relationships, thus documenting geologically coeval joint sets, therefore associated with the same remote stress field (CAPUTO, 1995). Only very few of the joints forming pervasive sets exhibit a component of shear, indicating their incipient evolution from fractures to faults. In some of these cases, joint sets are organized as two conjugate systems (with an acute angle of ~60°; e.g., Sal12c, fig. 4A) rather than as two orthogonal sets. The distinction between shear joints and incipient faults is beyond the scope of this work. For the sake of simplicity, in this paper we will refer to every fracture showing a shear component of motion as “a fault”, regardless of the entity of displacement, and to the dilational fractures as “joints”. Where joints accompany a fault, they generally parallel to it (sites Sal032, Sal055).

We organized all mesostructural data into a computer database. In many cases, kinematic indicators were other than striae (see figs. 5 to 8); along with the limited number of faults, this circumstance did not allow us to obtain the paleostress tensor by automatic inversion. Nevertheless, the data collected at some sites provided reliable although more general indications about the maximum horizontal shortening and extension. Such indications are given for example by:

(i) the fault seen at site Sal019 (figs. 4B and 5); its 46° dip and clear reverse displacement suggest it is a reverse fault characterized by roughly NW-SE shortening. The lack of striae precludes any inference on the strike-parallel component of motion, if any;

(ii) the main fault seen at site Sal032 (figs. 4B and 6); its geometry and 77° dip, the presence of a minor antithetic fault and the extensional displacement of over 1 m, all suggest it is a normal fault resulting from roughly SW-NE extension. Here too we observed only the normal component of motion and hence have no means of assessing strike-parallel motion, if any;

(iii) the fault seen at site Sal055 (figs. 4C and 7), that is part of a joint set showing consistent geometry. The fault dips 71° and exhibits 2 cm of reverse displacement.

DISCUSSION AND FINAL REMARKS

Our field surveys and data elaborations indicate that the southern Apulia has been affected by mild but discernible brittle deformation throughout the Middle and Late Pleistocene. The preliminary results presented in this work do not allow a tectonic stratigraphy (sensu Caputo & Pavlides, 1993) to be defined, and we underline that the possibility to have more than a single event of deformation in the Middle Pleistocene-Holocene lapse of time cannot be ruled out. Joints prevail at most of the investigated sites (fig. 10), whereas faults are rare and all characterized by small displacement. Figure 12 is a synoptic view of the prevailing directions of maximum horizontal extension for each site. Since most of the measured planes, both joints and faults, are either steeply dipping to subvertical, the extension direction is an appropriate way to summarize our results and can be useful for the discussion. Only in the case of folding or faulting with a reverse component of motion we preferred to represent the direction of maximum horizontal shortening.

Horizontal extension predominates throughout the study area, although the direction of extension varies (fig. 10). SW-NE to SSW-NNE extension is the most widespread and is generally seen at sites showing a well organized and defined pattern of planes with limited dispersion with respect to the dominant direction. For instance, this direction characterizes two portions of the study area respectively located to the southeast of Bari and around the Taranto Gulf (fig. 12). Further data recently acquired west of Lecce confirm this direction of extension all along the Taranto Gulf side of the study area (DI BUCCI *et alii*, 2007).

Significant departures from this scheme are observed northwest of Brindisi (fig. 12), where extension trends WNW-ESE. The sites sampled in this area, however, exhibit a much higher dispersion of the plane directions (fig. 4), or are cut by two orthogonal and coeval sets of joints. The WNW-ESE direction of figure 12 could hence be an oversimplified representation of a strain field not characterized by a strongly predominant direction of extension (i.e., an oblate ellipsoid characterized by vertical flattening). Whatever the case, the deformation style of this zone is different from the rest of the study area. Further complexities are seen to the southeast of Lecce (fig. 12), where extension directions are quite inhomogeneous and accompanied by faint NW-SE shortening (fig. 4).

Seen from a regional perspective, a Middle and Late Pleistocene SW-NE to SSW-NNE maximum extension is not surprising. For instance, NW-SE graben structures involving Plio-Quaternary deposits off-shore, southeast of the Salento peninsula, have already been described by Argnani *et alii* (2001). The same investigators interpret this deformation as outer-arc extension due to the flexure of the Adriatic foreland.

Different causes have been proposed in literature for this flexure, showing that the debate on the geodynamics of the Adriatic block is indeed a lively one. For instance, BILLI & SALVINI (2003) consider the Apulia flexure as the on-shore forebulge of the Adriatic foreland and interpret in this perspective of flexural processes the NW-SE systematic joints measured in the Mesozoic carbonate rocks.

Various investigators invoke buckling of a thick continental lithosphere, either within an active subduction beneath the Southern Apennines (DOGLIONI *et alii*, 1994) or due to horizontal compression (BERTOTTI *et alii*, 2001). Moreover, although most investigators set the end of Southern Apennines thrusting around the beginning of the Middle Pleistocene (e.g., BUTLER *et alii*, 2004; PATACCA & SCANDONE, 2004), others contend that at that time thrusting did not cease but rather shifted to the northeast, and as such it is now affecting the Adriatic “foreland” with the frontal part of the belt located in the Adriatic off-shore (FERRANTI & OLDOW, 2006). Within this scenario, SW-NE extension could be explained as the result of extrados stretching, that is to say, as the surface evidence of a deep ramp anticline associated with a thrust detachment rooting within the crystalline part of the Adriatic crust. Besides, Salento and its off-shore counterpart form the flexural bulge of the eastern, lateral portion of the Calabrian Arc (DOGLIONI *et alii* 1999; fig. 12), that is part of the ongoing subduction of a slab outlined by seismicity data (GIARDINI & VELONÀ, 1991), imaged by tomographic techniques and accompanied by a volcanic arc (FACCENNA *et alii*, 2003, with references). Therefore, the SW-NE active extension along the Taranto Gulf side of our study area could also be related to this deeper engine.

Finally, the general geodynamic frame of the Adriatic foreland is dominated by the NW-SE Eurasia-Nubia convergence (DE METS *et alii*, 1994; SELLA *et alii*, 2002; MCCLUSKY *et alii*, 2003; SERPELLONI *et alii*, 2007; fig. 12). As already suggested for the active deformation of other parts of the Adriatic foreland (e.g., the MSsz; DI BUCCI & MAZZOLI, 2003; VALENSISE *et alii*, 2004; DI BUCCI *et alii*, 2006; fig. 1), the general SW-NE extension of the study area, as well as the minor clues of weak NW-SE shortening to the southeast of Lecce (fig. 12), could be interpreted as a consequence of this convergence.

The WNW-ESE extension observed to the northwest of Brindisi (fig. 12), and more in general the state of deformation of this zone with respect to the rest of the study area, forms the object of an ongoing quantitative mesostructural survey devoted to the collection of a statistically significant number of fractures. Its results will hopefully allow us to (i) treat the dispersion of fracture directions analytically, (ii) obtain the paleostress tensor by automatic inversion, and (iii) derive a more reliable pattern of brittle deformation through time. If confirmed, this deformation could still fall within the frame of a global extension of the study area, possibly reflecting some regional variation of the general geodynamic frame. For instance, this deformation is compatible with that characterizing the opposite coast of the Adriatic Sea as testified by the intense seismicity of Albania (fig. 12; see also RENNER & SLEJKO, 1997). It is also compatible with the shortening observed between the Adriatic coasts of southern Apulia and Albania as revealed by GPS data (SERPELLONI *et alii*, 2007; fig. 12). The physical continuity of the Apulia Platform throughout the southern Adriatic and Ionian Seas up to the Albanides and Hellenides is well known since the beginning of the 20th century (see a review of Aubouin's studies in BLANCHET & MERCIER, 1978). This continuity of the Apulia Platform corresponds to the continuity of the Apulia lithosphere, that is supported by recent analyses of seismic reflection data (ARGNANI *et alii*, 2001; BALLAURI *et alii*, 2002; ROURE *et alii*, 2004) and of Sn raypaths (MELE, 2001). Apulia Platform deposits in the frontal part of the Albanides are also known to be involved in thrusting. Therefore our results from the Adriatic coast of Apulia could be interpreted as the far field evidence of Albanide deformation, and our study area as lying at the transition between the Apennine and Albanide foreland.

The suggested relationships of the Apulia foreland with the Albanian and western Greece domains may provide a key for interpreting (i) the eastern termination of E-W shear zones affecting the southern Adriatic foreland, and (ii) the location and mechanism of poorly understood Ionian earthquakes such as the 1743 (fig. 2). Concerning (i), if the E-W shear zones can be interpreted as reactivated by the NW–directed relative plate motion of Nubia, one can hypothesize this reactivation to be inhibited in areas that are simultaneously undergoing Albanide deformation. Concerning (ii), the structural continuity between southern Apulia and Albania suggests that earthquakes which are strongly felt in the study area do not necessarily imply a local source. More likely, they have been generated by a distant source, for instance one of the active faults along the Corfu-Lefkada alignment, and benefited from efficient seismic propagation. New geological and seismological data would possibly support this hypothesis and suggest significant implications for the seismotectonics of southern Adriatic foreland.

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Figure captions

Fig. 1 - Geological sketch map of Southern Italy (Calabrian Arc excluded). The Mattinata-Gondola shear zone (MGsz) is also shown.

Carta geologica schematica dell'Italia Meridionale (Arco Calabro escluso). È inoltre rappresentata la zona di taglio Molise-Gondola (MGsz).

Fig. 2 - Historical and instrumental earthquakes of the Central and Southern Apennines (M > 4.0; GRUPPO DI LAVORO CPTI, 2004; VANNUCCI & GASPERINI, 2004; HARVARD CMT PROJECT, 2006; FRACASSI & VALENSISE, 2007). The size of the square symbols is proportional to an equivalent magnitude derived from intensity data. The black thick line is the outer buried front of the Southern Apennines as in figure 1.

Terremoti storici e strumentali dell'Appennino Centrale e Meridionale (M > 4.0; GRUPPO DI LAVORO CPTI, 2004; VANNUCCI & GASPERINI, 2004; HARVARD CMT PROJECT, 2006; FRACASSI & VALENSISE, 2007). La dimensione dei quadrati è proporzionale alla magnitudo equivalente derivata da dati di intensità. La spessa linea nera rappresenta il fronte esterno sepolto dell'Appennino Meridionale (si veda anche fig. 1).

Fig. 3 - Location map of all analyzed sites (see outline in fig. 1 for location).

Ubicazione dei siti analizzati (si veda anche il riquadro in fig. 1).

Fig. 4 - A, B, C. Plots of mesostructural data (Schmidt projection, lower hemisphere). Each plot is keyed to one of the sites of figure 3.

Diagrammi dei dati mesostrutturali (proiezione di Schmidt, emisfero inferiore). Ciascun diagramma fa riferimento a uno dei siti indicati in figura 3.

Fig. 5 - Fault cutting late Lower Pleistocene deposits and showing a significant reverse component of motion (loc. Masseria Incalzi, Ostuni). The lack of kinematic indicators precludes any inference on the strike-parallel component of motion, if any.

Faglia che interessa depositi del tardo Pleistocene Inferiore con significativa componente inversa del movimento (loc. Masseria Incalzi, Ostuni). La mancanza di indicatori cinematici non permette di identificare un'eventuale componente orizzontale del movimento.

Fig. 6 - Fault cutting late Middle Pleistocene deposits and showing a significant normal component of motion (S. Maria delle Grazie quarry, Gallipoli).

Faglia che interessa depositi del tardo Pleistocene Medio con significativa componente normale del movimento (cava di S. Maria delle Grazie, Gallipoli).

Fig. 7 - Fault cutting Middle-Upper Pleistocene deposits and showing 2 cm of reverse motion (S. Pietro island).

Faglia che interessa depositi del Pleistocene Medio-Superiore e mostra 2 cm di rigetto inverso (isola di S. Pietro).

Fig. 8 - Incipient fault cutting the Upper Pleistocene deposits (loc. Torre S. Sabina).

Faglia incipiente, che interessa depositi del Pleistocene Superiore (loc. Torre S. Sabina).

Fig. 9 - Extensional joints organized into two coeval orthogonal sets (Gravina Fm., late Lower Pleistocene calcarenites; loc. San Vito abbey).

Fratture estensionali organizzate in due famiglie ortogonali coeve (Formazione di Gravina, tardo Pleistocene Inferiore; loc. Abbazia San Vito).

Fig. 10 - Cumulative plot showing the statistical distribution of the poles to the joints (Schmidt projection, lower hemisphere).

Plot cumulativo con la distribuzione statistica dei poli delle fratture (projezione di Schmidt, emisfero inferiore).

Fig. 11 - Field examples of: A. the vertical continuity of the joints across the strata of the entire wall; B. the horizontal continuity of the joints; C. the Middle Pleistocene *colluvium* cut by joints which affect both the underlying and the overlying deposits.

Esempi di terreno: A. della continuità verticale delle fratture, che attraversano tutti gli strati della parete; B. della continuità orizzontale delle fratture; C. del colluvio medio-pleistocenico, tagliato da fratture che interessano sia i depositi sottostanti che quelli sovrastanti.

Fig. 12 - Prevailing directions of maximum horizontal extension (black arrows) for all investigated sites. Directions of maximum horizontal shortening (grey arrows) are shown only when folding or a significant component of reverse motion is observed.

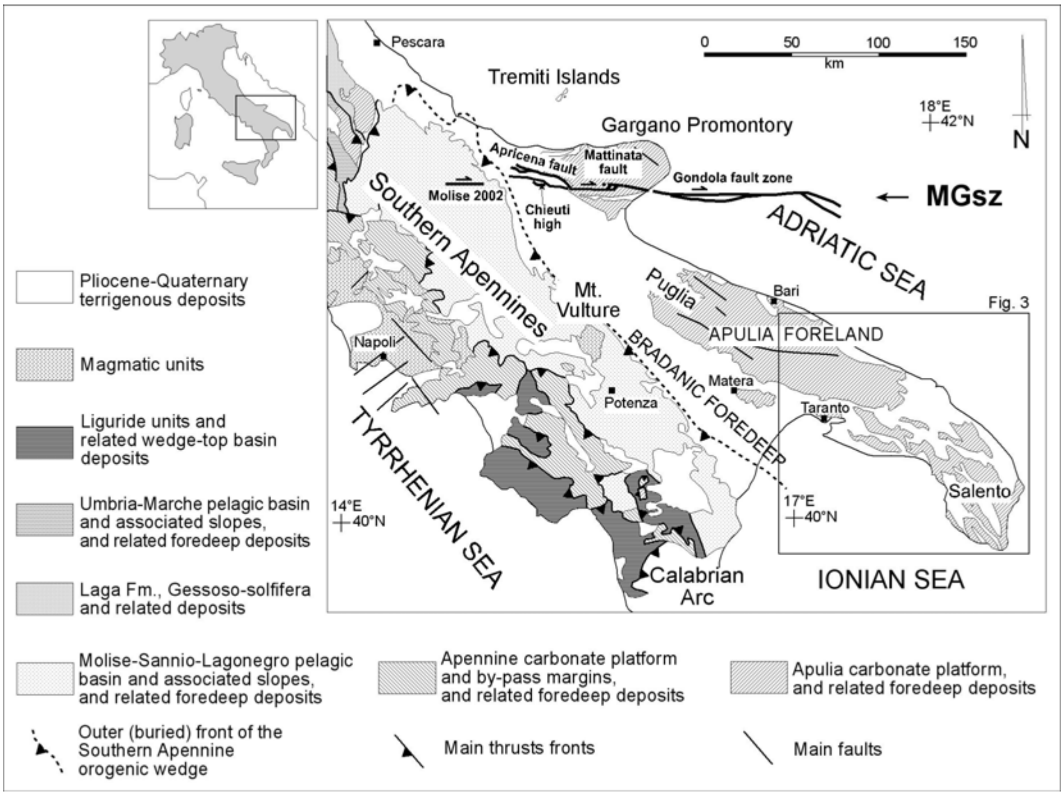
The general framework to the right is from SERPELLONI *et alii* (2005), modified. Earthquakes with M > 3 that occurred between 1973 and 2001 are taken from the NEIC Bulletin: http://neic.usgs.gov/neis/epic/epic.html. Earthquake focal mechanisms are from the Harvard CMT (http://www.seismology.harvard.edu/projects/CMT) and the European Regional CMT (http://www.ingv.it/seismoglo/RCMT) catalogues.

The large white, light grey and dark grey arrows at the bottom of the figure show plate motion vectors of Nubia with respect to Eurasia according to NUVEL-1A (DE METS *et alii*, 1994 = 6.9 mm/a), MCCLUSKY *et alii* (2003 = 4.8 mm/a), and SELLA *et alii* (2002 = 5.9 mm/a), respectively. The little grey arrows show selected GPS horizontal velocities given with respect to the Eurasian plate, for southern Apulia and Albanides (from SERPELLONI *et alii*, 2007). Key: SC, Sicily Channel; TG, Tindari–Giardini Fault; AI, Aeolian Islands; AE, Apulia Escarpment; KF, Cephalonia Fault; SAP, southern Apennines; GP, Gargano promontory. White stars: selected break-out data (σhmin) from MONTONE *et alii* (2004).

Direzioni prevalenti di massima estensione orizzontale (frecce nere) per i siti investigati. Le direzioni di massimo raccorciamento orizzontale (frecce grigie) sono riportate solo per quei siti in cui sono stati osservati piegamento o fagliazione con significativa componente inversa del movimento.

L'inquadramento generale, sulla destra della figura, è modificato da SERPELLONI et alii (2005). I terremoti avvenuti tra il 1973 e il 2001 con M > 3 sono tratti dal Bollettino NEIC: http://neic.usgs.gov/neis/epic/epic.html. I meccanismi focali sono tratti dai cataloghi Harvard CMT (http://www.seismology.harvard.edu/projects/CMT) ed European Regional CMT (http://www.ingv.it/seismoglo/RCMT).

Le grandi frecce in bianco, grigio chiaro e grigio scuro, in basso nella figura, rappresentano i vettori di moto della placca Nubia in relazione ad Eurasia, rispettivamente secondo NUVEL-1A (DE METS et alii*, 1994 = 6,9 mm/a),* *McClusky* et alii *(2003 = 4,8 mm/a) e Sella* et alii *(2002 = 5,9 mm/a). Le piccole frecce grigie mostrano le velocità orizzontali, da dati GPS rispetto alla placca Eurasia, per la Puglia meridionale e le Albanidi (da Serpelloni* et alii*, 2007). SC: Canale di Sicilia; TG: Faglia di Tindari–Giardini; AI: Isole Eolie; AE: Scarpata Apula; KF: Faglia di Cephalonia; SAP: Appennino Meridionale; GP: Promontorio del Gargano. Stelle bianche: dati di break-out* (σ_{hmin}*; da Montone* et alii*, 2004).*


Pescara
Tremiti Islands
Gargano Promontory
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km
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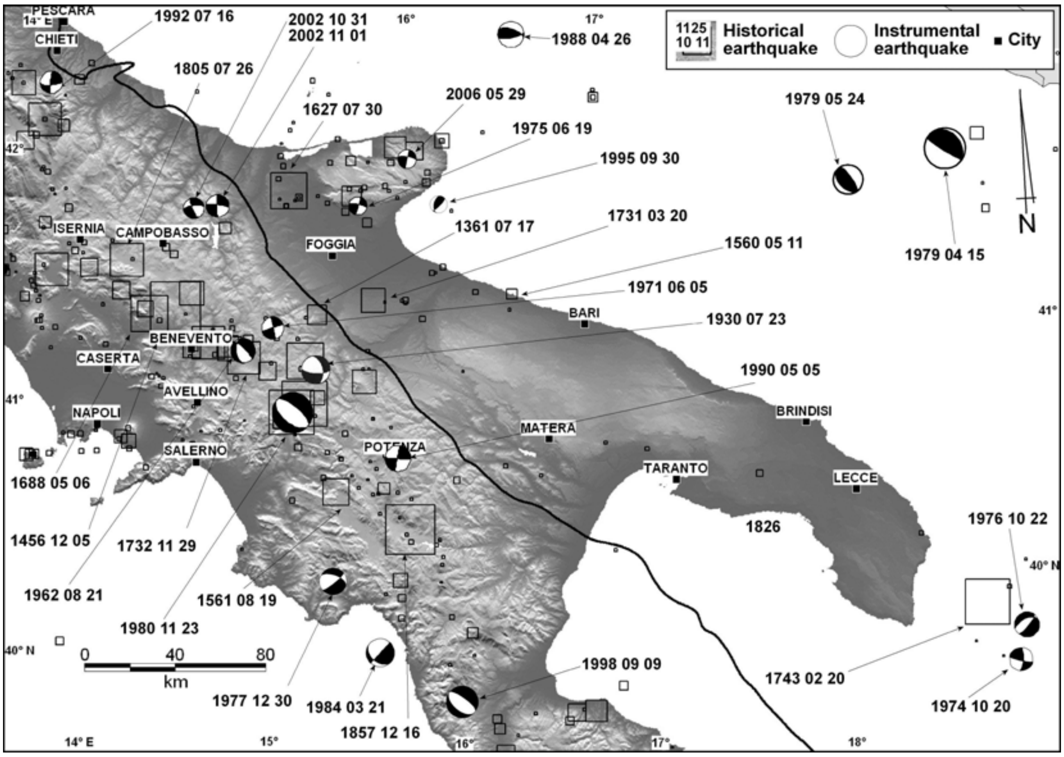
Apricena fault
Mattinata fault
Gondola fault zone
Molise 2002
Chieuti high
MGsz
ADRIATIC SEA
Southern Apennines
Mt. Vulture
Puglia
Bari
Fig. 3
APULIA FORELAND
Napoli
BRADANIC FOREDEEP
Matera
Potenza
Taranto
TYRRHENIAN SEA
14°E
40°N
17°E
40°N
Salento
Calabrian Arc
IONIAN SEA
Pliocene-Quaternary terrigenous deposits
Magmatic units
Liguride units and related wedge-top basin deposits
Umbria-Marche pelagic basin and associated slopes, and related foredeep deposits
Laga Fm., Gessoso-solfifera and related deposits
Molise-Sannio-Lagonegro pelagic basin and associated slopes, and related foredeep deposits
Apennine carbonate platform and by-pass margins, and related foredeep deposits
Apulia carbonate platform, and related foredeep deposits
Outer (buried) front of the Southern Apennine orogenic wedge
Main thrusts fronts
Main faults

Fig. 1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1805 07 26
2006 05 29
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1975 06 19
1979 05 24
42°
1995 09 30
ISERNIA
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1361 07 17
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1979 04 15
1560 05 11
1971 06 05
BARI
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1930 07 23
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LECCE
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1976 10 22
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1561 08 19
1980 11 23
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Fig. 2

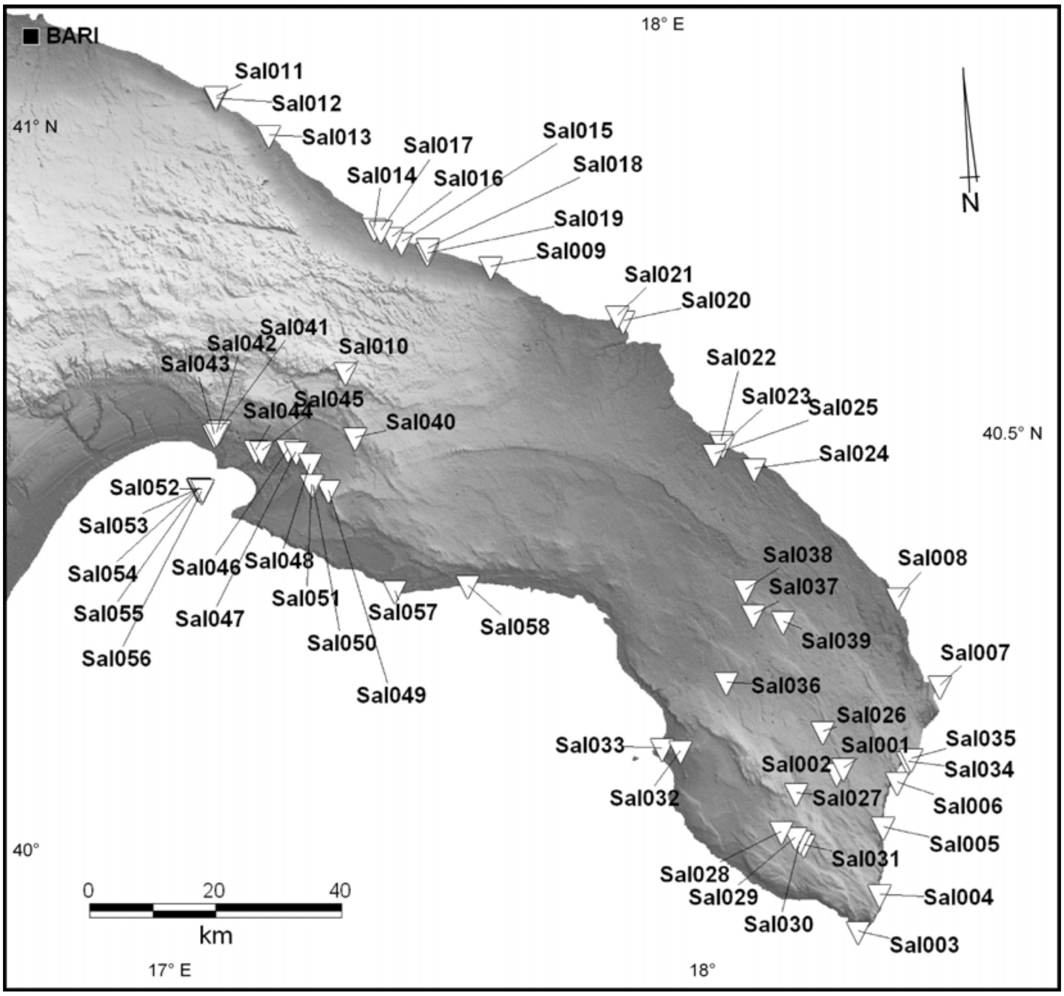
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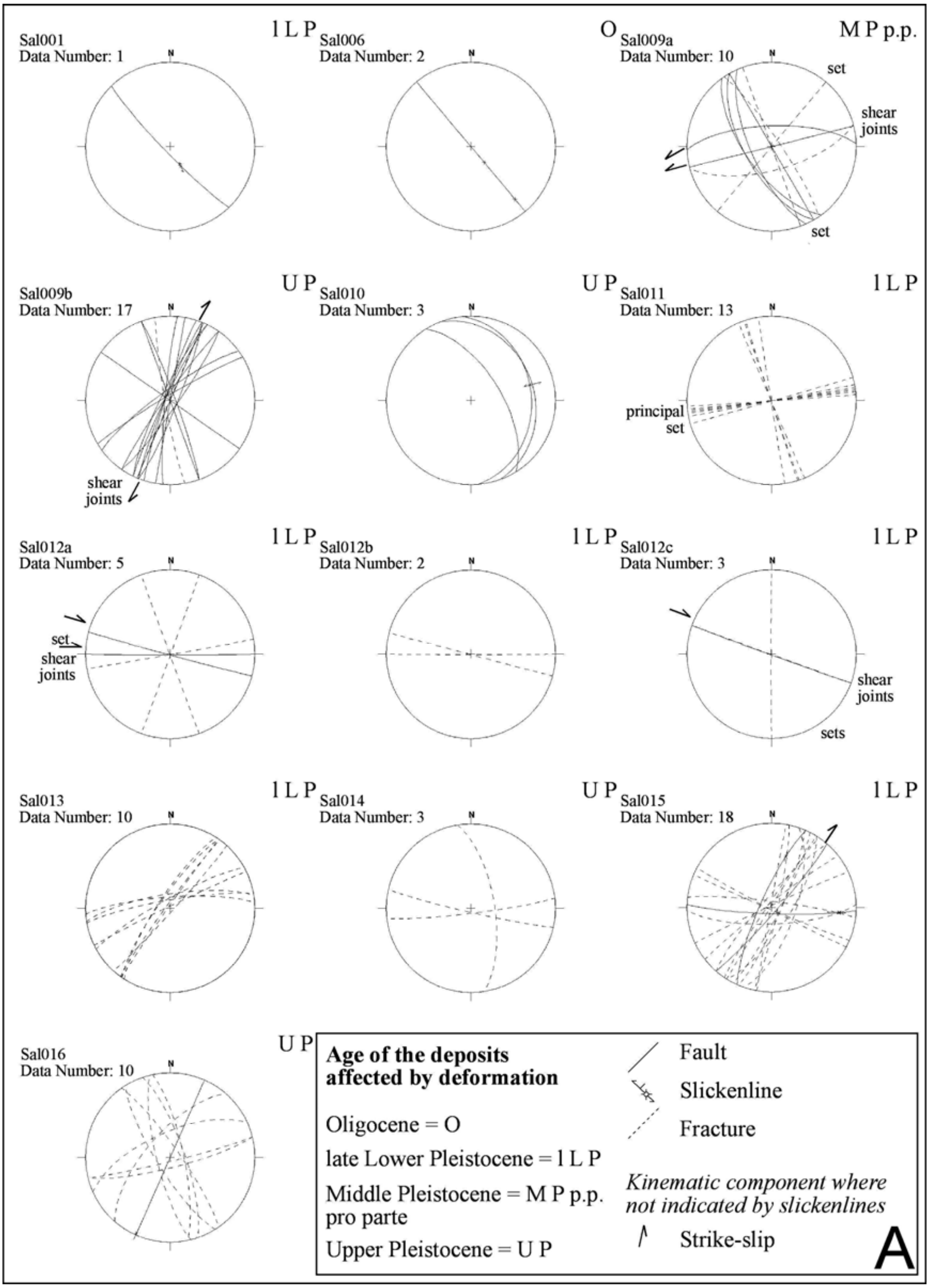
Fig. 3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shear joints
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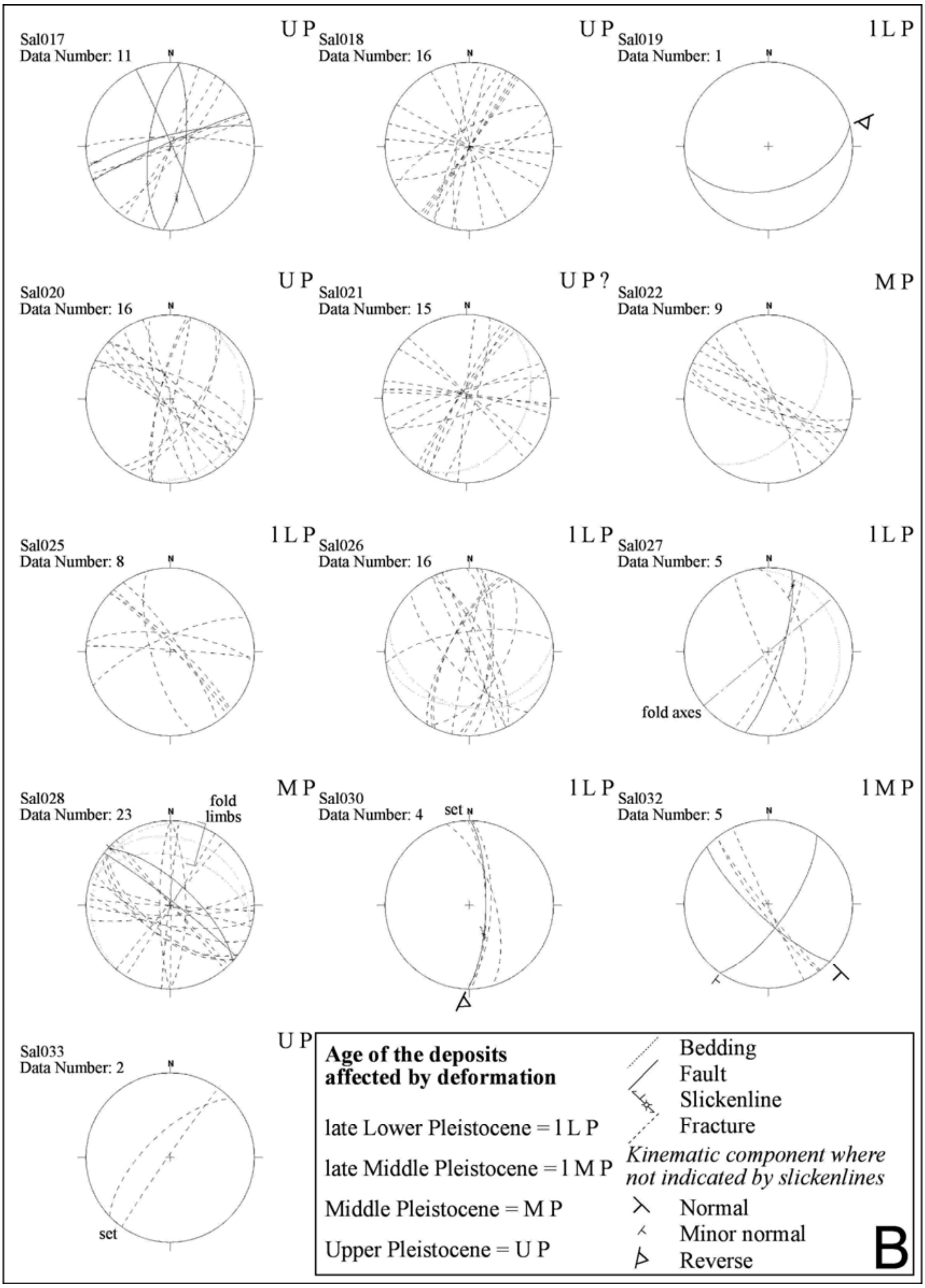
Sal010
Data Number: 3
U P
Sal011
Data Number: 13
principal set
l L P
Sal012a
Data Number: 5
set
shear joints
l L P
Sal012b
Data Number: 2
l L P
Sal012c
Data Number: 3
shear joints
sets
l L P
Sal013
Data Number: 10
l L P
Sal014
Data Number: 3
U P
Sal015
Data Number: 18
l L P
Sal016
Data Number: 10
U P
N
Age of the deposits affected by deformation
Oligocene = O
late Lower Pleistocene = l L P
Middle Pleistocene = M P p.p. pro parte
Upper Pleistocene = U P
Fault
Slickenline
Fracture
Kinematic component where not indicated by slickenlines
Strike-slip
A

Fig. 4A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U P
Sal018
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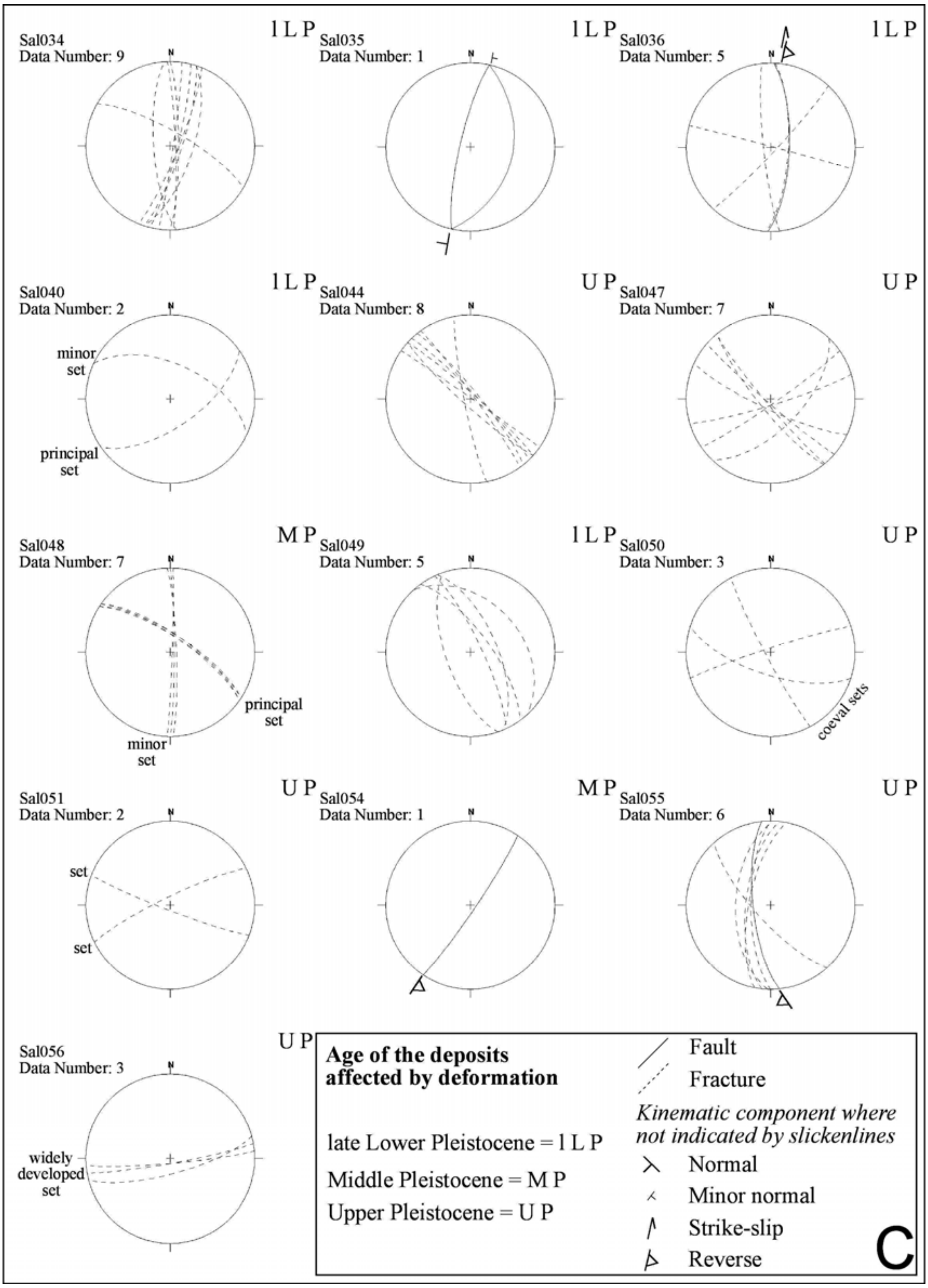
1 L P
Sal020
Data Number: 16
U P
Sal021
Data Number: 15
U P ?
Sal022
Data Number: 9
M P
Sal025
Data Number: 8
1 L P
Sal026
Data Number: 16
1 L P
Sal027
Data Number: 5
1 L P
fold axes
Sal028
Data Number: 23
fold limbs
M P
Sal030
Data Number: 4
set
1 L P
Sal032
Data Number: 5
1 M P
Sal033
Data Number: 2
set
U P
N
Age of the deposits affected by deformation
late Lower Pleistocene = 1 L P
late Middle Pleistocene = 1 M P
Middle Pleistocene = M P
Upper Pleistocene = U P
Bedding
Fault
Slickenline
Fracture
Kinematic component where not indicated by slickenlines
Normal
Minor normal
Reverse
B

Fig. 4B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l L P
Sal035
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Sal036
Data Number: 5
l L P
Sal040
Data Number: 2
minor set
principal set
l L P
Sal044
Data Number: 8
U P
Sal047
Data Number: 7
U P
Sal048
Data Number: 7
minor set
principal set
M P
Sal049
Data Number: 5
l L P
Sal050
Data Number: 3
coeval sets
U P
Sal051
Data Number: 2
set
set
U P
Sal054
Data Number: 1
M P
Sal055
Data Number: 6
U P
Sal056
Data Number: 3
widely developed set
U P
N
Age of the deposits affected by deformation
late Lower Pleistocene = l L P
Middle Pleistocene = M P
Upper Pleistocene = U P
Fault
Fracture
Kinematic component where not indicated by slickenlines
Normal
Minor normal
Strike-slip
Reverse
C

Fig. 4C

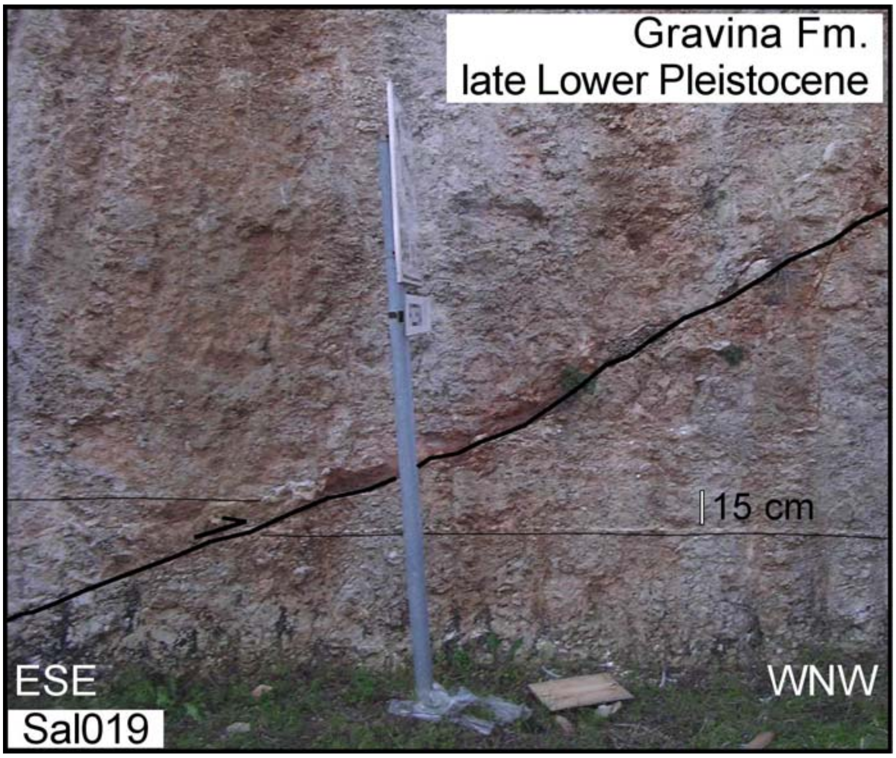
Gravina Fm.
late Lower Pleistocene
15 cm
ESE
WNW
Sal019

Fig. 5

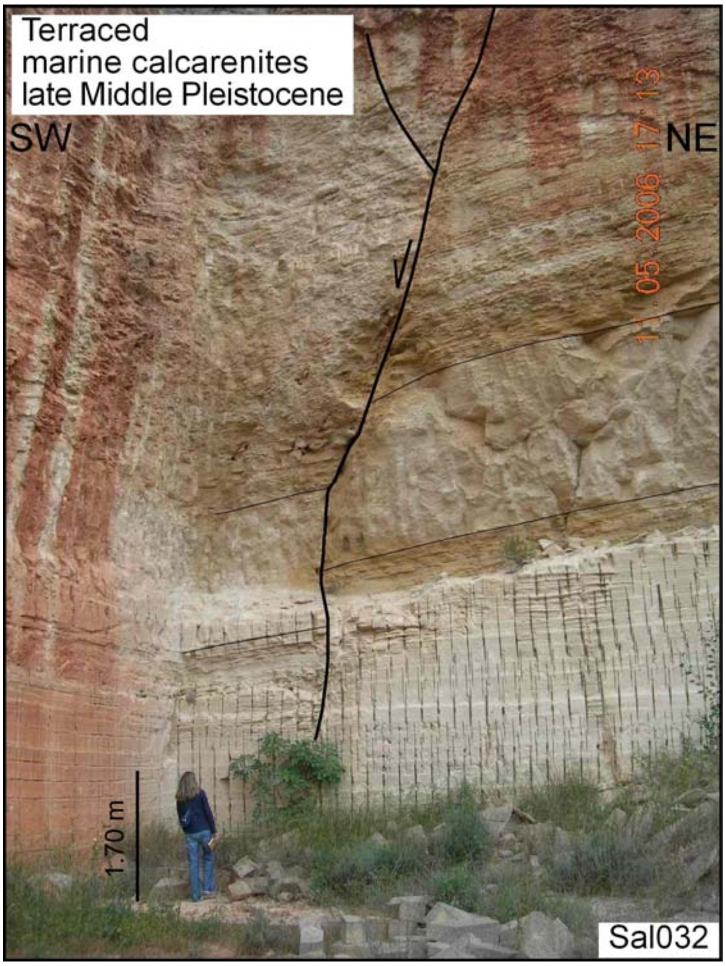
Terraced
marine calcarenites
late Middle Pleistocene
SW
NE
11 05 2006 17 13
1.70 m
Sal032

Fig. 6

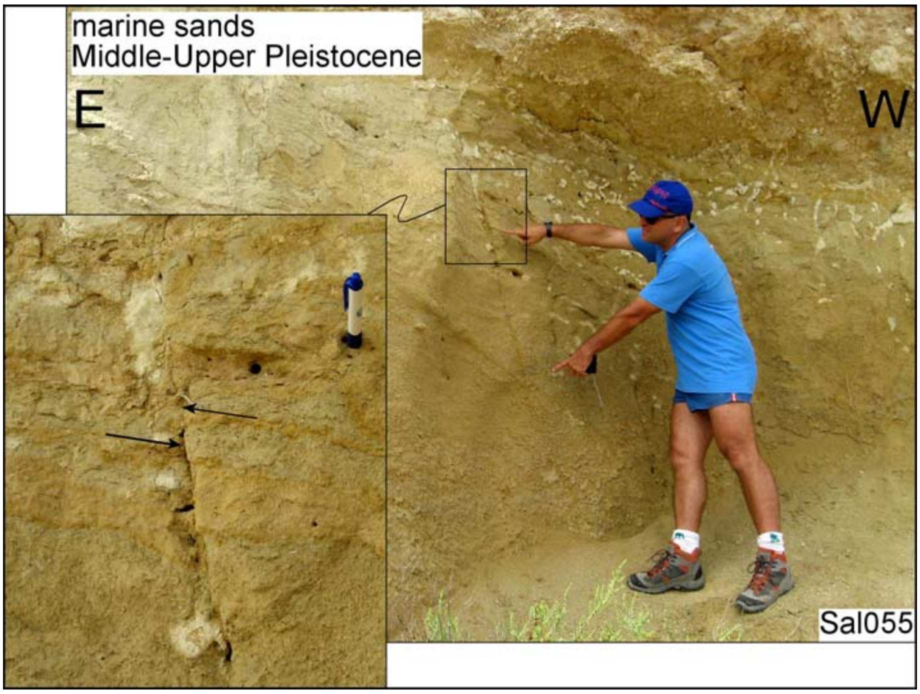
marine sands
Middle-Upper Pleistocene
E
W
Sal055

Fig. 7

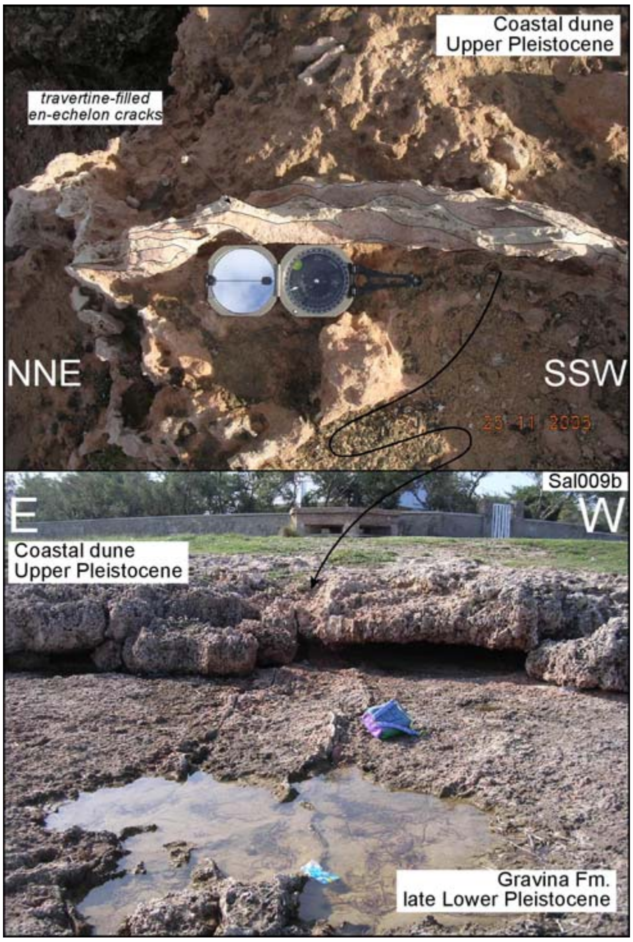
Coastal dune
Upper Pleistocene
travertine-filled
en-echelon cracks
NNE
SSW
23 11 2005
Sal009b
E
W
Coastal dune
Upper Pleistocene
Gravina Fm.
late Lower Pleistocene

Fig. 8

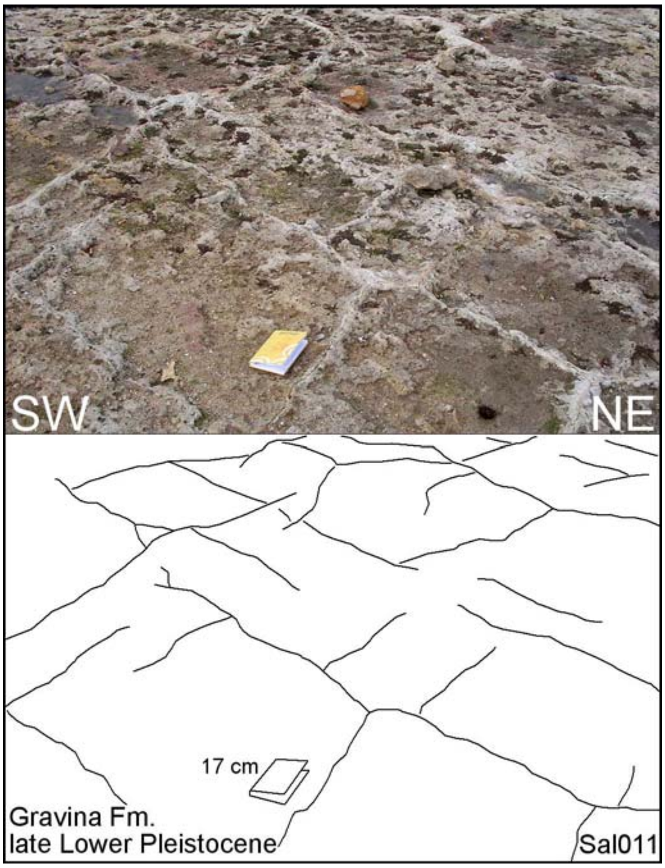
SW
NE
17 cm
Gravina Fm.
late Lower Pleistocene
Sal011

Fig. 9

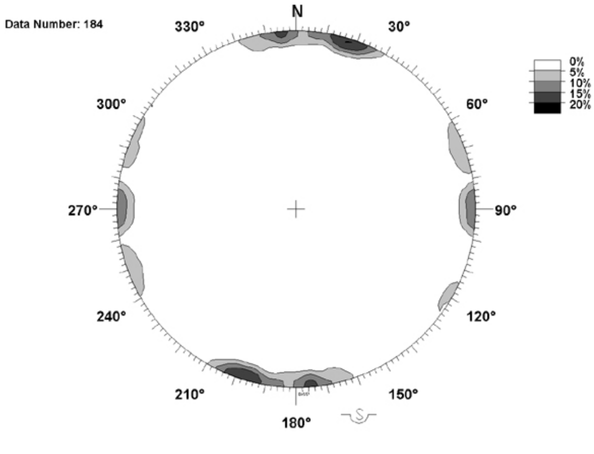
Data Number: 184
N
330°
30°
300°
60°
270°
90°
240°
120°
210°
150°
180°
S
0%
5%
10%
15%
20%

Fig. 10

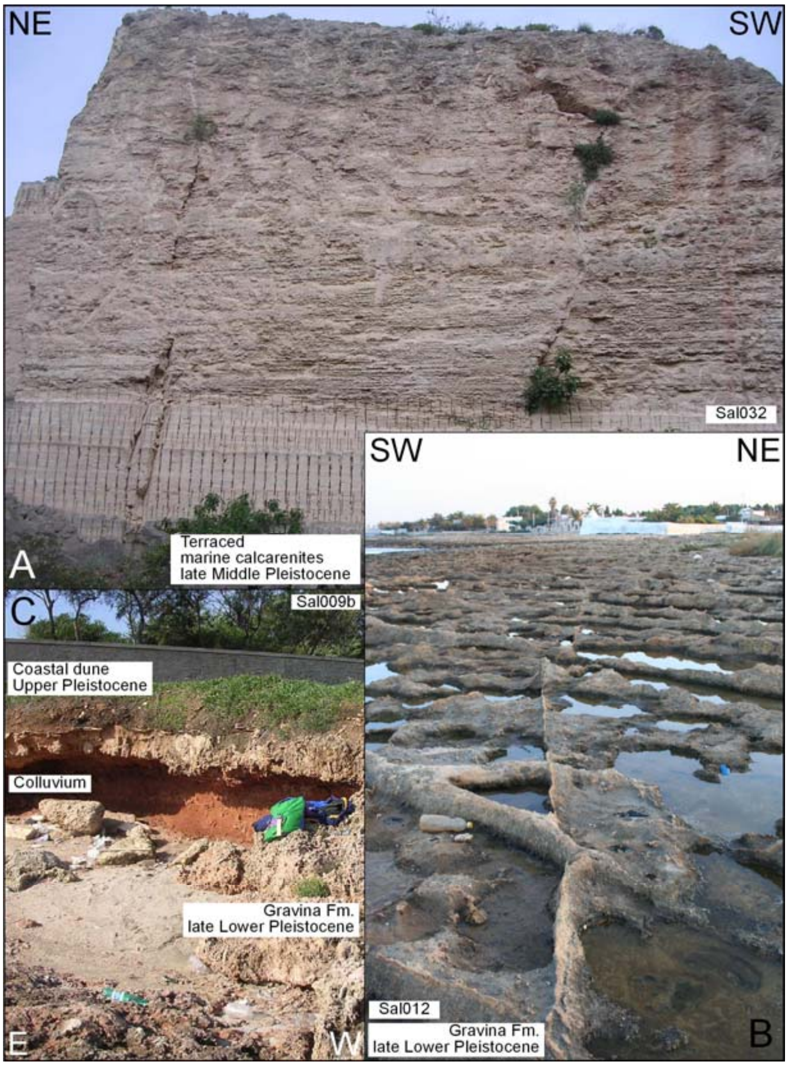
NE
SW
Sal032
A
Terraced marine calcarenites late Middle Pleistocene
SW
NE
C
Sal009b
Coastal dune Upper Pleistocene
Colluvium
Gravina Fm. late Lower Pleistocene
E
W
Sal012
Gravina Fm. late Lower Pleistocene
B

Fig. 11

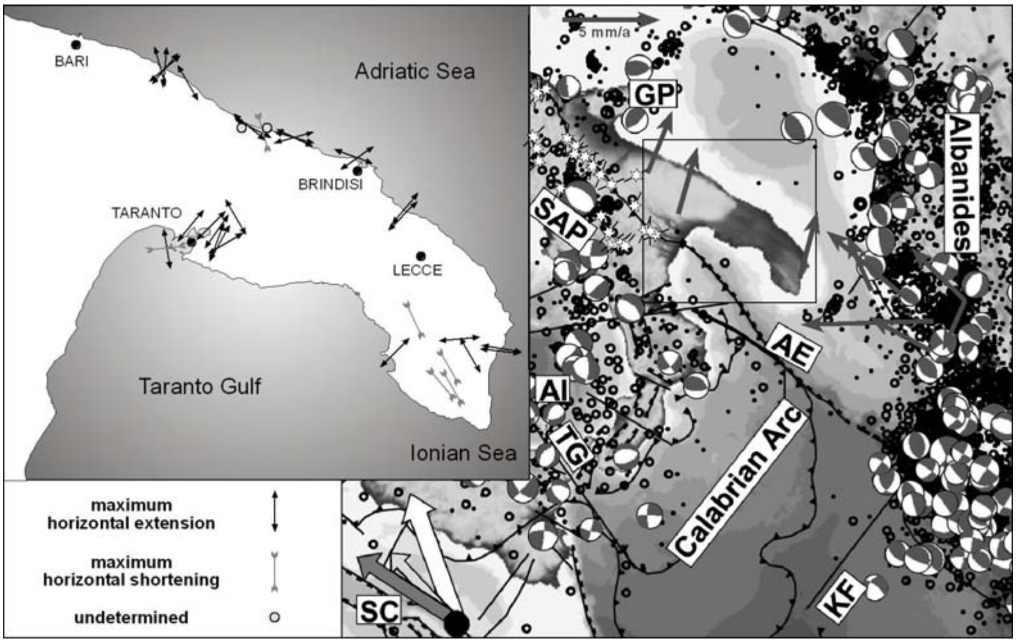
BARI
Adriatic Sea
BRINDISI
TARANTO
LECCE
Taranto Gulf
Ionian Sea
maximum horizontal extension
maximum horizontal shortening
undetermined
5 mm/a
GP
SAP
Albanides
AE
AI
TG
Calabrian Arc
KF
SC

Fig. 12