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Seismotectonic of Southern Apennines from recent passive seismic experiments

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ABSTRACT

We used data of local earthquakes collected during two recent passive seismic experiments carried out in southern Italy in order to study the seismotectonic setting of the Lucanian Apennine and the surrounding areas. Based on continuous recordings of the temporary stations we extracted over 15,600 waveforms, which were hand-picked along with those recorded by the permanent stations of the Italian national seismic network obtaining a dense, high-quality dataset of *P*- and *S*-arrival times. We examined the seismicity occurring in the period 2001–2008 by relocating 566 out of 1047 recorded events with magnitudes $M_L \geq 1.5$ and computing 162 fault-plane solutions. Earthquakes were relocated using a minimum one-dimensional velocity model previously obtained for the region and a V_p/V_s ratio of 1.83. Background seismicity is concentrated within the upper crust (between 5 and 20 km of depth) and it is mostly clustered along the Lucanian Apennine chain axis. A significant feature extracted from this study relates to the two E–W trending clusters located in the Potentino and in the Abriola–Pietrapertosa sector (central Lucania region). Hypocentral depths in both clusters are slightly deeper than those observed beneath the Lucanian Apennine. We suggest that these two seismic features are representative of the transition from the inner portion of the chain to the external margin characterized by dextral strike-slip kinematics. In the easternmost part of the study area, below the Bradano foredeep and the Apulia foreland, seismicity is generally deeper and more scattered. The sparse seismicity localized in the Sibari Plain, in the offshore area along the northeastern Calabrian coast and in the Taranto Gulf is also investigated thanks to the new recordings. This seismicity shows hypocenters between 12 and 20 km of depth below the Sibari Plain and is deeper (foci between 10 and 35 km of depth) in the offshore area of the Taranto Gulf. 102 well-constrained fault-plane solutions, showing predominantly normal and strike-slip character with tensional axes (*T*-axes) generally NE oriented, were selected for the stress tensor analysis. We investigated stress field orientation inverting focal mechanism belonging to the Lucanian Apennine and the Pollino Range, both areas characterized by a more concentrated background seismicity.

1. Introduction

The axial zone of the Southern Apennines mountain belt constitutes the backbone of the southern part of the Italian peninsula. Since the Early Pleistocene, active extension produced a broad and complex system of normal faults within the Apenninic chain. This extension superimposed and developed in the area previously affected by compression (Middle-Late Miocene) and characterized by an eastward migration of the Apenninic compressional front (Patacca et al., 1990; Hippolyte et al., 1994; Doglioni et al., 1996). The eastward migration of the extension–compression system of the Apenninic belt is related with the subduction process of old oceanic lithosphere beneath the Southern Apennines and Calabrian Arc and with the Tortonian opening and oceanisation of the Tyrrhenian basin (Patacca et al., 1990; Doglioni et al., 1996; Barberi et al., 2004). The Apenninic orogen is bordered East and Northeast by the thick continental Apulian swell which is clearly distinct, from a tectonic point of view, from the remaining of the peninsula. It represents an emerged portion of the relatively more rigid structure named Adriatic microplate, a promontory of Africa towards Eurasia, which is extending beneath the Adriatic sea (Channell et al., 1979; Anderson and Jackson, 1987). The Adriatic microplate, which is bordered by an almost continuous belt of orogenic chains (Apennines, Alps, Dinarides, Hellenides), plays the role of foreland for the more deformable bordering regions. In fact, these regions are affected by a diffuse seismic activity correlated to a general counter-clockwise motion of the microplate itself (Meletti et al., 2000).

The east-southeastward migration of the Tyrrhenian-Apennine subduction system (Malinverno and Ryan, 1986; Royden et al., 1987; Gueguen et al., 1998; Rosenbaum and Lister, 2004), followed by the asthenospheric wedging at the retreating subduction hinge beneath the Southern Apennines and the southern Tyrrhenian Sea

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(Doglioni et al., 1996), appears to have slowed and buckled during the Late Pleistocene after the collision with the thick continental lithosphere of the Apulia foreland at the front of the belt (Doglioni et al., 1994). Deep structures beneath the Southern Apennines can be generally explained with a thick-skinned tectonic model (Menardi Noguera and Rea, 2000). These Plio-Pleistocene contractional structures, related to a basement-involved thrust tectonics (Apulian Platform deformation), are evident from structural profiles. A further evidence of this basement-involved thrust tectonics is given by the Monte Alpi structure which actually represent remnants of a mélange zone originally interposed between the Apulian Platform carbonates and the overlying far-travelled detachment sheet (Corrado et al., 2002).

The complex geodynamic setting of this area is dominated by the NNW–SSE convergence between the African and the Euroasian plates, which are currently converging at a rate ~10 mm/year (Argus et al., 1989; De Mets et al., 1990). Geodetic observation, together with seismological studies, reveals that the Apenninic chain is undergoing a NE-trending extension, with seismic deformation rates higher in the southern portion (Di Luccio et al., 2005; D'Agostino et al., 2008). Southern Apennines is one of the main seismically active regions of Italy (Fig. 1). Historical seismic catalogue shows a completeness for the Italian highly energetic events occurred in the last four centuries (CPTI Working Group, 2004). Among the strongest earthquakes of the southern Apenninic belt, the 1694 Irpinia ($M_e = 6.9$; Serva, 1985) and the 1857 Basilicata events ($M_e = 6.9$; Branno et al., 1983; Branno et al., 1985) recorded both an epicentral XI degree on the Mercalli-Cancani-Sieberg (MCS) scale. Moreover, Irpinia experienced a macroseismic intensity X MCS in 1980 ($M_s = 6.9$) in the same area as the 1694 historical event (Postpischel et al., 1985). It is noteworthy to mention the 1561 complex seismic sequence located between the Vallo di Diano and the Upper Ofanto Valley, which is reappraised by Castelli et al. (2008). This sequence is characterized by two large earthquakes occurred within 20 days (31 July and 19 August) with maximum intensities in the range of X MCS ($M_e = 6.4$).

The northern part of Apulia (Gargano, Tavoliere and Ofanto Graben) is generally considered a remarkably seismogenic area (Piccardi, 2005; Tondi et al., 2005; Del Gaudio et al., 2005, 2007). Highly energetic events are historically documented as the 1627 earthquakes ($M_e = 6.8$; X degree MCS) that hit the northern Foggia province (Molin and Margottini, 1985). In the Ofanto Graben, the quite well-documented case of the 1560 earthquake ($M_e = 5.7$) which hit the Barletta and Bisceglie towns (macroseismic intensity differently estimated between VII-VIII and IX MCS, according to different catalogues), has been often considered an over-estimated event because of site amplification (Del Gaudio et al., 2005). On March 20, 1731, a strong earthquake ($M_e = 5.2$), with macroseismic intensity estimated between IX and X MCS, hit the southern part of the Foggia province, followed by several strong aftershocks (Molin, 1985). Another important seismic crisis, occurred on August 14, 1851, had its focus in the area of the extinct volcano Vulture, located at the front of the Apenninic chain. The mainshock ($M_e = 6.3$; X MCS) was followed by numerous aftershocks, some of which appear to have felt more strongly in Apulia at Canosa (Magri and Molin, 1979; Del Gaudio et al., 2005).

The Bradano foredeep and Apulia foreland areas, both to the South of the Ofanto river, do not show considerable historical seismicity, with the exception of the 1743 Salento earthquakes ($M_e = 7.1$) whose epicentral area was probably located offshore within the Otranto Channel (Margottini, 1981; Mastronuzzi et al., 2007). This event induced high amplification mainly in the villages of Nardò and Francavilla Fontana (IX-X MCS) founded on thin Pleistocene basins filled with soft sediments (Galli and Naso, 2008). It is also interesting to note the seismic activity characterized by sequences of moderate magnitude (strongest event with $M_L = 5.1$) occurred in the years 1974, 1977 and 1991 in the offshore fore-

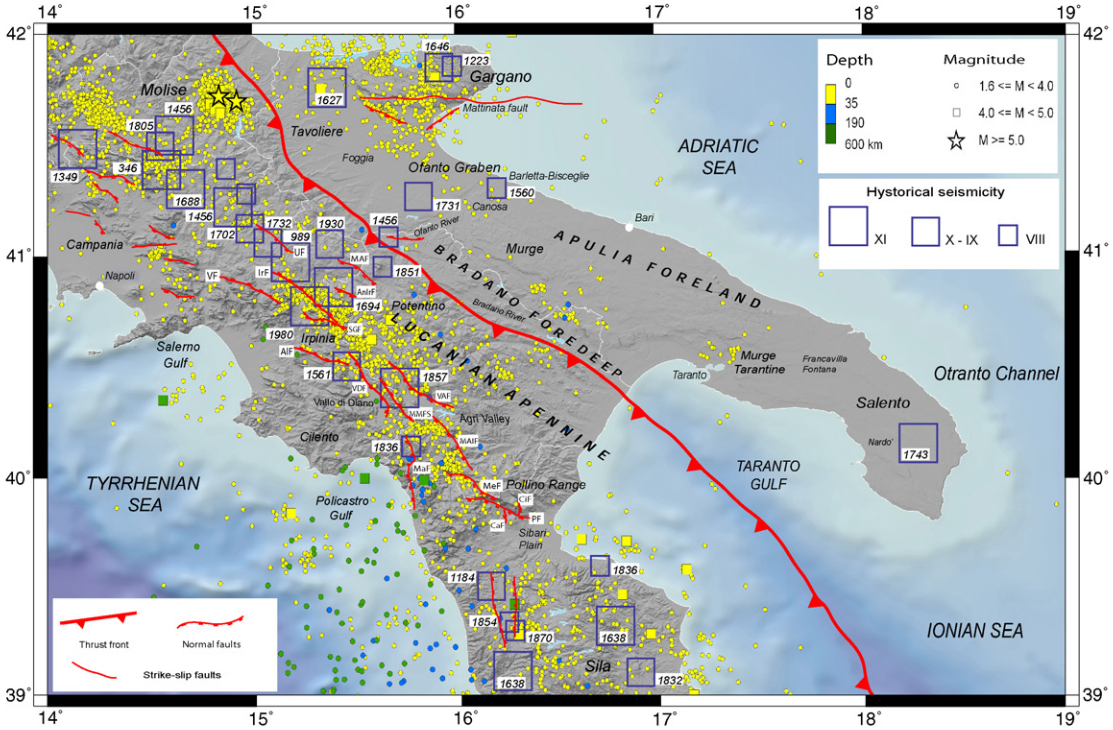

Fig. 1. Southern Italy historical and instrumental seismicity map. Historical seismicity from the CPTI Working Group (2004). Instrumental seismicity from Seismicity map of Italy, 2000–2007, INGV-CNT, Roma (Castello et al., 2008). Active faults from Galadini et al. (2000), Maschio et al. (2005) and Papanikolaou and Roberts (2007). Lucanian Apennine active faults: UF, Ufita fault; MAF, Mount Mattinata–Atella fault; VF, Volturara fault; IrF, Irpinia fault; AnIrF, Antithetic Irpinia fault; SGF, San Gregorio fault; ALF, Alburni fault; VDF, Vallo di Diano fault; VAF, Val d'Agri fault; MMFS, Monti della Maddalena fault system; MALF, Monte Alpi fault; MAF, Maratea fault; MeF, Mercure fault; PF, Pollino fault; CaF, Castrovillari fault; CiF, Civita fault.

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land region southeast of the Salento peninsula (D'Ingeo et al., 1980; Favali et al., 1990; Argnani et al., 2001).

In Southern Apennines, large part of the background seismicity is located along the main axis of the chain (Fig. 1, instrumental seismic catalogue 2000–2007, Castello et al., 2008). Only the Gargano promontory, belonging to the Apulia foreland and characterized by an E–W trending right-lateral strike-slip fault system (Piccardi, 2005; Tondi et al., 2005), shows denser clusters of background seismicity related to the known tectonic structures (Del Gaudio et al., 2007).

Clustered seismicity within the Apenninic chain is related to the main sequences of the last two decades. This aftershock activity probably is due to the post-seismic relaxation, a process that takes from several years up to decades to settle down. In the Potentino area, two seismic sequences occurred in May 5, 1990 (M_s = 5.4; I = VII MCS) and in May 26, 1991 (M_L = 4.7; I = VI-VII MCS; Tertulliani et al., 1992; Azzara et al., 1993; Ekström, 1994; Alessio et al., 1995), both produced by E–W oriented strike-slip structures with dextral kinematics. The same area was hit by two episodes of increasing seismicity in February 1983 (M_L = 4.0) and July 1986 (M_L = 4.2; Alessio et al., 1995). The 1983 and 1986 seismicity seems to indicate an activation of small structures to the southeast of the nearby 1980 Irpinia earthquake area. The 1990 and 1991 seismicity pattern in the Potentino area shows hypocenters that are generally deeper (Azzara et al., 1993) than those localized within the neighbouring Irpinia sequence area of the 1980 earthquake, which was produced by a normal mechanism of rupture (Deschamps and King, 1984; Boschi et al., 1990). Geological evidence of the 1980 event has been studied by Westaway and Jackson (1984) and Pantosti and Valensise (1990), while seismological studies indicate a complex fracturing episode characterized by occurrence of three subevents at 0, 20 and 40 s from the main shock (Crosson et al., 1986; Westaway and Jackson, 1987; Bernard and Zollo, 1989). Moreover, the Irpinia area was hit in 1996 by a small sequence which started with a main shock on April 3 (M_L = 4.9, Cocco et al., 1999). The main event was located in the area which separates the two first subevents of the 1980 Irpinia earthquake. Aftershocks of the 1996 seismic sequence occurred in an area where few aftershocks of the 1980 earthquake were located and which coincides with the gap in surface faulting observed by Pantosti and Valensise (1990). Cocco et al. (1999) suggest that the 1996 sequence between the 0 s and the 20 s faults is consistent with the hypothesis of the weak zone (low strength zone) and, therefore, this sequence can be considered as interevent seismicity.

West of the Gargano promontory, within the foredeep area, the October–November 2002 Molise seismic sequence (M_L = 5.4) was characterized by a pure transcurrent geometry with E–W right-lateral strike-slip faults (Valensise et al., 2004; Di Luccio et al., 2005). This sequence occurred in a transition zone located between the inner Apenninic belt, where normal faults dominate in the upper crust, and the Apulia foreland (Gargano promontory) where dextral strike-slip kinematics, with a non-negligible compressive component, is prevailing (Del Gaudio et al., 2007). Borehole breakouts analysis performed by Amato and Montone (1997) in southern peninsular Italy indicate a NW–SE orientation of S_{Hmax} toward the foredeep suggesting a strike-slip stress regime in this area. The Molise sequence and the 1990 and 1991 Potenza earthquakes supported this idea emphasizing the existence of E–W right-lateral strike-slip faults dissecting the belt (Scrocca, 2006; Di Bucci et al., 2006).

Background seismicity is more scattered in the Pollino and Sila areas. The seismic cluster located to the north-western border of the Pollino Range is related to the Castelluccio–Lauria seismic sequence of 1998 (M_w = 5.6) characterized by pure normal focal mechanisms (Michetti et al., 2000; Pondrelli et al., 2002; Brozzetti et al., 2009). The Pollino Range was considered to be a seismic gap or an area of aseismic deformation because of the lack of large-magnitude earthquakes in the historical record. Paleoseismological investigations in the Pollino Range (Cinti et al., 1997; Michetti et al., 1997) provide important contribution in determining the earthquake hazard of this region. Trenches across the Castrovillari fault scarps indicate that at least four surface-faulting earthquakes have occurred since Late Pleistocene time (Cinti et al., 1997). Fault length and slip per event suggest magnitudes ranging between 6.5 and 7.0 for the paleoearthquakes, highlighting an important seismogenic potential for this area.

In this study, we focus on the seismotectonics of this portion of the Apenninic chain and the Apulia foreland through a careful analysis of the background seismicity occurred in the present decade and a detailed mapping of the active stress field retrieved from fault-plane solution inversion. Present-day stress field information are important for the seismotectonic zonation, a basic tool for seismic hazard evaluation. The research take advantage of the dense seismic monitoring carried out in the area during the last decade through the deployment of three-component temporary arrays.

2. Data collection

Two passive seismic experiments were carried out in the period between June 2001 and December 2008. Fig. 2 shows the distribution of seismic stations used to record digital waveforms of local earthquakes occurred in southern Italy in the study period. At the same time, the Italian national seismic network (Fig. 2; white squares) improved significantly, increasing both the station coverage and the number of three-component broad band sensors. The two temporary arrays (Fig. 2; colored symbols) were deployed in the region for high-resolution studies of the lithosphere–asthenosphere system. The SAPTEX array (Fig. 2; green circles) was a long-term tomography experiment lasted from June 2001 to December 2004 (Cimini et al., 2006), while the SeSCAL array (Fig. 2; magenta triangles) has operated in the period between December 2007 and March 2009. This latter was planned specifically for the study of background seismicity and crustal structure of the Lucanian Apennines and surrounding areas. In both deployments, the portable seismographs were all equipped with high-dynamic digitizers and three-component extended band sensors. To avoid losing important seismic data, the stations were set to operate in continuous mode recording. In particular, the SAPTEX data were acquired at 50 sps, while the SeSCAL stations operated at 100 sps to better record low-magnitude, high-frequency local earthquakes.

We re-picked the arrival times of events recorded by the permanent network and picked those recorded by the temporary arrays. The ENI-AGIP network data were used only for some events located in the upper Val d'Agri and neighbouring areas. Our dataset consists of 15,666 *P*- and 9228 *S*-arrival times associated to 1047 earthquakes with magnitude $M_L \geq 1.5$. To each arrival time picks we assigned a weighting factor based on the uncertainty estimates. We used weight 1, 2, 3, and 4, respectively, for a picking accuracy of 0.05, 0.10, 0.25 and 0.50 s. Table 1 shows the comparison between our dataset and the data collected by Maggi et al. (2009) in order to quantify the improvement achieved in the last two years of the observing period (2007–2008) thanks to the SeSCAL passive experiment. The number of *P*- and *S*-waves arrival times are almost doubled, as well as the relocated events and the computed fault-plane solutions, which increased from 359 to 677, and from 58 to 102, respectively.

3. Earthquakes relocation

Seismicity located within the area between 39.5°N–42.0°N and 14.5°E–19.0°E is analyzed in this work. We relocated 677 events

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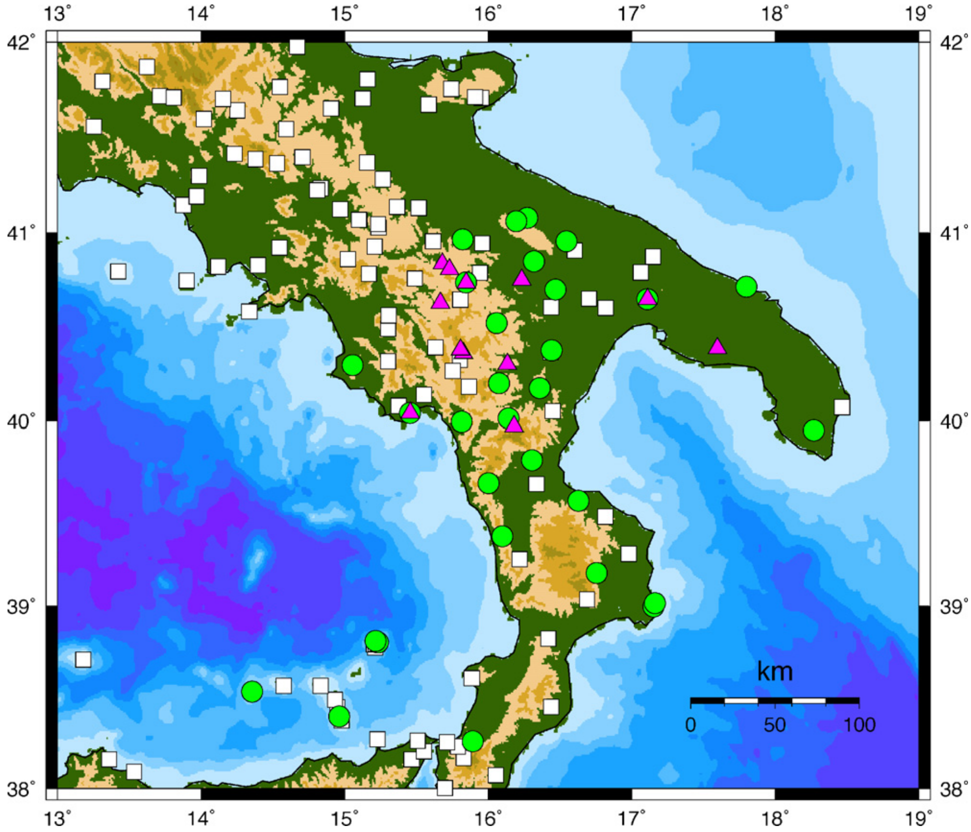

Fig. 2. Seismic stations used in this study. White squares indicate the telemetred stations of the Italian national network, green circles indicate the temporary stations deployed for the SAPTEX array (June 2001–December 2004) and magenta triangles indicate the temporary stations deployed for the SeSCAL project (December 2007–March 2009). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

Table 1
Local earthquake datasets examined by (A) Maggi et al. (2009) and (B) this study for the seismotectonic of Southern Apennines.

Dataset	Recording arrays	P-picks	S-picks	Relocated events	Quality A	Quality B	Quality C	Quality D	Focal mechanisms
A	RSNC, SAPTEX	7570	4956	359	226	69	31	33	58
B	RSNC, SAPTEX, SeSCAL	15,666	9228	677	319	155	92	111	102

out of 1047 recorded earthquakes using the Hypoellipse code (Lahr, 1989), the 1D velocity model and V_p/V_s ratio of 1.83 computed for the study region by Maggi et al. (2009) (Table 2). Hypocentral solutions with horizontal and vertical errors larger than 5.35 km and azimuthal gap > 180° (quality D; see Lahr, 1989) are rejected. The root mean square (rms) of the solution travel-time residuals for the 566 selected events is smaller than 1.0 s, with an average of 0.22 s. Most of the relocated earthquakes show rms between 0.10 and 0.40 s, maximum horizontal errors smaller than 2.0 km and vertical errors smaller than 3.0 km (Fig. 3). The denser station coverage yields a significant improvement in the hypocentral determination.

Fig. 4a shows the distribution of the background seismicity investigated in this study. Hypocentral depths range from 5.0 to 92 km, with the majority of solutions between 5 and 30 km (Fig. 4b,c). The pattern suggests that the pre-existing structures, developed during the Plio-Pleistocene compression and the mountain building, control the depth of the seismogenic layer. The main seismogenic zone includes the southern Apennine belt from the Irpinia region to the Pollino Range (Fig. 4a), with foci down to about 25 km depth. Within this region the seismicity concentrates in the Irpinia–Potentino area, and, more to the South, in the Moliterno–Castelluccio–Lauria area. Between these two zones we observe a rarefaction of events, with only a small cluster close to the locality of Marsico Vetere (Upper Val d'Agri). Moving from the Lucanian Apennines toward the Bradano foredeep, we recognize two seismic clusters which appear elongated in a E–W direction. The first and smaller cluster (15–25 km of hypocentral depth) is located in the Potentino sector in the same area of the two seismic sequences of 1990 and 1991 (Azzara et al., 1993; Alessio et al., 1995). The second one, in the Abriola–Pietrapertosa sector, seems to mark the northern boundary of the Upper Val D'Agri and extends more to the East reaching the Bradano foredeep with hypocentral depths between 15 and 40 km (Fig. 4b, cross-sections EF, GH). This result is very attractive as it shows a seismogenic layer which deepens to more than 30 km, following the flexure of the Adriatic subducting lithosphere.

Table 2
Southern Apennines velocity model computed with Velest code (Maggi et al., 2009).

Top of layer (km)	Velocity of model *Test8* (km/s)
0	4.27
−2	5.52
−11	6.1
−23	6.5
−35	7.31
−45	7.9

South of Pollino Range we observe a seismic gap, which separates the Lucanian Apennine seismogenic domain from the NE-elongated seismic zone including the sparse seismicity of the Sila Plateau, Crati Valley and Taranto Gulf (Fig. 4a). This gap has been

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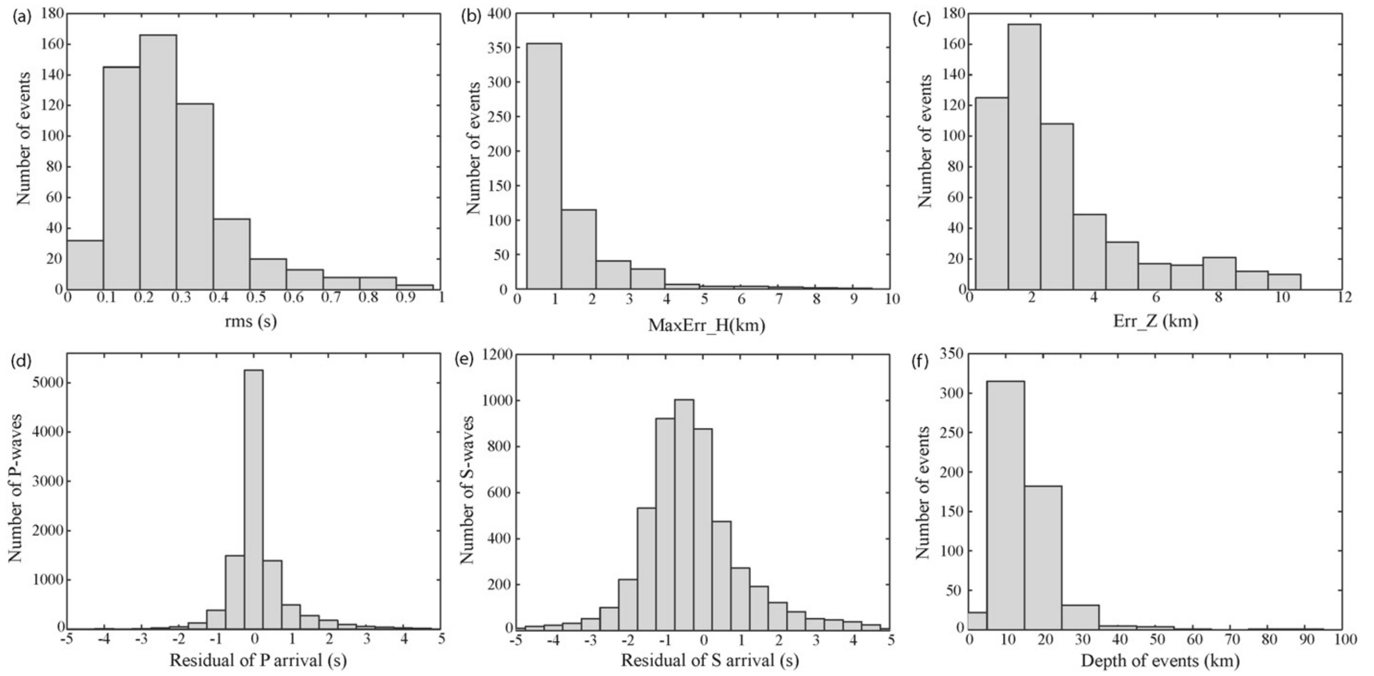

Fig. 3. Histograms showing the root mean square (rms) of the solution travel-time residuals (a), horizontal (b) and vertical (c) errors, P-phases (d) and S-phases (e) residuals versus frequency obtained from the location procedure. Number of events for different depth ranges (f).

described by Michetti et al. (1997) and Cinti et al. (1997). They demonstrated that this area, considered as a gap on the basis of historical and instrumental seismological data and hence evaluated of lower hazard, experienced large earthquakes in the Middle Age. Such events are missing in the historical sources or are mislocated as the 1184 (IX MCS) event, located about 50 km south of the Pollino region, or the 951-1004 (IX MCS) earthquake, located with great uncertainty offshore in the Taranto Gulf about 40 km southeast of the Castrovillari fault (Cinti et al., 1997). The Taranto Gulf offshore seismicity, in this work for the first time reliably relocated, is characterized by deeper foci (between 15 and 35 km) and appears clustered in the middle of the gulf (Fig. 5).

The seismicity pattern beneath the Bradano foredeep and the Apulia foreland (Fig. 4a) displays some distinctive features which are investigated in detail. To the North, beneath the Tavoliere, our relocations show hypocentral depths between 5 and 20 km (Fig. 4b, cross-section AB; Fig. 4c, cross-section OP), as previously observed by Del Gaudio et al. (2007). It is interesting to note the few events with depth between 20 and 35 km below the area hit by the 1560 Barletta-Bisceglie earthquake (Fig. 4b, cross-sections CD and OP). The Murge area seems to be aseismic with the exception of the central portion characterized by both shallow (around 5–10 km) and deep lower crust (20–40 km) earthquakes (Fig. 4b, cross-section GH; Fig. 4c, OP). Some low-magnitude earthquakes are also recorded in the Murge Tarantine area with depth between 5 and 20 km (Fig. 4b, cross-section IL; Fig. 4c, cross-section OP). The almost aseismic Salento peninsula shows only two deep crustal earthquakes located at 30 and 40 km, respectively (Fig. 4c, cross-section OP).

4. Focal mechanisms and stress tensor inversion

We computed focal mechanisms for the best located earthquakes by using the *P*-wave first motion polarity method and the FPFIT code (Reasenberg and Oppenheimer, 1985). The dataset consists of 162 fault-plane solutions with a minimum number of eight (8) observations homogeneously distributed on the focal sphere. From this dataset we selected 102 focal mechanisms with the two output quality factors Q_f and Q_p of the FPFIT code, ranging from A to C for decreasing quality (Table 3). Q_f gives information about the solution misfit of the polarity data F_j, while Q_p reflects the solution uniqueness in terms of 90% confidence region on strike, dip and rake. All fault-plane solutions having Q_f or Q_p equal to C were rejected. The 102 selected focal mechanisms for which A–A, A–B, B–A and B–B quality factors are obtained, are relatively well constrained (Table 4, Fig. 6). Focal mechanisms with quality A–A are 51, with A–B and B–A are 48 and with quality B–B are 3. By examining the plunge of the *P*- and *T*-axes we observe that around 57% of the focal solutions show normal faulting mechanisms whereas 28% are pure strike-slip. The other solutions show transtensional kinematics. *T*-axes for most of the solutions are sub-horizontal (plunge < 30°) with an average anti-Apenninic trend (N45°), whereas *P*-axes have an average plunge of 60–70° and trend mainly between 120° and 150° (Fig. 7).

We performed the stress tensor inversion of the 102 selected fault-plane solutions applying the inversion technique proposed by Gephart and Forsyth (1984) and further implemented by Gephart (1990).

Applying this method we can find the directions of the principal stress axes (σ_1, σ_2, and σ_3) and the dimensionless parameter $R = ((\sigma_2 - \sigma_1)/(\sigma_3 - \sigma_1))$ that describes the relative magnitudes of the principal stresses and hence constrains the shape of the deviatoric part of the stress tensor. This procedure cannot determine the absolute magnitude of the deviatoric and isotropic stresses. It only can identify the best stress tensor model that most closely matches all the fault-plane solutions of the source region. According to the method, we assume that the stress is uniform in space and time within the investigated crustal volume. Earthquakes are shear

Table 3
Quality factors for fault-plane solution.

Quality	Q_f	Q_p
A	$F_j \leq 0.025$	$\Delta s, \Delta d, \Delta r \leq 20^\circ$
B	$0.025 < F_j \leq 0.1$	20–40°
C	$F_j > 0.1$	>40°

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dislocations on pre-existing fault planes located within the brittle shallow crust and slip occurs in the direction of the resolved shear stress on the fault. A misfit measure computed through an angular rotation is given by the angular difference between the observed slip direction on a fault plane and the shear stress on that fault plane derived from a given stress tensor. The stress tensor orientation that provides the average minimum misfit is assumed to be the best stress tensor for a given population of focal mechanisms.

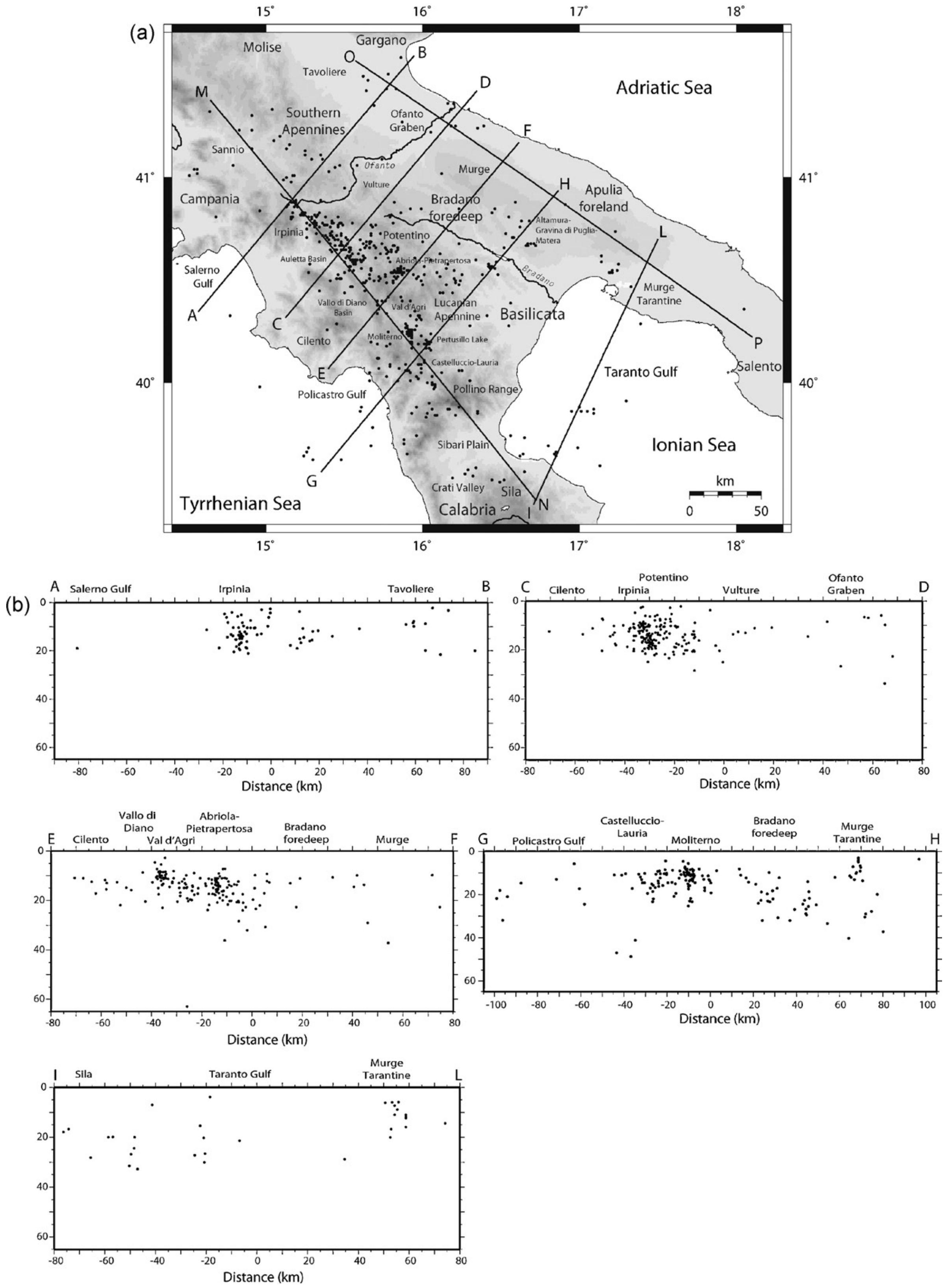

Fig. 4. (a) Map distribution of the 566 selected earthquakes (Hypoellipse quality A, B and C); (b) cross-sections AB, CD, EF, GH and IL; (c) cross-sections MN and OP. Width of cross-sections AB, CD, EF, and GH is 25 km, while for cross-sections IL, MN and OP is 30 km.

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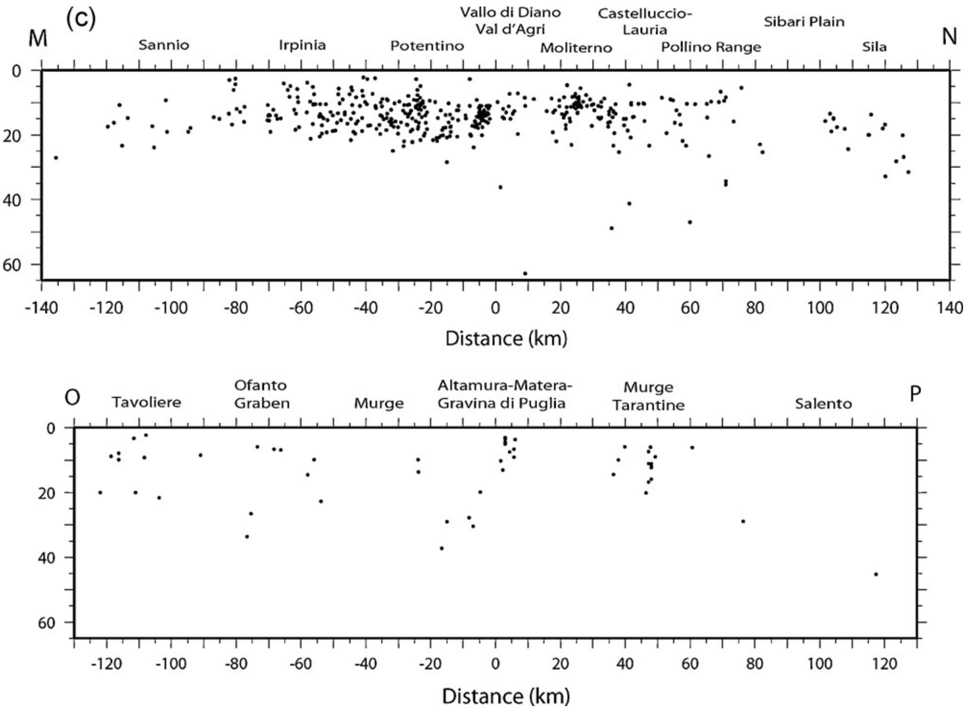

Fig. 4. (*Continued*.)

We performed the inversion by using only crustal seismicity (depth < 30 km) located and clustered beneath the Apenninic chain. For the surrounding areas (Bradano foredeep, Apulia foreland and peri-Tyrrhenian margin) we do not have a sufficient number of focal mechanisms to reliably apply the inversion method. This selection allows us to define the boundary of two smaller crustal volumes approaching better the assumption of the uniform spatial stress field. We performed a first inversion with 58 focal mechanisms located within the Apenninic chain from the Irpinia–Potentino area, to the NW, to the Abriola–Pietrapertosa sector, to the SE. The minimum average misfit is 8.0°, corresponding to a stress tensor with a horizontal σ_3 (plunge 11°) NE–SW directed, an NW–SE oriented σ_2 (plunge 12°) and a σ_1 (plunge 73°) (Fig. 8). The 95% confidence intervals of the principal stress axes are small, suggesting that the

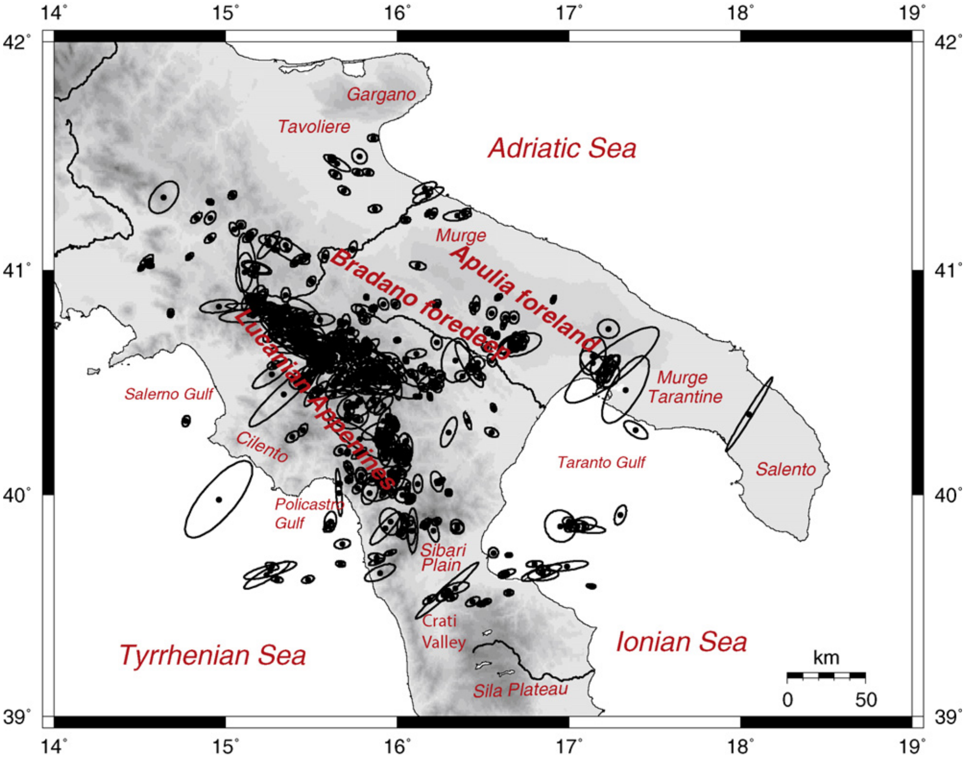

Fig. 5. Map distribution of the 566 selected events and error ellipses (99% confidence limit).

Table 4
Selected fault-plane solutions. Date in format year-month-day; O.T. = origin time (hour and minute); latitude north and longitude east; depth in km; M_L = local magnitude of events belonging to the 2001–2002 period from the Italian Seismic Catalogue (CSI) and belonging to the 2003–2008 period from INGV Seismic Bulletin; r.m.s. = root mean square of residuals; ERH and ERZ = horizontal and vertical location errors; strike, dip and rake of the first nodal plane; Q_f and Q_p = focal mechanism quality factors based on misfit and confidence regions; N.P. = polarities number; category = fault-plane solution type (SS = strike-slip, NS = normal fault with small strike-slip component, NF = normal fault, U = undefined solution category); area = geographical locality of event epicenter.

No.	Date	O.T.	Latitude	Longitude	Depth	M_L	r.m.s.	ERH	ERZ	Strike	Dip	Rake	Q_f	Q_p	N. P.	Category	Area
1	010914	08:02	40° 37.64	15° 43.67	20.81	2.4	0.38	0.8	0.7	120	45	−130	A	A	11	NF	Potentino
2	011104	10:22	40° 26.10	16° 06.65	12.32	2.1	0.62	0.4	1.0	130	20	−130	A	A	11	NF	Dolomiti Lucane
3	011104	10:28	40° 26.45	16° 07.53	14.19	2.3	0.60	0.3	1.1	110	30	−100	B	A	16	NF	Dolomiti Lucane
4	011113	13:21	40° 31.93	15° 56.46	36.15	1.9	0.79	0.5	0.8	130	65	150	A	A	13	SS	Potentino
5	011121	06:21	40° 32.14	15° 49.99	13.11	2.3	0.26	0.4	1.2	125	40	−120	A	B	12	NF	Potentino
6	011209	12:15	40° 47.72	15° 17.23	16.63	3.3	0.31	0.5	1.0	130	20	−80	B	A	15	NF	Irpinia
7	020102	02:17	40° 46.72	15° 25.04	15.40	2.8	0.23	0.6	1.5	140	75	−80	A	A	9	NF	Irpinia
8	020208	04:38	40° 15.45	15° 55.48	11.24	2.2	0.19	0.5	3.3	150	55	−60	A	A	10	NF	Moliterno
9	020226	17:12	40° 14.52	15° 55.59	5.45	2.1	0.29	0.3	0.8	15	40	−20	A	A	9	U	Moliterno
10	020402	04:22	40° 16.15	15° 53.45	13.70	2.7	0.66	0.4	1.3	165	85	−100	A	A	14	U	Moliterno
11	020413	08:44	40° 30.32	15° 49.80	13.12	2.4	0.30	0.4	1.3	120	75	−170	A	A	13	SS	Potentino
12	020413	10:48	40° 11.39	15° 55.51	12.36	2.1	0.21	0.5	1.1	285	60	−160	A	B	8	SS	Moliterno
13	020413	17:04	40° 33.91	16° 25.11	29.33	3.0	0.40	0.4	0.8	350	60	−120	A	A	32	NF	Basentano
14	020413	20:28	40° 33.60	16° 26.07	28.87	2.1	0.25	0.9	3.4	130	65	−110	A	B	8	NF	Basentano
15	020418	21:00	40° 35.30	15° 34.13	10.28	3.0	0.28	0.4	0.5	200	75	−10	A	B	17	SS	Savoia di Lucania
16	020418	21:36	40° 34.96	15° 34.39	9.60	2.2	0.24	0.6	0.5	200	80	−10	A	B	13	SS	Savoia di Lucania
17	020418	22:58	40° 35.00	15° 34.23	9.47	2.7	0.29	0.4	0.5	100	80	150	A	B	12	SS	Savoia di Lucania
18	020419	18:06	40° 35.72	15° 34.05	6.00	2.5	0.24	0.6	2.9	170	50	−50	A	A	10	NF	Savoia di Lucania
19	020504	09:41	40° 39.65	15° 32.20	15.77	2.3	0.39	0.4	1.1	160	45	−50	B	A	11	NF	Irpinia
20	020505	06:40	40° 37.31	15° 37.32	21.58	1.9	0.24	0.6	0.9	155	50	−150	A	A	8	NS	Irpinia
21	020508	19:29	40° 05.32	15° 59.62	14.50	2.9	0.29	0.4	1.1	280	85	−130	B	A	21	U	Northern Pollino
22	020512	20:20	40° 38.15	15° 46.51	18.47	2.1	0.32	0.4	1.0	100	65	170	A	B	11	SS	Potentino
23	020526	10:19	40° 32.96	15° 32.02	11.38	2.6	0.30	0.5	1.4	140	45	−70	A	A	8	NF	Vallo di Diano
24	020531	16:31	40° 14.93	15° 54.59	10.38	2.5	0.20	0.4	0.5	140	70	−40	B	A	13	NS	Moliterno
25	020611	20:02	40° 31.13	15° 43.45	13.97	2.1	0.45	0.3	0.6	140	50	−130	B	A	19	NF	Potentino
26	020618	23:31	40° 31.73	15° 45.47	10.97	2.3	0.37	0.3	0.5	255	75	0	A	A	19	SS	Potentino
27	020621	19:34	40° 05.56	15° 58.90	10.55	2.4	0.42	0.4	0.6	10	35	−20	B	A	13	U	Northern Pollino
28	020623	21:41	41° 15.02	16° 23.52	22.65	2.8	0.29	0.9	1.0	90	60	160	A	A	10	SS	Murge
29	020712	11:12	39° 59.24	16° 04.04	16.16	3.2	0.31	0.6	2.7	65	55	−80	A	A	13	NF	Northern Pollino
30	020713	05:57	39° 59.24	16° 03.42	9.22	2.1	0.47	0.4	0.7	145	30	−60	A	A	11	NF	Northern Pollino
31	020713	11:49	39° 58.52	16° 04.54	13.65	2.7	0.35	0.6	3.8	105	45	−100	A	A	8	NF	Northern Pollino
32	020718	08:28	39° 59.94	16° 03.61	9.01	2.5	0.46	0.4	0.7	100	45	−110	A	A	9	NF	Northern Pollino
33	020815	12:58	39° 44.47	15° 57.67	35.26	2.1	0.66	0.7	0.8	35	75	−170	A	B	12	SS	Orsomarso
34	020815	14:37	39° 44.16	15° 57.61	34.21	3.0	0.60	0.6	0.7	45	80	−150	B	A	20	SS	Orsomarso
35	020903	01:45	40° 30.11	15° 41.12	14.82	1.9	0.35	0.4	0.5	85	65	−130	B	A	16	NF	Potentino
36	021004	22:58	40° 15.13	15° 55.71	10.83	2.9	0.32	0.5	0.4	320	85	10	A	A	18	SS	Moliterno
37	021006	02:43	40° 14.41	15° 55.23	10.48	1.9	0.21	0.5	0.6	135	50	−60	A	A	12	NF	Moliterno
38	021109	01:53	40° 49.70	15° 51.78	13.52	2.0	0.25	0.6	1.9	145	60	−60	A	A	8	NF	Potentino
39	021119	16:53	40° 14.25	15° 55.05	8.98	1.8	0.19	0.5	1.1	50	80	0	A	A	10	SS	Moliterno
40	021129	10:54	40° 14.12	15° 55.04	10.50	1.9	0.22	0.5	0.9	40	70	0	A	A	9	SS	Moliterno
41	021130	01:19	40° 14.03	15° 54.69	10.57	2.4	0.23	0.4	0.6	120	40	−80	A	A	14	NF	Moliterno
42	021130	17:33	40° 13.84	15° 54.97	11.31	2.2	0.18	0.5	1.1	170	80	−40	B	A	13	SS	Moliterno
43	021201	00:30	40° 13.34	15° 55.54	7.58	2.1	0.28	0.3	0.8	5	50	−30	B	A	11	NS	Moliterno
44	021209	10:38	39° 10.24	16° 29.42	16.55	3.3	0.43	0.5	1.9	80	55	−60	B	A	14	NF	La Sila
45	030311	00:22	40° 53.06	16° 35.14	37.17	2.9	0.40	0.6	1.2	180	70	−40	B	A	16	NS	Murge
46	040224	05:21	40° 42.91	15° 24.39	16.51	3.8	0.26	0.7	1.5	135	25	−90	A	A	13	NF	Irpinia
47	040903	00:04	40° 41.25	15° 38.43	21.91	4.1	0.74	0.6	0.6	80	55	160	B	A	24	SS	Potentino
48	040903	01:22	40° 41.27	15° 39.87	10.75	2.8	0.24	0.7	0.7	20	55	−10	A	A	9	SS	Potentino
49	060107	04:27	40° 38.51	15° 49.77	17.21	2.3	0.23	0.5	2.2	25	50	−90	A	A	10	NF	Potentino
50	060314	03:15	40° 49.07	15° 19.58	10.46	2.7	0.29	0.4	0.6	155	50	−60	A	A	9	NF	Irpinia
51	060717	16:56	40° 46.46	15° 29.41	8.35	2.5	0.36	0.4	0.7	125	40	−90	A	B	9	NF	Irpinia
52	060907	15:31	40° 35.00	16° 09.53	30.70	3.9	0.41	0.3	0.6	65	25	−120	B	A	23	NF	Basentano
53	060915	17:55	40° 45.96	15° 23.03	16.17	2.4	0.17	0.6	1.6	70	85	−170	A	A	10	SS	Irpinia
54	060926	16:29	40° 43.32	15° 27.30	7.84	3.0	0.28	0.3	0.6	80	75	−110	B	A	15	NF	Irpinia
55	061022	00:38	40° 03.57	15° 53.35	16.98	2.4	0.25	0.6	1.1	25	45	−60	A	B	9	NF	Northern Pollino
56	061115	15:08	40° 20.24	15° 42.69	12.59	2.7	0.24	0.5	1.0	25	60	−90	A	A	10	NF	Vallo di Diano
57	061201	15:38	40° 46.48	15° 27.62	15.00	2.7	0.21	0.4	1.3	130	40	−120	A	A	12	NF	Irpinia
58	061205	06:20	41° 05.26	15° 17.29	16.73	2.5	0.41	0.5	1.1	175	70	−70	B	A	10	NF	Northern Irpinia
59	070607	17:16	40° 46.67	15° 28.84	5.28	2.3	0.20	0.9	0.2	160	70	−10	B	B	8	SS	Muro Lucano
60	070618	05:38	40° 38.74	15° 29.74	15.01	2.0	0.11	0.5	0.2	80	90	150	A	B	8	SS	Balvano–Irpinia
61	070619	00:01	40° 23.93	15° 52.24	62.92	2.8	0.38	1.3	0.4	115	75	130	A	A	41	TS	Marsico Vetere
62	070620	07:08	41° 08.31	14° 54.79	17.29	2.1	0.12	0.5	0.3	90	55	−140	A	A	8	NF	Beneventano
63	070714	02:27	40° 30.19	15° 43.36	20.22	2.6	0.22	0.7	0.3	105	5	−100	A	A	15	U	Brienza
64	070720	00:57	40° 31.83	16° 28.84	26.64	1.9	0.32	0.6	0.2	325	85	−140	A	A	10	U	Ferrandina
65	071206	21:25	40° 52.61	15° 09.77	14.09	2.8	0.94	0.6	0.1	95	50	−130	A	A	8	NF	Lioni–Irpinia
66	071208	07:09	39° 43.11	15° 52.51	284.09	3.4	0.71	0.6	0.3	130	25	−60	B	A	29	U	Northern Calabria
67	071226	19:20	41° 19.83	15° 02.34	23.26	2.6	0.27	0.6	0.2	295	85	180	A	B	11	SS	Beneventano
68	080114	22:58	40° 32.61	15° 47.77	23.83	2.3	0.35	0.5	0.2	345	35	−70	B	A	10	NF	Abriola
69	080115	02:38	39° 51.07	16° 20.78	25.25	3.0	0.31	0.9	0.3	125	40	−110	A	B	10	NF	Civita–Pollino
70	080120	20:55	40° 31.25	15° 58.11	11.16	2.2	0.47	0.5	0.2	345	35	−100	A	A	14	NF	Anzi
71	080202	00:13	40° 33.02	15° 49.08	17.37	2.3	0.16	0.7	0.2	0	90	−20	A	A	12	SS	Abriola
72	080213	04:09	40° 33.43	16° 09.12	21.97	1.9	0.19	0.7	0.2	175	65	−50	B	B	10	NS	Pietrapertosa

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Table 4 (*Continued*)

No.	Date	O.T.	Latitude	Longitude	Depth	M_L	r.m.s.	ERH	ERZ	Strike	Dip	Rake	Q_f	Q_p	N. P.	Category	Area
73	080220	23:26	39° 58.84	14° 57.89	301.86	3.2	0.63	2.8	1.1	40	15	60	A	A	26	U	Southern Tyrrhen.
74	080225	05:42	40° 39.89	15° 45.56	21.58	1.8	0.26	0.7	0.2	185	75	10	B	A	13	SS	Potenza
75	080310	10:33	39° 39.63	16° 50.98	20.00	3.3	0.32	0.8	0.4	25	25	−130	B	A	18	NF	Taranto Gulf
76	080405	10:09	40° 23.92	15° 44.42	14.50	1.8	0.30	0.7	0.1	340	75	−20	A	B	10	SS	Marsico Nuovo
77	080413	22:26	40° 03.43	15° 54.73	18.54	2.4	0.30	0.7	0.3	105	70	−120	A	A	11	NF	Lauria–Pollino
78	080520	22:56	39° 50.45	15° 47.54	227.49	3.4	0.21	4.3	1.2	140	40	80	A	B	29	TF	Northern Calabria
79	080527	16:19	40° 47.52	15° 18.82	14.12	2.7	0.45	0.6	0.2	105	55	−80	A	A	9	NF	Santomenna–Irpi.
80	080706	22:28	41° 13.92	14° 49.83	16.24	2.3	0.13	0.6	0.2	115	60	−50	A	A	10	NS	Beneventano
81	080810	12:35	40° 46.01	15° 23.68	5.65	2.3	0.40	0.5	0.3	20	40	−150	A	A	10	NS	Castelgrande–Irp.
82	080811	02:52	41° 13.95	14° 54.54	14.67	2.2	0.24	0.8	0.3	115	55	−140	A	A	10	NS	Beneventano
83	080812	21:21	41° 25.19	15° 38.50	9.81	3.0	0.46	0.6	0.1	265	80	180	B	B	22	SS	Foggia
84	080813	05:58	40° 29.03	16° 09.17	23.99	2.6	0.32	0.6	0.2	100	85	130	A	B	9	U	Accettura
85	080815	01:45	40° 32.63	16° 05.46	32.00	1.7	0.22	0.9	0.2	290	75	−140	A	B	14	NS	Pietrapertosa
86	080907	20:43	40° 29.87	15° 38.15	20.43	2.0	0.28	0.6	0.2	70	60	−130	A	A	13	TF	Brienza
87	080925	20:27	40° 48.62	16° 32.98	28.99	2.4	0.39	0.8	0.2	40	80	50	A	A	9	TS	Altamura
88	081103	05:24	40° 39.93	15° 28.05	13.90	1.8	0.14	0.6	0.2	280	70	−140	A	B	8	NS	Balvano–Irpinia
89	081108	09:24	40° 35.47	15° 33.47	12.08	2.8	0.36	0.6	0.2	20	30	0	B	A	21	U	Savoia di Lucania
90	081108	13:15	40° 11.12	16° 00.47	16.13	2.5	0.26	0.8	0.2	15	80	−80	A	A	9	U	Castelsaraceno
91	081112	19:31	40° 33.35	15° 51.45	14.42	2.4	0.36	0.5	0.2	145	45	−60	B	A	16	NF	Abriola
92	081114	01:59	40° 33.30	15° 51.49	14.13	2.8	0.31	0.5	0.2	160	40	−80	B	A	16	NF	Abriola
93	081114	20:44	40° 40.33	15° 48.75	20.68	2.9	0.31	0.6	0.1	10	75	10	A	A	21	SS	Potenza
94	081114	21:04	40° 40.31	15° 49.35	20.23	2.0	0.30	0.6	0.1	20	80	−10	A	B	9	SS	Potenza
95	081117	00:13	40° 33.47	15° 50.93	16.94	2.9	0.37	0.5	0.2	165	20	−60	B	A	17	NF	Abriola
96	081118	19:54	40° 33.45	15° 50.60	15.70	2.5	0.34	0.5	0.2	135	60	−20	B	A	16	NS	Abriola
97	081118	20:05	40° 33.57	15° 50.65	15.97	2.9	0.34	0.5	0.2	75	50	−100	A	A	19	NF	Abriola
98	081118	22:14	40° 33.09	15° 50.78	16.51	2.4	0.31	0.5	0.2	175	75	−10	A	B	14	SS	Abriola
99	081120	21:00	40° 32.62	15° 51.91	14.07	2.2	0.30	0.7	0.2	170	65	−40	A	A	12	NS	Abriola
100	081127	16:52	40° 33.05	15° 51.65	15.16	2.0	0.32	0.7	0.2	300	40	−150	A	B	9	NS	Abriola
101	081127	23:49	40° 32.90	15° 51.66	12.94	2.2	0.35	0.6	0.2	130	65	−80	A	A	14	NF	Abriola
102	081225	18:55	40° 21.00	15° 57.23	19.13	2.7	0.32	0.5	0.1	245	90	60	A	A	12	U	Viggiano

three axes are well constrained by the data. Stress ratio R near the solution is 0.5. This result is in agreement with the fault slip data of active faults available for the study area (Pantosti and Valensise, 1990; Hippolyte et al., 1995; Papanikolaou and Roberts, 2007) and with the regional stress field obtained previously by using moderate magnitude earthquakes (Frepoli and Amato, 2000; Frepoli et al., 2005; Maggi et al., 2009) and borehole breakouts (Montone et al., 1999; Cucci et al., 2004).

We performed the second inversion in the area located to the South of the seismic gap of the Vallo di Diano–Upper Val d'Agri sector using the available 22 focal solutions of the Moliterno–Pollino Range sector. This inversion shows a dimensionless parameter R of 0.4 and a misfit value of 6.2°. The minimum stress axis (σ_3) is sub-horizontal (plunge 5°) and NE–SW oriented, σ_1 is quite close to the vertical (71° of plunge) and σ_2 is sub-horizontal (plunge 18°) and NW–SE directed (Fig. 8). The two stress tensor inversions performed in this study show results very similar suggesting that the whole Southern Apennines, from Irpinia to the Pollino Range, is characterized by an almost horizontal and NE-trending σ_3 and sub-vertical σ_1.

5. Discussion

The background seismicity analyzed in this study closely follows the pattern delineated by the seismicity of the last three decades (Castello et al., 2005, 2008; Chiarabba et al., 2005). Most of the events shows hypocentral depths ranging between 5 and 25 km and are located in the Irpinia and Potentino areas, to the North, and in the Moliterno and north-western Pollino Range, to the South. The observed seismicity overlaps the area characterized by the most active normal faults of the Southern Apennines (DISS, 2006; Basili et al., 2008). Regional extension drives the activity of these major NW-trending seismogenic faults, either NE or SW-dipping (Pantosti et al., 1993; Benedetti et al., 1998; Cello et al., 2003; Maschio et al., 2005). This normal fault system crosscuts the pre-existing contractional structures and bound the large intermountain basins (Cinque et al., 1993). Large part of the studied microseismicity in the Southern Apennines could be explained with the post-seismic crustal deformation process (Reddy and Prajapati, 2009 and reference therein), which can last for several years or decades, related to the 1980 Irpinia, 1990–1991 Potentino and 1998 Castelluccio–Lauria sequences. Post-seismic relaxation process with stress transfer from the large 1980 Irpinia earthquake to the Potentino seismogenic zone was analyzed by Nostro et al. (1997).

As observed even in previous studies (Frepoli et al., 2005; Maggi et al., 2009), the Vallo di Diano–Upper Val d'Agri sector, located along the main axis of the Lucanian Apennine, is characterized by a scarcity of seismicity with only a few low-magnitude events recorded during our surveys (Table 4). The seismic activity in the Val d'Agri basin has been recently investigated by Valoroso et al. (2009) with a dense network operating for a period of 13 months. An intense swarm-type microseismicity was located to the south of the artificial Pertusillo lake defining a major cluster from 1 to 5 km depth and about 5 km wide. The 8-year long monitoring period of our study shows in the same area a clustered seismicity with depth ranging between 5 and 20 km (Fig. 4a,b, cross-section GH). The shallower events of this swarm could be related with the fast water level changes in the Pertusillo reservoir as proposed by Valoroso et al. (2009). Swarm-type activity is commonly observed in reservoir-induced seismicity examples (Talwani, 1997 and reference therein). Following the macroseismic data (Branno et al., 1983, 1985; Alessio et al., 1995) and the most recent geological and geomorphological studies (Benedetti et al., 1998; Cello et al., 2003; Maschio et al., 2005), the active fault related to the destructive 1857 Basilicata earthquake (M_e = 6.9; XI MCS) is hypothesized to be located within the Val d'Agri basin. Moreover, the background seismicity gap observed in the area is partially correlated in space with the epicentral zone of the complex seismic sequence occurred in 1561 (M_e = 6.4; X MCS; Castelli et al., 2008). From a geological and a tectonical point of view the two strong events of 1561 and 1857 are located in an area characterized by the extensional basins of the Vallo di Diano and the Auletta. These basins have been recently investigated by a set of seismic reflection profiles (Amicucci et al.,

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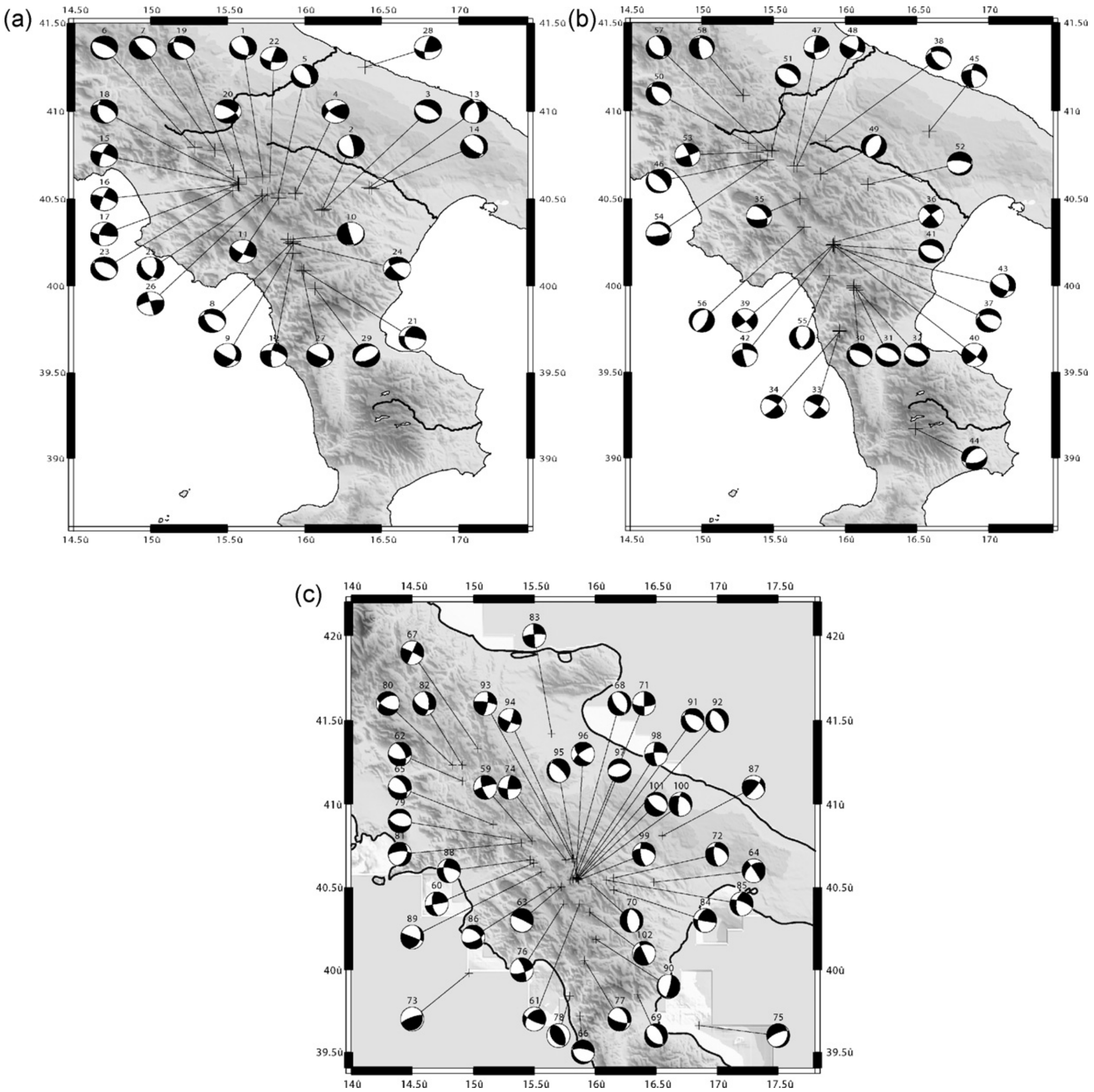

Fig. 6. (a–c) Location of the 102 selected fault-plane solutions. Event numbers of Table 4 are shown close to each focal mechanism.

2008). The authors provide a significant case history concerning the evolution of this segmented system of extensional faults and the related basins. These major NW-trending normal faults, generating the basins in Pliocene-Quaternary time, should be considered as potential seismogenic sources in the seismic hazard valuation of this area (Amicucci et al., 2008). Moreover, an important task in the context of studies related to the seismic hazard assessment in the Southern Apennines is the identification of time-occurrence distribution in earthquake sequences. In order to investigate the variation of the time-correlated properties of background seismicity with the seismogenic source zone, Telesca et al. (2005) have analyzed the clustering behaviour of Italian seismicity from 1986 to 2001. Aftershocks are removed from the catalogue in order to avoid the bias due to the presence of short-term clustering structures. One of the main findings of this work is the strong time-correlation behaviour mainly located along the Apenninic chain (Telesca et al., 2005).

Within the transition zone between the Apenninic chain and the Bradano foredeep in the central Lucanian region we observe two seismic clusters E–W elongated. The first and smaller one, to the North, is located in the same area of the two Potentino sequences of 1990 and 1991, and shows hypocentral depths between 15 and 25 km. Directly to the South, the second cluster extends from the Abriola–Pietrapertosa sector to the Bradano foredeep, where some deep crustal events are recognized with foci between 30 and 40 km depth. We suggest that these two significantly seismic features are representative of the transition from the inner portion of the chain, characterized by extension, to the external margin where dextral strike-slip kinematics is prevailing, as evidenced by the fault-plane solutions of the 1990 and 1991 Potentino seismic sequences (Azzara et al., 1993; Ekström, 1994) and, more to the North, of the 2002 Molise sequence (Di Luccio et al., 2005) and the Gargano seismicity (Del Gaudio et al., 2007). About the Molise and Gargano areas, it is important to note that the dextral strike-slip kinematics is related to the development of a lithospheric transfer zone produced by the differential retreat of two adjacent slab segments with the consequent segmentation of the thrust front (Scrocca, 2006).

Scattered seismicity with larger hypocentral depth (generally between 20 and 40 km) is localized beneath the Bradano fore-

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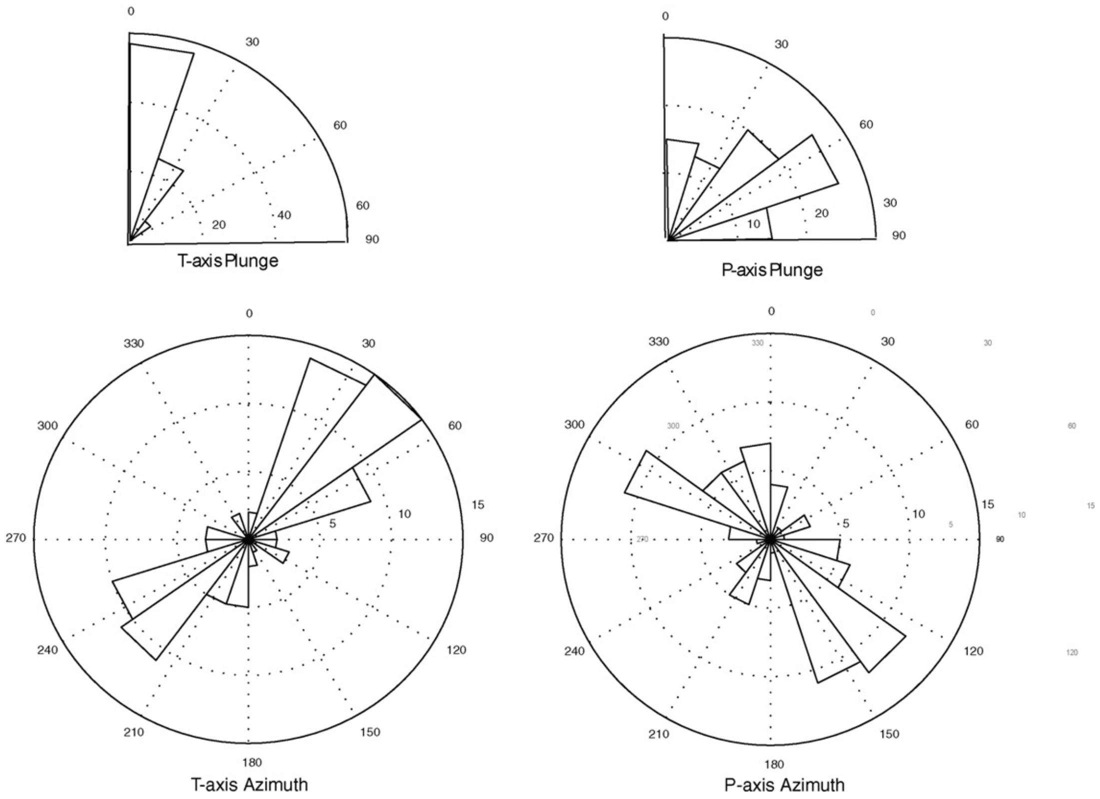

Fig. 7. Rose diagrams showing *P*- and *T*-axes plunge and azimuth distribution.

deep, Apulia foreland and Taranto Gulf. The denser seismic station coverage reached in the last decade provides a more complete low-magnitude earthquake dataset. Hypocentral determinations within the Apulia foreland are improved. Background seismicity beneath the Tavoliere (northern Apulia foreland) is located between the Mattinata fault (Gargano promontory) to the North and the Ofanto Graben to the South. This seismicity shows foci between 5 and 20 km depth. The only available focal mechanism for the area (#83 in Table 4; 9.8 km of depth) shows a pure strike-slip solution. Taking into account the main E–W oriented tectonic features of the Gargano area (Tondi et al., 2005; Piccardi, 2005; Argnani et al., 2009), this solution is consistent with the seismological observations reported by Del Gaudio et al. (2007) in which the northern Apulia foreland shows a regional stress combining NW compression and NE extension. The area hit by the 1560 Barletta–Bisceglie earthquake in the Ofanto Graben is characterized by few events of low magnitude with depth between 20 and 35 km and shallower events with depth ranging from 5 to 20 km. The focal mechanism #28 (Table 4), located in the Barletta–Bisceglie area at 23 km of depth, displays a strike-slip solution with a large inverse component (*P*-axis NW oriented), denoting a quite similar regional stress in this sector with that observed to the North in the Gargano area (Del Gaudio et al., 2007).

The central portion of the Apulia foreland seems to be aseismic with the exception of the Altamura–Gravina di Puglia–Matera area, where both shallow (around 5–10 km) and deep (20–40 km) earthquakes are recognized. Two focal mechanisms are available for this sector (#45 and #87 in Table 4) with hypocentral depth of 37 and 29 km, respectively. Both solutions display a *P*-axis NNW oriented but with different kinematics. The first one extensional while the second one with a large inverse component. New observations of such lower crust seismicity are needed in order to better understand the seismotectonic of this area and its relationship with the geodynamic evolution of the Adriatic microplate.

Within the Salento peninsula, only the area to the North of the Taranto city (Murge Tarantine) shows background seismicity with hypocentral depth scattered between 5 and 20 km. The crust beneath the Salento peninsula tip and its central part seems to be aseismic. Two small earthquakes, with depth around 30 and 40 km respectively, together with the deep Lucanian Apennine event (62 km of depth, $M_L = 2.8$), are representative of the flexure of the Adriatic lithosphere induced by the east-southeasterward migration of the Apenninic chain-thrust front system (Doglioni et al., 1994; Pieri et al., 1997; Gueguen et al., 1998; Rosenbaum and Lister, 2004). Offshore area southeast of the Salento peninsula was hit by seismic sequences of moderate magnitude in the years 1974, 1977 and 1991 (D'Ingeo et al., 1980; Favali et al., 1990; Argnani et al., 2001). Local stress accumulation due to the small radius of curvature of the Adriatic-Apulian plate under the double load of the Hellenides and Apennines–Calabrian arc was proposed to be the main triggering factor (Argnani et al., 2001).

The kinematics of the Lucanian and the southern Adriatic areas can be explained with the modern interpretation of the complex setting characterizing the central Mediterranean region dominated by the NNW–SSE Eurasia–Nubia plate convergence (D'Agostino and Selvaggi, 2004). The westward flexural bending of the Adriatic continental lithosphere beneath the Lucanian region, associated with the increasing depth of the seismogenic layer (Chiarabba et al., 2005), is consistent with the presence of positive Bouger anomalies and very high heat flow values related to the uprising asthenospheric material in the upper mantle below the Tyrrhenian margin of the Apenninic chain and the adjacent Tyrrhenian Sea (Scrocca et al., 2005; Tiberti et al., 2005). The doubling of the Moho beneath the Southern Apennines is interpreted as a "soft" asthenospheric wedge intruding between the subducted Adriatic plate and the overriding plate (Ventura et al., 2007). Asthenospheric material in the uppermost part of the mantle, just below the Moho discontinuity, is identified by Mele et al. (1996, 1997) through lateral

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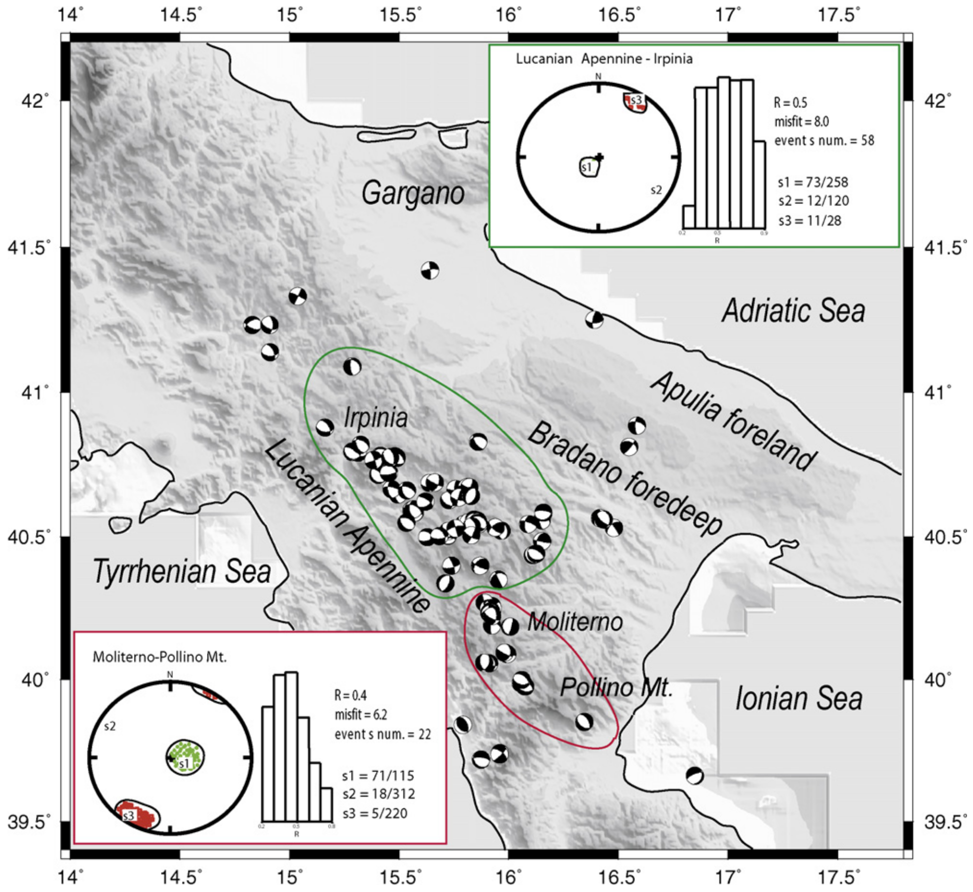

Fig. 8. Stress inversion results using (a) the 58 fault-plane solutions located in the Lucanian Apennines–Irpinia area (green line), and (b) the 22 focal mechanisms of the Moliterno–Pollino Range area (red line). For each solution the stereonet plot is shown with the 95% confidence limits for σ_1 and σ_3 and the histogram illustrating the uncertainty in the dimensionless parameter *R*. Plunge and trend for the three principal stress axes, stress ratio *R*, misfit and total number of fault-plane solutions are shown to the right of the histograms. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

variations of *Pn* propagation and shear wave attenuation studies. The uplift and crustal thinning with the consequent active rifting process along the Apenninic belt are triggering the shallower seismicity (5–15 km of depth) within the chain. In addition to these observations, geothermal gradient and tomographic studies point out a brittle–ductile transition at 28–30 km beneath the foredeep and foreland compared with the 15–18 km of depth of the same boundary beneath the chain (Harabaglia et al., 1997; Chiarabba and Amato, 1996). Our results show a seismogenic layer with depth of about 20 km beneath the chain (Fig. 4b, cross-sections AB, CD and EF), increasing down to over 30 km below the foreland area (Fig. 4b, cross-section GH).

Besides focal mechanisms of strong earthquakes, fault-plane solutions of background seismicity are helpful in delineating the main seismotectonic provinces of a study area. The widespread NE extension observed in this work is consistent with previous studies concerning focal mechanisms of low to moderate magnitude events (Frepoli and Amato, 2000; Frepoli et al., 2005; Maggi et al., 2009). Taking into account the background seismicity gap located in the Vallo di Diano–Upper Val d'Agri sector, along the main axis of the Apenninic belt, we subdivided our fault-plane solution dataset in two sub-datasets, one to the North with the Irpinia and Potentino area (58 focal mechanisms) and the other to the South including the Moliterno area and Pollino Range (22 fault-plane solutions). Both stress inversions display a very similar stress tensor orientation. The average misfit in the northern and more extended sector is quite large (8°). Probably this inversion result suffers from the influence of the stress field change within the selected area, from pure extension beneath the chain to a transpressive stress regime in the outer margin, as observed with the focal mechanisms of the two Potentino sequences of 1990 and 1991 (Azzara et al., 1993; Ekström, 1994). Moreover, as observed before, this tectonic shear regime characterizing the outer margin is also well shown by the fault-plane solutions of the 2002 Molise earthquake sequence (Di Luccio et al., 2005) and the focal mechanisms computed by Del Gaudio et al. (2007) for the Gargano area. However, the lack of pure reverse focal solutions in the southern foreland (Gargano and Apulia) suggests that accretion processes are not active at present.

The largest part of the seismic moment release along the Southern Apennines is observed within a relatively narrow belt of 80–100 km of width in which the seismogenic normal faults characterizing the SW–NE extension in the Apennines are concentrated. Selvaggi (1998) evaluate the total seismic moment tensor of recent and historical events observing an extension rate ranging from 0.3 mm/year in the Northern Apennines to 2.0 mm/year in the Central and Southern Apennines. Moreover, geodetic measurements of shear strain in a time span of 126 years confirm that the deformation is largely confined within a region of a few tens of kilometres wide (Hunstad et al., 2003). Considering seismic and aseismic deformation, regional extensional rates in the whole Apennines are in the range of 2.5–5 mm/year (Hunstad et al., 2003). Deformation rates inferred from geological observation of the geometry and kinematics of the normal fault system in the Southern Apennines, range from 0.3 to 1.5 mm/year (Papanikolaou and Roberts, 2007).

The buoyancy forces acting beneath the Southern Apennines and related to the westward subduction of the Adriatic continental lithosphere could be responsible for the observed widespread

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NE extension. Recent tomographic studies pointed out the presence of an almost continuous high-velocity body dipping SW-ward from about 100 km down to the upper mantle transition zone (De Gori et al., 2001; Cimini and De Gori, 2001; Cimini and Marchetti, 2006). This feature, generally interpreted as the expression of the deeper, probably oceanic, part of the Adriatic slab, appears not in continuity with the Apulian lithosphere due to the interposition, at uppermost mantle depths, of pronounced low-velocity zones. The high temperatures related to such asthenospheric wedging may have produced a fast thermal assimilation of the subducted lithosphere (Cimini and De Gori, 2001) with consequent decrease of the forces acting on it and possible slab breakoff (Spakman and Wortel, 2004). Moreover, the Southern Apennines subduction zone is characterized by the absence of seismicity at intermediate depth (70–300 km). Carminati et al. (2002) have suggested a continental composition of the subducted Adriatic lithosphere, which is expected to have ductile rather than brittle behaviour.

6. Conclusion

The new dataset of background seismicity examined in this study is a further contribution to the comprehension of the seismogenesis and state of stress of a tectonically complex region, such as the Southern Apennines, characterized by a very high seismic hazard. The significative improvement in the seismic monitoring of the area, reached using both the permanent Italian national network and two temporary arrays of three-component stations, allowed us to obtain a more detailed picture of the seismotectonic of the region, and particularly of the Southern Apennines foreland which has been generally considered substantially aseismic. As already emerged in previous studies, background seismicity occurs mostly beneath the mountain belt where the main seismogenic structures are localized. Our results show that this microseismic activity is substantially clustered at the borders of silent fault segments beneath the chain. Here the transition brittle–ductile is observed between 20 and 25 km. This boundary is located at around 35 km beneath the foredeep and foreland areas. We also suggest that the scarce background seismicity observed in some sectors along the Apenninic chain could be related to fault segments presently locked where possible large earthquakes might be expected in the future. We believe that a detailed active stress map integrated with historical seismicity data, background seismicity pattern determined from a dense instrumental monitoring and identification of time-occurrence distribution in earthquake sequences can give an important contribution to the seismotectonic zoning and the seismic hazard evaluation.

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