Sicily and Southern Calabria focal mechanism database: a valuable tool for local and regional stress field determination

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Abstract

In this paper, we present a new catalogue of focal mechanisms calculated for earthquakes recorded in Sicily and southern Calabria; it comprises about 300 solutions, for events with a magnitude ranging between 2.7 and 4.8, occurring between 1999 and 2011. We used P-wave polarities to compute the fault plane solutions. Two main goals were achieved: the first is that the catalogue allowed depicting the stress regime and kinematics characterizing the studied area at a regional and more local scale. In particular, moving along the tectonic lineament extending from the Aeolian Islands to the Ionian Sea, we observed a change between a regime characterised by sub-horizontal P-axes, ca. NW-SE directed, to an extensive one in the Calabro-Peloritan Arc, where T-axes striking in NW-SE direction prevail. Our results also show that part of the seismicity is clustered along main active seismogenic structures, of which the focal mechanisms indicate the kinematics. Finally, in the Etna volcano area, we found different stress fields acting at different depths, due to the combination of the regional tectonics, the strong pressurization of the deep magmatic system and the dynamics of the shallower portion of the volcano. As a second outcome, we highlight that the catalogue also represents a valuable tool, by the data distribution on the internet, for further studies directed toward improving the understanding of the geodynamic complexity of the region and for a better characterization of the seismogenic sources.

Key words: Focal Mechanisms, Local Seismic Network, Kinematics, Stress Regime, Regional Active Seismogenic Structure.
1. Introduction

Collision, subduction and active volcanism characterize the lithosphere of southern Italy. Here, geological and geophysical evidences can be interpreted in the framework of a geodynamic model assuming an approximately N-S convergence between the African and European plates (e.g. D’agostino and Selvaggi, 2004; Serpelloni et al., 2007). The boundary of these plates runs through Sicily and the Ionian Sea, giving rise to very complex tectonics with several lithospheric blocks, in which all the structural domains characterizing a collisional belt are exposed; in Sicily, these are represented by the Pelagian-Hyblean foreland, the Gela-Catania foredeep, and the Appennine-Maghrebian fold-and-thrust-chain (Figure 1). A major feature of this region is the active volcanism of two distinct areas: i) Etna, which is the most active European volcano and ii) the Aeolian Islands, which represent the emerged part of a submarine volcanic arc located within the Tyrrhenian Sea extensional back arc basin (Malinverno and Ryan, 1986). Other features of the area are the high gradient crustal thinning from the interior of Calabria and Sicily to the Tyrrhenian and Ionian basins (Dèzes and Ziegler, 2001) and a lateral change in geodynamic regime: from continental collision in Sicily to subduction of the Ionian oceanic lithosphere beneath the Calabrian Arc. This passage corresponds to a transition between the ongoing compressional (western and central Sicily) and extensional (northeastern Sicily and southern Calabria) crustal domains; this last likely related to the end or the final stage of the Ionian subduction and to the rollback of the slab (Malinverno and Ryan, 1986; Faccenna et al., 2001; Neri et al., 2005; Scarfì et al., 2009).

Seismological data are certainly one of the fundamental tools to provide important information for studies concerning the dynamics of an area. In particular, calculating the earthquake focal mechanisms is a way to determine the displacement type on seismogenic faults and improve our understanding of the stress direction and tectonics of the area. Moreover, source parameters resulting from these studies are used in seismotectonic analyses for the evaluation of seismic hazard.
However, some difficulties are encountered by scientists in collecting these parameters from the literature. Indeed, they are not easily available; searches must be made in many scientific articles and reports and often this information is not readily available for analyses by computer codes. For the Mediterranean area, and in particular for the zone considered in this work, Sicily and southern Calabria, the existing catalogues [i.e. the “Regional Centroid Moment Tensors” by Pondrelli et al. (2006, 2011) - see http://www.ingv.it/banche-dati/ - and the “EMMA” database by Vannucci and Gasperini (2003, 2004)] only include focal solutions for earthquakes with $M \geq 4$; this means there is an insufficient number of solutions to describe the complicated framework of the seismogenic sources at a local scale. On the other hand, earthquakes of small magnitude provide the much needed information to characterize the tectonic styles of an area well.

Focal mechanism computations are largely performed by using the polarities of the P-wave first-motion (e.g. Reasenberg and Oppenheimer, 1985), which, compared to other methods based on the S-waves polarization, S/P amplitude ratio or waveform inversion, has the advantage of making corrections for several factors, such as geometrical spreading, attenuation and site effects, unnecessary. However, the reliability of the obtained solutions (i.e. the ability to constrain the focal planes) depends on the numbers of the available polarities so that there is a good azimuthal coverage around the event source. Since the development of modern dense seismic networks in the last decade has made large amounts of data available, it has become possible to compile reliable calculated focal mechanisms for small earthquakes in regional catalogues. By exploiting data from a local seismic network managed by the Istituto Nazionale di Geofisica e Vulcanologia, we therefore started a project aimed at creating and maintaining a catalogue of fault plane solutions for events located in the area between Sicily and southern Calabria. In this work, we present this new catalogue, which can be consulted on the internet.

At the same time, we show the seismotectonic patterns, both at a regional and more local scale, which we inferred from the analysis of our database.
2. Data and method

Since the late 90's, continuous seismic monitoring activity on Etna, Aeolian Islands, Hyblean Plateau and the Calabro-Peloritan Arc has been performed by seismic stations operating in the framework of the “Poseidon Project”, then merged into the Istituto Nazionale di Geofisica e Vulcanologia in 2001. Between 2003 and 2007, this network was developed and upgraded and, to date, it consists of about 90 stations, many of which are deployed on Mt. Etna (Figure 2). Almost all are equipped with a broadband (40s) three-component sensor and with a high dynamic digitizer. All the stations use the same base time, set by GPS time and the continuously recorded data are transmitted, by means of radio links and V-SAT, to the Acquisition Centre located in Catania.

Through this local network, about 10000 earthquakes were recorded and localized in the period 1999 – 2011. In Figure 3, we show this seismicity as extracted from the “Catalogo dei terremoti della Sicilia Orientale - Calabria Meridionale (1999-2011). INGV, Catania”, named INGV-CT catalogue hereinafter (further details about the catalogue at: http://www.ct.ingv.it/ufs/analisti/catalogolist.php). Besides the earthquakes below the Etna volcano, we note a distribution of events that underlines the most important regional tectonic lineaments: the Southern Tyrrhenian Fault System and the fault belt which runs from the Calabro-Peloritan Arc (CPA) to the Malta Escarpment Fault System (MEFS) in the Ionian Sea and the faults characterising the Hyblean Foreland (see Figure 1).

From the INGV-CT catalogue, we calculated focal solutions for earthquakes shallower than 60 km, by using the first motion P-wave polarities and the well-known software FPFIT (Reasenberg and Oppenheimer, 1985). A magnitude threshold of 2.7 was chosen, considering those values that could provide well-constrained focal mechanisms, on the basis of the network configuration and the resulting available polarities. Moreover, we selected the events by taking account of only those with at least 10-15 available polarities and with sufficient station
coverage on the focal sphere (see below GAP and STDR parameters). To this end, we carefully checked the polarities which could be overlooked by the operator, particularly where the first arrival was emerging, and added others by analysing recordings of the National Seismic Network (Data source: ISIDe at http://iside.rm.ingv.it).

Figure 4 shows the map and the cross-sections of the considered earthquakes (about 330); their distribution is fairly well representative of the seismicity of the various areas; typical seismogenic depth is from very shallow to 10-15 km for the Etna volcano, 8-15 km for the Aeolian Islands and CPA, while for the other areas it is between 15 and 30 km. The hypocentral locations are taken from the INGV-CT catalogue, which provides the best possible estimate with the available data and standard location methods (i.e. HYPOELLIPSE, see Lahr, 1989); the associated errors for the selected events, expressed as mean and standard deviation are 0.5±0.4 km and 0.6±0.5 km, for horizontal and vertical coordinates, and 0.2±0.1 s for the root-mean-square (rms) traveltime residuals. The ray-tracing is calculated by using HYPOELLIPSE with the known velocity structures of the region (see Hirn et al., 1991; Musumeci et al., 2003; Langer et al., 2007; Gambino et al., 2012). The azimuthal gap is 106°±49, on average.

Starting from the hypocentral parameters and the ray-tracing, FPFIT finds the double-couple fault plane solution (source model) by a grid search procedure that best fits a given set of observed first motion polarities of an earthquake. The software formally estimates the uncertainty in the focal parameters (strike, dip, rake), that result in a misfit score bounding the 90% confidence interval, and provides other quantities designed to characterize the quality of the final solution (e.g. the numbers of used observations and the stations distribution ratio). Essentially, we rejected those mechanisms with uncertainties > 40° in the focal parameters (the catalogue contains very few solutions with variance > 40° in only one of the fault-plane sets) or with a station distribution ratio (STDR) less than 0.4; this last parameter, ranging between 0 and 1.0, is sensitive to the distribution of the data on the focal sphere, relative to the radiation pattern - i.e. a solution with STDR < 0.5 is less robust than one for which STDR > 0.5 (see
Reasenberg and Oppenheimer, 1985; Kilb, 2001). For our solutions STDR is mostly higher than 0.6-0.7.

The code adopted in this work also implies (commonly to most seismological studies) the assumption that the earthquake source can be explained in terms of shear-fault mechanism called “double couple” (DC). However, several studies show that the earthquake source may be incompatible with a pure shear faulting; indeed “non-double-couple” (non-DC) earthquakes have been observed in many environments, including particularly volcanic and geothermal areas, where non-DC components of their mechanism have been related to fluid dynamics phenomena or source complexity (e.g. Foulger et al., 2004 and references therein). On Etna, non-DC source component (20-60%) was found by analysing earthquakes occurring in the period immediately before the 1991-93 and 2001 eruptions (see Saraò et al., 2001, 2010).

We cannot entirely exclude that some earthquakes, among those we analysed and located on Etna, could have a source mechanism with a non-DC component; further investigations and other methods are needed. Nevertheless, we can confirm that the distribution of the polarities and the clear presence of S-phases are fully compatible with a double-couple mechanism and that, therefore, our solutions can be considered, at least, representative of the shear component of the analysed seismic events.

Our analysis covers the period 1999 - 2011, except for the Etna volcano, for which the years between 1999 and 2002 will be the objective of a future work, due to the several hundreds of earthquakes stored in the database, recorded in response to the 2001 and 2002 eruptions.

For further information on the catalogue, the quality of solutions and how to access online, see the Appendix.

4. Seismotectonic deformation fields

While individual focal mechanism solutions are not the primary focus of this paper, it is worthwhile describing the overall spatial structure of the seismotectonic deformation field, as
inferred from the analysis of our catalogue. Indeed, we can make the assumption that the earthquake focal mechanisms reflect the state of stress of the studied areas, implying that the P- and T-axes, at a first approximation, correspond to the principal stress axes $\sigma_1$ and $\sigma_3$, respectively.

Figures from 5 to 9 show the focal mechanisms, their classification, according to Zoback (1992), and the orientation of the P- and T-axes. Note that we decided to show and discuss the fault plane solutions within the Mt. Etna area separately, given the influence that the magmatic system of the volcano undoubtedly produces on the stress field at various depths; moreover, the stereonets shown in Figure 6, representing the direction and plunge of the P- and T-axes, are related to the sub-areas traced in Figure 4, which we established by grouping our solutions according to the studied tectonic zones and the similarity of the examined focal parameters.

4.1. Regional pattern

From Figures 5 and 6, excluding the Calabro-Peloritan Arc, we observe that the Aeolian Islands, eastern Sicily and the Ionian Sea are predominantly characterised by P- and T-axes striking in ca. NW-SE and NE-SW directions, respectively. The majority of the events are strike-slip or oblique type (about 70%). Instead, the earthquakes located between the Gulf of Patti and the CPA reveal a clear change of the stress field as T-axes striking in NW direction prevail; moreover, the events here, particularly in the offshore and onshore of the Gulf of Patti, mostly show normal fault mechanisms (80%).

As highlighted by several geological and geophysical studies, the regional geodynamic processes, related to the ca. N-S Africa and Europe convergence, are expressed here by active contraction between the Sicilian-Hyblean and Tyrrhenian blocks, west of the “Aeolian Islands-Tindari-Giardini” lineament (ATG – see Figure 1), and by an extension in northeastern Sicily and western Calabria; this latter is oriented about N130°E, perpendicular to CPA and parallel to the direction of the subduction of the Ionian oceanic crust underneath CPA (e.g. Ghisetti, 1979;
Tortorici et al., 1995; Neri et al., 2005; Pepe et al., 2005; Ferranti et al., 2008; Scarfi et al., 2009; Serpelloni et al., 2010; Cuffaro et al., 2011). The reason for the coexistence of these two deformational domains is far from being well understood; the debate on the most appropriate model is still open and several often contrasting hypotheses have been proposed, ranging from rifting to back-arc extension in the Tyrrhenian Sea or regional deep-induced uplift (see e.g. Serpelloni et al., 2010 and Palano et al., 2012 for a more detailed discussion and references).

The accommodation between the two domains occurs along the ATG fault, a main regional shear zone extending from the Ionian Sea, north of Mt. Etna, to the Aeolian Islands (e.g. Neri et al., 2005; Argnani, 2009; Billi et al., 2010). It is considered by some authors to be the northward continuation of the Malta Escarpment Fault System (Ghisetti, 1979; Lanzafame and Bousquet, 1997; Govers and Wortel, 2005), which is a NNW-SSE-striking Mesozoic lithospheric boundary in the offshore of south-eastern Sicily, made up of a diffuse transtensional fault system, separating the Ionian oceanic basin from the thick Hyblean continental crust (Westaway, 1990; Nicolich et al., 2000).

Apart from the interpretative models, this outlined geodynamic framework matches fairly well with our observations, which show predominantly normal fault solutions between the Gulf of Patti coastal area, the Messina Strait and southern Calabria, with NW-SE extensional (T) axes and, westward, strike-slip and some thrust faults with NW-SE compressional (P) axes. Moreover, in a narrow band west of the ATG slightly south of Capo d’Orlando, some earthquake clusters, with normal mechanism type and with fault planes striking both in NE-SW and NW-SE directions, seem to indicate the transition between compressional and extensional domains (Figures 5 and 6c).

In greater detail, several mechanisms illustrate the seismic activity of the main regional tectonic structures. From north to south, in the Aeolian Islands area, dextral strike-slip solutions reveal the kinematics of the Southern Tyrrhenian Fault Systems (Figure 5). In particular, here the geometry traced by the event locations and the orientation of the nodal planes of the FPSs
computed indicate the presence of WNW-ESE and NW-SE oriented structures, consistent with the Sisifo and the northern section of ATG fault systems, which characterize the area (see also Gambino et al., 2012). The occurrence of some earthquakes, east of Lipari-Vulcano at about 10 km of depth, with thrust fault mechanisms, may be related to a compressive zone generated at the edge between the ca. NW-SE dextral displacement of ATG and the extension characterising the southern Tyrhenian-CPA area.

The extension of the ATG inland is not so seismically obvious, while it has very impressive morphological expression in the Peloritani Mountains through vertical and right-lateral offset of the Tyrhenian terraces (Ghisetti, 1979). On the other hand, as above mentioned, the existence of an important crustal discontinuity is highlighted by a clear change in the seismic pattern to both sides of the fault lineament. Moreover, the continuation of the ATG to the coast of the Ionian Sea can be recognised through some right-lateral mechanisms of earthquakes located near the town of Giardini, at a depth of about 10 km. Considering also the presence of two inverse solutions, one might deduce a transpressive zone related to a different deformation pattern characterising the Malta Escarpment Fault and the Ionian Sea area, though we cannot confirm this owing to the small number of events.

Further south, left-lateral motion on NNW-SSE to NNE-SSW trending planes is observed in proximity of the Ionian coast and offshore along the MEFS, with an orientation of the maximum compressive stress axis in agreement with the regional compression (Figures 5 and 6e). Westward, in the Hyblean Plateau, some NNE-SSW left-lateral strike-slip mechanisms can be related to the “Scicli-Ragusa” Fault System. These findings match quite well with other seismological studies (see Musumeci et al., 2005) and also with the GPS measurements, which for the southern Sicily, show a northward motion, according to a long-term Eurasia-Nubia convergence, and a small but detectable extension orthogonal to the Sicily Channel (e.g. Mattia et al., 2012; Palano et al., 2012).

Recent studies also indicate a NW-SE contraction between the frontal thrust belt of Appennine-
Maghrebian Chain and the Hyblean Plateau (Ferranti et al., 2008; Devoti et al., 2011) and that E-W striking normal faults as well as NNE-SSW-striking right-lateral faults, cutting the northern rim of the plateau, have been reactivated in reverse motion during the last 0.85 Myr (Catalano et al., 2008). Unfortunately, the limited focal mechanisms available on the frontal belt of southern Sicily preclude confirming these processes in this sector.

Finally, in Figure 5, focal mechanism solutions, reported in literature for some major earthquakes occurring in the area, are shown (see Gasperini et al., 1982; Amato et al., 1995; Pino et al., 2009); the comparison with our calculated mechanisms indicates a similarity in the displacement type.

4.2. Mt. Etna pattern

On Mt. Etna, different stress fields can act at different depths, due to the combination of the regional tectonics, the strong pressurization of the magmatic system (Cocina et al. 1998; Patanè and Privitera 2001; Barberi et al. 2004; Patanè et al. 2004), the dynamics of the shallower portion of the volcano and, in particular, the marked displacement of its eastern flank (e.g. Puglisi and Bonforte, 2004; Rust et al., 2005; Solaro et al., 2010; Bonforte et al. 2011). To better investigate this issue, we analysed the focal mechanisms by separating them into three different depth levels, i.e. down to 3, 10 and below 10 km; this on considering that other studies assume a possible pressurization source at 3-5 km of depth (Bonaccorso et al., 2005, 2006; Bonforte et al., 2008; Bruno et al., 2012) and a transition between regional and local stress field 10-15 km deep, beneath the volcano (Cocina et al. 1998; Patanè and Privitera 2001). In the shallower level (Figure 7), northward, we distinguish a group of focal mechanisms, mostly of strike-slip, related to events no deeper than 1 km b.s.l., which well-depict the kinematic of the “NE Rift” and the “Pernicana Fault” System (see Figure 1). Characterised by left-, oblique-slip movements, it dissects the entire northeastern flank of Mt. Etna and is widely recognised as a structural limit between a severely unstable sector to the south and a stable area.
to the north, controlling the seaward movement of the volcano’s eastern flank (e.g. Acocella and Neri, 2005; Solaro et al., 2010; Azzaro et al., 2012). The system is seismically very active and is also characterized by frequent shallow seismicity (Alparone et al., 2012). Most of the other focal solutions found at this depth range can be related to this kind of dynamics too, acting through the fault belt of mainly extensional structures characterising the eastern flank of the volcano (see Azzaro et al., 2012).

In the intermediate depth (3-10 km), the analysed earthquakes are again mainly located in the eastern flank (Figure 8) at a depth of 4-7 km. The focal mechanisms, mostly strike- and oblique-slip (70%), show a slightly radial distribution of the P-axes, with respect to the craters. Similar results were found by Alparone et al. (2011) who, analysing the seismic pattern before the onset of the 2004–2005 eruption, explain this trend as due to the effect of a pressurizing source (the feeding system of the volcano) located at a depth between 3 and 5 km. Several other studies, through GPS measurements, model a spreading source beneath the upper south-eastern flank of the volcano at a depth of 4 – 5 km, induced by the pressurizing of the plumbing system; this would cause an areal dilatation during inflation periods and would act chiefly on the instability of the eastern flank of Etna, favouring its continuing eastward sliding (e.g. Bonaccorso et al., 2005, 2006; Bonforte et al., 2008; Bruno et al., 2012). Our findings may support such model.

Finally, in the deeper portion of the crust, the calculated focal solutions are for events located in two small areas, i.e. in the northeastern and central-southern sectors of the volcano (Figure 9). Most of the earthquakes occurred as swarms. The events of the northeastern cluster are 20-30 km deep and mainly show oblique or strike-slip fault mechanisms with P-axes striking NW-SE. Given their depth and the orientation of the compression axes (P), it is likely that they are related to regional tectonic structures. The other cluster is 10-13 km deep, with P-axes uniformly directed NE-SW of strike-slip fault type. The occurrence of deep seismicity in this sector of the volcano was related to a shear failure of the structure of the volcano, in response to
a continuous injection of magma from depth into the shallow (depth of 3 to 5 km) reservoir (see Patanè et al., 2003). Since several events of this cluster were recorded in January and May 2006, before the July eruption, it is likely that our analysed seismicity can be referred to the same dynamics.

5. Conclusion

In this paper, we present a new catalogue of focal mechanisms calculated for earthquakes with magnitude $\geq 2.7$, recorded by a local seismic network in Sicily and southern Calabria. To date, the catalogue encompasses about 300 solutions for events ($2.7 \leq M_l \leq 4.8$) occurring between 1999 and 2011. By analysing our data, we were able to show an overview of the stress regime and kinematics that characterize the studied area, at a regional and more local scale. In particular, we clearly observe the compressive regime, NW-SE directed, that characterizes Sicily, westward of the “Aeolian-Tindari-Giardini” lineament, changing to an extensive one, NE-SW directed, in the Calabro-Peloritan Arc. Several normal faults detected between Capo d’Orlando and Etna, striking both in NE-SW and NW-SE directions, seem to reveal the transition zone between compressional and extensional domains.

Our results also show that part of the seismicity is clustered along active seismogenic structures, hence underlining their important role in the regional dynamics. In the Aeolian Island zone, dextral strike-slip faults are evidence of the ATG, the continuation of which is likely marked by the occurrence of some earthquakes with similar mechanism in the Ionian Sea, near the town of Giardini. Strike-slip faulting is observed in proximity of the Ionian coast and offshore along the “Malta-Escarpment” Fault System; westward, in the Hyblean Foreland, some NNE-SSW left-lateral strike-slip mechanisms can be related to the “Scicli-Ragusa” Fault System.

In the Etna volcano, we found different stress fields acting at different depths. In particular, at the shallower and intermediate levels (down to 3 and 10 km), the stress field is governed by the
combination of the strong pressurization of the magmatic system and the dynamics of the shallower structures of the volcano, whereas, at greater depths, the regional dynamics is again the main driving force.

In addition to these findings, we would also emphasize that our database can be considered a valuable and essential tool for all advanced studies aimed at improving the knowledge of the geodynamics of the region; indeed, the data are entirely available (see the Appendix) and can be represented as they are or reprocessed by different techniques.

In future work, we plan to maintain and expand this catalog to provide a comprehensive record of source parameters for the region. Moreover, calculating focal mechanisms in the Etna volcano, to cover the 1999 to 2002 period, will also be pursued to complete the database.

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Figure captions

Figure 1 - Maps illustrating the main geological and tectonic features of Sicily and southern Calabria. Etna structural map is modified after Alparone et al. (2011). Abbreviations are as follows: SFS, Sisifo Fault System; ATG, Aeolian-Tindari-Giardini Fault System; SRF, Scicli-Ragusa Fault System; CO, Capo d’Orlando.

Figure 2 - Map of the seismic stations, belonging to the local (red) and national (green) networks, used to compute the focal mechanisms.

Figure 3 - Map view, N-S and W-E cross sections of the seismicity located by the local network for the period 1999-2011, from the “Catalogo dei terremoti della Sicilia Orientale - Calabria Meridionale (1999-2011). INGV, Catania”.

Figure 4 - Map view, N-S and W-E cross sections of the earthquakes selected for the focal mechanism computation. Dotted lines contour sub-areas (indicated by letters) in which focal mechanisms were divided (see text for further details).

Figure 5 – Computed focal mechanisms shown in map (a), with P- (b), and T-axes (c). Colours of the mechanisms indicate: red = strike-slip fault, blue = normal fault, black = inverse fault and brown = unknown regime, according to the Zoback (1992) classification. Grey fault mechanisms are solutions reported in literature for some major earthquakes occurring in the area (see Gasperini et al., 1982; Amato et al., 1995; Pino et al., 2009). Note that the solutions for the Etna area are shown in the following figures.

Figure 6 - Equal area Schmidt nets of P- and T-axes. Letters a to e refer to the sub-areas
indicated in figure 4.

Figure 7 – (a) Focal solutions for the shallower earthquakes (-1.0 – 3.0 km b.s.l.) in the Etna area; (b) P- and T-axes (c); map and time occurrence of the related events (d); (e) Stereonet of P- and T-axes.

Figure 8 – The same as Figure 7 but for the earthquakes 3.0-10 km deep.

Figure 9 - The same as Figure 7 but for the earthquakes with depth >10 km. (e) Stereonets refer to the northern (left) and southern (right) clusters.

Figure 10 - Histograms showing the events analysed and the focal mechanisms computed as a function of their magnitude (a) and time (b).

Figure 11 - Histograms showing the distribution of (a) the uncertainty in the parameters (strike, dip, rake) and (b) the STDR of the focal solutions.

Figure 12 – Search page of the web catalogue presented in this paper.
Figure 1
Figure 3
Figure 10

(a) Graph showing the number of earthquakes by magnitude. The bars represent the calculated data, and the grey bars represent the analysed data.

(b) Line graph showing the percentage of earthquakes over the years. The percentage increases significantly from 1999 to 2007 and then stabilizes.
Figure 11
Figure 12
Appendix

The catalogue

The catalogue presented here comprises focal solutions for about 300 earthquakes; of these, slightly less than half refer to the Etna area. The histograms in Figure 10 show the frequency distribution of events considered and successfully analysed as a function of their magnitude (Figure 10a) and time (Figure 10b). A fairly steady increase in the number of solutions successfully obtained from 2004 can be noted, which can be attributed to the increase in the number of seismographs in operation, as well as to their technological upgrading. Geographic location is often a limiting factor; in particular, events occurring in the Tyrrhenian Sea (except the area between the Aeolian Islands and the Gulf of Patti), as well as in the Channel of Sicily and to a lesser degree in the Ionian Sea, suffer from an high azimuthal gap. In these instances determination of the focal mechanism becomes rather difficult. Conversely, the station coverage in central and western Sicily is improving and, currently, allows detecting events also of low magnitude. Another element that sometimes limited our success ratio is that, particularly on Etna, earthquakes often occur as swarms (events very close in space and time) and their first arrivals at the stations can be blurred by the foreshock event.

The histograms in Figure 11 show some statistics about the quality of the obtained mechanisms. For most of the focal solutions, the range in the uncertainty of each parameter (strike, dip, rake) is within 15°, while the STDR is mostly higher than 0.6-0.7. A further test on the reliability of the focal mechanisms of the catalogue was obtained by comparing our solutions with those found by Damico et al. (2010), computed by waveform inversion method, in the southern Calabria – Peloritan area; the comparison shows a good agreement for almost all the mechanisms.

Finally, since that, for a given set of observed first motion polarities of an earthquake, multiple solutions, corresponding to significant relative minima in misfit, may be returned by FPFIT, we rejected the calculation with more than two alternative solutions. When two solutions are
identified for an event (about 20% for the current database), our choice of preference is done by considering the earthquake distribution, the comparison with data from literature or other well-constrained mechanisms leading to the same source area and the quality of each solution; the alternative focal mechanism is also reported in the catalogue.

**Data distribution on the World Wide Web**

The catalogue is available on the internet at http://sismoweb.ct.ingv.it/Focal/ and is updated yearly. After having accessed the main page of the database, one can view and extract the data contained in the catalogue through the “Catalogue search page”; there, a main menu is displayed with some choices about the area of interest and the depth and magnitude range of the events that the user wishes to consider. By clicking the “Search” button, the data are returned in tabular and graphical format (Figure 12). The table lists the main hypocentral and focal parameters of the selection; a map shows the beach balls of the same selection. Moreover, by clicking over a beach ball on the map, a pop-up menu is displayed, containing the same information of the table, relating to that earthquake. In this way, the mechanisms are immediately usable for drawing maps or making further computations.