Agreement INGV-DPC 2007-2009

Project S5 : "High-resolution multi-disciplinary monitoring of active fault test-site areas in Italy"

Lucia Margheriti, *Senior Researcher, Istituto Nazionale di Geofisica e Vulcanologia -Centro Nazionale Terremoti*

lucia.margheriti@ingv.it, +39-06-51860519, +39-393-7721411

URL : http://www.cnt.ingv.it/margheriti

Aldo Zollo, *Full Professor, Department of Physical Sciences – University of Naples"Federico II"*

aldo.zollo@unina.it, +39-081-2420315, +39-348-9385716

URL: http://people.na.infn.it/~zollo/

project web site: http://dpc-s5.rm.ingv.it/

Scientific Report - II phase

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Section 1: Report on the S5 project by Lucia Margheriti and Aldo Zollo
Results of the project

S5 project was aimed at supporting and integrating the ongoing research on three selected Italian test sites (the Alto Tiberina Fault (ATF), the Messina Strait and the Irpinia fault system) where advanced multi-parametric monitoring infrastructures are available. A new site (L'Aquila) has been added to the S5 project in September 2009 after the occurrence of the Mw 6.3 earthquake on April 6th 2009.
The main objective of the project was to improve the understanding of earthquake generation processes in Italy and to characterize the earthquake source and medium properties in the sites by developing and applying innovative methodologies aimed at the massive processing, analysis and modelling of multi-parametric geophysical data available in real-time and off-line data banks.
The work breakdown structure was organized according to scheme with four main Tasks each of them dedicated to the research activities developed in the selected active fault test sites (Alto-Tiberina fault, Irpinia fault, the Messina Strait and 2009 L'aquila fault system). A description of products and results of the project, divided by task is detailed in the following.

Task 1. Test site "Alto Tiberina Fault" (responsible: *Lauro Chiaraluce*)

Research objectives. The works carried out over the past two years have been devoted to foundation of the permanent ***Alto Tiberina Fault*** (ATF) ***test site*** from a multidisciplinary point of view.
There was the need to:

- turn on the observing system to begin with the generation of the seismological catalogues by preparing a modular automatic procedure for the management and analysis of a continuous seismic data stream (D1);
- enhance the image of the shallow fault zones (D2) for the identification of a optimum site for the installation of a borehole seismometer (D3) by acquiring a high resolution seismic profile;
- revise and update (D4) the geodetic data to compute the deformation pattern of the extensional velocity field (D5);
- revise the available geophysical information to improve the 3-dimensional geometry of the ATF at depth (D6 and D7);
- produce a geomorphological map of the Tiber basin (D8).

Data. With the UR1 we performed a high resolution seismic exploration survey aimed at obtaining reflectivity and V_P shallow images to provide insights both on the shallow architecture of the Quaternary Tiber basin and the ATF system, together with information to optimize the location of shallow drillings to install borehole seismometers planned in the framework of the AIRPLANE Project. The geodesist of the ATF Test site collected and analysed all the available continuous GPS data in the interval 1994-2010 integrating the national network with the regional one.
For the geological reconstruction of the subsurface of the ATF and for the restoration of three geological sections across the system we (UR2) re-considered all surface (geological maps) and subsurface (boreholes and commercial seismic data) data both at ATF foot-wall and hanging-wall.
Finally, the team working on the production of 1:10,000 geological and geomorphological map of the high Tiber Valley from San Sepolcro to Perugia collected the existing geological maps produced

in the framework of previous national and/or regional projects and integrated them by original geological geomorphological surveys and aerial photograph interpretation.

Methods. The most important methodological development of the Alto Tiberina Fault site came from the seismological group of UR1. We answered the question: how can we observe the seismicity pattern that characterises the activity of a normal fault system for a long period of time with the least manual work? We set up a modular and semi-automatic procedure that goes from continuous waveforms to high-resolution event location, computation of magnitude and focal mechanism. The core code is an automatic picker (*MannekenPix*) for P- and S-wave arrival times and P-wave polarity. The process comprises also other independent codes to monitor with time a series of parameters such as network detection threshold, catalogue completeness in terms of magnitude, the rate of seismic release, *b*-values and V_P/V_S ratio at single station and the level of noise. A final modulus analyses the generated datasets to produce maps and graphs for interpretation. During the project period of time the INGV has finalised (April 2010) the monitoring infrastructure in the ATF region, composed of a dense network of co-located seismological and geodetic instruments with real-time connection and we are now starting to apply the techniques developed on the new data. The occurrence of the L'Aquila earthquake in April 2009 forced us to implement, calibrate and test the procedure for the analysis of seismological data on the aftershock sequence (see Task4, Chiaraluce et al 2010).
In analyzing high resolution active seismic profiles were applied standard CDP processing of reflection data and refraction multiscale tomography. The GPS data were processed using the GIPSY software (Zumberge et al., 1997), as part of a regional, ambiguity-resolved network solution computed by the Ambizap software (Blewitt, 2008; D'Anastasio et al., 2008), with station velocities and their uncertainties determined using the CATS software (Williams, 2003).
To improve the 3-dimensional geometry of the ATF at depth we performed the depth conversion (*MoveTM* package) and sequential balancing of three geological sections across the ATF. The interpretation of these sections, as well as the interval V_P velocities adopted for the depth conversion of the seismic profiles, are calibrated by three deep boreholes (~5 km), S.Donato1, M.Civitello1 and Perugia2.
The geological and geomorphological surveys were aimed at producing an integrated and homogeneous scheme for the stratigraphy of the continental deposits (< 1.8 Ma), characterized also from a sedimentary and structural point of view. The map derived by original surveys on Quaternary deposits was integrated with observations derived from 1:33,000 scale aerial photographs (GAI) and 10 m and 90 m resolution Digital Elevation Models (DEMs).

Results. The results obtained using the modular procedure developed by UR1 (D1) in the locations of L'Aquila earthquake sequence are impressive. We underline here that all the P- and S-wave arrival times catalogue have been generated using a semi-automatic procedure: we did not hand pick a single seismogram. In the UR report and in the Task4 we show examples of the achieved results (Chiaraluce et al. 2010), such as the L'Aquila fault system geometry, a great improvement in location resolution mainly due to the homogeneity of the weighted scheme and the very low M_C of the retrieved catalogue. We believe that the availability of this procedure represents a high innovation with regards to manual time consuming procedures.
The seismic sections (HR reflectivity images) show interpretable events down to 400-500 m depth. We show in Figure1.1 the western Line where it is visible a coherent and laterally continuous

reflector, which define the internal geometry of the Quaternary continental infill along the western side of the basin. A noticeable result is the detection of an eastward dipping extensional fault along the western hill-slope, which did not appear in published geologic maps. The tilting and growth of fluvio-lacustrine strata towards this high-angle fault evidence its syn-sedimentary activity, while truncation of near-surface reflectors (<30-50 m depth) referable to Late-Pleistocene–Holocene terraced deposits documents recent slip along this structure.

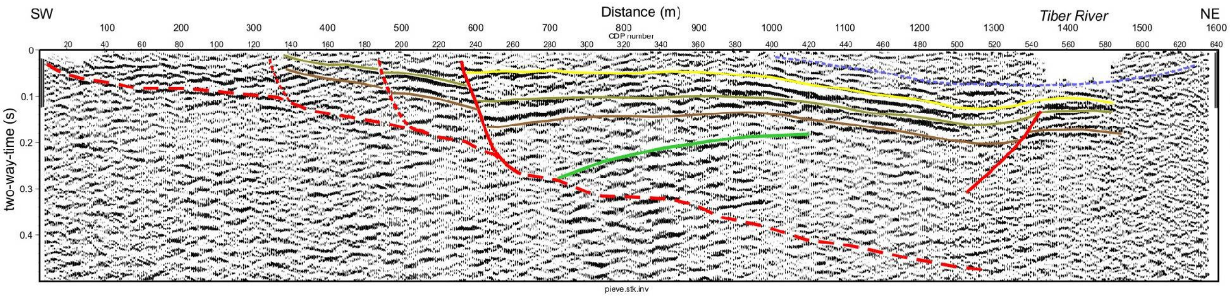


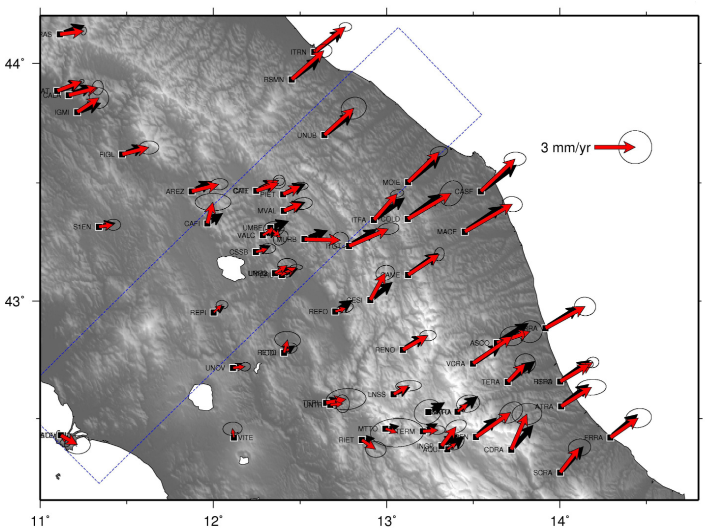
Figure1.1 Stack section with schematic line drawing of Line A. The red dashed Line A. line outlines the low dipping ATF. Note the synthetic high angle extensional splay positioned at 600 m.

Our investigations suggest that the anti-formal structure detected along the Line B (see Scientific Report) consisting of high-V_P flysch deposits buried at ~150 m depth below Quaternary clastics, can be a suitable target for shallow drillings to install borehole seismometers planned within AIRPLANE Project.

The availability of stations with more than 2.5 years of data located on the west coast of the Italian peninsula allowed us for the first time to refer the GPS velocities relatively to the Tyrrhenian coastal region. The retrieved geodetic velocity field showed in Figure 2.2 illustrates a relatively simple pattern of crustal extension in which Tyrrhenian-fixed velocities southwest of the Apennines divide are not statistically significant, whereas crossing the drainage divide the velocities progressively align with the north-eastward motion of the Adriatic micro-plate. The observed crustal extension is not uniformly accommodated across the Apennines, but deformation appears to concentrate across the alignment of historical and recent seismic events. There is a further increase of north-eastward velocity beyond the Alto-Tiberina Valley (see section Fig2.2) and overall extension is about 3 mm/yr. We computed the spatial distribution of the tectonic strain rate on a regular 0.1°x0.1° grid following the methodology outlined in D'Agostino et al. (2008). The strain distribution shows a continuous band of deformation running along the crest of the Apennines coinciding with the maximum release of historical and instrumental seismicity. The geodetic strain rate has been converted in geodetic moment rate (see UR1 report).

The set of balanced geological section obtained by UR2 (Mirabella et al. 2010) shows that the long-term slip-rate (~3 Ma) is similar to the present-day extension rate (2.7 mm/yr) suggesting an almost continuous process through time. Moreover, the distribution of the long-term offset suggests that the ATF is a single continuous fault at depth even if its splays at shallow depth may be segmented. The restoration also shows: a) the kinematic interaction between the ATF and the SW-dipping normal faults (e.g. Gubbio and Corciano faults); b) the influence of the staircase geometry of the ATF on the onset and evolution of the Tiber basin at its hanging-wall; c) the pre-extensional geometry of the compressional structures. The ATF isobaths map images the dip variations along the fault dip. The identification of discrete areas with similar dips can affect the fault segmentation

possibly affecting the maximum expected magnitude.
Within the high Tiber valley, three main sub-basins separated by thresholds (namely, North to South: Sansepolcro, Umbertide and Ponte Pattoli basins), have been finely distinguished and classified. The genesis and evolution of these sub-basins is clearly driven to the activity of the recent most (~2 Ma) splays of the ATF.



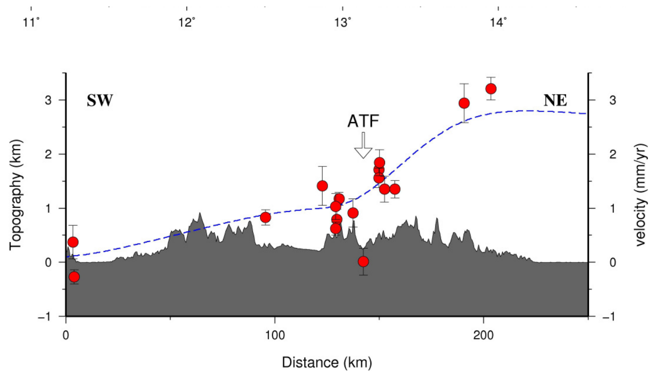


Figure2.1 Left: GPS velocity field of the Northern Apennines. The vectors show velocities relative to a reference frame obtained by minimization of the horizontal velocities of GPS stations on the Tyrrhenian coast. Ellipses show velocity uncertainties at 95% confidence interval. Black arrows are the velocities calculated from the interpolation algorithm. The box encloses the swath used to project the horizontal velocities showed in the section. Right: blue dashed line is the projection of the horizontal velocity calculated by the interpolation algorithm.

We also mapped the distribution of the river terraces along the Tiber valley. We recognized at least two orders of terraces along the river and sparse older palaeo-surfaces at higher elevations. The presence of these terraces is not uniformly distributed along the Tiber valley. In the northern Sansepolcro sub-basin, the valley is characterized by the overall absence of fluvial terraces. Along the other two sub-basins, south of Città di Castello, two orders of fluvial terraces were recognized. These variations can be interpreted as the results of the interference between two opposite driving mechanisms, the regional uplift (about 0.5 mm/yr) and the local subsidence of faulted blocks. Our results indicate that the recent (Late Pleistocene to Holocene) evolution of Sansepolcro basin is dominated by local subsidence (i.e. tectonics), while in the southern basins the faults activity is less vigorous, hence the uplift dominates promoting river incision. This result is reinforced by the observed thickness of the recent alluvium (up to 150 m) infilling the Sansepolcro basin, much larger than in the other basins.
The detailed subsurface geometry of the fault and of the top of the basement can now be compared with the seismicity distribution to study how the structural setting at depth and the mechanical stratigraphy of the region affect the seismic release.
The distribution of the historical and instrumental seismicity together with the geological evidences found in this studies indicate a stronger tectonic activity in the northernmost portion of the High Tiber Valley (San Sepolcro basin) if compared to the other segments of the Tiber valley.

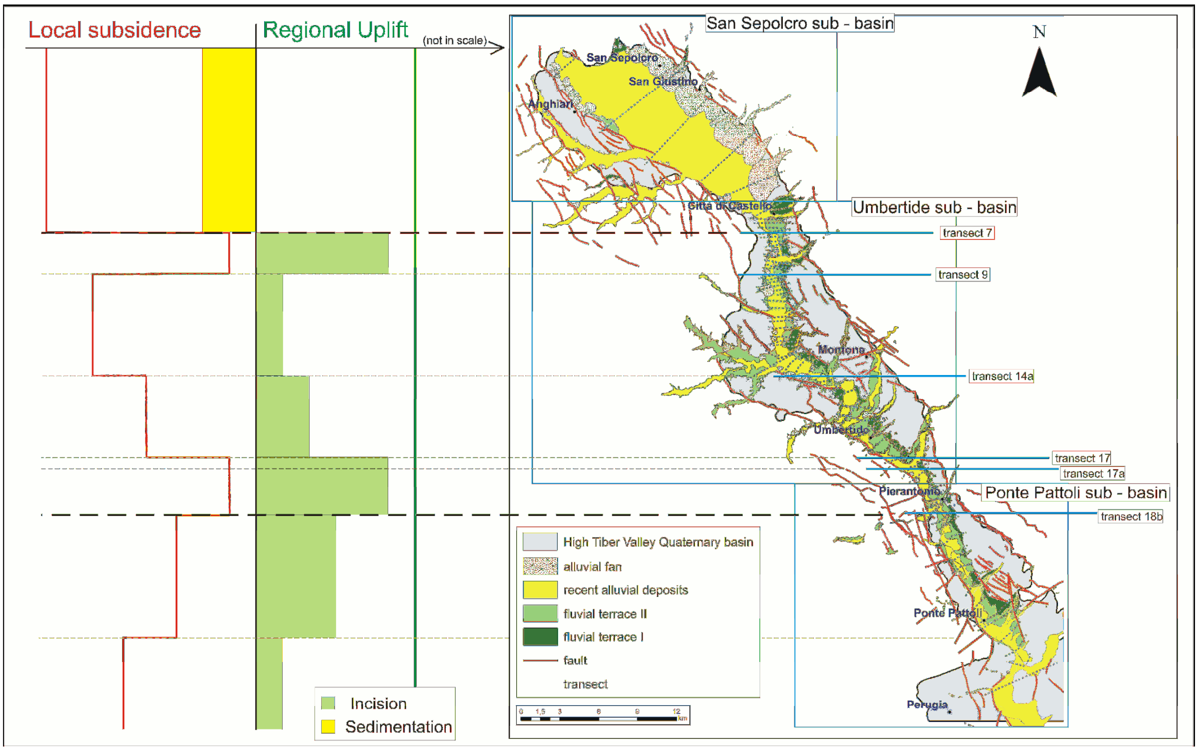


Figure3. Schematic distribution of the alluvial deposits and fluvial terraces along the Tiber valley from Sansepolcro to Perugia (right) and synthesis of the local uplift-subsidence relationships along the river (left).

Task 2. Test site "Messina Strait" (responsible: *Lucia Margheriti*)

Objectives. The Messina Strait in 1908 was the site of one of the largest event ever recorded in central Mediterranean (Mw=7.1). Studies done in this century agree in identifying a normal fault located inside the Strait but the precise location and dip of the fault is still debated (Pino et al. 2000 and references therein). Even more controversial is the geodynamic framework in which active extension in the Messina Strait occurs. To help clarifying these issues the INGV promoted and financed a research project "Messina 1908-2008" 15 temporary seismic stations were deployed at the end of 2007 to densify the permanent network. A dense permanent geodetic network operate in the region and several repeated geodetic surveys are available.
As a complementary research to the "Messina 1908-2008" project, the S5 project had the following objectives:

- to test and improve the Ocean Bottom Seismometers developed by the Gibilmanna Laboratory
- to collect new data in the region: deploying five Ocean Bottom Seismometers (OBS), and promoting new geodetic campaign measurements;
- to build procedures for integrating the temporary and permanent seismic monitoring system into a seismic SEED data archive
- to identify the sources of background seismicity in the area
- to develop and apply standard and innovative methodologies to characterize the strain-field in the Messina Strait in the framework of the Calabro-Peloritani arc.

Data. This is the first seismic passive experiment in Italy in which INGV submarine seismic stations are deployed together with on-land stations. The deployment and test of the OBS stations (D9, D10; D'Anna et al 2009), is an important technological contribution to development of advanced seismic monitoring systems.
GPS data were collected in a campaign in 2008 and integrated with all of the available data in the region from permanent stations and temporary campaigns, this allows us to obtain a detailed spatial

resolution of the ongoing crustal deformation. Different groups are starting to share data coming from old temporary GPS campaign in ftp://ftp.ingv.it/pro/s5-data/.

One of the most valuable results achieved during the work on S5 project is the implementation of a new temporary network data management that allows the integration in EIDA of the temporary deployment together with all other seismological data produced by INGV. The Messina (Figura 2.1) data archive http://dpc-s5.rm.ingv.it/en/Database-MessinaFault.html (D11) is the first example in Italy of complete integration of permanent networks. The waveform archive collects in SEED format (- *Standard for the Exchange of Earthquake Data*) continuous seismic recordings (Moretti et al 2010)
The new data collected and described above were analyzed by the project together with previous data coming from permanent seismic networks and periodical and continuous GPS data collected between 1996and 2008. Some of the techniques developed in the project were tested on other datasets (i.e L'Aquila seismic sequence, etc)

Methods. In S5 Task2 we decide to develop and apply standard and innovative methodologies to characterize the strain-field using both the seismological and geodetic approaches. The larger earthquakes were located using different standard codes. Innovative techniques for evaluating the seismic anisotropy and earthquake focal mechanisms were improved, implemented and tested. We developed a semi-automatic procedure, starting from a manual code (Pastori et al 2009), able to evaluate the anisotropy of S waves and applied it to the crustal earthquakes for characterizing the deformation and fracture field of the crust. The automatic estimation of the splitting parameters presents difficulties because the effect of the anisotropy on the seismogram is a second order effect not very easily detectable. The code (D13) is now able to retrieve the anisotropy parameters of S waves using a simple, fast and robust approach based on the cross-correlation of the two horizontal traces, selecting automatically high quality waveforms suitable for shear wave splitting analysis.
This makes possible to analyze large number of events and to monitor spatial and temporal variations of the anisotropic parameters. We compared our code with two different semiautomatic codes SPY (Bianco & Zaccarelli 2008) and Sheba (Wüstefeld et al 2010) finding consistent results.
We applied in the Messina Strait area the "Cut And Paste" (CAP) method for moment tensor estimation (Zhao and Helmberger, 1994). To obtain the Green's functions we performed the frequency-wavenumber (f-k) integration as described in Zhu and Rivera (2002). CAP has been shown to be very stable also for earthquakes of magnitude as small as 2.5÷3, which turns out to be suitable to analyze data in the Messina Straits area. In order to have an additional check of CAP, we performed several tests and comparisons with the waveform inversion technique of Herrmann (2008) to get the moment tensor solution.
Standard techniques were applied to GPS data in order to obtain a detailed spatial resolution of the ongoing crustal deformation and the dilatation strain-rate pattern (Mattia et al 2009). An analysis based on the approach called "elastic block modeling" on the same dataset evidenced the inter-seismic slip rate of the fault possibly responsible of the 1908 earthquake (Serpelloni et al. 2010).Moreover, the geodetic groups in S5 carried out a critical examination of the recorded leveling data of Loperfido (1909) using the Genetic Algorithms (Goldberg, 1989) and the Pattern Search (Lewis and Torczon, 1999) approaches and applied a Finite Element method to obtain the displacements on faults in the Strait as the Armo fault and as the summary model of Valensise et al. (2008).
Results. The anisotropic parameters in the crust individuate the fracture field geometries connected with the active stress field, and might be sensible to stress variations. The application of the code to the earthquakes recorded in the Messina area during the project was not achieved because we are starting just now to evaluate the locations of microearthquakes, but we did apply our code to other datasets.

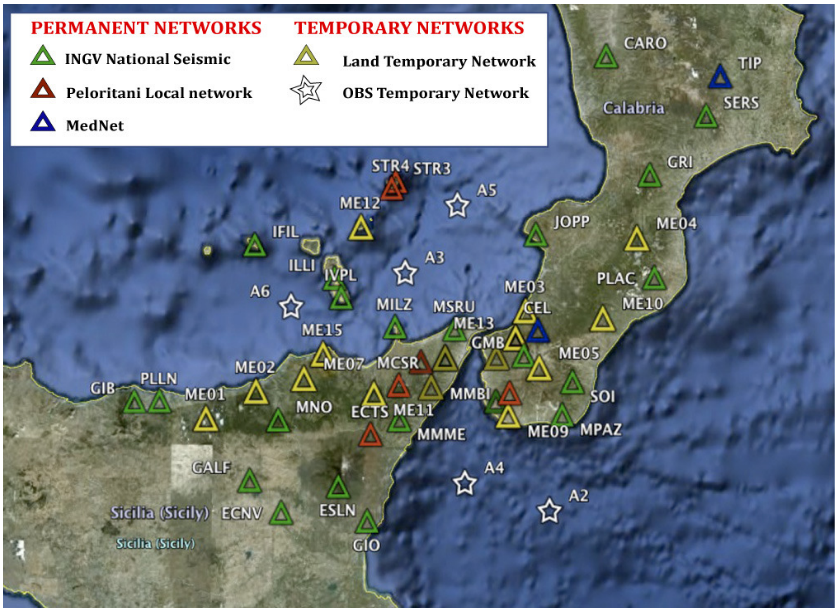


Figure 2.1– Above: the map of the seismic networks: permanent stations in green blue and red; temporary stations in yellow. Below the EIDA web interface

In general, we found a good agreement of the average splitting parameters with the stress field orientation in the analyzed regions (fast direction perpendicular to the Shmin; D13, DAQ7). We observe significant spatial variations of anisotropic parameters and we are investigating the relation between occurrence of seismicity and variations in time of the anisotropic parameters in the crust.

The new moment tensor solutions using the “cut and paste” method (D16) show that the regime of faulting significantly changes in the Strait region from north to south: normal faulting prevails clearly in the north while it appears mixed to strike-slip in the south (D17) (D’Amico et al. 2010). Normal faulting (with NW-SE preferential direction of extension) is probably the response to the residual rollback of the subducting slab and south-eastward trench retreat still occurring at very low speed in southern Calabria. In fact, seismogenic normal faulting characterized by this study is more pronounced in the northern portion of the area (sub-area A Fig. 2.2) more favorably oriented with respect to trench retreat. The subducting trench retreat combined with the continuing plate convergence due to northwestward Nubia motion generates a dextral transfer zone across northeastern Sicily and the Messina Straits and, therefore, explains the strike-slip mechanisms and the different orientation of $\sigma 3$ found in the southern part B of our study area.

We obtained a detailed spatial resolution of the ongoing crustal deformation analyzing GPS data (D14; Figura 2.2). The dilatation strain-rate pattern is dominated by a clear compression of about 0.65 μstrain/yr on a small area located between the Vulcano and Lipari islands. A compression of about 0.1 μstrain/yr can be recognized also between Stromboli and Lipari islands. Across the Nebrodi-Peloritani and the Messina Strait areas the dilatation strain pattern is positive. The areas having maximum values of positive dilatation strain-rate (about 0.15 μstrain/yr) are localized along the two main active fault systems cutting the investigated area: the Messina Strait fault system and the Aeolian-Tindari-Letojanni fault system (Mattia et al 2009). The “elastic block modelling” has evidenced that the inter-seismic slip rate of the fault responsible of the 1908 earthquake is of about 3 mm/yr (Serpelloni et al 2010).

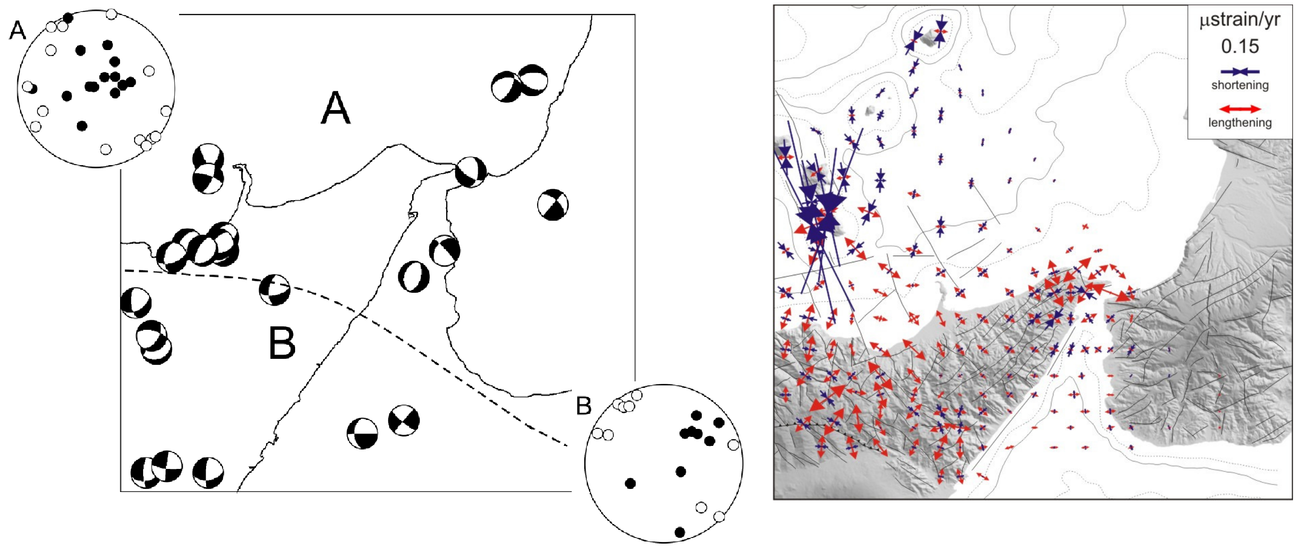


Figure 2.2 Left-Focal mechanisms estimated in the present study by the CAP waveform inversion method. The polar plots of P and T axes relative to sub-areas A and B are also shown. Black and white dots in the polar plots correspond to P and T axes, respectively. Right -Maps of geodetic strain (GPS): 1 Axis of Strain

Modelling of the source responsible for the December 28, 1908 earthquake, by using a numeric approach (i.e. finite element) we obtained that the solutions are not well constrained by the the leveling data (Loperfido, 1909). Because of these uncertainties, we retain that the available leveling data only are not sufficient to discriminate between different faults which is the 1908 source.

Task3 The Irpinia Fault System (responsible: Aldo Zollo)

Objectives. The third selected test-site of project S5 is the Irpinia fault system, which is located along the Southern Apenninic belt across the Campania and Lucania regions. This test-site offers the unique scientific opportunity of analysing in near real-time massive, high-quality microearthquake data collected by a dense and wide distributed seismometric, accelerometric and geodetic networks owned by INGV, Department of Civil Protection and AMRA a public consortium of universities and research centres in Regione Campania (Figure 3.1). The research activities within Task 3 have been mainly focused on the development and application of real-time and off-line methodologies for the analysis of seismic noise, microearthquake and high-rate GPS data collected by ISNet (Irpinia Seismic Network) and INGV seismic networks and RING the geodetic network of INGV. The final aim of TASK 3 was to investigate and determine the medium and earthquake source properties using an advanced earthquakes monitoring infrastructure which jointly use the high frequency seismic and geodetic observation. We explored the robustness and the properties of the Green functions extracted from the cross-correlation of data recorded by the seismic network ISNet. Techniques for dispersion curve analysis and modelling have been developed extending standard techniques to high frequencies (WP3.1). Methods to retrieve high resolution images of the Irpinia active fault system have been developed and tested based on the accurate determination of location, size and fault mechanisms of microearthquakes in the magnitude range 1<M<3 (WP3.2). Reflection seismology techniques have been developed and adapted to work on microearthquake data with the aim to improve the images of crustal P- and S-velocities and subsurface discontinuities beneath the test-site (WP3.3). Finally, we have performed experiments to investigate the feasibility of high rate GPS monitoring of earthquake faults and near real-time recording of co-seismic displacement (WP3.4).

Data. In WP3.1 the records of cross-correlated seismic ambient noise have been used for the extraction of the propagation features associated to surface waves, which dominate the Green functions when both source and receivers are located at the Earth free-surface. We used broad-band records at five stations of the ISNet collected along two years (from June 2008 to May 2010), and processed them in order to keep only phase information and cancel out any artifact related to anomalous amplitudes (earthquakes, spikes, atmospheric effects, etc.). For that, data have been equalized in both frequency and time domains by whitening and one-bit normalizations. Finally records from couples of stations have been cross-correlated and stacked to build up a database of Green's functions from ambient noise.

In WP3.2 and 3.3 the primary data source are seismic waveforms recorded by the continuosly recording, real-time Irpinia Seismic Network (ISNet), which comprises 28 6-components stations (accelerometers and short-period or broadband velocimeters) deployed around the Irpinia fault system. The developed procedures for automatic event detection and analysis of local earthquakes recorded at the ISNet, resulted in the ISNet bulletin (http://lxserver.ov.ingv.it/cgi-bin/isnet-events/isnet.cgi). The completeness threshold for located events is about ML 1.3, after visual inspection of helicorders following the automatic detection. The data set is further extended and integrated by data from closest stations of the Italian Seismic Network, managed by INGV. The current database comprises more than 900 events (from Aug 2005 to April 2010) inside the network and in the surrounding area with $0.5 < Mw < 4$. An accurate manual re-picking has been performed on the whole data set, for a total number of about 57000 3-component recordings.

Data analysed and modeled in WP3.4 were acquired by the continuous GPS network (RING, http://ring.gm.ingv.it) set up by INGV in order to study the complex pattern of deformation in the Central Mediterranean, at the plate boundary between Africa and Eurasia. In the test-site most of the CGPS sites, acquiring at 1Hz and 30s sampling rate, are integrated either with broad band and very broad band seismometers or accelerometers for an improved definition of the seismically active regions.

Methods. In WP3.1 the used methodologies are aimed at the pre-processing of the noise recorded at the single stations and the computation of the cross-correlation, which include whitening, recursive filtering and time-frequency multi-filter analysis. Analysis of dispersion curves and preliminary 1D models are determined by standard modeling of group velocity dispersion curves.

In WP3.2 standard methods to infer an appropriate 1-D velocity model (VELEST, Kissling et al., 1994) and station static corrections for earthquake location, and focal mechanism from P-polarities (FPFIT, Reasemberg and Oppenheimer 1985) have been preliminary used. Earthquake locations in this new model have been obtained through a joint hypocentral determination, using a non-linear, probabilistic location software (NonLinLoc, Lomax et al. 2000). Then, the whole catalog has been relocated using the HypoDD code (Waldhauser and Ellsworth, 2000). The P- and S-displacement spectra from velocity and acceleration sensors have been inverted using the non-linear Levenberg-Marquardt least-square algorithm for curve fitting and assuming the Boatwright's (1980) spectral model. A new method for the multi-step inversion of path attenuation, site response and source parameters from microearhquake records have been developed and applied.

In WP3.3 signal processing methods as in exploration seismology are developed and applied to local micro-earthquakes, aiming toward a 3-D structural image of the crust in the greater Irpinia region. Of particular interest are the reliable identification of reflected/converted waves and of direct S-wave arrivals, which are required for more accurate hypocentral locations (in cooperation with WP3.2). Applied methods include polarization analyses, multichannel processing and moveout corrections of trace gathers, array beamforming or migration for reflected/converted events as well as for the earthquake sources themselves, and first-arrival tomography to obtain a 3-D velocity model.

In WP3.4 most of the methodological work addressed the issue of how to perfom an efficient and reliable analysis the acquired high rate GPS data. For this aim several standard packages have been tested and applied to get a kinematic solution for each high frequency GPS site , the position of each site with respect to its nominal a-priori precise position and the clock/troposphere delay. The occurrence of Mw 6.3 L'Aquila earthquake represented an unique opportunity to record and analyze 10 Hz sampling GPS co-seismic data at two sites nearby an active fault and for the first time in Italy, 10 Hz GPS data provided with the near-source, co-seismic displacement record of a moderate size earthquake

Results. The research activities within Task 3 of the S5 project led to a number of important results, based on the experimentation of innovative approaches to investigate the micro-seismicity and ground deformation associated with a complex system of active faults in southern Apennines. Here we critically revise the most relevant scientific achievement and briefly outline the future research perspectives.
Extraction of Green's function from the noise recordings. The analysis of very long time series of seismic noise (> 6 month) revealed the feasibility of using the continuous noise recording to get information on the 1D earth structure at a regional scale in southern Apennines. We observe that most of the energy is concentrated in the low-frequency band 0.15-0.5 Hz, with a minimum localized at 0.2-0.3 Hz, indicating the presence of mostly 1D layer underlying the investigating area. Some energy is observed also at lower frequencies (between 0.04 and 0.05 Hz), with low group velocities, which well propagates in the area of interest, but the origin of which has still to be investigated. On the other hand, strong limitations appear in using such a technique to investigate the more incoherent , high frequency noise (>0.5 Hz), which precludes to infer high resolution details of the crustal structure. There are two main directions to pursue in order to improve the resolution of seismic noise analysis. The first is to increase the station density and possibly installing borehole sensors, which allows the optimal detection of coherent signals emitted by high frequency sources. Second, the development of more advanced signal processing techniques, e.g. which are able to discriminate and locate the local/regional sources of noise and use this information to better extract the Green function from waveform cross-correlation.

Observing the background micro-seismicity of active faults The 4-years experience of monitoring the microearthquake activity along the Irpinia fault system by the high density multi-component seismic network ISNet, has confirmed the significant gain in information which is brought by the detailed analysis of microseismicity in terms of earthquake location and source parameter determination.

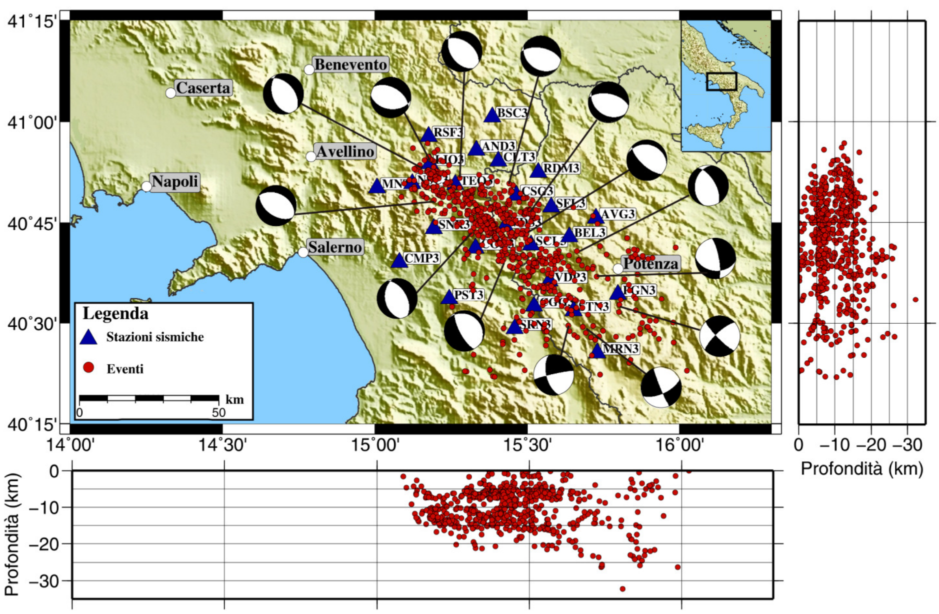


Figure 3.**1** Refined earthquake locations and selected focal mechanisms. The ISNet stations are also shown

The advanced sensor, data-logger, data transmission and network management technologies and methodologies allowed for a drastic decrease of the magnitude detection threshold of the network down to M 1.5, which is also the completeness magnitude threshold for precisely located events (error on space coordinates smaller than 500 m).The project S5 has given the opportunity to test the network capability to get very accurate earthquake locations (accuracy of the order of tens o meters), when high quality manual phase pickings are replaced by time delays obtained through waveform cross-correlation and semblance/stack analyses. The systematic implementation and application of waveform cross-correlation techniques (even in real-time) to get refined re-picking of P- and S-arrival time phases is the future research development for modern digital seismic networks around active fault systems, with the aim to get accurate locations of the background seismicity location and refined 3D images and, possibly, the time variation (4D tomography) of the fault structure and of the embedded geological medium.

Microearthquake source parameters and scaling laws The work done in S5 well illustrates the need for adequate correction of path attenuation and site effects in order to get reliable and consistent estimates of source parameters (seismic moment, fracture size, seismic energy and stress release; Zollo et al., in preparation). But also the use of using multi-component records (accelerometer and velocimenter time series) from an high number of stations allows for the reduction of data scatter and uncertainties on measurements. We observed a self-similar earthquake scaling (near-constant static stress drop of 10 MPa and 2 MPa,respectively using the Madariaga,1976 or Brune,1970 circular fault models) down to moment magnitude about 2, while a clear high frequency cut-off is observed for smaller magnitudes. Interestingly, apparent stress drop (obtained from the radiated seismic energy)and static stress drop (as obtained from corner frequencies and the Brune,1970 formula for source radius) scale linearly in the whole explored magnitude range with a constant ratio of 0.05-0.15, similar to what observed by Abercrombie,1995 on Canjon Pass borehole data and about 4 time smaller than measurements in laboratory. This is a clear indication for a significantly positive dynamic stress overshoot (Beeler et al., 2003), which reflects a high dynamic strength relative to the stress level, e.g. a dynamic stress smaller than static stress releases, which is the cause for additional fault slippage during the post-rupture phase.

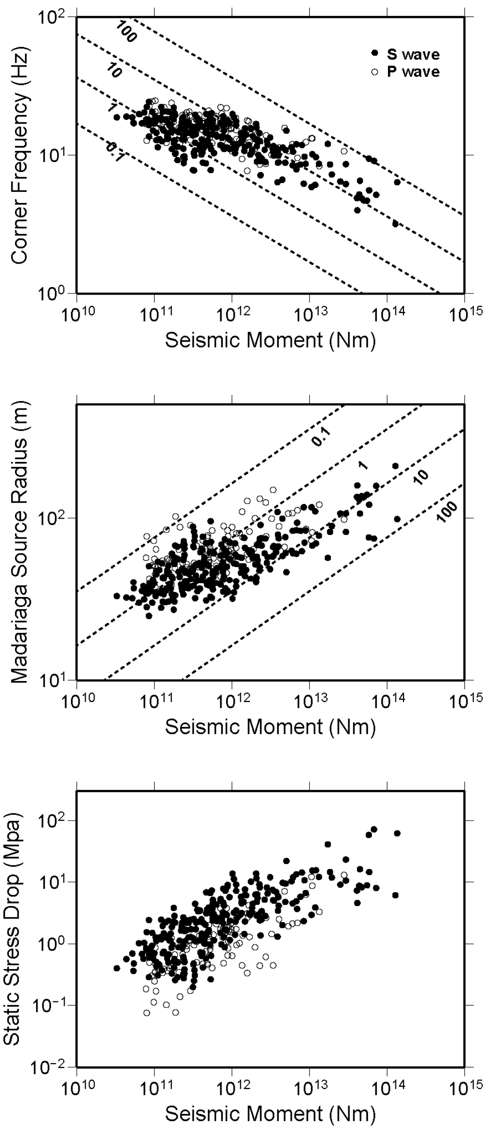


Figura 3.2 Source parameter (Lanceri and Zollo 2008) scaling laws from the Irpinia fault system as inferred from the inversion of microearthquake displacement spectra. Top. Corner frequency vs Seismic moment. Closed and open circles represent S- and P-wave spectra, respectively. Constant stress-drop lines are indicated by dashes lines.. Middle. Source radius vs Seismic moment. Radii are computed according to the Madariaga (1976) circular crack model. Bottom. Static stress drop vs seismic moment, with source radii computed using the Madariaga source model. Static stress drop values using the Brune(1970) source radius are a factor 4.5 smaller than the ones plotted in the figure. A violation of self-similarity is observed for events with seismic moment < 1e12 Nm. This is related to the saturation effect of corner frequency measurement for frequencies higher than about 20-30 Hz.

3D seismic tomography, eqk location and amplitude information to image the subsurface structure First arrival times from well-located local earthquakes have been inverted for a 3-D velocity model for the upper crust in the Irpinia region (Vp and Vp/Vs), starting from an initial 1-D model. Preliminary 3D P- and S- velocity images are retrieved from best quality, hand-picked P- and S-arrival times (De Matteis et al 2010; Matrullo et al., in preparation). At this stage of the analysis the model resolution is around 2-5 km in both vertical and horizontal directions, but a complete resolution study is still on-going. However results on refined earthquake locations, clearly indicate that additional arrival picks, refined by cross-correlations, and double difference tomography are likely to provide with event locations and velocity model with a largely improved spatial resolution (hundred of meters). During the course of this project, software tools and processing procedures for phase identification, based on polarization filtering and lateral waveform coherence and imaging with micro-earthquake data have been developed. Processing methods and seismic source imaging have been applied successfully, but a structural image of the Irpinia region from reflected/converted waves cannot be provided yet. Reliable identification of secondary phases, including direct S-waves, has been more difficult and time-consuming than anticipated, e.g. due to local scattering effects in this complex geological environment. However, the recently improved station corrections and refined locations from WP3.2, as well as the accomplished tasks described above will improve the accuracy of ISNet event locations and the applicability of migration techniques to image subsurface structures in the region.

Continuous high frequency GPS (1 Hz) In the framework of Task 3 we have carried out a very interesting and innovative experiment for Italy, by setting a real or near-real time data transmission for all the RING sites located in Irpinia area by using satellite telemetry, GPRS/UMTS or Wifi technology. This development is expected to have a very high impact for further studies on near real-time GPS seismology in Italy. As concerning the processing, the kinematic analysis of HF-GPS has been applied to the L'Aquila earthquake, providing for the first time a very high-rate GPS solutions with a single station analysis.

We confirm the feasibility of a procedure allowing to obtain a mean co-seismic displacement with a 1day latency. This result can have a potentially high scientific relevance, because a customized procedure could allow to retrieve first co-seismic displacements of the permanent GPS sites to constrain the slip and geometry of an activated fault, only one day after the event before any discrete GPS field survey results (3-4 days). Finally the analysis of high-rate GPS data acquired during the strongest shocks (Mw > 4) of the 2009 L'Aquila sequence showed that only dynamic displacements related to main aftershock (Mw 5.6), occurred on April, 7th, 2009 at a depth of about 15 km have been revealed by the continuous HF-GPS network. This may be set as the low magnitude threshold for an event detection by a HF-GPS network.

Task 4. Test site "L'Aquila" (Responsible: *Alessandro Amato*)

Objectives. Task 4 of project S5 has been devoted to the L'Aquila test site. This area was chosen after the disastrous earthquake of April 6, 2009, in order to optimize some of the activities triggered by the L'Aquila shock. The goal of this Task is multifold, with both technological and research topics, concentrated in a short time frame (9 months). Technological efforts made by UR 7 were devoted to improve existing seismic and GPS networks and make data well organized and easily accessible. The network coverage (both seismic and GPS) has been optimized to map post-seismic deformation and seismicity migration in the months after the main shock of April 2009, in order to identify possible hints of activation of adjacent faults.

Research activities carried out in this Task on aftershock data collected by the permanent and temporary networks include hypocentral locations with various velocity models (UR7), focal mechanisms of aftershocks with original techniques (UR4), the estimation of source and attenuation parameters, (UR6) . Moreover, we have tried to find out "a posteriori" space-time variations in crustal properties from seismological data (Vp/Vs and anisotropy), that could be linked to the preparatory phases of main and aftershock occurrence. To this regard, we have performed a feasibility study to improve earthquake forecasting models by incorporating different geophysical observables (UR8). Other important research activities carried out by UR8 were devoted to the characterization of the main fault (the Paganica fault) with surface geology and paleoseismology (accurate mapping and trenches), as well as with exploration geophysics (high-resolution shallow seismic profiles across the Middle Aterno Valley).

Data. For aftershock locations and source parameters estimations we have analyzed many, high quality seismological data from both permanent and temporary networks (seismic and strong motion), including data collected by the seismological ad geodetic networks installed and archived specifically in this Task (DAQ1, DAQ2, DAQ3, http://dpc-s5.rm.ingv.it/en/Database-AquilaFaultSystem.html). Original data on active surface faults (DAQ12, DAQ13) and datings of some of them were retrieved from extensive field work and paleoseismological trenching (Figure 4.1), as well as from high resolution seismic profiles across the Middle Aterno Valley.

Methods. We have used both standard and original methodologies. The seismological techniques were developed in other Tasks of project S5 and have been adapted to the huge amount of data collected during the L'Aquila sequence.

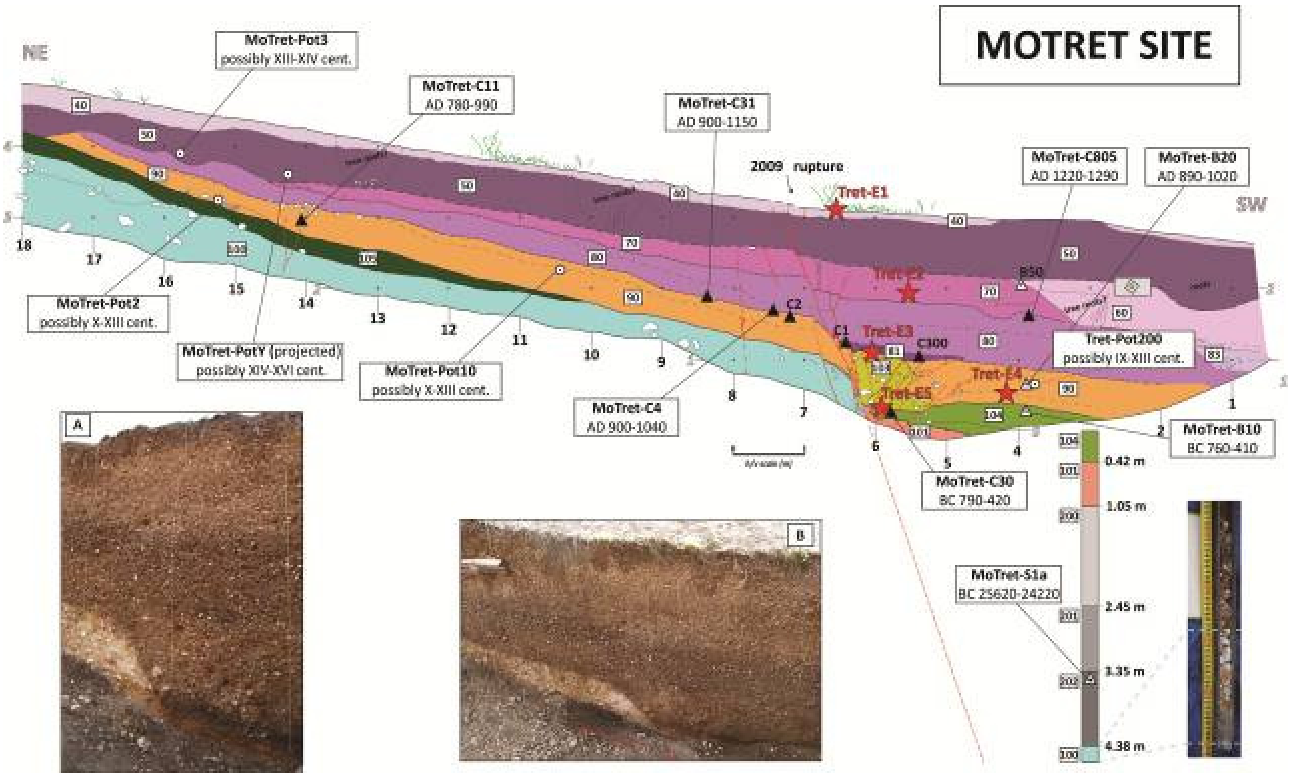


Figure 4.1. One of the most significant paleoseismological trenches on the Paganica fault, in which 5 past events were recognized and dated. See Deliverable D.. and UR8 report for details

These include the procedure to integrate temporary stations into the SEED Archive (DAQ3), the automatic detection and location of massive aftershock dataset (DAQ4, Figure 2a), the fault plane solutions determined with the "Cut-And-Paste" (DAQ5 Figure4.2b) technique (see UR4 report), the estimation of source and attenuation parameters from the non-linear inversion of displacement spectra (DAQ6; Maercklin et al 2010aeb). High-resolution, shallow seismic profiles use conventional instruments but their use in active normal faults is original and rarely applied worldwide (DAQ8-10). Paleoseismological studies used classical trenching techniques, but for the first time they provided data on normal faults with such a small surface offset (DAQ11-14).

Results. Many new information on the active faults of the L'Aquila region came out from this Task, including refined estimates of fault geometries (DAQ4; Figure 4.3; Chiaraluce et al 2010; Cheloni et al. 2010), kinematics (DAQ5, D'amico et al 2010), rupture process (DAQ6, Maercklin et al 2010aeb), recurrence times of paleo-earthquakes (DAQ14), details of the fault structure in the near-surface (UR8; Di Bucci et al. 2010; Roberts et al. 2010) and at depth (UR7), time variations of crustal properties (DAQ7). Moreover, UR8 (in collaboration with UR7) provided a detailed review and a feasibility study for a future earthquake forecasting model (DAQ15; Marzocchi et al. 2010).

The most innovative results are:

- o Automatic hypocentral locations starting from continuous data streaming of a dense seismic network with thousands of shocks(Chiaraluce et al. 2010). During this period, concern had raised for regions both north and south of the L'Aquila area -Reatino and Frusinate, respectively- where increased seismicity rates were observed thanks to the improved monitoring system.
- o The work done in S5 well illustrates the need for adequate correction of path attenuation and site effects in order to get reliable and consistent estimates of source parameters (seismic moment, fracture size, seismic energy and stress release; Bobbio et al 2009).

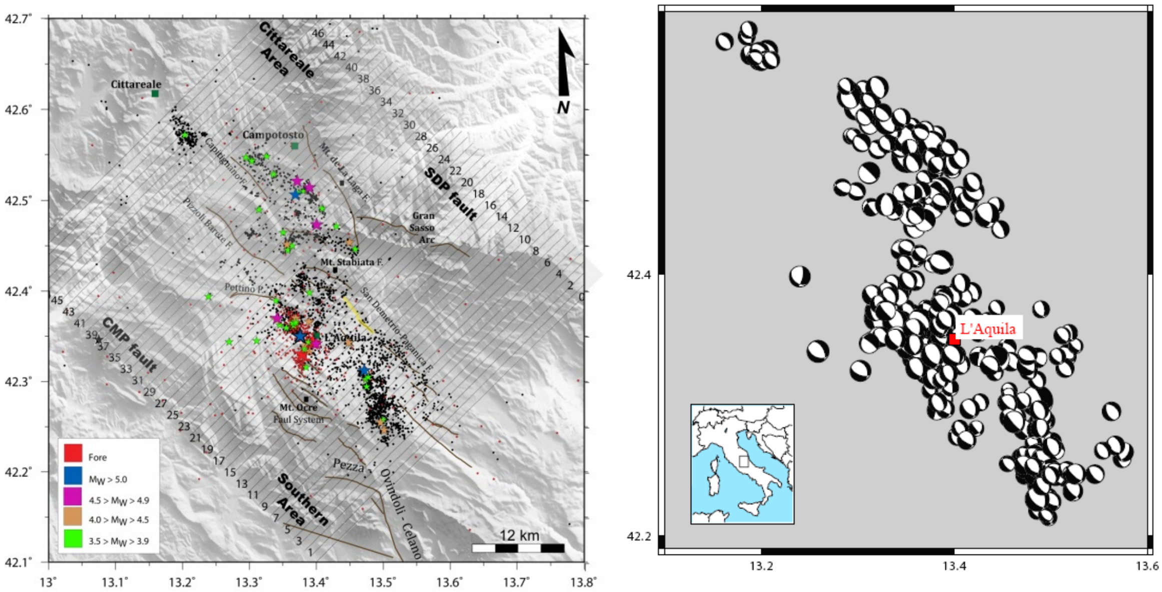


Figure 4.2. a)Left: aftershock locations in map view (color scale defines magnitude ranges as in the inset). b) Right: fault plane solutions with CAP technique (see UR4) show the normal faulting process dominant in the area.

- o Variation of elastic and anisotropic parameters during the preparatory phase of L'Aquila earthquake has demonstrated that a complex sequence of dilatancy and fluid diffusion processes affected the rock volume surrounding the nucleation area. This may have important implications in studying future earthquake occurrence (Lucente et al. 2010).
- o Focal mechanisms of ~300 small and moderate magnitude aftershocks with CAP technique describe well the normal faulting process characterizing the area (D'Amico et al. 2010).
- o Source parameters estimation for aftershocks .

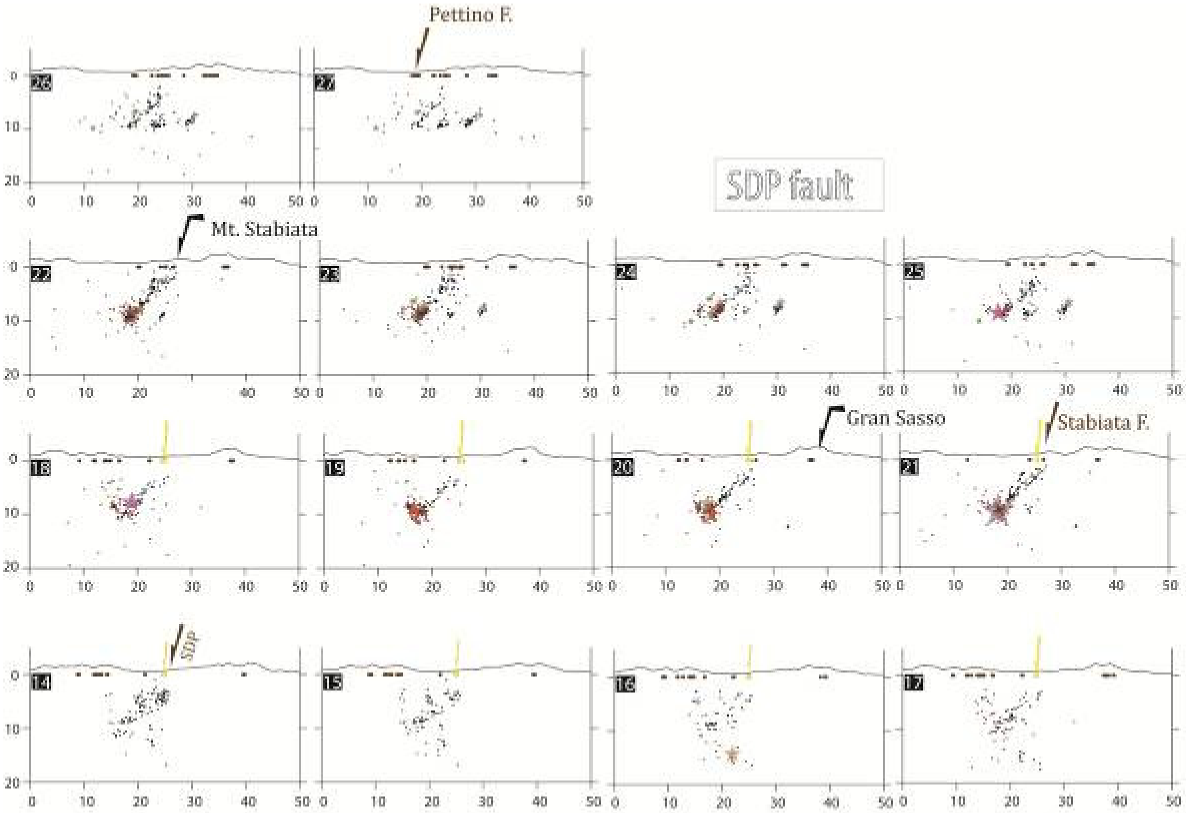


Figure 4.3. Vertical sections of aftershock locations illuminate the fault structure (see D4 for details)

- The complex surface fault structure of the region disclosed by an updated, detailed map of active faults in the area, reported also in a Geodatabase.
- Identification of at least 4 paleo-earthquakes on the Paganica fault, including the 1461 AD event, with an average recurrence time of ~700 years over the past ~2800 years.
- The fine structure of the fault near the surface based on seismic profiles (in progress).
- The identification of post-seismic deformation in some regions of the fault (Cheloni et al 2010).
- A feasibility study pointing to a future forecasting model.

Relevance of project results for Civil Protection

Within the Seismological Framework Program of DPC-INGV projects, Project S5 has the peculiarity of being strongly focussed on the development and testing of advanced and innovative technologies and methodologies for the high resolution imaging of active fault zones in Italy. This makes the S5 project having a relatively high content of fundamental research as also required by the co-financing projects, that, for each of the investigated test-areas, contributed for the large part of technological developments. Nevertheless, as often occur in science development, fundamental and applied research are strictly connected and mutually interacting, with frequent jumps from one to the other depending on results and impacts deriving from the practical implementation of theories and methods. The same can happen for ideas and approaches developed in S5, some of them have been preliminary tested in active fault zones of Italy during the relatively short duration of the 2-year framework program, some other ones have been applied off-line to data acquired in the past in the same or other areas.
As specifically concerning the relevance of S5 scientific achievements for Civil Protection these can be classified in the broad categories of technological developments, advanced data processing and mining, and methodologies for data modelling and interpretation. One of the relevant project

key-words is the “process automation”, which implies the development of software and hardware systems and tools which are able to manage (in real- or near-real-time) massive data streams acquired by dense seismic and geodetic network deployed in active fault zones.

Technological developments

- Development of a high spatial density, high dynamic range multi-component seismic network, with real-time (dead-line: 1 sec), mixed-technology data transmission protocols and signal/noise processing in continuous acquisition mode.
- The development of ocean bottom seismographs (OBS) to integrate them in the National Seismic Network is an important target for monitoring the Italian territory (D9)
- The data management procedures to archive seismic data gathered in temporary experiments inside a common the SEED archive (EIDA) make the continuous recordings available to the scientific community
- Setting a real or near-real time continuous/high frequency GPS data transmission by using satellite telemetry, GPRS/UMTS or Wifi technology.

Data processing and mining

- The development of automatic procedures for a/ single trace P- and S-phase picking b/ spectral inversion and source/attenuation/site parameter estimation c/ evaluate anisotropic parameters from shear wave splitting d/ noise spectral and cross-correlation analysis
- Refined repicking by using the waveform cross-correlation and clustering analysis
- Implementation and application of amplitude methods for the estimation of earthquake focal mechanisms of earthquakes down to M about 2.5
- Procedures for the kinematic analysis of HF-GPS (applied to the L’Aquila earthquake records), providing with a very high-rate GPS solutions with a single station analysis.

Methodologies

- High-resolution shallow crust imaging techniques to locally assess the long-term and short-term extension rates of active faults integrating oil industry/morpho-structural data and geodetic measurements (e.g. Alto-Tiberina fault).
- Integrated, multidisciplinary approach (geological, geodetic and seismic) to investigate the ground deformation pattern of an active fault zone (e.g. ATF and Messina strait test-sites).
- Extract green’s function of the medium and monitoring the health state of seismic stations using long-series of noise recordings (e.g. Irpinia test site).
- Refined earthquake locations (accuracy of the order of tens of meters), when high quality manual phase pickings are replaced by time delays obtained through waveform cross-correlation and semblance/stack analyses (e.g. ATF and Irpinia test sites).
- Continuous monitoring the space-time variation of elastic and anisotropic parameters in an active fault zone (e.g. L’Aquila case study)
- The complex surface fault structure disclosed by an updated, detailed map of active faults and paleo-seismological studies

Table of Deliverables

#	Description	Type	Authors	Restrictions	Contact person	Relevance
D1	Standard modular automatic procedures for the management and analysis of a continuous seismic data stream.	Applications (e.g. codes).	Di Stefano R., L. Valoroso, D. Piccinini, L. Chiaraluce, P. De Gori.	Any use should be defined in agreement with Raffaele Di Stefano	raffaele.distefano@ingv.it	The automatic procedure sto produce fine locations will allow us a new way to look at seismicity

D2	2 HR and VHR stack sections and VP images of the Tiber basin (~500 m deep) and of the shallow fault zones (100-150 m deep) belonging to western splays of the ATF.	Profiles.	L. Improta, P. P. Bruno, D. De Rosa, S. Pierdominici, F. Varriale, F. Villani, A. Castiello.	Any use should be defined in agreement with Luigi Improta	luigi.improta@ingv.it	High resolution images help in locally asses the extension rate of ATF and can help in defining site response of the basin
D3	Definition of an optimal site for a 200 m deep drilling in the Tiber basin to install borehole seismometers.	Lat. Lon.	L. Improta, P. P. Bruno, D. De Rosa, S. Pierdominici, F. Varriale, F. Villani, A. Castiello.	Any use should be defined in agreement with Luigi Improta	luigi.improta@ingv.it	Good installaions of borehole seismometers help in the studies of seismic sources
D4	Time series of GPS stations at ATF test site in the ITRF2005 reference frame. GPS velocity field in the ITRF2005 and Eurasian reference frames.	Files	N. D'Agostino, S. Mantenuto, E. D'Anastasio, D. Cheloni.	Any use should be defined in agreement with Nicola D'Agostino	nicola.dagostino@ingv.it	Integration of data from different GPS networks improves the definition of the velocity field
D5	Map of strain rate and geodetic moment rate at ATF test site.	Map	N. D'Agostino, S. Mantenuto, E. D'Anastasio, D. Cheloni.	Any use should be defined in agreement with Nicola D'Agostino	nicola.dagostino@ingv.it	The geodetic moment rate gives valuable information for seismic hazard assessment
D6	Balanced sections across the ATF	Tables	Mirabella F., Barchi M.R.Brozzetti F.,,	Authorization by the authors is requested	Mirabella F. mirabell@unipg.it Barchi M. mbarchi@unipg.it	Balanced sections are important to define long term extension rate of ATF
D7	Isobath maps of the ATF and of the top of basement	Maps	Mirabella F., Barchi M.R., Brozzetti F., Lupattelli A.	Authorization by the authors is requested	Mirabella F. mirabell@unipg.it Barchi M. mbarchi@unipg.it	In a 3D image the ATF images dip variations which can affect the fault segmentation
D8	Geological and geomorphological map of the high Tiber valley	Maps	Barchi M., Melelli L., Pazzaglia F., Pucci S., Saccucci L.	Authorization by the authors is requested	Mirabella F. mirabell@unipg.it Barchi M. mbarchi@unipg.it	Different evolution of the basin is found along the High Tiber Valley
D9	Test of marine seismic deployment	Report and Video	D'Anna, G., Mangano, G., D'Alessandro, A., D'Anna, R., Passafiume G., Speciale S., Passarello S.	None	Giuseppe.danna@ingv.it , giorgio.mangano@ingv.it alessandro.dalessandro@ingv.it	The development of an Italian OBS network is very important

D10	Test of the acoustic link to get quasi-real time data from OBS stations was done only in the lab, will be done at sea in October 2010	Done only in the lab see report	OBS Lab Gibilmanna, Experimental Seismology Laboratory – CNT	None	Giuseppe.danna@ingv.it	The acoustic link is fundamental for the development of OBS quasi-real time acquisition
D11	Integrated data archive of continuous recordings for the period October 2007-December 2010 at the Messina strait test-site	Data	Moretti Govoni Margheriti Mandiello Baccheschi Lauciani Pintore	Available on the S5 web site	milena.moretti@ingv.it	In this archive seismic data are available to the scientific community
D12	Refined earthquakes locations in the Tyrrhenian and Ionian regions around Messina Strait to define seismogenic structures	Not done, work in progress	Moretti Margheriti Castellano Govoni Basili Bono	None	milena.moretti@ingv.it	
D13	Code for automatic shear wave splitting evaluation	Script and manual	Piccinini, Pastori, Margheriti, Bianco,Zaccarelli, Wüstefeld	Available on request	Davide.piccinini@ingv.it	The code speed up anisotropy evaluations but results should be interpreted by an expert
D14	Processing of all available GPS data for the Messina strait area, map of the horizontal strain-rate field and computation of the inter-seismic strain loading and deep geometry of the 1908 Messina fault	maps	Mattia M., Palano, M., Bruno, V. and Cannavò F., Serpelloni, E., Bürgmann R., Anzidei M., Baldi P., Mastrolembo B.	Available on request	mattia@ct.ingv.it	It helps understanding the tectonics of the Messina region
D15	Modelling of the source responsible for the December 28, 1908 earthquake, by using a numeric approach (i.e. finite element)	maps	Marco Aloisi	Work in progress	aloisi@ct.ingv.it	It is a work in progress which underlines the difficulties in constraining the 1908 source
D16	Focal mechanism estimated in the Messina Staits area	Digital table	D'Amico, S., Orecchio, B., Presti, D., Zhu, L., Herrmann, R. B., Neri, G.	None	sebdamico@gmail.com; dpresti@unime.it	Focal mechanisms of low/moderate earthquakes have been useful to detect stress changes in the Messina Straits area
D17	Main parameters of the stress fields	Digital table	D'Amico, S., Orecchio, B., Presti, D., Neri, G.	None	orecchio@unime.it;dpresti@unime.it	The new moment tensor better defined the tectonic stress accumulation mechanisms and consequent processes of seismogenic faulting

D18	Green's function database from ambient seismic noise for the ISNet network (Irpinia test-site)	D	G.Festa	None	festa@na.inf.it	Use of noise to determine velocity models and health of stations
D19	Resolution analysis for the cross-correlation technique at high frequency	R	G. Festa	None	festa@na.infn,.it	Investigate the limits of applicability of the seismic noise cross-correlation method
D20	Refined re-picking arrival time catalogue and earthquake locations (Irpinia test-site)	D	C. Satriano	None	aldo.zollo@unina.it	Refined estimates of arrival times and eqk locations
D21	Parametric catalogue of micro-earthquakes including source parameters (Irpinia test-site)	D	C. Satriano	None	aldo.zollo@unina.it	Refined estimates of source and attenuation parameters. Scaling laws.
D22	Digital 3 D velocity model including interface and event re-location (Irpinia test-site)	NM	N. Maercklin	None	aldo.zollo@unina.it	Small scale 3D P- and S- velocity model for eqk location.
D23	Catalogue of reflected/converted phase arrival times from micro-earthquake data	Not Done work in progress				
D24	Acquisition, storage, analysis and modelling of high-rate GPS data in the Irpinia test site	Data and description of the analysis	D'Ambrosio C., Falco L., Avallone A.,	Data storage temporarily with restricted access	Avallone A.	High rate GPS opens new research fields and helps in evaluating coseismic displacement

#	**description**	**type**	**authors**	**restrictions**	**contact person**	**relevance**
DAQ1	Five additional continuous GPS stations integrated into the RING	Data	Cecere, Abruzzese, D'Ambrosio, De Luca, Falco, Mammolo,Minichiello , Zarrilli	Data available only to the INGV users ftp:\\gpsgiving.gm.ingv.it	Cecere Gianpaolo	It improved the monitoring during the aftershock sequence
DAQ2	Five additional seismic stations with real time acquisition	Data	Cecere, Abruzzese, De Luca, Falco, Zarrilli	Data available to the public http://iside.rm.ingv.it/ http://eida.rm.ingv.it/	Cecere Gianpaolo	It improved the monitoring during the aftershock sequence

DAQ3	Integrated SEED waveform database	Databank	Govoni, Di Stefano, Chiaraluce, Moretti, Pintore, Lauciani	Data available to the public (see text above)	aladino.govoni@ingv.it	In this archive seismic data are available to the scientific community
DAQ4	Refined hypocentral locations of the seismic sequence (complete)	Scientific paper - File (+map and table)	Chiaraluce, L., De Gori, P., Di Stefano, R. et al. see UR report	Hypocentral data available under request	pasquale.degori@ingv.it lauro.chiaraluce@ingv.it	It identifies faults activated during the seismic sequence
DAQ5	focal mechanism estimated in the L'Aquila area	Digital table	D'Amico, S., Orecchio, B., Presti, D., Zhu, L., Herrmann, R. B., Neri, G.	Available on request	sebdamico@gmail.com; orecchio@unime.it	Moment tensor solutions for small and moderate earthquakes.
DAQ6	Report on the refined estimates of source and attenuation parameters inferred from the analysis of aftershock records of the L'Aquila 2009 earthquake sequence	R/D	A.Orefice	None	aldo.zollo@unina.it	Refined estimates of source and attenuation parameters. Scaling laws.
DAQ6b	Strong motion data base of L'Aquila aftershock sequence (RAN and INGV networks)	D	A.Orefice	For RAN, a data subset will be distributed through ITACA (S4)	aldo.zollo@unina.it	Earthquake source parameters and scaling law. Refined ground motion prediction equations
DAQ7	Variations in time of structural characteristics (Vp/Vs, anisotropy) (complete on foreshock data, in progress on aftershocks data)	Scientific paper	Lucente, F.P., De Gori, P., Marheriti, L., Piccinini, D., Di Bona, M., Piana Agostinetti, N.	Article	pasquale.degori@ingv.it	This study contribute to the understanding of the seismogenic process
DAQ8	High-resolution reflectivity images and Vp models of the Middle Aterno Valley	Work in progress See report			Luigi.improta@ingv.it	
DAQ9	Geometry of active faults in the Middle Aterno	Delayed See report			Luigi.improta@ingv.it	

DAQ10	Buried geometry and velocity structure of Quaternary basins in the Middle Aterno Valley	Delayed See report			Luigi.improta@ingv.it	
DAQ11	List of parameters describing active faults	File *.pdf	Vittori, E.; Cinti, F.R.; Pucci, S.; Pantosti, D.; Vannoli, P.; De Martini, P.M.; Montone, P.; Gori, S.	None	Cinti, F.R.; Pucci, S.	Preparatory for the mapping of active faults and basis for the Geo-database
DAQ12a	Map of active faults	File *.jpg	Cinti, F.R.; Pucci, S.; et al. see UR Report	None	Cinti, F.R.; Pucci, S.	Improvement of previous compilations improves the assessment of earthquakes hazard.
DAQ12b	Geodatabase	Files: *.gdb; *.mxd; *.mdb;	Patera, A.	Restricted to participants of the S5 Project	Cinti, F.R.; Pucci, S.	Facilitate the input and extraction of collected and archived information;
DAQ13	Log of the Mo'tretteca trench and core, ages of layers, interpretation of the events	Files *.pdf; Table *.pdf	Cinti, F.R.; Pucci, S.; Pantosti, D.; De Martini, P.M.; Civico, R.; Pierdominici, S.; Cucci, L.; Brunori, C.; Pinzi, S.	Restricted to participants of the S5 Project	Cinti, F.R.; Pucci, S.	New data on the seismic behavior of the Paganica Fault
DAQ14	Suggested future activities	Files *.pdf;	Cinti, F.R.; Pucci, S.; Pantosti, D.; De Martini, P.M.; Civico, R.; Pierdominici, S.; Cucci, L.; Brunori, C.; Pinzi, S.	No	Cinti, F.R.; Pucci, S.	Development of rupture segmentation models for the Paganica Fault and the faults in the surrounding region
DAQ15	Vision paper on possible developments of short-term earthquake forecasting models	Document *.doc	Marzocchi, W.	Confidential	MarzocchiW.	The document reports possible guidelines for future research on short-term earthquake forecasting

Management

The S5 activities have been developed in according to a Work Breakdown Structure and a work plan which has been discussed and agreed among Task and research unit Responsibles. In the two year of activities, project S5 had some plenary meetings and several internal workpackage workshops. One can access to the presentations at the meetings and the programs of the workshops through the project website: http://dpc-s5.rm.ingv.it/en/Meetings.html.
The project started with a kick-off meeting that was held on the July, 4, 2008 in Rome, where the plan and content of activities has been presented and discussed.
In October 2008, each research group met to prepare the presentations for the International Evaluation Committee; preliminary results have been also presented to the CIV (International Evaluation Committee of INGV) in November of the same year.
With the celebration, in 2008, of the centennial of the 1908 Messina earthquake, a conference promoted by the Dipartimento Protezione Civile was organized in collaboration with INGV and Messina University, in Reggio Calabria in December 2008, with a high attendance and participation of S5, TASK2 researchers.
In March 2009, the velocity fields of the Messina Strait area that were obtained by the different groups were presented and discussed in a joint workshop between projects S5 and S1.
WP 2.3 analyzed anisotropic parameters at different sites, the results of which will be discussed and interpreted together with Daniela Di Bucci in the framework of a collaboration with DPC (Interscambio di professionalita' nell'ambito della convenzione DPC-INGV 2007- 2009).
A coordination meeting of researchers of Task 3 was held on April,2009 at the University of Naples, with the aim to overview the achieved results and organizing the reporting activities for the end of the project.
On 19-21 ottobre 2009 there was in Rome the First Annual Meetingl of the Seismological projects DPC-INGV 2007-2009 where we presented a general description of the project advances and several applications of the skills acquired in S5 to the L'Aquila dataset. Moreover in the poster sessions all the studies developed in the project were shown.
On the March,24 2010 the second year S5 project meeting has been held at INGV Rome, where final results, criticalities and future perspectives have been discussed among Workpackage, task responsibles and coordinators.

Problems and difficulties

Some of the activities were delayed for technical problems (see UR reports) in general the occurrence of the L'Aquila earthquake on April 2009 introduced a new scientific priority in the working program of the INGV staff and of the Italian seismological community and introduced a delay in the working program of the Test sites. On the other hand the INGV emergency management during the L'Aquila seismic sequence strongly benefited of the work done in S5.

Conclusions, perspectives and open issues

The development of dense seismic and geodetic networks to be integrated into the National Seismic Networks is an important target for improving the monitoring of the Italian territory. In fact thanks to the work done in the test sites we have developed automatic and semi-automatic data management procedures to archive seismic data gathered in temporary experiments inside a common SEED-format archive (EIDA) making the continuous recordings available to the scientific community.
This technological upgrade was also accompanied by the development of procedure to improve imaging of fault structures through

- the refined analysis of background seismicity and microearthquake source parameters the seismic sources and the crust.
- the integration of seismic and geological methods to reconstruct subsoil images

- the monitoring of fault structures through high frequency continuous GPS
- the determination of stress orientation from seismic anisotropy and focal mechanisms and GPS
- the methodological development aimed at the detailed 3D images integrating travel time tomography, reflected/converted wave imaging and Green's function extraction from ambient noise cross-correlation and stacking

The final target is to improve our capability to image and monitor the spatial and temporal changes of the earthquake source and crustal parameters in relation to occurrence of background seismicity along active fault zones.

New skills have been acquired in S5 project thanks to the scientific and technological efforts done in the occasion of the 2009 L'Aquila earthquake sequence, were the monitoring networks were deployed rapidly after the earthquake occurrence, and some of techniques developed in S5 have been used to analyze the data arriving from the mobile networks.

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http://dpc-s5.rm.ingv.it/ ;

http://lxserver.ov.ingv.it/cgi-bin/isnet-events/isnet.cgi

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