A MULTI-METHOD APROACH TO IDENTIFY OUTCROPPING AND BURIED ACTIVE FAULTS: CASE STUDIES

P. Luiso[1], V. Paoletti[1], G. Gaudiosi[2], R. Nappi[2], F. Cella[3], M. Fedi[1]
[1] *Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse, Università degli Studi «Federico II», Napoli, Italy*
[2] *Istituto Nazionale di Geofisica e Vulcanologia, Sezione OV, Napoli, Italy*
[3] *Dipartimento di Scienze della Terra, Università degli Studi della Calabria, Arcavacata di Rende (CS), Italy*

Introduction. This study consists in a multiparametric data analysis carried out by the integration of tectonic, seismic and gravimetric datasets in GIS (Geographic Information System) environment, with the aim of identifying seismogenic structures and constrain their geometry. We have chosen three areas to test this innovative approach:

- Abruzzo area (central Italy), one of the most active zones from a geodynamic point of view of the Italian Apennines. It is characterized by the occurrence of intense and widely spread seismic activity. The NE–SW extensional regime affecting this portion of the chain generated subparallel NW–SE trending normal fault systems and large intermountain extensional basins such as the L'Aquila, Sulmona and Fucino ones (Lavecchia *et al.*, 2012). The L'Aquila area was struck by the Mw 6.1 earthquake (on April 6, 2009) and by its sequence;
- San Giuliano di Puglia area (Molise, southern Italy), whose 2002–2003 seismic sequence (two main events with Ml 5.4 and 5.3, recorded on October 31 – November 1, 2002) was close to the frontal thrust of the Apennine units. Nevertheless, the hypocentral depths indicate that the earthquakes were located below the underlying Apulian shelf-carbonate sequence (Valensise *et al.*, 2004; Galli *et al.*, 2004; Chiarabba *et al.*, 2005);
- Massico Mt., a NE trending carbonatic horst in the northern Campanian region (southern Italy) bordered by two anti-Appenninic normal faults that separate it from the two depressions of Garigliano and Volturno rivers (Billi *et al.*, 1997). The fault in the northern sector of the Massico Mt. has a subvertical geometry and the fault in the southern sector of the mount is a normal fault dipping 70° SE.

Data analysis. The "*fault dataset*" was built by merging all outcropping and buried faults extracted from geological and geophysical papers (Cinque *et al.*, 2000; Billi and Salvini, 2000; Galadini and Galli, 2000, 2003; Milia *et al.*, 2003; Boncio *et al.*, 2004; Valensise *et al.*, 2004; Vezzani *et al.*, 2010; Falcucci *et al.*, 2011; Moro *et al.*, 2013) and from the available structural and geological maps: ITHACA catalogue; DISS database, several geological sheets 1:50,000 from ISPRA-CARG project; the Neotectonic Map of Italy 1:500,000 (Ambrosetti *et al.*, 1987); the Structural Map of Italy 1:500,000 (Bigi *et al.*,1992); Geological Map 1:100,000; Geological Map of the southern Apennines 1:250,000 (Bonardi *et al.*, 1988), the Geological- Structural map of the central-southern Apennines (Vezzani *et al.*, 2010). The faults extracted have been digitalized and plotted on the shaded relief maps of the corresponding three areas. We created an attribute table containing for each fault: ID number, age, geographical coordinates, slip rate, bibliography.

The "*earthquake dataset*" consists of seismic data extracted from the available historical and instrumental catalogues: CPTI15 Catalogue of Parametric Italian Earthquakes (Rovida *et al.*, 2015) containing the earthquakes locations from year 1000 to 2014 A.D.; ISIDE (Italian Seismological Instrumental and Parametric Database) database containing all the Italian earthquakes since 1985 recorded by the Italian permanent seismic network. Seismic data have been merged in a single data set and an attribute table that includes the date of the seismic event, geographic coordinates and the focal parameters for each earthquake was created.

As regards the "*gravimetric dataset*", we performed a *Multiscale Derivative Analysis* (MDA, Fedi *et al.*, 2005) of the gravity field, which makes use of the good resolution properties of the *Enhanced Horizontal Derivative* signal (EHD, Fedi and Florio, 2001), a high-resolution edge estimator. We used the MDA to interpret the Bouguer anomalies of the three studied areas. Gravity data are extracted from the Bouguer Gravity Anomaly Map of Italy published by CNR (Carrozzo *et al*., 1986; reduction density: 2.4 g/cm^3) with a step grid of 1 km. The inclusion of higher vertical derivatives in the EHD allows a good detail for shallower sources. By computing a medium scale EHD, we are able to recognize both shallow and deep structures. From the MDA gravimetric maps, we have mapped the gravimetric lineaments and created a layer with an associated attribute table in which, for each MDA maximum, we reported the correlation with the local topography and the correlated fault and earthquakes. Moreover, we used the *DEXP method* (*Depth from Extreme Points*, Fedi, 2007; Fedi and Pilkington, 2012) to constrain the geometry of the identified seismogenic faults (dip angle).

The three different datasets (faults, earthquakes and gravimetric lineaments) were overlapped above the DEM of the studied areas. This multi-method approach allowed us to highlight four possible scenarios:

- a strong correlation between faults identified by literature, earthquakes epicentral distribution and MDA lineaments could confirm the presence of active faults already known in literature;
- a clear correlation between MDA maxima and an associated spatial distribution of earthquakes epicentral location, but without the presence of faults known from geological data, could suggest the existence of buried active faults;
- the presence of MDA maxima correlated with faults reported in the geological datasets and literature but with no associated earthquakes could imply the existence of inactive or silent faults;
- the existence of faults, both active and inactive, identified from the literature but not correlated with MDA maxima could be due to faults putting in contact two lithologies with a similar density.

In Fig. 1 we show the map of faults and earthquakes overlapped on medium scale MDA of the study areas.

The Abruzzo region is marked by MDA maxima with NW–SE and NE–SW strikes. Our study is focused on the area hit by the 2009 L'Aquila seismic sequence. A trend of MDA maxima runs parallel to the Paganica Fault but shifted westward of about 6 km. In the hypothesis of correlation with a tectonic contact, this trend is compatible with a fault model displacing rocks with different densities in the depth range of 5–15 km, along a flat surface dipping westward with an angle of 45°. A good agreement exists between such a model surface and the fault plane defined by the hypocenters of the seismic events correlated to the Paganica Fault (Chiaraluce *et al*., 2011), even though they are limited within the depth range of 4–10 km (Luiso *et al*., 2016a). This suggests that only the intermediate part of the fault plane could have been reactivated during the recent 2009 seismic swarms.

The San Giuliano di Puglia area, hit by the 2002–2003 seismic sequence, is marked by strong Apennine MDA anomalies and minor anti-Apennine ones. The town of San Giuliano di Puglia is located above a NW–SE normal fault dipping SW, characterized by scarce seismicity. The seismic swarm is concentrated in the western part of the area correlated with different trends of gravimetric anomaly, including an E–W MDA maximum (Luiso *et al*., 2016b).

The third studied area, the Mt. Massico area, is bordered by two NE–SW gravimetric anomalies, coincident with two normal faults known from the literature (Gaudiosi *et al*., 2012). The 3D hypocentral map of earthquakes after relocation highlights clustering of events coincident with the two main faults.

Conclusion. In this paper a multiparametric data analysis has been applied to the Abruzzo (central Italy), San Giuliano di Puglia (Molise, southern Italy) and Mt. Massico (Campania, southern Italy) areas through merging of seismicity, tectonic and gravity data, with the aim of identifying structural lineaments responsible for seismic activity. Accordingly, three thematic data sets have been generated for these areas: “fault”, “earthquake” and “gravimetric” datasets, in order to collect and integrate the whole set of existing information. The GIS system has

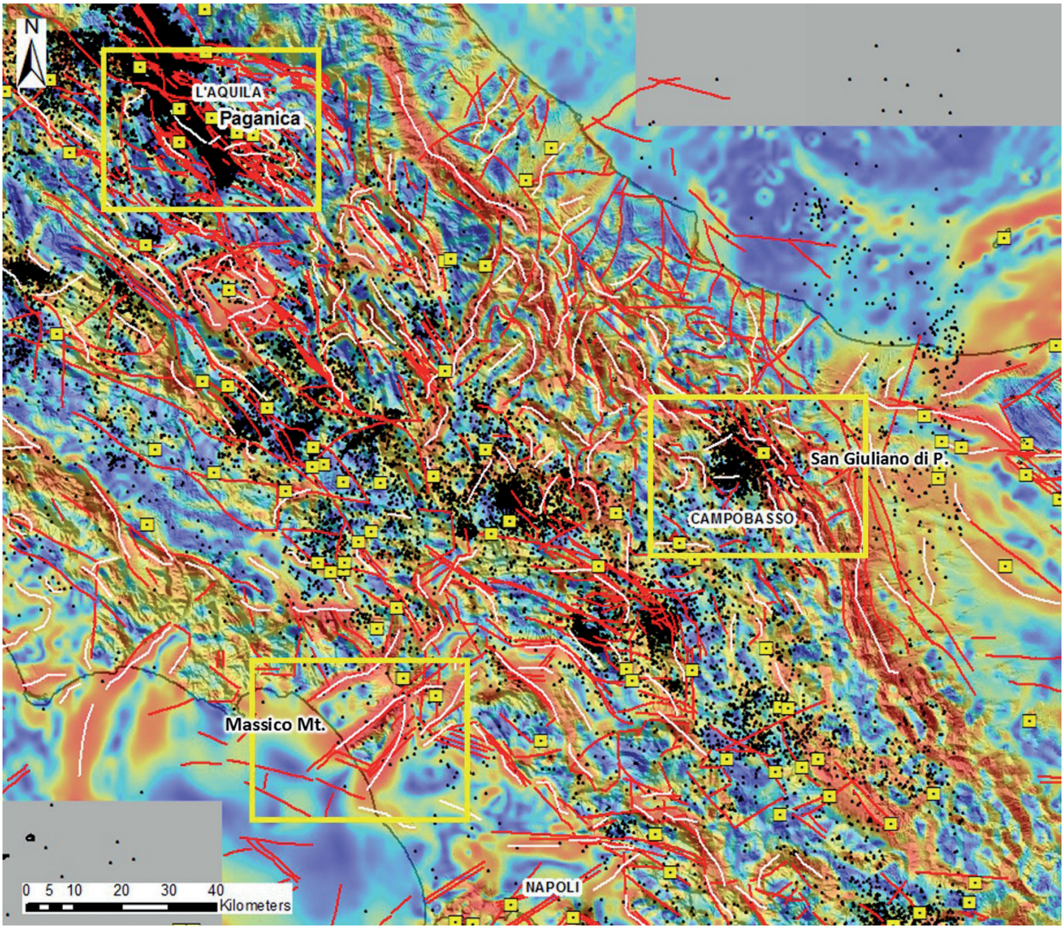

Fig. 1 – Map of the faults and earthquakes datasets overlapped on a medium scale MDA. Red lines: faults from geological maps and scientific studies; white lines: maxima of the MDA map; black dots: earthquakes from ISIDE catalogue; yellow squares: earthquakes from CPT11. The yellow boxes show the three studied areas.

proved to be a necessary tool and a powerful instrument for such interdisciplinary research, allowing managing and combining large amount of geological, geophysical and territorial data. Moreover, the *DEXP method* (*Depth from Extreme Points*, Fedi, 2007) has been employed to constrain the geometry of the seismogenic faults (dip angle). Our multiparametric approach has provided a contribution to the seismotectonic assessment of these three areas and can be effectively applied to other areas to identify outcropping and buried active faults and give a contribution to seismic hazard assessment.

References

Ambrosetti P., Bartolini C., Bosi C., Carraro F., Ciaranfi N., Panizza M., Papani G., Vezzani L., Zanferrari A.; 1987: *Neotectonic Map of Italy (Scale 1:500.000)*. C.N.R., P. F. Geodinamica.

Bigi G., Cosentino D., Parotto M., Sartori R., Scandone, P.; 1992: *Structural model of Italy and gravity map, scale 1:500,000*. Progetto Finalizzato Geodinamica CNR, Quad. Ric. Sci. 3, 114.

Billi A., Bosi V., De Meo A.; 1997: *Structural characterization of Mount Massico in the framework of the Quaternary evolution of the coastal depressions of the Garigliano and Volturno Rivers (northern Campania, Italy)*. Italian Journal of Quaternary Sciences 10(1), 1997, 15-26.

Bonardi G., D'Argenio B., Perrone V.; 1988: *Carta Geologica dell'Appennino Meridionale in scala 1:250.000*. Mem. Soc. Geol. It, 41, 1341.

CARG-ISPRA: Istituto Superiore per la Protezione e la Ricerca Ambientale. *http://sgi.isprambiente.it/geoportal/catalog/content/project/carg.page*.

Carrozzo M.T., Luzio D., Margiotta C., Quarta T.; 1986: *Gravity anomaly map of Italy*. Progetto Finalizzato Geodinamica. Sottoprogetto: Modello Strutturale Tridimensionale: Rome, Italy, CNR

Chiarabba C., Jovane L., DiStefano R.; 2005: *Mainshocks and aftershocks of the 2002 molise seismic sequence, southern Italy*. Journal of Seismology. October 2005 DOI: 10.1007/s10950-005-0633-9.

Chiaraluce L., Valoroso L., Piccinini D., Di Stefano R., De Gori P.; 2011: *The anatomy of the 2009 L'Aquila normal fault system (central Italy) imaged by high resolution foreshock and aftershock location*. Journal of Geophysical Research 116, B12311, doi:10.1029 /2011JB008352, 2011

DISS Working Group; 2015. *Database of Individual Seismogenic Sources (DISS), Version 3.2.0: A compilation of potential sources for earthquakes larger than M 5.5 in Italy and surrounding areas*. http://diss.rm.ingv.it/diss/, Istituto Nazionale di Geofisica e Vulcanologia; DOI:10.6092/INGV.IT-DISS3.2.0

Falcucci E., Gori S., Moro M., Pisani A.R., Melini D., Galadini F., Fredi P.; 2011: *The 2009 L'Aquila earthquake (Italy): what next in the region? Hints from stress diffusion analysis and normal fault activity*. Earth Planet. Sci. Lett. 305, 350–358.

Fedi M., Cella F., Florio G., Rapolla A.; 2005: *Multiscale Derivative Analysis of the Gravity and Magnetic Fields of the Southern Apennines (Italy)*. CROP PROJECT: Deep Seismic Exploration of the Central Mediterranean and Italy, Edited by I.R Finetti, 281–318.

Fedi M., Florio G.; 2001: *Detection of potential fields source boundaries by enhanced horizontal derivative method*. Geophysical Prospecting, 2001, 49, 40–58.

Fedi M.; 2007: *DEXP: A fast method to determine the depth and the structural index of potential fields sources*. Geophysics 72(1) doi: 10.1190/1.2399452 72(1), I1–I11.

Fedi M., Pilkington M.; 2012: *Understanding imaging methods for potential field data*. Geophysics 77(1), G13–G24 doi: 10.1111/j.1365-2478.2009.00808.x

Galadini F., Galli P.; 2000: *Active tectonics in the Central Apennines (Italy). Input data for seismic hazard assessment, Natural Hazards* 22, 225–268, doi 10.1023/A: 1008149531980.

Galadini F. & Galli P.; 2003: *Paleoseismology of silent faults in the central Apennines (Italy): the Mt. Vettore and Laga Mts. Faults*, Annals of Geophysics, 46, 815-836.

Galli P., Molin D.; 2004: *Macroseismic Survey of the 2002 Molise, Italy, Earthquake and Historical Seismicity of San Giuliano di Puglia*. Earthquake Spectra, Volume 20, No. S1, July 2004 S39–S52.

Gaudiosi G., Alessio G., Cella F., Fedi M., Florio G., Nappi R.; 2012: *Multiparametric data analysis for seismic source identification in the Campanian area: merging of seismological, structural and gravimetric data*. Bollettino di Geofisica Teorica ed Applicata Vol. 53, n. 3, 283–298; September 2012, doi 10.4430/bgta0050.

ISIDe Working Group INGV; 2010: *Italian Seismological Instrumental and parametric database*. http://iside. rm.ingv.it.

ITHACA-ISPRA: Istituto Superiore per la Protezione e la Ricerca Ambientale. *http://www.isprambiente.gov.it/it/progetti/suolo-eterritorio-1/ithaca-catalogo-delle-faglie-capaci*.

Lavecchia G., Ferrarini F., Brozzetti F., De Nardis R., Boncio P., Chiaraluce L.; 2012: *From surface geology to aftershock analysis: Constraints on the geometry of the L'Aquila 2009 seismogenic fault system*.. Ital. J. Geosci., 131, 330–347.

Luiso P., Paoletti V., Gaudiosi G. Nappi R., Cella F., Fedi M.; 2016a: *Identification of active faults in Abruzzo area (central Italy) through the analysis of geological, seismological and gravimetric data*. Geophysical Research Abstracts Vol. 18, EGU2016-681, 2016 EGU General Assembly 2016.

Luiso P., Paoletti V., Gaudiosi G., Nappi R., Cella F., Fedi M.; 2016b: *Analysis of the San Giuliano di Puglia (Southern Italy) active faults: an integrated approach*. Rend. Online Soc. Geol. It., Suppl. n. 1, Vol. 40, 109.

Milia A., Torrente M.M., Russo M., Zuppetta A.; 2003: *Tectonics and crustal structure of the Campania continental margin: relationships with volcanism* .Mineralogy and Petrology 79: 33–47 doi 10.1007/s00710-003-0005-5

Moro M., Gori S., Falcucci E., Saroli M., Galadini F., Salvi S.; 2013: *Historical earthquakes and variable kinematicvbehaviour of the 2009 L'Aquila seismic event (central Italy) causative fault, revealed by paleoseismological investigations*. Tectonophysics 583, 131–144.

Rovida A., Locati M., Camassi R., Lolli B., Gasperini P.; 2016: *CPTI15, the 2015 version of the Parametric Catalogue of Italian Earthquakes*. Istituto Nazionale di Geofisica e Vulcanologia. doi:http://doi.org/10.6092/INGV.IT-CPTI15

Valensise G., Pantosti D., Basili R.; 2004: *Seismology and tectonic setting of the 2002 Molise, Italy, earthquake*. Earthquake Spectra 20, 23–37, doi: 10.1193/1.1756136

Vezzani L., Festa A., Ghisetti F.; 2010: *Geological-Structural Map of the Central-Southern Apennines, Italy, in Geology and Tectonic evolution of the Central-Southern Apennines, Italy*. Geological Society of America Special Paper 469.