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Geodetic, geological and geophysical evidence of active tectonics in south-western Sicily and offshore

Giovanni Barreca ([a]), Valentina Bruno ([b]), Chiara Cocorullo ([b]), Fabrizio Cultrera ([a]), Luigi Ferranti ([c]), Francesco Guglielmino ([b]), Laura Guzzetta ([c]), Mario Mattia M. ([c]), Carmelo Monaco ([a]) & Fabrizio Pepe ([d])

([a]) Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Sezione di Scienze della Terra, Università di Catania, Corso Italia 57, 95129 Catania, Italy. E-mail: g.barreca@unict.it
([b]) Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo - Sezione di Catania, P.zza Roma, 2, 95123 Catania, Italy.
([c]) Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse (DiSTAR), Università di Napoli "Federico II", Largo S. Marcellino 10, 80138 Napoli, Italy.
([d]) Dipartimento di Scienze della Terra e del Mare, Via Archirafi 22, 90123 Palermo, Italy.

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ABSTRACT

Starting from the analysis of interferometric data, which reveal a differential ground motion on a SW-NE alignment between Campobello di Mazara and Castelvetrano (south-western Sicily), we analyzed the evidences of active tectonics in this frontal sector of the orogen. The alignment falls within the seismogenic zone where the 1968 Belice earthquake sequence occurred. Even though this is the strongest seismic event recorded in Western Sicily in historical times, focal solutions provide different hypothesis on trend and kinematics of possible faulting mechanism. The discovery of dislocated archaeological and recent markers within the seismogenic zone enabled us to provide, for the first time, the likely evidence of surface expression for recent coseismic-related deformation. The geological data were complemented by new marine geophysical and GPS surveys with the aim to verify a possible correspondence between geodetic and geological-morphological data. The results confirm that oblique thrusting and folding, in response to current NW-SE oriented compression, is still active and this aspect must be seriously analysed in the evaluation of the seismic hazard of this densely populated part of Sicily.

KEY WORDS: Sicilian fold and thrust belt, geodesy, active tectonics.

INTRODUCTION

Before the 1968 Belice seismic sequence (equivalent moment magnitude of the main shock ~ 6), the westernmost segment of the Sicilian Fold and Thrust Belt (hereafter, SFTB) was considered a rather seismically quiescent region. Moreover, focal planes solutions provided by many authors show controversial interpretations about the possible geometrical and kinematic pattern of the 1968 seismogenic source. Computed focal solutions provide in fact different hypothesis on trend and kinematics of possible faulting mechanism that range from pure thrusting on a WSW-ENE striking plane to right lateral transpression on a NNW–SSE striking plane (Bottari, 1973; McKenzie, 1972; Gasparini et al., 1985; Anderson & Jackson, 1987; Frepoli & Amato, 2000). These ambiguities still remain unresolved due to the fact that the 1968 earthquake sequence did not produce a typical seismic landscape (sensu Michetti et. al, 2005) and that, as result of low magnitude of the seismic events, coseismic fault ruptures were never reported. Monaco et al. (1996), based on geological and morphostructural analysis, suggested a NNW-dipping crustal blind thrust ramp as the possible seismogenic source for the 1968 Belice earthquake sequence. Accordingly, Lavecchia et al. (2007), consider this area as part of a unique regional-scale seismogenic structure (named Sicilian Basal Thrust) whose focal mechanisms are compatible with a nearly average N–S shortening and with some field evidence of active fold-and thrust deformation at the Sicilian chain front.

New interferometric data reveal a differential ground motion on a SW-NE alignment between Campobello di Mazara and Castelvetrano (fig. 1) within the seismogenic zone where the 1968 Belice earthquake sequence occurred. So, new field, marine and GPS surveys, supported by the morphometric analysis of a 2x2m grid resolution DEM, have been carried out with the aim to verify possible correspondence between interferometric data and geological-morphological ones. In correspondence of the offshore extension of the alignment, a shaded relief representation of sea-floor bathymetry has been elaborated and new seismic lines have been acquired and interpreted. Moreover, the discovery of dislocated archaeological and recent marker near the epicentral area of the 1968 seismic sequence enabled us to provide, for the first time, the likely evidence of surface deformation related to coseismic faulting. Finally, we aimed at verifying if stress accumulation is presently occurring on the structure. To this aim, we surveyed some benchmarks of a GPS network of the Italian Istituto Geografico Militare realized in 1994 for cartographic and geodetic purposes.

GEOLOGICAL SETTING

Western Sicily (fig. 1A) is a segment of the south-verging foreland-ward migrating SFTB, the emerged portion of a larger orogenic system which developed in the central Mediterranean region as result of the Neogene-Quaternary Africa-Europe collision processes (Ben Avraham et al., 1990). The westernmost segment of the SFTB is a NE-SW oriented contractional belt, deriving from deformation of Meso-Cenozoic successions of the Africa paleo-margin. The structural architecture of the belt is imaged by deep seismic

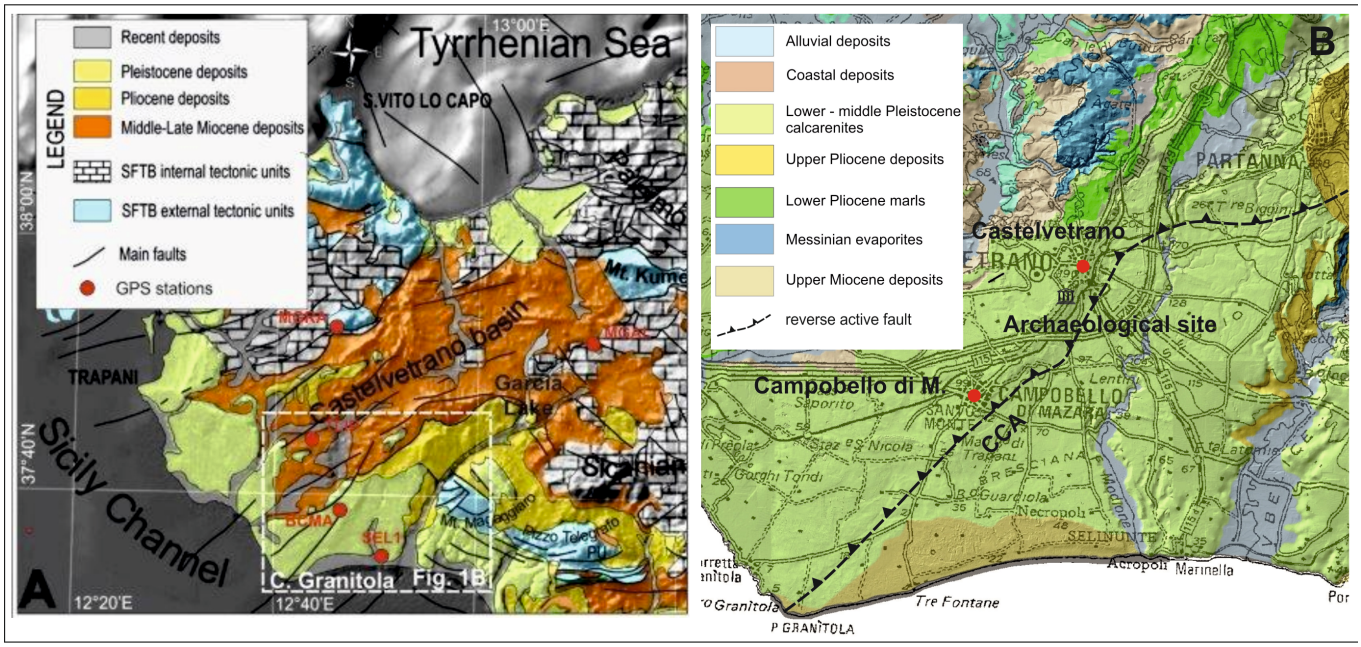

Fig. 1 – A, Tectonic sketch map of western Sicily. B, Geological shaded-relief map of the outcropping area of the Campobello di Mazara-Castelvetrano alignment (CCA).

explorations that show a 1-3 km thick fold and thrust system developed since middle Miocene and superposed on a ~10 km thick thrust duplex (Catalano et al., 2000; Bello et al., 2000; Finetti et al., 2005; Barreca & Maesano, 2012). Deep-seated thrusting refolded and breached the previously stacked rock units (e.g. the overlain thrust system) and was accompanied by the development of large syntectonic marine basins at the footwall of major structures (e.g. the Castelvetrano Basin, see fig 1for location). The top of the sedimentary succession is represented by Pleistocene terraced calcarenites, locally deformed by the frontal contractional structures.

Frontal thrusting in south-western Sicily is still seismically active, as indicated by the 1968 Belice Valley destructive earthquake sequence (Monaco et al., 1996; DISS Working Group, 2010). Accordingly, seismotectonic processes accommodate active compression at the front of the SFTB and particularly along deep-seated thrust planes (Lavecchia et al., 2007). Geoarchaeological evidences also suggest the occurrence of two ancient earthquakes, occurred between 370 and 300 B.C. and between the 300 and 600 A.D., that destroyed the old Greek colony of Selinunte (Bottari et al., 2009). Anyhow, with the exception of these destructive earthquakes, historical and instrumental records (ISIDE data base; http://iside.rm.ingv.it/iside/standard/index.jsp; see also Rigano et al., 1999; Rovida et al., 2011) reveal that the seismicity of south-western Sicily is characterised by only few moderate magnitude earthquakes with epicentres located from the contractional belt to the Sicily Channel rift (fig. 1A).

EVIDENCE FOR ACTIVE TECTONICS FROM MULTIDISCIPLINARY APPROACH

DInSar PS data

We measured ground deformation rates in western Sicily via the Stanford Method for Persistent Scatterers [StaMPS] (Hooper, 2008) using image data from the ESA ENVISAT satellite spanning the time period 2003-2010. Focused SAR images are produced using the ROI−PAC software package developed by JPL (Rosen et al., 2004) and the interferometric processing is performed using the Doris software package developed by the Delft University of Technology. The SAR dataset analysed in this work comprises 37 ENVISAT images from 2003-2010, acquired from Track 308 descending orbit. The external DEM (SRTM NASA mission) used to remove the topographic component from the interferometric phase has a resolution of 80 x 80m, with a vertical accuracy less than 10 meter.

Inspection of the Line Of Sight (LOS) mean velocity map evidenced two areas characterized by differential ground motion (fig. 2): (i) the first area is located between the villages of Marsala and Mazara del Vallo, placed on a broad zone of active limestone quarries, which probably have caused the perturbation in the LOS velocity map; (ii) the second one marks, with a roughly SSW-NNE orientation, the abrupt decay of ground velocity along the Campobello di Mazara-Castelvetrano alignment (hereafter the CCA).

Field data

New field surveys were performed with the aim to verify if ground deformation provided by satellite data agree with geological and morphological features along the inferred alignment. Successively, the main morphological features, including hydrographic network and sea-floor bathymetry, were analyzed by using high-resolution DEM. The analysis was extended to the epicentral area of the Belice Valley earthquake (Fig. 1B). Preliminary results indicate that south-west of Castelvetrano, the differential ground motion provided by interferometric data (fig. 2) matches with vertical offset of lower-middle Pleistocene terraced calcarenites of ~ 60 m along the hinge of a large SSW-NNE trending anticline just west of

the CCA (fig. 1B). At more detailed scale, an ancient street (from Bronze to ancient Greek age; De Miro, personal communication) is dislocated by a N30E striking oblique (sinistral) reverse fault that dips toward SE at ~ 50° (fig. 3). Moreover, at the epicentral area of the Belice sequence, a concrete side-wall of the road by-passing the Garcia Lake (fig. 1A) is currently dislocated by a W-E trending reverse fault.

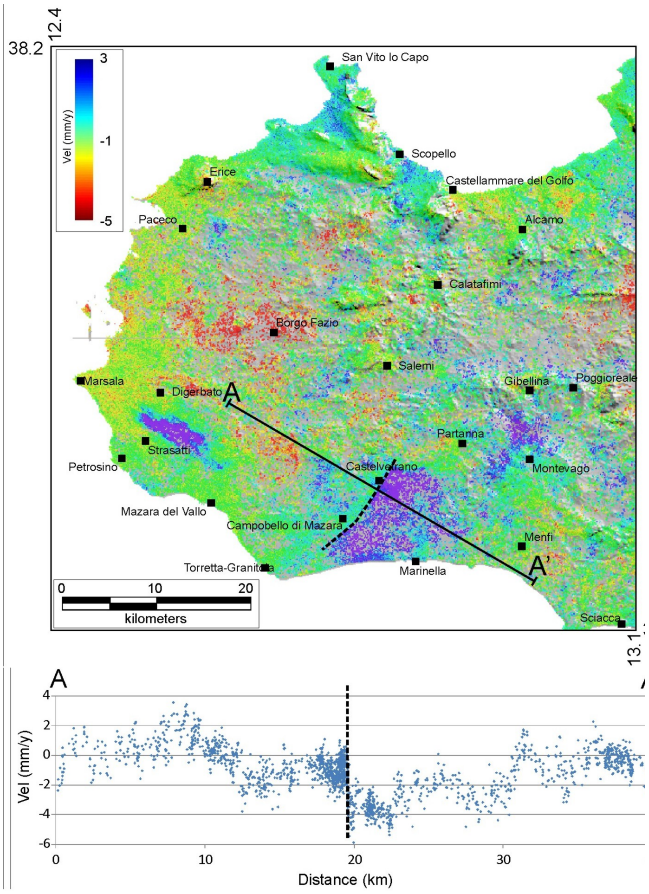

Fig. 2 - 2003-2010 Mean LOS velocity map obtained by StaMPS package using descending ENVISAT SAR image.

Marine seismic reflection profiles

A grid of high-resolution reflection seismic profiles was recorded in August 2013 along the continental shelf of Capo Granitola with the purpose of verifying the south-west, offshore prolongation of the CCA. The acoustic source used during seismic prospecting was a 1 kJ Sparker power supply with a multi-tips Sparker array.

Preliminary results indicate that the lower-middle Pleistocene calcarenites, largely outcropping on-land, are also widespread along most of the offshore area between Mazara del Vallo and Capo Granitola. Along the offshore prolongation of the CCA, small scale, reverse faults, predominantly dipping to the NW and SE, affect the calcarenites and their upper Pleistocene-Holocene sedimentary cover (fig. 4). This latter is thin or absent at water depths less than ~30 m, suggesting that a SW-NE contractional belt experienced uplift during Quaternary. Fluid expulsion from the deformed calcarenites is also preferentially concentrated along the belt.

GPS data

In 1992 the Italian IGM (Istituto Geografico Militare - www.igmi.org) started the GPS measuring of a network made up of 1260-bechmarks, about 20 km far from each other and extended over Italy. We have reoccupied five IGM benchmarks nearby to the CCA (fig. 1B) in order to calculate the velocities map of some benchmarks very close to the alignment revealed

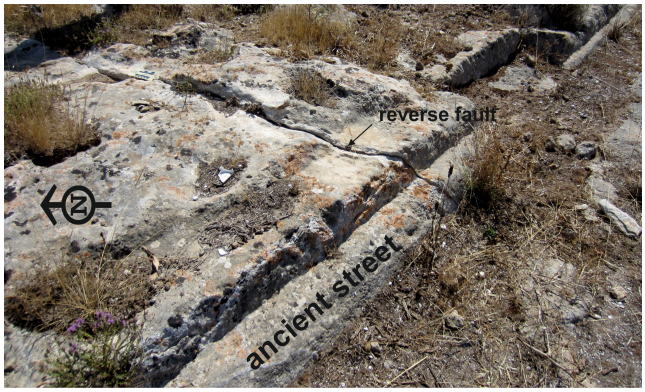

Fig. 3 - Ancient street (from Bronze to ancient Greek age; De Miro, personal communication) dislocated by a N30E striking back-thrust along the Campobello di Mazara-Castelvetrano alignment (see fig. 1B for location).

by interferometric data. The GPS survey was carried out by using Leica GX1220 receivers and AR10 antennas, whereas thw instruments used by IGM in 1994 were Trimble 4000 SSE receivers and Trimble compact with groundplane (model 22020-00) antennas.

We processed the GPS data using the GAMIT/GLOBK software (Herring et al. 2006) with IGS (International GNSS Service) precise ephemerides and Earth orientation parameters from the IERS (International Earth Rotation Service). We tied the measurements to an external global reference frame by including in our analysis the data from seven CGPS stations belonging to the IGS and EURA networks and operating since 1994 (GRAZ, HERS, JOZE, MADR, ZIMM). The quasi-observations were then combined with global solutions (IGS1, IGS2, EURA) provided by the Scripps Orbital and Permanent Array Center (SOPAC) at UC San Diego. The loosely constrained daily solutions were transformed into ITRF2005 (2005 International Terrestrial Reference Frame; Altamimi et al., 2007) and then rotated into a fixed Eurasia frame.

The Eurasian velocity field (fig. 1B) shows that the GPS stations of the western Sicily move with velocities ranging from about 2.6 to 3.6 mm/yr along NNW to NW directions. In particular, velocity values decrease from South to North from about 3.1 mm/yr (SEL1 GPS station) to 2.5 mm/yr (BCMA and TLIP).

DISCUSSION AND CONCLUSIONS

New field surveys along the Castelvetrano-Campobello di Mazara alignment, compared with interferometric data, suggest that active contraction occurs in south-western Sicily within the seismogenic zone of the 1968 Belice earthquake sequence. Preliminary observations indicate that it is accommodated by thrusting and folding at the front of the chain where recent Pleistocene deposits, artefacts and buildings

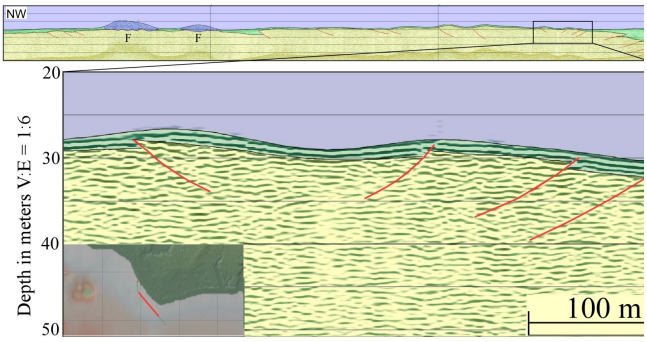

Fig. 4 – The offshore extension of the Mazara-Castelvetrano alignment as imaged in the high-resolution, depth-converted seismic Sparker profiles and its seismic interpretation. Yellow, lower- middle Pleistocene calcarenites; Green, upper Pleistocene-Holocene sediments; F, Fluid escape. Inset shows closely spaced, NW and SE-vergent reverse faults affecting lower-middle Pleistocene calcarenites in the offshore area between Mazara del Vallo and Capo Granitola.

have been dislocated. In particular, the observed active deformation occurs along a large NE-SW oriented and segmented thrust system that extends from Garcia Lake to Capo Granitola (fig. 1A). New seismic profiles along the offshore show that active thrusting continues to the south-west, in the Sicily Channel. Moreover, new measurement of the 1994 IGM GPS network have shown a velocity decrease compatible with the presence of the discontinuity highlighted by the interferometric analysis and with the observed geological and archeological markers in the investigated area.

These observations confirm that a NNW-SSE oriented compression is still going on and this aspect must be seriously analyzed for the evaluation of the seismic hazard of this densely populated area of Sicily. However, the analysis suggests that the stress may be accommodated both by multiple ruptures or aseismic creep along a seismogenic volume rather than along a single fault plane, as also shown by the great number of events that characterized the 1968 sequence. In conclusion, further investigations, such as exploratory trenches along the main displacement zone, are needed to verify if recent activity has been recorded and to evaluate more precisely its kinematics, age and rate.

REFERENCES

Altamimi Z., Collilieux X., Legrand J., Garayt B. & Boucher C. (2007) - ITRF2005: A new release of the International Terrestrial Reference Frame based on time series of station positions and Earth Orientation Parameters. J. Geophys. Res., 112, B09401.

Anderson H. & Jackson J. (1987) - Active tectonics of the Adriatic Region. Geophys. J.R. Astr. Soc., 91, 937-983.

Barreca G. & Maesano F.E. (2012) - Restraining stepover deformation superimposed on a previous fold-and thrust-belt: A case study from the Mt. Kumeta–Rocca Busambra ridges (western Sicily, Italy). J. Geodynamics. doi:10.1016/j.jog.2011.10.007.

Bello M., Franchino A. & Merlini, S. (2000) - Structural model of eastern Sicily. Mem. Soc. Geol. It., 55, 61–70.

Ben-Avraham Z., Boccaletti M., Cello G., Grasso M., Lentini F., Torelli L. & Tortorici L. (1990) - Principali domini strutturali originatisi dalla collisione neogenico-quaternaria nel Mediterraneo centrale. Mem.Soc.Geol.It., 45, 453–462.

Bottari A. (1973) - Attività sismica e neotettonica della Valle del Belice. Ann. Geof., 26, 55-83.

Bottari C., Siros S.C. & Teramo A. (2009) - Archaeological evidence for destructive earthquakes in Sicily between 400 B.C. and A.D. 600. Geoarchaeology, 24, 147-175.

Catalano R., Franchino A., Merlini S. & Sulli A. (2000) - Central western Sicily structural setting interpreted from seismic reflection profiles. Mem. Soc. Geol. It., 55, 5–16.

Finetti I.R., Lentini F., Carbone S., Del Ben A., Di Stefano A., Forlin E., Guarnieri P., Pipan M. & Prizzon A. (2005) - Geological outline of Sicily and Lithospheric Tectonodynamics of its Tyrrhenian Margin from new CROP seismic data. In (Ed): I.R. Finetti, CROP PROJECT: Deep Seismic Exploration of the Central Mediterranean and Italy, Elsevier.

Frepoli A. & Amato A. (2000) - Spatial variation in stresses in peninsular Italy and Sicily from background seismicity: Tectonophysics, 317, 109–124.

Gasparini C., Iannaccone G., Scandone P. & Scarpa R. (1982) - Seismotectonics of the Calabrian Arc. Tectonophysics, 84, 267-286.

Hooper, A. (2008) - A multi-temporal InSAR method incorporating both persistent scatterer and small baseline approaches, Geophys. Res. Letters, 35, L16302.

Michetti A.M. (2005) - Future trends in paleoseismology: Integrated study of the seismic landscape as a vital tool in seismic hazard analyses: Tectonophysics, 408, 3–21.

Mckenzie D. (1972) - Active Tectonics of the Mediterranean Region. Geophys. J. R. Astr. Soc., 30, 109-185.

Lavecchia G., Ferrarini F., de Nardis R., Visini F. & Barbano S. (2007) - Active thrusting as a possible seismogenic source in Sicily (Southern Italy): some insights from integrated structural-kinematic and seismological data, Tectonophysics, 445, 145–167.

Monaco C., Mazzoli S. & Tortorici L. (1996) - Active thrust tectonics in western Sicily (southern Italy): the 1968 Belice earthquakes sequence. Terra Nova, 8, 372-381.

Rigano R., Antichi B., Arena L., Azzaro R., Barbano M.S. (1999) - Sismicità e zonazione sismogenetica in Sicilia occidentale. Atti 17° Convegno GNGTS, Rome, November 10–12 1998.

Rovida A., Camassi R., Gasperini P. & Stucchi M. (2011) - CPTI11, the 2011 version of the Parametric Catalogue of Italian Earthquakes. Milano, Bologna, http://emidius.mi.ingv.it/CPTI.