LOW-ANGLE QUATERNARY EXTENSION IN NORTHERN CALABRIA: CONSTRAINS FROM FIELD GEOLOGY AND GEOPHYSICAL DATA

D. Cirillo, F. Brozzetti, G. Lavecchia
CRUST-DiSPUTer, Università G. d'Annunzio Chieti, Italy

Introduction. A number of works, dealing with the Quaternary extension of the Italian Apennines, highlighted the role of *Low Angle Normal Faults* (LANFs) in accomodating large amount of crustal stretching (Carmignani and Kligfield, 1990; Artoni *et al.,* 1992; Barchi *et al.,* 1999; Boncio *et al.,* 2000; Collettini and Barchi, 2002; Brozzetti *et al.,* 2009; Mirabella *et al.,* 2011).

In this work, we suggest that two ~ N-S striking, east-dipping LANFs, outcropping over distance of nearly 90 km, have been driven the Pleistocene to present extension of the Calabro-Lucania boundary and of the northern Calabrian Arc (Fig. 1).

Through detailed geological mapping, integrated with structural analysis and, locally, with interpretation of seismic lines, we have defined the surface and subsurface geometry of these regional structures and defined their kinematics. Moreover along two nearly W-E oriented transects, we investigated the relationships with the related basins and with the sin-and antithetical associated fault sets.

The Lucania-northern Calabria Detachment Fault (LCDF). The structure, hereinafter referred to as the *Lucania-northern Calabria Detachment Fault* (LCDF) developes along the east slope of the Mts Gada-Ciagola ridge which is juxtaposed between the Mercure Quaternary basin and the Thyrrhenian sea. Evidence of the LCDF are documented, in the field, for nearly 30 km but further north (Fig. 1), its possible continuation can be recognized in the widespread younger-on-older tectonic contacts, described in the literature and mapped in the published geological maps (D'Argenio *et al.,* 1987; D'Argenio and Ietto, 1988).

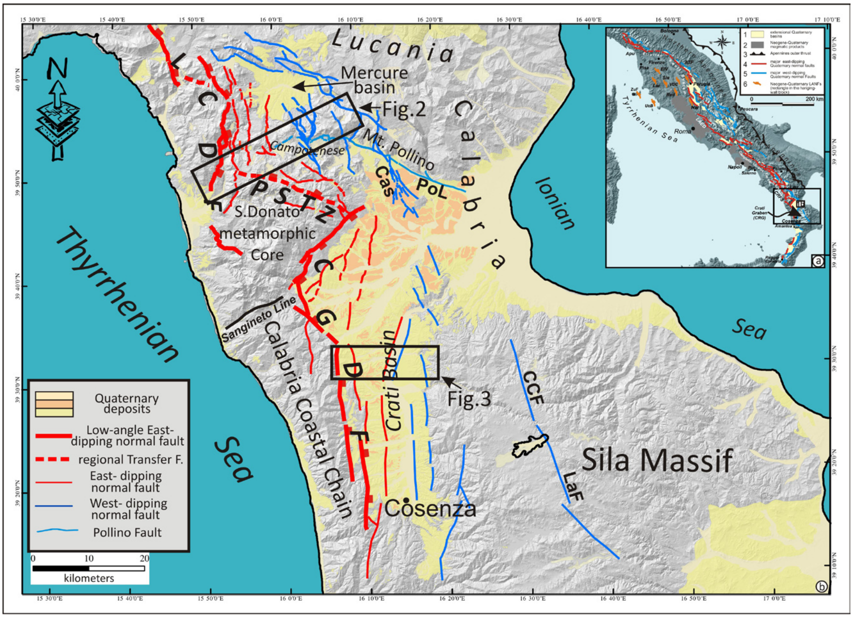

Fig. 1 - a: Structural sketch map of the Thyrrhenian-Apennine system showing Quaternary extensional fault systems and the Neogene-Quaternary LANFs recognized in the literature. Red heavy lines refer to the east dipping normal fault, blue lines depict the major west-dipping normal faults; b: the main east-dipping (red) and west-dipping (blue) Quaternary normal faults affecting the study area are shown: most of these faults were highlighted during a recent and original survey carried out in the frame of a research project funded by the Dipartimento della Protezione Civicile and by Istituto Nazionale di Geofisica e Vulcanologia (DPC-INVG Seismological project S1).

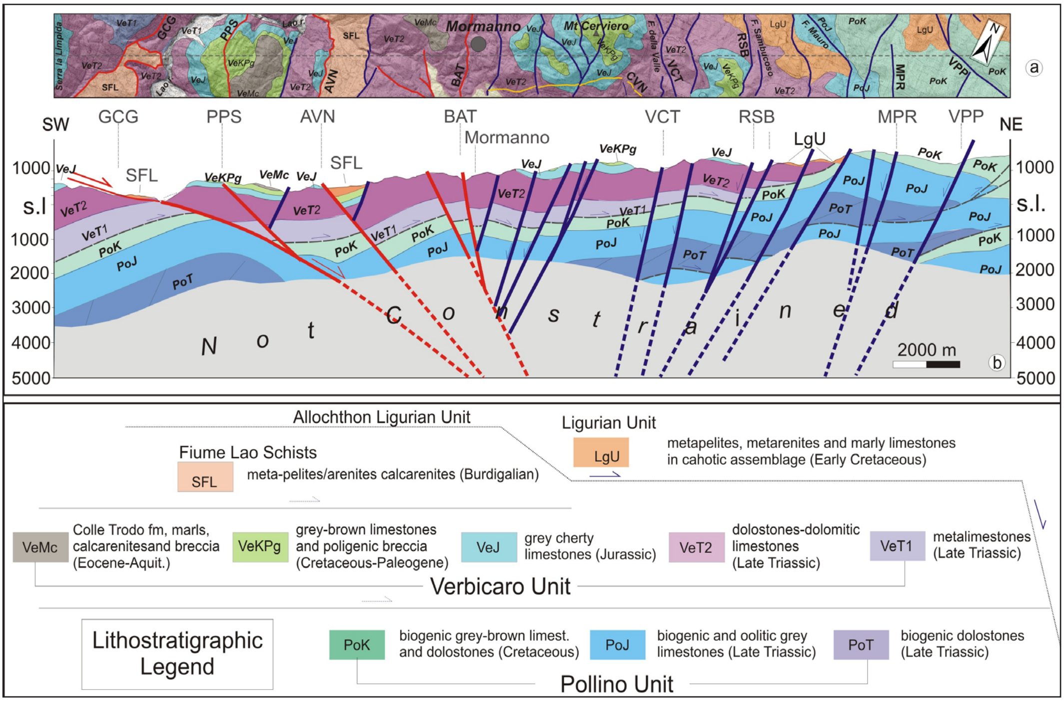

Fig. 2 - Detailed geological map (a) in a 2 km-wide strip centered in the section trace A-B and its interpretative section (b). Stratigraphy of the three major superimposed units (Ligurian allochthon = LGU, Verbicaro = Ve and Pollino = Po units) are reconstructed through literature data integrated with original surveys; key: T1 = Middle-Late Triassic; T2 = Late Triassic; J = Jurassic; K = Cretaceous; Pg = Paleogene; Mc = Miocene. SFL = “Scisti del Fiume Lao Fm”; thick red and blues lines = east- and west-dipping Quaternary normal faults; thin grey dashed line = pre-existing thrust structure.

The best exposure of the LCDF is a a low-angle east-dipping plane (15°-30°) cropping out along the eastern slope of Serra la Limpida (Lao valley, Fig. 2a) referred to as the Gada-Ciagola LANF (GCL). There, it puts in contact the ligurian unit (topmost allochthon unit of the southern Apennines) on the Triassic dolostones of the Verbicaro unit (placed some km below, in the tectonic pile). Some spectacular mirrors of the GCL, on which we performed a detailed structural analysis, display normal, dip-slip kinematics. Conservative assessment of its associate displacement provide a value of ~ 2 km (Fig. 2b). On these same outcrops it was possible to define the relative temporal sequence of the observed faulting-related brittle structures. They show an articulated deformation history ended with the progressive flattening and doming of the original fault plane, due to exhumation processes.

Moreover, fieldwork highlighted that the GCL is the westernmost structure belonging to a set of synthetic sub-parallel normal faults whose dip-angles increases from west to east (Fig. 2b), whereas their associated offset decreases eastward. The aforesaid geometrical pattern is compatible with a tectonic model in which the whole fault set branches from a common east-dipping detachment surface (LCDF) gently dipping toward east and whose break-away zone coincides with the GCL itself.

The distribution of the seismicity recorded during the 2010-2014, “Pollino” seismic sequence, as shown by Brozzetti *et al.* (2017a) provides an indirect confirmation of our reconstruction.

A geologically-constrained estimate of the cumulative displacement, occurred on the LCDF and on its major synthetic splays, gives a value of nearly 3300 m. This value results considerably higher than the offset associated to the antithetic, west-dipping, faults along a regional section extending eastward to the Mt Pollino ridge (Fig. 2b).

The Crati Graben Detachment fault (CGDF). A southern structure, hereinafter referred to as the *Crati Graben Detachment Fault* (CGDF), was reconstructed in the field for nearly 60 km, along the eastern sides of the San Donato di Ninea Metamorphic core and of the Catena Costiera Calabra (Fig. 1). The CGDF bounds to the west the Castrovillari and Crati Quaternary basins and its surface expression can be recognized, moving from north to south, in the S. Sosti-Saracena Fault and in the San Fili - San Marco Argentano fault. Both these faults show normal kinematics with slightly-oblique component.

In the central part of its trace, it is crossed in W-E direction, by a commercial seismic reflection line, availbale for reasearch purpose (ViDEPI, 2017) extending eastward to the Sila slope (Fig. 3a), which was interpreted and converted in order to better constrain the CGDF geometry in the subsurface and its associated system of extensional fault (Fig. 3b,c).

This section confirms that the CGDF reaches the surface along the eastern slope of the Catena Costiera Calabra and dips eastward, with a complex trajectory, but at an average dip-angle of 30° (Fig. 3c).

As well as providing a clear image of the extensional fault pattern, the line also allowed us to distinguish the main units stacked in northern Calabrian arc (Fig. 3b,c) that here are represented by Quaternary syn-extensional deposits and Miocene siliciclastics successions, overlying the crystalline basement.

The thickness variations affecting the Quaternary succession due to the main normal faults, confirm their syn-sedimentary activity.

In most part of the line, the reflections TBa (top of the basement), Mev (Messinian evaporites), TPl (top of the Pliocene succession) and TGe (Top of the Gelasian clays) are confidently recognised (Fig. 3b). At pseudo-depths increasing eastward from 0.3 to 1.5 sec twt, all of these reflectors interrupt onto an east-dipping prominent reflection (shp 240-400), whose surfacing fits the outcrop of the Torano-Martorano normal fault (TMF) mapped in the field (compare Figs. 3a, and 3b). Other low-angle reflections, aligned with the TMF, can also be detected. We interpret these features as the trace of the CGDF which plays the role of a deep boundary for all the extensional fault set. The seismic trace of the fault gradually shallows westward and emerges at the western edge of the basin along the San Fili - San Marco Argentano fault. On the deepest east side of the section, certain weak signals consistent with the down-dipping prosecution of the CGDF, occur at 2.5-3 sec twt.

The subsurface geometry of the syn-tectonic deposits, their structural setting and the detailed review of their stratigraphy, suggest that the high-angle normal fault set, branching upward from the CGDF is, also in this case, characterized by a progressive eastward-younging trend with the recent-most splays bounding the western edge of the present Crati valley floodplain.

The Seismic interpretation makes possible also a rather precise assessment of the cumulative displacement due to the CGDF and to its major synthetic splays, providing a minimum value of 4000 meters in the central part of the structure.

The lack of a robust dataset of instrumental relocated earthquakes, prevents the possibility to test convincingly the seismogenic role of the CGDF in the study area. However, the compatibilty of the available hypocentral determinations with an east-dipping moderately inclined source, has been recently evidenced by Brozzetti *et al.* (2017b).

The Papasidero-Saracena Transfer Zone (PSTZ). Poor data are available on the N110E striking transfer zone connecting the LCDF and the CGDF. Preliminary results of our mapping suggest that it corresponds to a nearly E-W striking alignment of high-angle faults, dipping to north, then sub-parallel but antithetical to the well-known Pollino Fault.

The structural data collected on these transfer faults, record normal to normal-dextral movements.

In correspondence of this regional tectonic line, the axial zone of the active extensional belt, undergoes an abrupt shift of nearly 20 km, from the Mercure-Lao sector (north of the PSTZ) to the Castrovillari-San Sosti-Crati basins (south of the PSTZ).

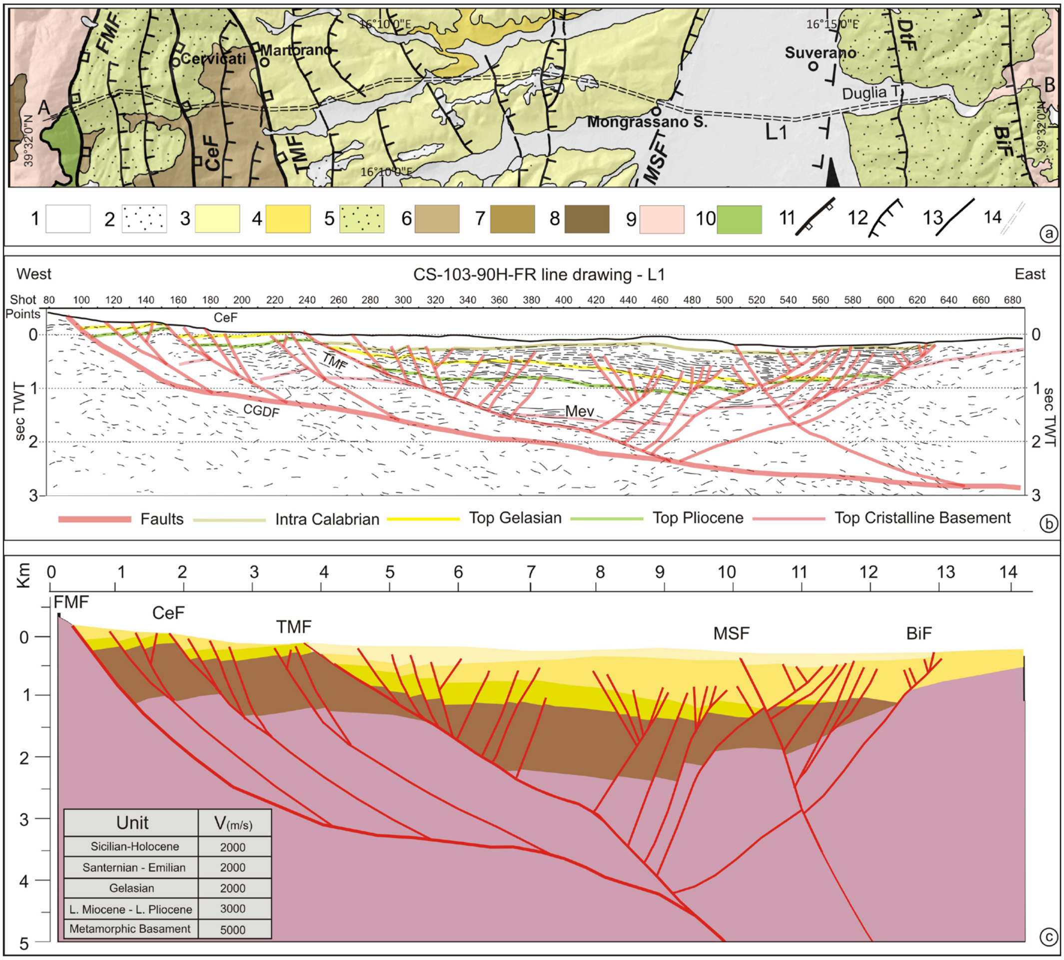

Fig. 3 - a) Geological map of the Cervicati-Bisignano area and detailed location of the L1 seismic line; Key map 1: Holocene; 2: Middle-Upper Pleistocene marine terraced deposits; 3: Upper Calabrian sand and conglomerate; 4: Middle Calabrian silty clays; 5: Lower Calabrian sands, sandstones and conglomerates; 6: Gelasian grey-blue clays; 7: Pliocene conglomerates; 8: Miocene sands and calcarenites; 9: Sila unit; 10: Ophiolite bearing units; 11: major east-dipping normal faults: 12: normal faults; 13: other tectonic contacts; 14: Trace of the seimic line L1. b) Line drawing of the main reflectors recognized in the interpreted seismic line L1, with the recognised key reflectors and main normal faults; the low-angle heavy red line is the inferred trace of the CGDF = Crati Graben Detachment Fault; TMF = Torano-Martorano fault; CeF = Cervicati fault; Mev = Messinian evaporites; The Tops of Crystalline basement, Pliocene units, Gelasian deposits and an intra-Calabrian reflection, possibly corresponding to the Emilian-Sicilian boundary. c) Conversion to depth through the Move (tm) software (seismic velocities used for conversion are listed in the table).

The PSTZ seems to have significantly influenced the development of the recent “Pollino seismic sequence” possibly acting as a barrier to the southward propagation of the seismogenic ruptures (Brozzetti *et al.*, 2017a).

Timing of activity. The timing of activity of the two recognized detachment faults are yet to be accurately constrained. Some scattered outcrop of ancient slope debris involved in the GCL fault zone, suggest for the LCDF an onset not older than Early Pleistocene.

An Early-to-Middle Pleistocene age is furthermore attributed, in the literature, to the continental infill of the basins which generated in the hanging wall of the LCDF and of the PSTZ, as the Mercure, Campotenese and Morano Calabro basins (Schiattarella *et al.,* 1994, Schiattarella, 1998; Giaccio *et al.,* 2014).

Similar inferences can be formulated for the CGDF, based on stratigraphic data (Lanzafame and Zuffa, 1976, Spina *et al.,* 2011) and on the geometry of the syn-extension sedimentary prism, detectable from seismic interpretation (Fig. 3b).

Finally, the hypothesized association with instrumental seismicity and their possible role as lower boundary of high-angle seismogenic fault, are elements supporting the present activity of both the investigated structures.

References

Artoni A., Bernini M., Papani G., Vescovi P. and Zanzucchi G.; 1992: Sezione geologica schematica Bonassola (SP) – Felino (PR). Studi Geologici Camerti, 2, 61-63.

Barchi M.R., Paolacci S., Pauselli C., Pialli G. and Merlini S.; 1999: Geometria delle deformazioni estensionali recenti nel bacino dell'Alta Val Tiberina fra S Giustino Umbro e Perugia: Evidenze geofisiche e considerazioni geologiche. Boll. Soc. Geol. It., 118, 617-625.

Boncio P., Brozzetti F. and Lavecchia G.; 2000: Architecture and seismotectonics of a regional low-angle normal fault zone in central Italy. Tectonics, 19, 1038-1055.

Brozzetti F., Cirillo D., de Nardis R., Cardinali M., Lavecchia G., Orecchio B., Presti D. and Totaro C.; 2017: Newly identified active faults in the Pollino seismic gap, southern Italy, and their seismotectonic significance. J. Struct. Geol., 94, 13-31.; http://dx.doi.org/10.1016/j.jsg.2016.10.005).

Brozzetti F., Cirillo D., Liberi F., Piluso E., Faraca E., De Nardis R. and Lavecchia G.; 2017: Structural Style of Quaternary Extension in the Crati Valley (Calabrian Arc): Evidence in support of an East-Dipping Detachment Fault. Ital. J. Geosci., Vol. 136, No. 3 (2017), pp. 434-453, 12 figs.; doi: 10.3301/IJG.2017.11)

Brozzetti, F., Lavecchia, G., Mancini, G., Milana, G. and Cardinali, M.; 2009: Analysis of the 9 september 1998 Mw 56 Mercure earthquake sequence (southern Apennines, Italy): a multidisciplinary approach. Tectonophysics 476, 210-225.

Carmignani L. and Kligfield R.; 1990: Crustal extension in the Northern Apennines: the transition from compression to extension in the Alpi Apuane core complex. Tectonics, 9, 1275-1303.

Collettini C. and Barchi M.; 2002: A low-angle normal fault in the Umbria region (Central Italy): a mechanical model for the related microseismicity. Tectonophysics, 359, 97-115.

D'Argenio B. and Ietto A.; 1988: Tettonica distenaiva da faglie normali a basso angolo (LANFs) nell'Appenino meridionale. Atti del 74° congresso della Società Geologica Italiana 1988, pp 225-231.

D'Argenio B., Ietto A. and Oldow J.; 1987: Low Angle Normal Fault in the Picentini Mountains, Southern Apennines. Rendiconti Soc. Geol. It., 9(2), 113-122.

Giaccio, B., Galli, P., Peronace, E., Arienzo, I., Nomade, S., Cavinato, G.P., Mancini, M., Messina, P. and Sottili, G., (2014: A 560-440 ka tephra record from the Mercure Basin, southern Italy: volcanological and tephrostratigraphic implication. J. Quat. Sci. 29 (3), 232-248. http://dx.doi.org/10.1002/jqs.2696. ISSN 0267-8179.

Lanzafame G. and Zuffa G.G.; 1976: Geologia e Petrografia del Foglio Bisignano (Bacino del Crati, Calabria). Geologica Romana 15, 223-270.

Mirabella F., Brozzetti F., Lupattelli A. and Barchi M.; 2011: Tectonic evolution of a low-angle extensional fault system from restored cross-sections in the Northern Apennines (Italy). Tectonics. 30, TC6002. doi:101029/2011TC002890.

Schiattarella M.; 1998: Quaternary tectonics of the Pollino Ridge, Calabria-Lucania boundary, southern Italy. In: Holdsworth, R.E., Strachan, R.A., Dewey, J.F.; Eds.), Continental Transpressional and Transtensional Tectonics, vol. 135. Geological Society, London, pp. 341-354, Special Publication.

Schiattarella, M., Torrente, M. and Russo, F.; 1994: Analisi strutturale ed osservazioni morfotettoniche nel bacino del Mercure (Confine calabro-lucano). Il Quat. 7, 613-626.

Spina V., Tondi E. and Mazzoli S.; 2011: Complex basin development in a wrench-dominated back-arc area: Tectonic evolution of the Crati Basin, Calabria. J. Geodyn., 51, 90-109.