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► **To cite this version:**

Stefano Catalano, Salvatore Torrisi, Giuseppe Tortorici, Gino Romagnoli. Active Folding Along A Rift-Flank: The Catania Region Case History (Se Sicily). *Journal of Geodynamics*, 2010, 51 (1), pp.53. 10.1016/j.jog.2010.08.001 . hal-00701257

HAL Id: hal-00701257

<https://hal.science/hal-00701257>

Submitted on 25 May 2012

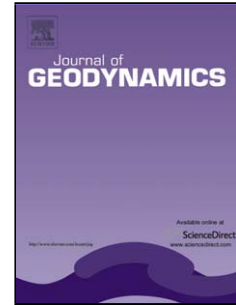
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Accepted Manuscript

Title: Active Folding Along A Rift-Flank: The Catania Region Case History (Se Sicily)

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PII: S0264-3707(10)00114-6
DOI: doi:10.1016/j.jog.2010.08.001
Reference: GEOD 1016

To appear in: *Journal of Geodynamics*

Received date: 30-11-2009
Revised date: 29-7-2010
Accepted date: 14-8-2010

Please cite this article as: Catalano, S., Torrisi, S., Tortorici, G., Romagnoli, G., Active Folding Along A Rift-Flank: The Catania Region Case History (Se Sicily), *Journal of Geodynamics* (2010), doi:10.1016/j.jog.2010.08.001

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ACTIVE FOLDING ALONG A RIFT-FLANK: THE CATANIA REGION
CASE HISTORY (SE SICILY)

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1 **Abstract**

2 In this paper a new kinematic and dynamic model on the Recent and active contractional
3 deformation of the Catania region, eastern Sicily, is discussed. The study area represents one of the
4 most seismically active region of the Mediterranean, located at the intersection between the front of
5 the Sicily collision belt and the seismogenic Siculo-Calabrian Rift-Zone. The analysed contractional
6 tectonics form an active triangle zone that originated from the tectonic inversion of a Lower-Middle
7 Pleistocene extensional basin, which was located at the northern edge of the African foreland. The
8 triangle zone consists of two antithetic ENE-WSW oriented thrust-ramps that show evidence of
9 motion during the Holocene and bound a folded belt that involves alluvial deposits as young as 40
10 ka. These contractional structures represent the final product of the positive tectonic inversion of
11 extensional features located, in the Hyblean Plateau in SE Sicily, along the flank of the active rift-
12 zone. The Late Quaternary motions along the inverted structures was accommodated to the west by
13 a major N-S oriented left-lateral fault zone, which separates the active contractional domains from
14 the adjacent sectors of the African margin. As a whole, the Late Quaternary contractional tectonics
15 of SE Sicily have been related to a NW-verging crustal stacking, related to a Mantle intrusion
16 beneath the Hyblean Plateau that developed as effect of the rift flank deformation. The crustal
17 lineaments, which compose the new kinematic model, represents potentially active seismogenic
18 sources that might be considered in the frame of the seismotectonic picture of the Catania region.

19
20 **Keywords:** active tectonics, contractional structures, morphological responses, eastern Sicily, rift-
21 flank deformation and seismotectonics

22

23 **1. Introduction**

24 In the Catania region, in eastern Sicily (Fig. 1), several Authors (Labaume et al., 1990;
25 Lanzafame et al., 1997; Monaco, 1997; Monaco et. al., 2002) have documented the growth of
26 Middle Pleistocene (> 200 ka) contractional structures, along the southern margin of Mt. Etna

27 Volcano, at the front of the Maghrebian Collision Belt (Fig. 1). More recent studies (Catalano et al.,
28 2004; 2007) described the occurrence of younger ENE-WSW oriented folds that, coherently with
29 the active NNW-SSE oriented Nubia-Eurasia convergence, deform alluvial terraces as young as the
30 40 ka. This younger fold system developed along the western flank of the roughly N-S oriented
31 Siculo-Calabrian Rift Zone (**SCRZ**) (Monaco & Tortorici, 2000; Catalano et al., 2008a), which
32 consists of NNW-SSE trending major extensional faults located in the immediate Ionian off-shore
33 area (Fig. 1). The seismological data (Neri et al., 2005) and stress-in-situ measurements along the
34 western flank of the rift zone (Bousquet et al., 1988; Ragg et al., 1999) demonstrate the occurrence
35 of a still active compressional regime, which is centred in the Mt. Etna region. This suggests that
36 the growth of contractional structures can be still active and related to the seismicity of the Catania
37 region. In this study, the geometry and the morphological evidence of the Late Quaternary
38 contractional structures of the Catania region are analysed in order to define the displacement-rate
39 and the mechanism of their evolution in the frame of the regional dynamics and seismotectonics of
40 this densely populated area. The methodology includes morphometric analyses, applied on the Late
41 Pleistocene alluvial terraces and the Holocene alluvial plain of the Simeto and Dittaino rivers
42 (Catania Plain), and the study of channel morphology along the two main streams. The
43 morphological data are augmented by surface geological information, derived from 1:10.000 scale
44 field mapping, combined with the results of electrical resistivity tomography, performed across the
45 Holocene alluvial plain.

46

47 **2. Regional setting**

48 Eastern Sicily is located along the Nubia-Eurasia convergent boundary (Dewey et al., 1989;
49 Serpelloni et al., 2007), where the Neogene-Quaternary southeastern-verging Maghrebian Thrust
50 Belt originated from the tectonic inversion of the former Africa continental palaeomargin (see inset
51 in Fig. 1). The geometry of the collision belt consists of two imbricated continental blocks
52 (Panormide and Pelagian blocks) and a thin-skinned Neogene-Quaternary accretionary wedge,

53 which is sandwiched between them (Roure et al., 1990)(Fig. 2). A main E-W oriented, N-dipping
54 crustal oblique (dextral) thrust (Mt. Kumeta-Alcantara Line of Ghisetti and Vezzani, 1982), which
55 crops out in northern Sicily, represents the leading edge of the Panormide Block, also playing the
56 role of back-stop of the Neogene-Quaternary accretionary wedge (Roure et al., 1990). This is
57 emplaced on the Pelagian continental crust that, being buried beneath the entire eastern Sicily,
58 culminates in the south-eastern sectors of the island, where it forms the Hyblean foreland domain
59 (Ben Avraham et al., 1990). The present geometry of the Pelagian Block is the result of the
60 Neogene-Quaternary flexure beneath the SE-verging orogenic belt. During Quaternary; this process
61 was associated with the reactivation of a main N-S oriented dextral transform fault zone, the Scicli
62 Line (Grasso & Reuther, 1988)(Fig. 1). To the west of this fault zone, the Hyblean Foreland
63 sequences have also been flexured to form the Early Pleistocene NE-SW oriented Gela Foredeep
64 (Grasso & Reuther, 1988; Grasso et al., 2000). To the east of the Scicli Line, the Hyblean Foreland
65 sequences form a wide plateau, bordered to the north by two Middle Pleistocene collapsed basins,
66 the Scordia-Lentini Graben and the Simeto Graben (Fig. 1)(Ghisetti & Vezzani, 1980) that are
67 superimposed on the previous foredeep basin developed in the Catania region. Recent studies
68 (Bousquet & Lanzafame, 2004; Catalano et al., 2008b) have documented a Late Quaternary tectonic
69 inversion along both the Scicli Line, from right- to left-lateral, and along the margins of the
70 associated Scordia-Lentini Graben, from extensional to contractional. As a consequence, during the
71 Late Quaternary, the eastern portions of the Hyblean Plateau have been displaced to the northwest,
72 towards the Catania Plain, at a rate estimated to be about 1.4 mm/a (Catalano et al., 2008b).

73 The entire collision belt of eastern Sicily is confined, to the east, by the Siculo-Calabrian
74 Rift Zone (**SCRZ**) (Monaco & Tortorici, 2000); this is the tectonic expression of an incipient
75 divergent margin, which separates the Adria-Ionian microplate from the colliding Tyrrhenian and
76 Pelagian lithospheric domains (Serpelloni et al., 2007) (Fig. 1). The rift zone, in the Catania area, is
77 composed of NNW trending oblique (dextral) extensional faults that are distributed from the eastern
78 flank of Mt.Etna to the Ionian off-shore of the Hyblean Plateau, (Monaco et al., 1997; Monaco &

79 Tortorici, 2000; Catalano et al., 2008a).

80

81 **3. Late Quaternary deformation and seismotectonics of Sicily**

82 Sicily has been affected by intense Late Quaternary deformation, associated with high-level
83 seismicity, which can be related to distinct seismogenic domains (Neri et al., 2005). Low to medium
84 magnitude events ($4 < M < 6$) affect the deformation belt, which is related to the Eurasia-Nubian
85 convergent boundary (see inset **a** in Fig. 1). The seismicity is concentrated along the Tyrrhenian
86 off-shore and the northwestern sectors of the island, where available focal mechanisms constrain a
87 stress field characterised by a $N130^\circ$ oriented maximum compression. Similarly, focal mechanisms
88 indicating motions along NE-SW oriented thrust fault have been reconstructed for the 1968 Belice
89 seismic sequence ($4.6 \leq M \leq 5.4$; Anderson & Jackson, 1987; Monaco et al., 1996) that affected the
90 external areas of the orogen, in the southwestern Sicily (see inset **a** in Fig. 1).

91 In eastern Sicily, the present-day stress field has a different orientation because the σ_{hmax}
92 follows the trend of the **SCRZ**, being NE-SW, in the Eolian Islands, and NNW-SSE, in the Mt.
93 Etna region (Neri et al., 2005). A $N145^\circ$ oriented σ_1 has been obtained by the inversion of
94 seismological data in the Hyblean region (Musumeci et al., 2005). This evidence is in good
95 agreement with the focal mechanism of the 1990 Augusta earthquake (Amato et al., 1995), that
96 indicates a NW-SE compression and a NE-SW tension (see inset **a** in Fig. 1).

97 Seismological data at a regional scale are consistent with the geodetic deformation that can be
98 obtained by GPS-determined velocities with respect to stable Eurasia. Motions are constantly
99 parallel to the maximum compression of the stress tensor. At sites LAMP and TRAP (see inset in
100 Fig. 1; Hollestein et al., 2003) the measured NW-oriented GPS-velocities vs. Eurasia are parallel to
101 the direction of the maximum compression measured in the western Sicily seismogenic domains.
102 The slightly clockwise rotated NOTO vector (see inset **a** in Fig. 1) parallels the σ_1 orientation in the
103 Hyblean-Mt. Etna subdomain. It is noteworthy that the difference between NOTO and LAMP
104 vectors is largely accommodated by the left-lateral motions along the Scicli Line (Catalano et al.,

105 2008b).

106 Geodetic deformation also indicates that about 2.6 mm/a of shortening, representing the 63%
107 of the entire NW-SE oriented Africa-Eurasia convergence, is accommodated by folding and
108 thrusting within the Sicily collision belt (NOTO site vs. USTICA site; see inset **a** of Fig. 1), while
109 the residual convergence (1.5 mm/a) measured at Ustica site must be accommodated further to the
110 north.

111 In-situ stress measurements also fit well the seismological and geodetic data, as they indicate
112 mean σ_{hmax} orientation of about N131°, in western Sicily, and N148° in the Hyblean foreland areas
113 (Ragg et al., 1999).

114 Nevertheless, the main destructive ($M > 6.5$) historical earthquakes of Sicily (A.D. 1169, 1542,
115 1693) have been localised along the Ionian coast of the island (Postpischl, 1985; Boschi et al., 1995;
116 1997; Bianca et al., 1999; Monaco & Tortorici, 2000). They define a major seismogenic zone which
117 is related to the occurrence of the active normal fault segments of the **SCRZ** (Fig. 1). Available
118 crustal focal mechanisms in the Straits of Messina area (Anderson & Jackson, 1987; see inset **a** in
119 Fig. 1), coupled with kinematic analyses on fault planes along the eastern flank of Mt.Etna (Monaco
120 et al., 1997; Monaco & Tortorici, 2000), indicate that motion along the normal fault belt occurred in
121 response of a N100° oriented maximum extension. The analysis of seismic lines across the off-
122 shore active fault segments (Bianca et al., 1999) and morpho-structural investigations carried out
123 along the on-shore fault planes (Monaco et al., 1997) suggested Late Quaternary average
124 extensional-rates ranging from 1.7 to 3.7 mm/a. These data are in good agreement with GPS
125 measurements carried out in southern Italy (Hollestein et al., 2003). In more detail, a mean active
126 extension of about 3.5 mm/a has been calculated in the Messina Straits Region (D'Agostino &
127 Selvaggi, 2004).

128

129 **4. Late Quaternary evolution of the Catania region**

130 The town of Catania is located on the northern margin of the NE-SW oriented Middle

131 Pleistocene Simeto Graben (Fig. 1) that originated at the front of the Maghrebian Thrust Belt and is
132 filled by more than 1000 m of pelagic sediments (1.2 to 0.6 Ma-old; Di Stefano and Branca, 2002).
133 The seismic lines across the basin and bore-hole data (Torelli et al., 1998; Fig. 3) emphasize that the
134 Simeto Graben sequence seals the tectonic contact of the frontal nappe of the allochthonous edifice
135 (Gela Nappe) upon the Early Pleistocene horizons of the Catania Foredeep (P-Q in Fig. 3)(Lentini
136 and Vezzani; 1978; Bianchi et al., 1987; Lentini et al., 1996 and references therein), which are
137 located at the top of the flexured Hyblean carbonate sequences (Roure et al., 1990; Lentini et al.,
138 1994)(Fig. 3). The southern margin of the Simeto Graben is represented by the Primosole Horst
139 (Fig. 3), where Middle Pleistocene extensional features are still preserved (Torelli et al., 1998).
140 Conversely, the northern border of the basin has been completely obliterated by younger (200 ka)
141 ramp-thrusts that bound the Dittaino-Simeto and the Terreforti highs (Monaco, 1997; Catalano et
142 al., 2004). Seismic lines across the deposits of the Simeto Graben image an incipient NW-ward
143 gently dipping detachment that ramps from the base of the allochthonous units through the Middle
144 Pleistocene horizons. This detachment has been recognised at a depth of about 2000 m, beneath the
145 Catania Plain and it approaches the surface near the coast (Fig. 3; Torelli et al., 1998). The deposits
146 of the Simeto Graben are now covered by the alluvial plain of the Simeto and Dittaino Rivers
147 (Catania Plain).

148 The Simeto Graben sequence is extensively exposed in the hangingwall of the thrust bordering
149 the basin to the north. Along the Terreforti High (Fig. 3), Late Quaternary clastic deposits engrave
150 several orders of terraced abrasion platforms, which have been modelled at the top of the Middle
151 Pleistocene clay sequence. The terraced deposits represent regressive marine sequences (S_1 - S_7 in
152 Catalano et al, 2004), upward grading into alluvial conglomerates (T_1 - T_7 in Catalano et al, 2004;
153 see also Chester and Duncan, 1982; Monaco, 1997; Monaco et al., 2000)(Tab. 1), that were
154 accumulated during successive periods of highstand, under the control of active tectonic uplift and
155 deformation (Fig. 3). The fluvial terraces along the left side of the Simeto River (Chester and
156 Duncan, 1982) can be, thus, interpreted as cyclic features, strictly related to the eustatically

157 controlled marine sequences distributed along the coastal slope of the town of Catania. This implies
158 that the age of the marine deposits can be extended also to the correlative alluvial deposits (Caputo
159 et al., 2008).

160 The older terraced sequence (S_1 and T_1 in Catalano et al, 2004)(Tab. 1) rests on an abrasion
161 platform undercutting 320-250 ka-old subaerial subalkaline lavas (Gillot et al., 1994) and is
162 intruded by 200 ka-old sub-volcanic rocks (Del Negro et al., 1998), while the youngest sequence (S_7
163 and T_7 in Catalano et al, 2004)(Tab. 1) is largely covered by subaerial lava flows from the modern
164 central volcano (< 35 ka-old; Gillot et al., 1994). Taking into account the relation between eustacy
165 and terracing, the age of the terraced sequences is thus constrained within the OISs (Oxygen Isotope
166 Timescale Stages) to have occurred since 250 ka B.P., as also demonstrated by occurrence of
167 volcanic pebbles from the Etnean sub-alkaline lavas (320-250 ka old; Gillot et al., 1994) in the
168 coarse grained levels (Monaco et al., 2002).

169 In more detail, the lowermost five terraced sedimentary wedges and the correlative alluvial
170 terraces (T_3 - T_7 in Catalano et al, 2004) (Tab. 1) undercut the 180 ka-old alkaline volcanics and can
171 be thus related to the five main highstands between the OIS 5.5 (125 ka) and 3.1 (40 ka)(Tab. 1).
172 This indirect dating, based on geomorphic evidence, is also supported by the occurrence of volcanic
173 pebbles from the ancient alkaline lavas in the coarse-grained levels (Monaco, 1997). This implies
174 that the lowermost fluvial terrace (T_7 ; Tab. 1), flanking the courses of the Simeto and Dittaino
175 Rivers, can be assigned to the OIS 3.1 (40 ka).

176 The Middle Pleistocene (240-200 ka) terraced deposits are severely deformed by the
177 contractional structures developed by the positive tectonic inversion of the northern margin of the
178 Simeto Graben as a result of the propagation of a dextral shear zone from the collision belt. These
179 structures are mostly represented by E-W oriented ramp-thrusts associated with major NW-SE
180 oriented dextral strike-slip fault zones (Fig. 3 and Tab. 1; Catalano et al., 2004). In contrast, the
181 Upper Pleistocene deposits, ranging in age from 125 to 40 ka, have been severely uplifted, as a
182 consequence of the deformation along the extensional faults of the **SCRZ**, located in the Ionian off-

183 shore region (Tab. 1; Monaco et al., 2002; Catalano et al., 2004). During the last 40 ka, the syn-rift
184 deformation has been accompanied by the propagation through the Catania Plain of a set of ENE-
185 WSW oriented gentle folds (Contrada Agnelleria, Contrada Rotondella and Sigonella anticlines in
186 Fig. 3; Catalano et al., 2004), that has deformed the most recent alluvial terrace (T_7 ; 40 ka)(Tab. 1).

187

188 **5.** The most impressive contractional structure of the Catania region is represented by a N70
189 oriented, northwest-dipping ramp thrust. It involves terraced deposits as young as 80 ka (Monaco et
190 al., 2002), as observed in the southern sector of the town of Catania, in a quarry (Fig. 4). In this
191 area, the alluvial conglomerates belonging to terrace T_5 (OIS 5.1; Monaco et al., 2000) (Tab. 1)
192 unconformably cover the 200 ka-old marine sandy sequence (S_2)(see inset **a** of Fig. 4), which is
193 severely tilted towards the south, at the eastern termination of the Terreforti High (Fig. 3; Catalano
194 et al., 2004). The syn-rift thrust-ramp is responsible for the local overthrusting of the marine
195 terraced sequence (S_2 ; 200 ka) onto the alluvial conglomerates of the T_5 (80 ka)(see inset **b** of Fig.
196 4). The total vertical displacement along the structure has been estimated at about 10 m, considering
197 the off-set of the 80 ka-old unconformity across the ramp. In the hanging-wall of the structure, the
198 motion along the ramp has produced the propagation of a fan of minor slip planes that isolate a
199 N70° oriented kink band, which has further tilted the S-dipping strata (Fig. 4).

200 The described thrust-ramp developed at the forelimb of the N70° oriented Sigonella Anticline
201 (Fig. 3), a wide box-fold that extends towards the SW, as far as 13 km from the urban area of
202 Catania. The anticline is well exposed in the area of the village of San Giorgio, on the northern
203 margin of the Catania Plain, where it deforms 60 ka-old terraced alluvials (T_6 in Catalano et al.,
204 2004) (Tab. 1) as well as several older (125 to 80 ka) marine terraced deposits (S_3 - S_5 in Catalano et
205 al., 2004) (Tab. 1). The marine strandline of the OIS 5.5 (125 ka) is involved in the inner flank of
206 the box-fold, along which is regularly increasing in elevation from 120 to 150 m a.s.l.. The 100 ka-
207 old (OIS 5.3) marine strandline crosses the crest of the structure, showing a change in elevation
208 from about 80 m a.s.l., at the base of the inner flank, to 120 m a.s.l., at the crest of the anticline. The

209 younger marine strandlines, as well as the 60 ka-old alluvial deposits, are confined to the forelimb
210 of the anticline, being deformed as far as 2 km from the crest of the structure. The morphological
211 features of different ages that are involved in the structure, as a whole, suggest a wavelength of the
212 fold of about 4 km with an estimated amplitude of about 40 m.

213 Towards the southwest, the crest of the anticline has been buried by the Holocene deposits of
214 the Catania Plain. The stratigraphy of the uppermost 60 m thick levels of the alluvial plain have
215 been investigated, by a series of electrical resistivity surveys, across the southwestern prolongation
216 of the Sigonella Anticline, near the confluence between the Simeto and Dittaino rivers. North and
217 south of the structure (cross-sections 1 and 3 in Fig. 5), the reconstructed resistivity pseudocross-
218 sections have imaged three well defined superimposed electrostratigraphical units, each
219 corresponding to as many sedimentary units: the shallower 15-25 m thick level ($R= 8 - 4 \text{ Ohm}\cdot\text{m}$)
220 is represented by the Holocene alluvial sands and conglomerates, the intermediate 35 m thick level
221 ($R= 10 - 30 \text{ Ohm}\cdot\text{m}$) corresponds to the Late Pleistocene sands and conglomerates (T_7 ; 40 ka),
222 while the deeper very low-resistivity ($R<4 \text{ Ohm}\cdot\text{m}$) layer corresponds to the top of the Middle
223 Pleistocene marly-clay levels of the Simeto Graben. The tomographic model to the north of the fold
224 crest (profile 1 in Fig. 5) shows a slight N-ward tilting of the layering, with the consequent S-ward
225 narrowing of the Holocene alluvial deposits from 25 to 15 m, on a distance of about 300 m
226 ($\text{dip}=2^\circ$). The tomographic model crossing the buried crest of the Sigonella Anticline (profile 2 in
227 Fig. 5) reveals a further narrowing ($< 5 \text{ m}$) of the Holocene alluvial deposits. In the resistivity
228 pseudo cross-section, the forelimb of the fold is also marked by the occurrence, at depth, of a NE-
229 dipping body that, characterised by higher resistivity values (20 to 35 $\text{Ohm}\cdot\text{m}$), cutting at high angle
230 the sub-horizontal layering. The geometry of this resistivity anomaly is consistent with the
231 occurrence, as well as in the Catania area, of heavy fractured fault-rocks, associated with a NE-
232 dipping thrust-ramp. As similar to the Catania town section, the tomographic model across the
233 structure suggests a very small vertical displacement that can be estimated at about 10 m, if

234 measured on the offset of the base of the sandy levels, while it is reduced to about 5 m, considering
235 only the offset of the base of the Holocene alluvial deposits.

236 In the northwestern sector of the Catania Plain and in the adjacent Terreforti High, further two
237 Late Quaternary N70 oriented anticlines (Contrada Rotondella and Contrada Agnelleria anticlines
238 of Catalano et al., 2004) can be recognised (Fig. 3). These two gentle folds show very low
239 amplitude (20 and 40 m) and long wavelength (3 to 4 km, respectively). The Contrada Agnelleria
240 and Contrada Rotondella folds appear as slight flexures of the top-surface of the youngest terraced
241 alluvial deposits (T_7 ; 40 ka) (Tab. 1), showing interlimb angles that approximate the 180° (Fig. 6).
242 The geometry of these folds shows almost uniform amplitude and length on surface of different age,
243 where they deform the older terraced alluvial deposits (T_1 - T_6 ; Tab. 1). The morphology of the folds
244 is completely absent in the Holocene floodplain, which shows a very low-gradient (0,3%)
245 longitudinal profile, almost parallel to that of the active channel of the Simeto River.

246 Out of the folded area, the T_7 terrace (Tab. 1) is regularly dipping, at very low-angle (0.34°),
247 towards the Ionian sea. In contrast, in the folded area, the T_7 terrace shows evident undulations, as it
248 culminates to form ENE-WSW elongated ridges, corresponding with the well-rounded hinge zones
249 of the anticlines, which are separated by wide U shaped topographic depressions that have
250 developed where the terraced surfaces have been subsided at the core of the synclines (Fig. 6).
251 Approaching the crest of the Contrada Agnelleria and Contrada Rotondella anticlines, the T_7 terrace
252 (Tab. 1) shows a slight divergence (1.34°) from the alluvial plain, coupled with convergence (0.40°)
253 towards the intermediate synclines. The steeper and shorter NNW-dipping limbs suggest a NNW
254 vergence of the folds. To the southeast of the Rotondella anticline, the 40 ka-old fluvial deposits
255 have been covered by the Holocene deposits of the Catania Plain.

256 The syn-rift contractional deformation has also controlled the evolution of the Holocene
257 fluvial morphology of the Catania Plain, which formed by the merging of the Simeto and Dittaino
258 river floodplains (Fig. 3). The final tract of the Simeto River is characterised by an arcuated
259 meandering course that, varying in direction from the N-S to the NW-SE, crosses at high-angle the

260 Late Quaternary anticlines of the Catania region (Fig. 3). At a distance of about 25 km from the
261 mouth, the active channel of the Simeto River as well as the top of the Holocene floodplain show a
262 very low-gradient (about 0.3 %), crossing undisturbed the folds that deform the 40 ka-old alluvial
263 terrace (**T**₇).

264 In the Catania Plain, a very impressive change in the sinuosity index (**S**) of the river channel
265 occurs at the intersection with the Sigonella Anticline (from the reach 6 to 7; Fig. 7). This variation,
266 even if partly obliterated by modification due to the human activities, has been estimated taking into
267 account the topographic data from the 1867 1:50.000 topographic map, the 1:100.000 topography
268 reported in the geological map of the end of the XIX century (Gemmellaro and Travaglia, 1885;
269 Gemmellaro et al., 1885) and, finally, the 1960 edition of I.G.M.I. 1:25.000 topographic map. If
270 measured on the XIX century topography, the variation of the sinuosity can be estimated from 1.75
271 to 3.75. A reduced change of the sinuosity (from 1.75 to 2.5) is imaged in the 1960 topography, as a
272 consequence of the cut-offs of meanders that occurred in the last century.

273 To the west of the Simeto River, the Dittaino River is characterised by a prevalent NW-SE
274 oriented meandering course, which flows from the external areas of the Maghrebian Orogen to the
275 Catania Plain, crossing roughly perpendicular the NE-SW oriented termination of the Scicli Line.
276 At the intersection with the structure, which is located between the reach 2 and the reach 3 (Fig. 7),
277 the Dittaino River shows an evident increase of the sinuosity, of about the 100% (from 1.5 to 3),
278 that was attenuated at about 60%, due to the cut-off of meanders in the reach 3 during the last
279 century. From the Scicli Line to the mouth, the sinuosity of the river remains almost uniform and
280 constant in the time. Nevertheless, the Dittaino displays a large scale deflection, which bounds the
281 western terminations of the Rotondella and Sigonella anticlines, as it enters in the Catania Plain
282 (Fig. 7).

283

284

285

286 6. Discussion and conclusions

287 A Late Quaternary fold and thrust system that developed along the flank of an active rift zone
288 in the Catania region has been described. The Late Quaternary contractional structures as a whole
289 generate a triangle zone, involving the Lower-Middle Pleistocene deposits of a former extensional
290 basin (Simeto Graben) and deforming Upper Pleistocene and Holocene morphological features (Fig.
291 3). The south-verging active boundary of the triangle zone is represented by the ramp-thrust
292 outcropping in the town of Catania, here referred to as Catania-Sigonella Thrust (**CST**), responsible
293 for adjustments in the fluvial morphology along the Simeto River. At the intersection between the
294 river and the structure, a dramatic change in the sinuosity is documented by several historical
295 topographic maps (Fig. 8). The synoptic analysis of the 1:50.000 scale topographic map, edited in
296 the 1867, of the topography reported in the 1:100.000 scale geological map of the end of the XIX
297 century (Gemmellaro and Travaglia, 1885; Gemmellaro et al., 1885) and of I.G.M.I. 1:25.000
298 topographic map, edited in 1960, demonstrates that the difference in the sinuosity, between reaches
299 6 and 7 (Fig. 8), has in about 100 yrs progressively decreased from 2 to 0.75. The **CST** accumulated
300 a total vertical displacement of about 10 m, half of which is related to Holocene motions as
301 suggested by the clear control on the fluvial morphology. This implies that the structures developed
302 in the last 20 ka, with an averaged vertical displacement-rate of about 0,5 mm/a.

303 The opposite north-verging tectonic boundary of the active triangle zone can be located along
304 the northern limb of the Agnelleria Fold, on the prolongation of the active NE-SW oriented splay of
305 the Scicli Line, here designated as the Sferro-Paternò Thrust (**SPT**), displacement on which has
306 caused the morphological responses recognised along the Dittaino River. The intersection between
307 the river and the structure is also in this case marked by a well defined change in sinuosity, only
308 partially attenuated in the last century. The recognised responses of the fluvial morphology, which
309 have been modelled in the literature by Holbrook & Schumm (1999), document very recent
310 longitudinal tilting of the active channels of the Simeto and Dittaino Rivers, at the intersection with

311 the two tectonic boundaries of the triangle zone and, thus, directly related to recent motion along the
312 **SPT** and the **CST**.

313 Conversely, the undeformed Holocene morphological features, which are incised into the
314 entire fold belt, and the geometry of the Late Pleistocene fluvial terraces suggest that the folding is
315 restricted to the time interval from 40 to 10 ka. Considering the evolution of these contractional
316 structures, the Late Pleistocene anticlines can be interpreted as fault-propagation folds affected by
317 opposite vergences, that deactivated when the thrusts reached the surface. Thereafter, the entire
318 triangle zone was uplifted, confined to the west by the large scale deflection of the Dittaino River.

319 The cumulative shortening across the entire triangle zone can be estimated taking into account
320 the vertical displacement of the Late Quaternary terraces and the shortening due to the gentle
321 folding (< 3 m). The terracing of the 40 ka-old fluvial deposits is confined at the hangingwall of the
322 **SPT**. These old alluvial sediments were deposited during OIS 3.1, when the base level was about 40
323 m lower than Present (Bassinot et al., 1994). Considering an average elevation of the terrace of
324 about 30 m above the modern Simeto River, a cumulative uplift of about 70 m is implied. A large
325 portion of this uplift can be related to the regional signal that has been estimated to be about 0.8
326 mm/a (Catalano et al., 2004). The residual amount of uplift (38 m) can be interpreted as the tectonic
327 contribution of the **SPT**. Considering that the reverse faulting developed along a former extensional
328 margin, a dip of 60° for the inverted fault-plane can be tentatively assumed. This would imply a
329 conversion of the vertical motion into a shortening of about 22 m. Taking also into account the
330 motion along the **CST** and the gentle fold deformation, a shortening of about 35 m has been
331 accommodated by the entire triangle zone in the last 40 ka, at a deformation-rate of about 0.8-0.9
332 mm/a. A rough estimate of the depth of the sole-thrust of the triangle zone can be obtained
333 comparing the amount of the relief produced at the surface by the Late Quaternary thrust motion
334 with the related cumulative shortening. Assuming plane-strain deformation, a depth of the sole-
335 thrust of about 7500 m is obtained by analysing the deformation of the 40 ka-old alluvial terrace
336 (**T₇**) along the topographic profiles, drawn perpendicular to the trend of the contractional structures

337 (Fig. 6). This implies, considering a depth of about 2000 m of the sole-thrust of the allochthonous
338 units beneath the Catania Plain (T_1 in Fig. 3), that the relation between the Late Quaternary
339 deformation of the triangle zone and the migration of the front of the orogen is unrealistic.

340 The geometry, the estimated depth of the basal detachment and the deformation-rate of the
341 triangle zone are, however consistent with the Late Quaternary contractional deformation affecting
342 the Hyblean crustal block, which is bounded to the west by the Scicli Line. In this region, the Early
343 Pleistocene extensional features (e.g. Scordia-Lentini Graben) experienced a diffuse Late
344 Quaternary positive tectonic inversion, associated with the inversion of the sense of motion along
345 the Scicli Line (Catalano et al., 2008b). The authors have constrained the positive tectonic inversion
346 of the Scordia-Lentini Graben, connected to the left-lateral motion along the southernmost segments
347 of the Scicli Line, at about 850 ka. Recent studies (Catalano et al., 2010) have interpreted the
348 inversion tectonics as related to a rift-flank deformation, affecting the eastern sectors of the Hyblean
349 Plateau, located at the footwall of the **SCRZ**. The authors have related the surface inverted tectonics
350 of the southern margin of the Scordia-Lentini Graben to the emergence of a NNW-verging crustal
351 ramp that originated from a Mantle intrusion, which has been inferred at a depth of about 25 km.

352 It is worth noting that the described surface inverted structures have accommodated only a
353 small amount (30%) of the sinistral strike-slip motion along the Scicli Line, thus suggesting that
354 part of the contraction should be taken up along blind structures, located more to the north. The
355 present study suggests that a NNW-ward propagation of the inverted contractional structures may
356 have migrated for about 30 km in the last 850 ka (Fig. 8). The overall surface geometry of these
357 younger inverted structures is compatible with a detachment, located at depth of about 7500 m,
358 along the Permo-Triassic levels at the base of the sedimentary succession of the Hyblean Plateau
359 (Bianchi et al., 1987), that ramps to form the **SPT**, since about 40 ka. In this context, the **CST**,
360 which forms the opposite boundary of the triangle zone would represent a secondary back-thrust,
361 characterised by a very low cumulative displacement. The measured shortening-rate (0.8-0.9 mm/a)
362 along the inverted triangle zone of the Catania Plain is comparable with the residual left-lateral

363 deformation-rate (≈ 1 mm/a), affecting the northernmost segments of the Scicli Line, to the north of
364 the Scordia-Lentini Graben. According to this new kinematic model, the active contractional
365 deformation of the Catania region can be related to the dynamics affecting the whole of
366 southeastern Sicily, driven by mantle intrusion triggered by the rift-flank deformation along the
367 **SCRZ**, rather than to the late evolution of the collision belt (Catalano et al., 2010).

368 This new kinematic and dynamic model has consequences for the regional seismotectonic
369 picture, if the contractional deformation of the Catania region is to be related to motion along the
370 northern segments of the Scicli Line and the southern inverted margins of the Scordia-Lentini
371 Graben. These tectonic alignments represent major crustal structures that must be considered as
372 potential seismogenic sources for locating historical earthquakes. As well, the measured
373 deformation rates are significant and should be accounted for when evaluating the recurrence-time
374 of seismicity in the area.

375

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377

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501

502 **Figure captions**503 **Fig. 1:** Geological sketch map of the Catania region, eastern Sicily.

- 504 Key: (1) Holocene deposits (a) Late Würmian-Holocene alluvial fan (b); (2) Etnean Lavas: recent
 505 alkaline products (80 ka to Present) (a); ancient alkaline products (180-100 ka) (b) (chronological
 506 data from Gillot et al., 1994); (3) sub-alkaline products of Mt. Etna volcanic district (320-200 ka)
 507 (chronological data from Gillot et al., 1994); (4) Middle Pleistocene deposits of the Simeto and
 508 Scordia-Lentini Graben and Late Quaternary marine terraces; (5) Early-Middle Pleistocene deposits
 509 of the Gela Foredeep; (6) Undifferentiated Meso-Cenozoic Maghrebian allochthonous units; (7)
 510 Pliocene-Early Pleistocene volcanics of the Hyblean Plateau; (8) Meso-Cenozoic foreland
 511 sequences of the western Hyblean Plateau; (9) Meso-Cenozoic foreland sequences of the eastern
 512 Hyblean Plateau; (10) buried front of the Maghrebian allochthonous units; (11) Pliocene- Early
 513 Pleistocene fault; (12) Middle Pleistocene extensional fault (Simeto and Scordia-Lentini Graben);
 514 (13) Late Quaternary and active tectonics and volcano-tectonics: strike-slip fault (a); normal fault of
 515 the “Siculo-Calabrian Rift Zone” (b), thrust (c), anticline (d) dry and eruptive fissure (e); (14) main
 516 transform fault zone; (15) maximum horizontal extension in the Etnean area and in the Ionian

517 offshore; (16) maximum horizontal compression in the Catania Plain area; (17) main earthquake
 518 (a): in the map the major ($M \geq 7$) historical earthquakes are reported; the inset also shows the main
 519 instrumental events, with available focal mechanisms (b)(the location of epicentres are from
 520 Postpischl, 1985; Boschi et al., 1995 and 1997; Bianca et al., 1999; Monaco & Tortorici, 2000;
 521 Focal mechanisms are from Anderson & Jackson, 1987; Amato et al., 1995; Pondrelli et al., 2002;
 522 2004); (18) GPS vector; (19) rift-flank volcanoes (see in the inset **a**).

523 The inset **a** shows the deformation belts connected to the active Nubia-Eurasia convergent boundary
 524 and the SCRZ respectively. The inset **b** refers to the relative motion between the plates.

525

526 **Fig. 2:** Schematic geological profile across the eastern portion of the Sicily collision belt.

527 (for the location see inset **a** in Fig. 1)

528

529 **Fig. 3:** Geological map of the Simeto Graben (for location see box in Fig. 1). Note that the southern
 530 border of the collapsed basin (Primosele Horst) still shows the original (Middle Pleistocene)
 531 extensional features, while the northern margin (Dittaino-Simeto Horst) has been completely
 532 replaced by the Late Pleistocene contractional structures of the Terreforti High. In addition, within
 533 the basin Recent (< 40 ka) to active ENE-WSW oriented folds and thrusts developed.

534 Key: (1) Holocene alluvial deposits; (2) Recent etnean lava flows (< 80 ka); (3) 40-ka old alluvial
 535 terraced deposits; (4) Middle-Late Pleistocene alluvial terraces; (5) Middle Pleistocene marine
 536 terraced sequences; (6) Ancient alkaline lavas (180-100 ka); (7) sub-alkaline lavas (320-200 ka); (8)
 537 Middle Pleistocene deposits of the Simeto Graben (1,2-0,6 Ma); (9) allochthonous units; (10)
 538 Pliocene-Early Pleistocene volcanics of the Hyblean Plateau; (11) Carbonate foreland sequence of
 539 the Hyblean Plateau; (12) Late Quaternary tectonics: (a) normal fault, (b) strike-slip fault, (c) thrust;
 540 (13) Recent and active anticline (a), inverted reverse fault (b).

541 Dashed boxes in the figure refer to the location of Fig. 5 and Fig. 6, respectively.

542 The stereoplots (Schmidt net, lower hemisphere projection) in the inset refers to measured
543 bedding of marine terraces of the following Oxygen Isotope Stages (OISs): a) OIS 7 (240-200 ka);
544 b) OIS 5.5 (125 ka); c) OIS 5.3 (100 ka); d) OIS 5.1 (80 ka); e) OIS 3.3 (60 ka); f) OIS 3.1 (40 ka).

545 In the geological profiles, which has been drawn on the basis of surface data, supported by
546 bore-hole logs and seismic lines (Torelli et al., 1998), the tectonics related to distinct deformation
547 stages are reported: **T₁**) sole thrust of the allochthonous nappe; **T₂**) Middle Pleistocene (> 850 ka)
548 normal faults of the Simeto Graben; **T₃**) Middle Pleistocene (600-200 ka) ramp thrust; **T₄**)
549 reactivated portion of **T₁** (< 40 ka).

550

551 **Fig. 4:** Photo showing the Late Quaternary (< 80 ka) thrust ramp (**CST**) exposed in the Catania
552 Town. For details on the involved deposits, see the schemes **a** and **b** in the inset.

553

554 **Fig. 5:** Geoelectric tomographies in the Catania Plain, across the southwestern prolongation of the
555 Sigonella Anticline. For location of the area see dashed box in Fig. 3. For locating the resistivity
556 pseudocross-sections with regards to the investigated tectonics, see the inset.

557

558 **Fig. 6:** Digital elevation model (DEM) of the topography across the Sigonella, Rotondella and
559 Agnelleria anticlines. In the model, the 40 ka-old alluvial terrace is evidenced. The cross-sections
560 evidence the geometry of the surface at the top of the alluvial terrace (dashed grey line) compared
561 with the reconstructed longitudinal profiles of modern rivers (dashed black line).

562

563 **Fig. 7:** Evolution of the sinuosity along the Simeto and the Dittaino rivers, across the Late
564 Quaternary tectonics of the Catania Plain.

565 In the diagrams, the variation of sinuosity within successive reaches of the Simeto and the Dittaino
566 rivers has been plotted, with reference to the 1867 and 1960 topographic maps, respectively.

567

568 **Fig. 8:** Evolution of the Late Quaternary positive tectonic inversion at the flank of the **SCRZ**, in the
569 Catania region.

570

571 **Tab. 1:** Chronostratigraphic scheme of Upper and Middle Quaternary terraced sequences of the
572 northern margin of the Simeto Graben. For each sequence, the correlative OIS and the age are
573 reported.

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Terraced sequence	OIS	Age (ka)
(S ₁) (T ₁)	7.5	240
(S ₂) (T ₂)	7.1	200
(S ₃) (T ₃)	5.5	125
(S ₄) (T ₄)	5.3	100
(S ₅) (T ₅)	5.1	80
(S ₆) (T ₆)	3.3	60
(S ₇) (T ₇)	3.1	40

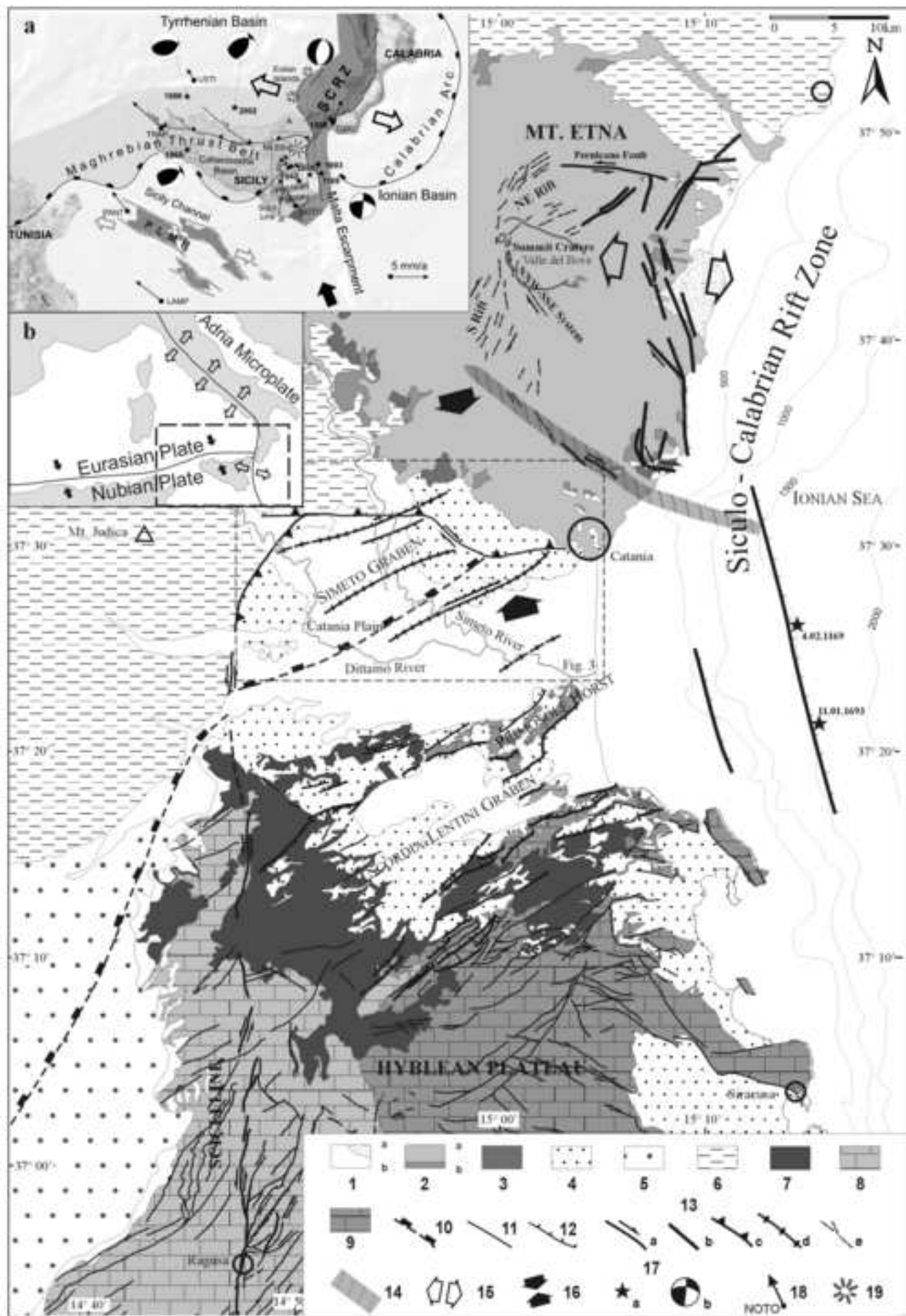
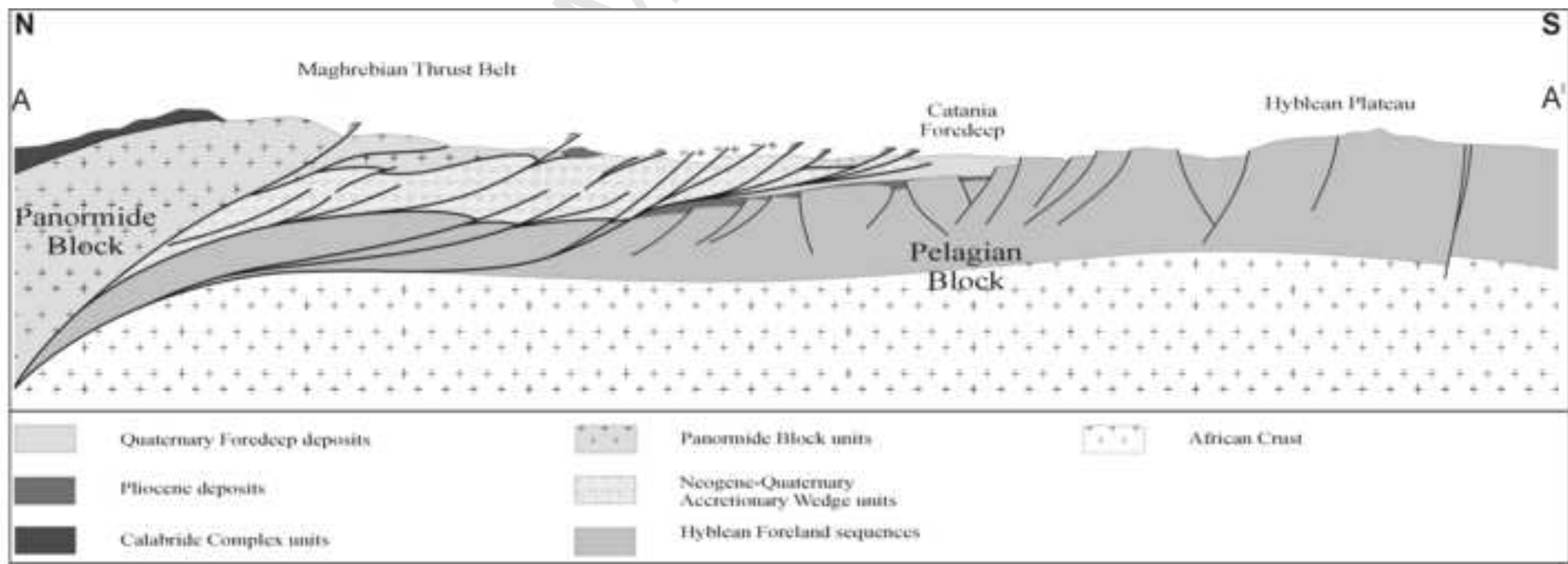
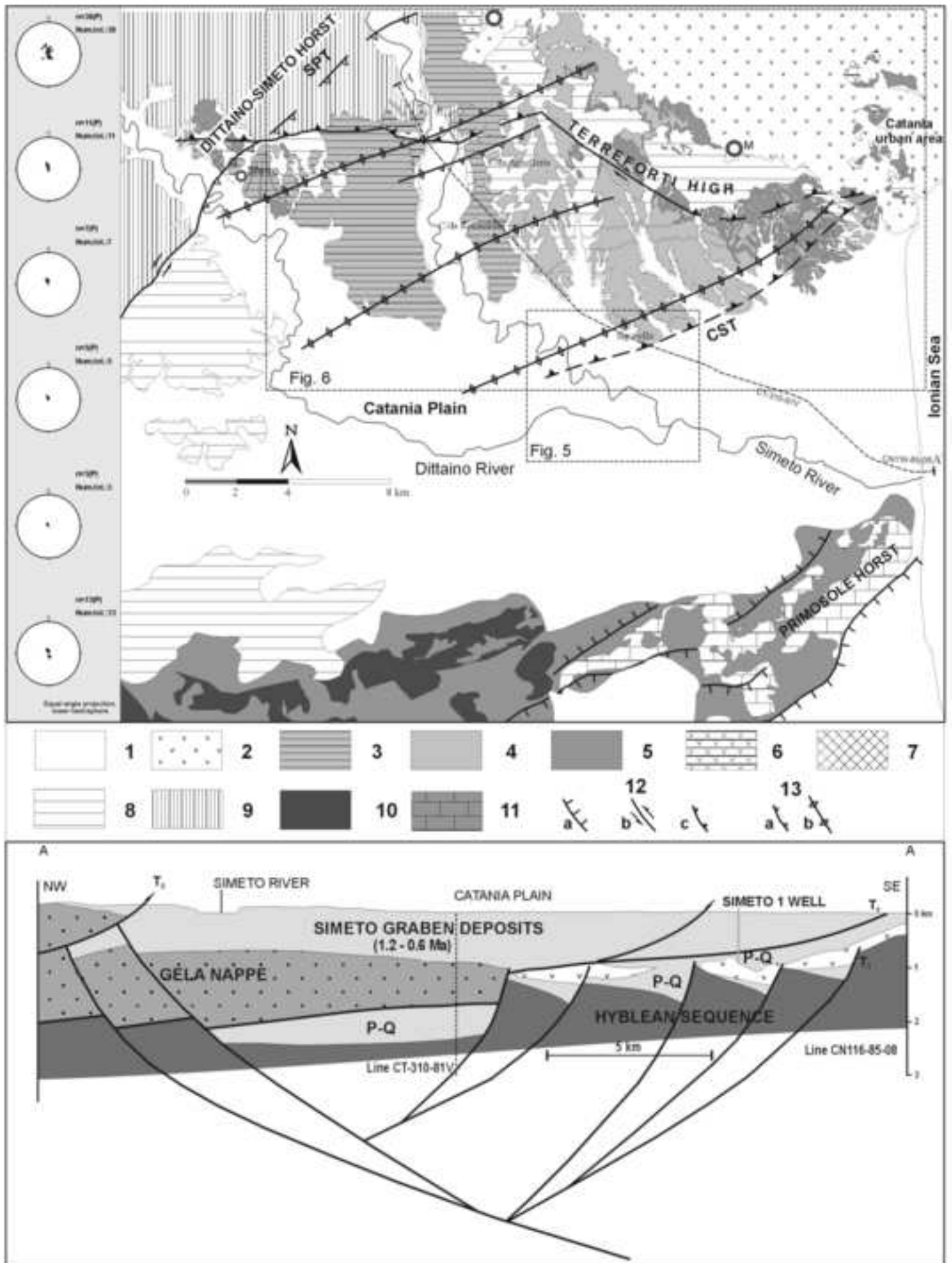


Figure 2





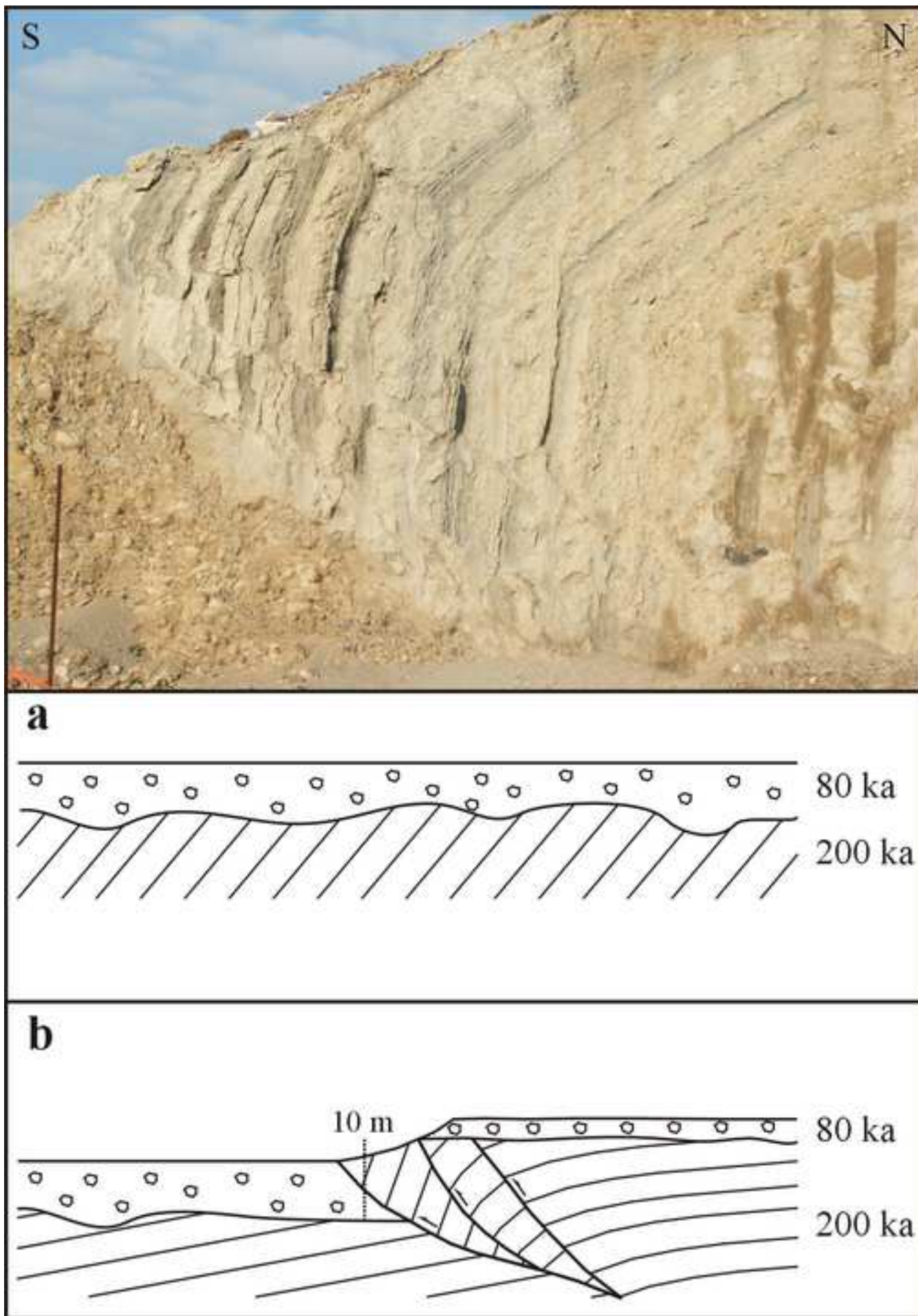


Figure 5

