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1 | **Approaching the ~~potential~~ seismogenic source of the Calabria 8 September 1905 earthquake:**
2 | **New geophysical, geological and biochemical data from the S. Eufemia Gulf (S Italy)**

3
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15
16
17 | **Abstract**

18 | Recognizing the seismogenic source of major historical earthquakes, particularly when these have
19 | occurred offshore, is a long-standing issue across the Mediterranean Sea and elsewhere. The
20 | destructive ~~The~~ earthquake (M ~7) that struck western Calabria (southern Italy) ~~occurred on the~~
21 | night of 8 September 1905 is one such case ~~is one of the strongest events that ever affected western~~
22 | Calabria. ~~This event caused 557 casualties, more than 2000 injured, and left about 300,000 people~~
23 | ~~homeless. The mainshock was followed by a feeble tsunami and hundreds of aftershocks. During~~
24 | ~~the last 15 years, having~~ various authors ~~proposed hypotheses~~ proposed a ~~for a~~ seismogenic source
25 | ~~causative of the 1905 earthquake, with~~ apparently diverse hypotheses and without ~~an~~ achieving a
26 | unequivocal unique solution. ~~To study the active tectonics of the region and t~~ To gain novel ~~n~~ insight
27 | into ~~a potential seismogenic source responsible~~ the crustal volume where ~~for the 1905~~ this event ~~the~~

28 1905 earthquake took place and to seek a more robust solution for the seismogenic source
29 associated with this destructive event, we carried out a well-targeted multidisciplinary survey within
30 the Gulf of S. Eufemia (SE Tyrrhenian Sea), ~~(summer 2010) in the frame of the ISTEGE project,~~
31 ~~using the R/V OGS *Explora*.~~ ~~The acquired dataset consists of~~ collecting geophysical data,
32 oceanographic~~al~~ measurements, and biological, chemical and sedimentary samples.

33 ~~The analysis of the geophysical data.~~ We identified (330 km of MultiChannel Seismic, 2223
34 ~~km of sub bottom Chirp profiles, and 2231 km² of high resolution morpho bathymetric data)~~
35 ~~allowed the identification of some main morpho structural features characterizing the sedimentary~~
36 ~~basin hosted within the S. Eufemia Gulf. The three main tectonic~~ structures/features ~~shaping~~
37 ~~affecting the sedimentary basin in the Gulf of S. Eufemia; and its sedimentary bodies are:~~ 1) a NE-
38 SW striking, ca. 13-km-long, normal fault, ~~here- named S. Eufemia Fault~~ E-dipping large normal
39 fault, N31° oriented; 2) a WNW-~~trending striking~~ polyphased fault system; and 3) a likely E-W
40 trending lineament-fault with dip slip motion. Among these, the large-normal fault shows evidence
41 of activity, ~~as-witnessed by the deformed recent sediments; and by~~ ~~the its lineament due to~~
42 ~~consistent seabed rupture observed on the seafloor~~ along which, locally, fluids leakage occurs.
43 ~~Finally, Features in agreement with the evidence of probable geothermal activity is reflected by the~~
44 anomalous distribution of prokaryotic abundance and biopolymeric C content, resulted from the
45 shallow sediments analyses, ~~whereas no such evidence comes from water temperature analysis~~
46 ~~(CTD measurements).~~

47 The ~~various numerous~~ seismogenic sources proposed in the literature during the past 15 years
48 make up a composite framework of this sector of western Calabria, ~~and can b~~ that we reviewed
49 tested against a) ~~in the light of~~ the geological evidence ~~arising~~ from the newly acquired
50 ~~multidisciplinary dataset~~, and b) ~~the against~~ regional seismotectonic models. Such assessment—
51 with surprising results allows us to propose the NE-SW striking normal fault as the most probable
52 candidate for the seismogenic source of the 1905 earthquake. Re-appraising ~~such~~ a major historical
53 earthquakes as the 1905 one ~~one located within poorly explored submarine areas, promisingly~~

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54 enhances the seismotectonic picture of western Calabria. ~~A comprehensive~~ Further understanding of
55 the region and ~~better robust constraining of the~~ constraining the location of the e-seismogenic source
56 ~~of the 1905 earthquake~~ may ~~arise from an~~ be attained through integrated interpretation of our data
57 together with a) on-land field evidence, and b) seismological modeling.

58
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60 **Keywords:** seismogenic source, earthquake, seismotectonics, prokaryotes, Calabrian Arc

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62

63 1. Introduction

64 Calabria is one of the Italian regions ~~showing with a very high seismicity rate (Fig. 1; Gasparini et al.,~~
65 ~~1982; Castello et al., 2006; Calò et al., 2012), major~~ the largest concentration of seismic moment
66 release (~~Fig. 1; Gasparini et al., 1982; Westaway, 1992; Castello et al., 2006; Calò et al.,~~
67 ~~2012~~ Westaway, 1992); and highest probability of occurrence of major earthquakes (Rotondi, 2010),
68 mainly located between ~~two main shear zones,~~ the Tindari Fault (TF), to the south-west, and the
69 Cirò-Benevento Fault (CBF) Zones (Fig. 1) to the north. Most earthquakes affecting ~~the~~ Calabria
70 ~~and its western offshore~~ Arc are characterized by a normal fault plane solution (D'Agostino and
71 Selvaggi, 2004; Vannucci and Gasperini, 2004), ~~describing confined within~~ a continuous
72 extensional belt parallel to the Calabrian Arc.

73 The earthquake that struck western Calabria on the night of 8 September 1905 ~~is can be~~
74 ~~considered as~~ one of the strongest events ~~of in~~ the Italian catalogue (M_w up to 7.5, according to
75 Michelini et al., 2006). ~~B~~ Besides the ~~28 December~~ 1908 earthquake (M_w 7.1), that struck ~~southern~~
76 ~~Calabria and the~~ the Messina Straits, ~~the 1905 event is one of the catastrophic earthquakes (M_w →~~
77 ~~6.5) that, together with and~~ the numerous ones occurred ~~during 1638 and 1783~~ in the 17th and 18th
78 ~~century, that~~ severely ~~devastated hit~~ large parts of the Calabria region (Postpischl, 1985; Boschi et
79 al., 2000; Guidoboni et al., 2007). The ~~1905 is~~ earthquake caused 557 ~~victims deaths~~ (Baratta,

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80 1906), most of them around the Capo Vaticano ~~Promontory~~^{promontory}, with the highest intensity
81 values (Mercalli-Cancani-Sieberg = XI) recorded between the towns of Tropea, to the west, and
82 Vibo Valentia, to the east (Fig. 2; Tiberti et al., 2006). ~~This earthquake injured more than 2000~~
83 ~~people, and left 300,000 inhabitants homeless (Boschi et al., 2000; Guidoboni et al., 2007).~~
84 ~~Historical documents reported several triggered ground failures~~~~environmental effects were~~
85 ~~recorded in coeval sources, including ground effects~~ (landslides, rock falls and lateral spreads),
86 hydrological changes (stream-flow variations, liquefaction, rise of water temperature and turbidity),
87 ~~and~~ earthquake “lights” and “sounds” (Guidoboni et al., 2007; Tertulliani and Cucci, 2008, 2009).
88 Finally, a tsunami, ~~if albeit~~ modest, was reported by contemporary observers both in the open sea
89 and along the coast of the Sant’Eufemia (S. Eufemia, hereafter) Gulf (~~SE Tyrrhenian Sea~~) (see blue
90 ~~small waves in Fig. 2~~), with few meters of maximum run-up and sea flooding in some beaches up to
91 30 m (Tinti and Maramai, 1996 and references therein; Guidoboni and Ebel, 2009; NGDC/WDC,
92 2012).-

93 Although this earthquake ~~can be is considered~~ one of the most catastrophic ones recorded in
94 the region, ~~its age and the~~ poor documentation ~~resulting from this early 20th century~~
95 ~~earthquake event has have long~~ caused it to go relatively overlooked and not fully ~~constrained~~
96 ~~understood~~ in terms of magnitude and epicentral location. ~~Uncertain M estimates, particularly when~~
97 ~~so diverging among each other, and dubious location, especially when the latter is at sea, make~~
98 ~~earthquake assessment all the more problematic. Together with the underlying geology, these are~~
99 ~~among the primary ingredients to search the seismogenic source (i.e., the causative fault) of a~~
100 ~~damaging earthquake, to ultimately enhance the seismic hazard pattern of a given region.~~ -To
101 address these issues and to ~~aerue~~ ~~build~~ on the knowledge ~~concerning~~ ~~of~~ the seismotectonic
102 framework and the seismogenic potential of ~~the western Calabria~~ region, we performed a well-
103 targeted multidisciplinary survey during the summer of 2010 in the S. Eufemia Gulf (gray
104 transparent square in Fig. 1) ~~aboard the R/V OGS-Explora. The new acquired multidisciplinary~~
105 ~~dataset provided us with promising, unexpected results.~~ ~~Biological and geochemical data, collected~~

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106 ~~to detect hydrothermal activity of potential seismotectonic relevance. Combining and the~~ evidence
107 stemming from the analysis of geophysical ~~data (mMultiChannel sSeismic - MCS), sub-bottom~~
108 ~~Chirp profiles - Chirp and;~~ high resolution morpho-bathymetry) ~~and biological and geochemical~~
109 ~~data, allowed us we hereto~~ propose a ~~_solution for a potential seismogenic causative~~ source
110 ~~causative of~~ the 1905 earthquake, while reappraising previously proposed solutions in the light of
111 the new geological evidence.

112

113

114 **2. Geological and seismotectonic framework**

115

116 *2.1 Geological Setting*

117 ~~Our study area, the The~~ S. Eufemia Gulf, lies between ~~the Calabrian Arc and~~ the SE Tyrrhenian
118 Basin ~~and the Calabrian arc~~ (Fig. 1), ~~which . The Tyrrhenian Basin is the~~ a Neogene back-arc basin
119 ~~formed west~~ of the Apennines subduction system ~~of the Apennines thrust belt~~ (Patacca et al., 1990,
120 1993, 2004, and references therein). Subduction migrated eastward from the Tortonian to Early
121 Pliocene, and south-eastward from the Late Pliocene to Early Pleistocene (Patacca et al., 1990;
122 Sartori, 2003). ~~Interaction between the migrating system and the buoyant lithosphere of the Apulian~~
123 ~~and Pelagian foreland caused: 1) the slow down of subduction along the central Apennines, and 2)~~
124 ~~the switching direction in the opening of the back arc basin (Argnani and Savelli, 1999; Sartori,~~
125 ~~2003).~~

126 The Calabrian arc (Fig. 1) is an independent arcuate continental block (~~Calabria Peloritani~~
127 ~~Ferrane;~~ Bonardi et al., 2001) that bridges the NW-SE trending southern Apennines with the SSW-
128 NNE ~~_~~ trending Apennines in Sicily. Several authors have considered the Calabrian arc as an
129 uprooted fragment of the Alpine belt (e.g., Amodio-Morelli et al., 1976; Malinverno and Ryan,
130 1986; ~~y~~ Van Dijk et al., 2000 and references therein). Its arcuate shape can be attributed to the
131 diachronous collision of the Apennine chain with the Apulian foreland, to the north, and ~~of the with~~

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132 ~~the Pelagian-Hyblean foreland block~~, to the south (Malinverno and Ryan, 1986; ~~v~~Van Dijk et al.,
133 2000). ~~These processes~~ Such collision also controlled (1) the clockwise rotations of Sicily and
134 Calabria, (2) the counter-clockwise rotation of the southern Apennines (Cifelli et al., 2007), that
135 ~~ceased at the end of the Pleistocene in Calabria~~ ~~ceased during the end of the Pleistocene~~ (Mattei et
136 al., 2007), and (3) the intense fragmentation of the Calabrian Arc in NW-SE ~~striktrending~~ blocks
137 (Knott and Turco, 1991; ~~v~~Van Dijk, 1991, 1992; Del Ben et al., 2008; Barone et al., 2008). Since
138 the ~~M~~middle-Pleistocene, the Calabrian Arc experienced rapid uplift of up to ~~about ca.~~ 1 mm/y
139 (Westaway, 1993; Bordoni and Valensise, 1998; Anzidei et al., 2012) ~~and a ESE-trending forearc~~
140 ~~advancement, of the forearc~~ shown by GPS data (D'Agostino et al., 2011; Devoti et al., 2011).
141 Uplift was in part accommodated ~~locally by repeated displacement along the~~ by major ~~active,~~
142 ~~mainly~~ normal faults (Monaco and Tortorici, 2000; Catalano et al., 2003), frequently bounded by
143 NW-SE ~~striktrending~~ shear zones (Fig. 1; van Dijk, 1991; Tansi et al., 2007). ~~GPS vectors show a~~
144 ~~ESE forearc advancement (D'Agostino et al., 2011; Devoti et al., 2011).~~

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145 The ~~S. Eufemia~~ sedimentary sub-basin, hosted by the S. Eufemia Gulf ~~corresponding to the~~
146 ~~southern part of the large Paola Basin (Fig. 2),~~ is bounded by the Capo Vaticano
147 ~~Promontory~~ promontory to the south, by the Calabrian ~~Are~~ landmass to the east, and by the steep
148 submarine slope ~~that leaves room~~ extending to the Marsili abyssal plain to the west (see Figs. 1 and
149 2). The S. Eufemia ~~sub~~ basin is filled by a ca. 2-km-thick, Plio-Quaternary ~~sedimentary~~ sequence,
150 overlying intensely deformed Miocene units (Argnani and Trincardi, 1993; Milia et al., 2009;
151 Loreto et al., 2012). ~~Within~~ The S. Eufemia and the Paola slope basins, considered by (Argnani
152 and Trincardi, 1993) ~~as slope basins,~~ includes several turbiditic, large mass-failure and drape
153 deposits (Trincardi et al., 1995). Finally, Milia et al. (2009) identified a sub-vertical fault system
154 showing a polyphased history, ~~(including fault inversion)~~ coeval with the early N-S extensional
155 ~~phase, that gave rise to the Paola basin and the S. Eufemia sub basin.~~

156

157 2.2 Seismogenic source models of the 1905 earthquake

158 Numerous epicentral locations and M_w estimates of the 8 September 1905 earthquake have been
159 proposed in the literature. According to Rizzo (1906), Boschi et al. (2000), and Guidoboni et al.
160 (2007), the epicenter of the 1905 earthquake was onshore (Fig. 2), whereas ~~locations by~~ Ruscetti
161 and Schick (1975), Camassi and Stucchi (1997), Michelini et al. (2006), and a recent macroseismic
162 ~~one study~~ by Rovida et al. (2011) all place the epicenter offshore (Fig. 2). Assigned M magnitudes
163 values range from instrumental estimates at 7.3 (Mulargia et al., 1984) and of at M 7.0 (Martini and
164 Scarpa, 1982) and M 7.5 (Michelini et al., 2006), to the macroseismic ones ~~at of M~~ 6.7 (Guidoboni
165 et al., 2007), M 7.0 (Gruppo di Lavoro CPTI04, 2004; Rovida et al., 2011) and M 7.1 (Postpischl,
166 1985).

167 Over the ~~last past~~ 15 years, various researchers hypothesized a ~~possible~~ tectonic seismogenic
168 source responsible for the 1905 earthquake (see Table 1, Fig. 3). ~~Perhaps Peruzza et al. (1997) the~~
169 ~~first attempt to~~ presented the first seismotectonic model for ~~some of~~ the largest Calabrian
170 earthquakes ~~was that of Peruzza et al. (1997).~~ These authors proposed a segmentation model
171 ~~and with~~ large normal faults sub-parallel to the extensional axis of ~~the western~~ Calabrian ~~arc~~.
172 ~~Source models included key parameters and,~~ for the 1905 earthquake case, Peruzza et al.
173 ~~(1997) these authors proposed maintained~~ an E-dipping, NNE-SSW ~~trending striking~~ source (PE in
174 Fig. 3). ~~onland yet along shore, using based on~~ an onshore epicenter. Monaco and Tortorici (2000)
175 presented a seismotectonic model of the Calabrian Arc and eastern Sicily and proposed causative
176 faults for key destructive earthquakes. For the 1905 event ~~(Fig. 2),~~ these authors proposed
177 hypothesized the Capo Vaticano Fault, a NW-dipping, NE-SW ~~striktrending~~ normal fault (MT in
178 Fig. 3), along the NE shore of the Capo Vaticano Promontory, using with an offshore epicenter.

179 Valensise and Pantosti (2001b) presented a regional seismogenic source model and proposed
180 a large 40-km-long, SE-dipping, NE-SW ~~strikingtrending~~ normal fault affecting near the edge of
181 the S. Eufemia Gulf (VP in Fig. 3), and extending on land the northern sector of the Capo Vaticano
182 Promontory and the S. Eufemia Plain. Searching for an explanatory source of the tsunami caused
183 associated with by the 1905 earthquake, Piatanesi and Tinti (2002) ~~took into account and~~

184 parameterized the Capo Vaticano and the Vibo Valentia faults ([Monaco and Tortorici, 2000](#)), two
185 NW-dipping, NE-SW ~~oriented-striking~~ normal faults ~~proposed by Monaco and Tortorici (2000) that~~
186 ~~straddling affect the northern shore of the Capo Vaticano promontory and~~ the internal sector of the
187 gulf ~~and the shore of the Capo Vaticano Promontory~~ (CV and VV in Fig. [23](#); Table 1). **Finally,**
188 Cucci and Tertulliani (2006; 2010) suggested the Coccorino Fault, a [large 29-km-long](#) S-dipping,
189 WNW-ESE ~~trending-striking~~ normal fault ~~affecting the southern sector of~~ ~~in~~ affecting the [southern](#)
190 ~~sector of the~~ Capo Vaticano ~~Promontory~~ ~~promontory~~ and the northern ~~portion of the~~ Gioia Tauro
191 Plain ([CT](#) in Fig. [23](#)).

192
193

194 **3. Acquired ~~d~~Data and Methods**

195 *3.1 Geophysical data*

196 ~~The present study is based on MultiChannel Seismic (MCS), very high resolution seismic data~~
197 ~~(Chirp profiles) morpho-bathymetric, biological, chemical, and oceanographic data (Fig. 4).~~ Nine
198 ~~MCS-multichannel seismic~~ profiles, organized in a tight grid (thin yellow lines in Fig. 4), were
199 acquired using a [1500-m-long streamer](#) cable, with a [120-channels](#) array and a [12.5 m](#) trace
200 interval. The energy source consisted of two GI-guns with [a total volume of 8 liters](#) shooting every
201 [25 m](#), ~~and the~~ with a resulting [seismic coverage is of 30](#) for each investigated depth point. ~~During~~
202 ~~the acquisition low cut (3 Hz) and high cut (anti alias) filters were applied.~~ The seismic data were
203 processed following a standard procedure, in order to get post-stack time migrated seismic sections;
204 ~~SRME technique was applied to improve signal quality and to attenuate the multiple signal.~~ More
205 details about acquisition parameters and processing [performed to improve Signal/Noise ratio](#) can be
206 found in Loreto et al. (2012).

207 More than 2200 km of ~~sSub-b~~ ~~Bottom~~ ~~Chirp-p~~ Profiles ([Chirp](#)) were acquired using a
208 Benthos CAP-6600, consisting of 16 [keel mounted](#) transducers ~~keel mounted~~. Sweep ranges
209 between 2 and 7 kHz, with the resulting configuraton ensuring a full ocean depth investigation.

210 Chirp data image in detail the ~~shallower uppermost section of the~~ sedimentary cover ~~from the~~
211 ~~seafloor to~~ down to a ~~maximum ca. depth of~~ 75 m depth, assuming a constant ~~sound speed of about~~
212 1550 m/s sound speed within the shallowest sediments.

213 The high resolution morpho-bathymetric map (Fig. 4) was obtained using two hull mounted
214 ~~m~~ Multibeam echosounders, ~~(MBES): a Reson Seabat 8111 (100 kHz), and a Reson Seabat 8150~~
215 ~~(12 kHz). We employed the Seabat 8111 up to 400 m depth, reaching the maximum swath~~
216 ~~width (maximum swath width of 7.4 times the water depth), and working in less than 150 m of~~
217 ~~water, was used in waters up to 400 m deep. On the other hand, the Seabat 8150, used within for~~
218 water depth greater than 500 m, ~~has a~~ (maximum swath width of 4.5 times the water depth), and
219 both echosounders for the 400-500 m depth range. ~~Finally, The~~ data were processed to remove
220 spikes due to navigation system problems and/or to the acquisition system.

221

222 3.2 Chemical, ~~B~~ biological and ~~O~~ ceanographic data

223 We collected 12 biological samples (white triangles in Figs. 4), at the top of gravity cores using a
224 sterile spoon and frozen at -20 °C, and performed 10 CTD (Conductivity-Temperature-Depth)
225 profile measurements in the sector near the tectonic features recognized in the multichannel data.
226 ~~loser to the area of maximum damage caused by the 1905 earthquake (white triangles in Fig. 4).~~
227 Small quantities of sediment, taken at the seafloor, were sampled at the top of the 12 gravity cores.
228 These samples were used to evaluate prokaryotic abundance, and to perform Total Carbon (TC),
229 Total Nitrogen (TN), and Total Organic Carbon (TOC) chemical analyses. ~~On board, sediment~~
230 ~~samples were collected using a sterile spoon and immediately frozen at -20 °C.~~

231 For ~~Total Carbon (TC), Total Nitrogen (TN) and Total Organic Carbon (TOC)~~ analyses,
232 triplicate sub-samples of homogenized and freeze-dried sediment (< 250 µm) were weighed directly
233 in capsules (5x9 mm). Before the TOC determination, sub-samples were treated with increasing
234 concentrations of HCl (0.1N and 1N) to remove carbonates, following the procedure by
235 Nieuwenhuize et al. (1994). Carbon and nitrogen were determined using a CHNO-S elemental

236 analyzer according to the methods of Pella and Colombo (1973) and Sharp (1974). Sub-samples of
237 homogenized sediment were freeze-dried and processed to determine carbohydrates, lipids, and
238 proteins following the procedure described by Cibic et al. (2008). The sum of carbohydrates, lipids
239 and proteins carbon was referred to as Biopolymeric Carbon (BPC).

240 Prokaryotic abundance was determined using the centrifugation method by Ravenschlag et
241 al. (2000) and a modified protocol by Lunau et al. (2005). Sediment samples were diluted to a final
242 concentration of 1:110 and filtered on black Nuclepore polycarbonate 0.2- μ m-pore-size filters.
243 Filters were mounted on microscope slides, stained with a SYBR Green I-mounting medium Mowiol
244 solution (1:15) and counted by epifluorescence microscopy (LEICA DM2500) at 1000 X
245 magnification under a blue filter set (BP 450-490 nm, BA 515). A minimum of 300 cells were
246 accounted for each filter in at least 40 randomly selected fields.

247 The CTD measurements are done using the ~~s~~Sea-bird ~~e~~Electronics (SBE) 911plus system
248 with sensors mounted on the Carousel SBE32 frame with 12 Niskin bottles. ~~The-We~~ measured
249 ~~parameters-are~~: Pressure (db); Conductivity (mS/cm); Temperature ($^{\circ}$ C); Oxygen (uA0);
250 Fluorescence (ug/l); and optical backscatter, with a 10^{-3} accuracy. Lacking a high accuracy
251 altimeter, the last measurement was done at ~~about-ca.~~ 10 m from the seafloor to avoid problems of
252 interaction with the seafloor morphology.

253

254

255 4. Results

256 4.1 ~~Morphological-Morpho-bathymetric~~ features

257 ~~The-Our~~ high resolution morpho-bathymetric ~~map-data-of-the-S. Eufemia Gulf~~ (Fig. 4) allowed us to
258 identify some ~~mainkey~~ ~~elements/features~~: 1) a large submarine ~~Angitola~~ canyon, ~~—already~~
259 ~~known/shown~~ by Argnani and Trincardi (1988) as ~~Angitola Channel (Gamberi and Marani, 2004)~~,
260 characterized in the ~~internal-near-shore~~ part of the gulf by an ~~unusually~~ straight trend, ca. ENE-
261 WSW oriented for about 20 km, and in the ~~external-distal~~ part by a meandering trend; 2) a NW-SE

262 oriented morpho-structural high (hereafter: MS-High) ~~located~~ offshore the town of Tropea,
263 recognized as the seaward prolongation of the Capo Vaticano ~~pp~~romontory, ~~and~~ surrounded by
264 several slide scars (Loreto et al., 2012). ~~However, A a more~~ detailed analysis (Fig. 5) allowed us to
265 identify other noteworthy ~~morphological~~ features, ~~located~~ between the northern internal slope of the
266 gulf and the Angitola Channel, ~~like incisions and such as~~ small slides or slumps (see white thick
267 arrows) and ~~a an evident prominent~~ N31°E-trending, 3-m-high, and 8-km-long ~~morphological~~
268 ~~escarpment scarp~~. ~~Among the towns of Lamezia Terme and Briatico, the seafloor is affected by this~~
269 ~~morphological escarpment trending N31° well visible across the 150-m, as also highlighted by~~
270 contour line ~~at 150 m~~ (i.e., the shelf break; see inset in Fig. 5).

271

272 4.2 Tectonic features

273 ~~The analysis of the multichannel seismic data allowed us to map new interesting tectonic features.~~

274 Seismic profile GSE10-05, NE-SW oriented (Fig. 4), shows a thick and well stratified
275 sedimentary sequence ~~laying at the top of overlying~~ a poorly reflective and poorly stratified ~~one~~
276 ~~sequence~~ (Fig. 6). Based on previous works (Argnani & Trincardi, 1993; Trincardi et al., 1995;
277 Milia et al., 2009; Pepe et al., 2010) and on ~~evidence from deep the Marisa~~ industrial well
278 ~~information (Figs. 4 and 7; Marisa well (Fig. 7) included in the open access VI.D.E.PI. Project,~~
279 ~~(www.videpi.com), the sedimentary imaged sequence can be constrained as probably is~~ the Plio-
280 Quaternary basin infill deposited on top of the ~~Miocene, which correspond to the~~ Messinian units.
281 ~~The Data from the Marisa well information lacks~~ the upper part from Pleistocene to present that
282 could be associated with the uppermost, condensed ~~sediment~~ layer. ~~The Pliocene formation is~~
283 ~~composed mainly by silty claystones with local sandy intercalations laying in angular unconformity~~
284 ~~on top of the Messinian deposits. The Messinian top is covered by a thin layer of evaporites~~
285 ~~underlain by a thick conglomerates layer.~~ The boundary between the Miocene and Pliocene
286 generates a strong acoustic contrast, due to lithology, seismically associated with a high amplitude
287 horizon, ~~that~~ here ~~we call defined~~ Top Horizon.

288 The southern levee of the Angitola Channel (see SL; Fig. 6, ~~Box~~) shows a ~~morphological~~
289 scarp ~~about~~ 200 m high, ~~and corresponding i.e. to about~~ 150 m, assuming a fixed seismic water
290 velocity of 1500 m/s. Sediments next to the levee show gentle folding (see black thick arrow)
291 involving only the well-stratified Plio-Quaternary sequence, ~~never affecting~~ ~~leaving~~ the Top
292 Horizon ~~undisturbed~~. ~~Combined with these elements,~~ ~~t~~The ~~morphological-straight~~ trend of the
293 Angitola Channel (~~i.e., the straight trend~~) ~~combined with these elements~~ leads us to hypothesize that
294 a ~~shallow ca. E-W striking~~ fault (see AF? in Fig. 6, box ~~and inset~~), with a likely ~~dipstrike~~-slip
295 motion, ~~probably controls~~ passively ~~controls~~ the ~~edge of the~~ channel ~~trend~~ (Loreto et al., 2012).

296 Plio-Quaternary sediments of the central basin (Fig. 6) are deformed by two gentle ~~and~~ wide
297 anticlines, the main one ~~controlled~~ ~~bounded~~ by ~~the compressional phase of a SW-dipping~~ fault
298 ~~southwest ward dipping~~. ~~The amount of deformation~~ ~~Folding~~ decreases with depth ~~and~~ ~~fades out at~~
299 ~~mid-sequence up to the null point~~ (see black dot). ~~The underlying~~. ~~Below the null point,~~ sediments
300 thicken ~~forming into~~ a syn-rift sequence ~~deposited during~~ ~~controlled by~~ the extensional ~~phase~~
301 ~~activity~~ of the bordering fault. Assuming a constant seismic velocity of 2200 m/s for Plio-
302 Quaternary sediments (Pepe et al., 2010; Marisa well ~~by VIDEPI project~~), we ~~calculated~~ ~~estimate an~~
303 ~~offset at that~~ the Top Horizon ~~of is offset~~ ca. 350 m ~~along a fault plane~~ ~~58° SWS dipping~~ (see Trc
304 num 61050 in Fig. 6). ~~We interpret such deformational style as due to a N93° striking Polyphased~~
305 ~~Fault (from here on, PF) and 58° SSW-dipping (Fig. 6, inset), visible in~~ ~~Similar deformations are~~
306 ~~well identifiable only within~~ two seismic profiles (GSE10_04A and GSE10_05), ~~allowing us to~~
307 ~~define a major Polyphased Fault, N93° oriented and, based on the available data, 10 km long~~. Up-
308 ward, contractional ~~deformation~~ abruptly stops below a thick and chaotic body perching in
309 stratigraphic unconformity (dotted line; ~~)~~ ~~above the folded sediments~~ (Fig. 8). ~~No sign of fault~~
310 ~~activity~~ ~~There is no evidence of surface rupture,~~ ~~such~~ as a ~~morphological-escarpment~~ ~~scarp~~, ~~is~~
311 ~~identifiable at on~~ the seafloor (Fig. 8, left), confirming that ~~this polyphased fault~~ ~~PFs system~~ ~~is~~
312 ~~fossilized~~, sealed by ~~the upper section of the~~ Plio-Quaternary deposits.

313 The analysis of the E-W-striking GSE10_07 seismic profile (Figs. 4 and 9) allowed us to
314 identify two main features: 1) ~~the incisions of the the~~ Angitola Channel, ~~also here~~ characterized by
315 steep and deep levees, ~~to the west~~; and 2) a normal fault ~~affecting extending through~~ the whole
316 ~~imaged~~ sedimentary ~~stacks~~ succession, ~~to the east including the Plio-Quaternary sequence and the~~
317 ~~Miocene units~~ (Fig. 9, Box). Discontinuities and deformations ~~affecting of~~ the Plio-Quaternary
318 sediments, ~~expressed as the~~ gentle folds ~~at in~~ the foot-wall (thick white arrows) and small drag folds
319 (thick black arrow) ~~at in~~ the hanging-wall ~~(Fig. 9, Box)~~, can be recognized within older ~~(deeper)~~
320 and recent sediments ~~(Fig. 9, Box)~~. ~~Moreover, t~~These folded and faulted recent deposits are well
321 imaged on ~~the~~ Chirp profile CH_39 (Fig. 10B), acquired north of seismic profile GSE10_07, that
322 crosses the ~~morphological escarpment well shown~~ notable scarp on the high-resolution morpho-
323 bathymetric ~~map data~~ (Fig 5). ~~Northward over the seafloor scarp zone, the discontinuities and~~
324 ~~deformations affect the shallow deposits without reaching the seafloor (see chirp profile CH_52 in~~
325 ~~Fig. 10C); farther north, the deformation of the recent sediments strongly decreases and only a~~
326 ~~weak, structurally-controlled offset is detectable (see chirp profile CH_71 in Fig. 10D).~~ Combining
327 evidence from all geophysical ~~observations data~~ (MCS, ~~C~~chirps, and bathymetry ~~data~~), we mapped
328 a N31° trending ~~normal fault, 38° ESE-dipping, ca. 13-km-long normal fault whose fault plane~~
329 ~~rupturing~~ the seafloor for about 8 km along strike (Figs. 9, Box and 10).

330 Assuming a constant seismic velocity of 2200 m/s for Plio-Quaternary sediments, the
331 normal fault, that here we called S. Eufemia Fault (Fig. 10), offsets the upper Miocene ~~unit top of~~
332 ~~ca. about 460 m and plunges southeast ward with an estimated 38° angle. The vertical offset along~~
333 ~~this fault and Using the commonly accepted~~ fault scaling relationships ~~by (Kanamori and Anderson,~~
334 ~~1975; Walsh and Watterson (1988; Wells and Coppersmith, 1994) to compute fault length from~~
335 ~~cumulative offset, we lead us to believe estimate~~ that the S. Eufemia Fault ~~length ranges from 20 to~~
336 ~~30 km, is much longer than the length we could assess from the the 13 km we measured on the~~
337 ~~seismic geophysical grid data (see Fig 10). the coastline and shallow waters posed evident~~
338 ~~geographical constraints to the extents of the seagoing survey. We measured the maximum~~

339 ~~displacement caused by this fault.~~In other words, the S. Eufemia Fault credibly propagates along-
340 strike toward the mainland, to the north-east and to the south-west. ~~Based on analytical relationships~~
341 ~~by Walsh and Watterson (1988) that derive ranges of expected fault lengths from cumulative~~
342 ~~displacement, we tentatively estimate a 25 km length for the S. Eufemia Fault (see Fig 10, left).~~
343 Considering an estimated median fault length of 25 km, and based on formulations by Wells and
344 Coppersmith (1994) and by Kanamori and Anderson (1975), we estimate a M_w ranging from 6.5 to
345 6.8, respectively (Table 2) - the latter being directly influenced by the amount of slip per event.
346 Based on data from comparable Italian earthquakes with normal faulting mechanism, like the 1908
347 Messina-Reggio Calabria one (Valensise, 1988; Amoruso et al., 2002; Pino et al., 2009), we infer 2
348 m to be a credible slip amount, which therefore leads us to tentatively adopt ~~a~~ M_w 6.8 M_w for this
349 fault.

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352 4.3 Chemical and biological analyses

353 The stations (St.) sampled (~~see white triangles in Fig. 11~~) for chemical and biological parameters in
354 the sediments ~~are can be~~ grouped into three transects (~~see white triangles in Figs. 4 and 11~~), with
355 inshore-offshore direction and located a) north (N Tran. in Fig. 11), b) along (AC Tran. in Fig. 11),
356 and c) south (S tran. in Fig. 11) of the Angitola channel. ~~The “northern” transect (water depth~~
357 ~~between 202 m and 425 m) includes St. 1, 11 and 12; the “Angitola channel” transect (water depth~~
358 ~~from 268 m to 548 m) includes St. form 2N to 7; the “southern” transect (water depth between 111~~
359 ~~and 181 m) includes St. 8, 9 and 10.~~ Water temperature close to the sea-bottom was almost constant
360 in all stations and ~~varying-varied~~ in a range of 13.97 °C (St. 3) - 14.18 °C (St. 12).

361 ~~In this study,~~The results of both chemical and biological parameters are reported in Table 3.
362 TN, TC and TOC did not show any evident differences ~~s~~ among stations, except for the southern
363 transect, along which we observed a small decreasing gradient from inshore to offshore. ~~Moreover,~~
364 ~~the highest values of TN, TC and TOC were measured at the shallowest station, i.e. St. 8. In~~

365 general, TN content ranged from $0.66 \pm 0.01 \text{ mg N g}^{-1}$ (St. 10) to $0.89 \pm 0.04 \text{ mg N g}^{-1}$ (St. 8). TC
366 varied from $18.21 \pm 0.04 \text{ mg C g}^{-1}$ (St. 5) to $21.16 \pm 0.08 \text{ mg C g}^{-1}$ (St. 8) while the organic fraction
367 of carbon (TOC) from $6.19 \pm 0.12 \text{ mg C g}^{-1}$ (St. 12) to $8.20 \pm 0.09 \text{ mg C g}^{-1}$ (St. 8).

368 According to the biological analysis, proteins were the main constituent of the BPC,
369 followed by lipids and carbohydrates (Fig. 12, left). Their values Protein content did not change
370 remarkably among stations since with their ranged from $888 \pm 18 \text{ } \mu\text{g C g}_{\text{dry}}^{-1}$ (St. 12) to 1113 ± 28
371 $\mu\text{g C g}_{\text{dry}}^{-1}$ (St. 8). An exception is represented by of St. 7, showing characterised by the highest
372 proteins content value ($1623 \pm 25 \text{ } \mu\text{g C g}_{\text{dry}}^{-1}$; Table 3). The other components of the BPC (Lipids,
373 CHO-H₂O and CHO-EDTA) showed a slightly higher variability, particularly along the Angitola
374 channel. Along the southern transect, a decrease of lipids, from $626 \pm 78 \text{ } \mu\text{g C g}_{\text{dry}}^{-1}$ (St.8) to $229 \pm$
375 $24 \text{ } \mu\text{g C g}_{\text{dry}}^{-1}$ (St. 10), was measured as depth increased. Colloidal carbohydrates (CHO H₂O) are
376 characterized by a high variability and no evident pattern was detected (Fig. 12, left). The lowest
377 contents were measured along the Angitola channel, ($14 \pm 1 \text{ } \mu\text{g C g}_{\text{dry}}^{-1}$ at St. 4 and St. 5),
378 whereas maximum content was found at St. 8 ($55 \pm 2 \text{ } \mu\text{g C g}_{\text{dry}}^{-1}$). Carbohydrates extracted in
379 EDTA were varied from a minimum of $61 \pm 6 \text{ } \mu\text{g C g}_{\text{dry}}^{-1}$ (St. 10) to a maximum of $218 \pm 12 \text{ } \mu\text{g C}$
380 $\text{g}_{\text{dry}}^{-1}$ (St. 2), with higher than in the other stations (Table 3). values along the “Angitola channel”
381 transect (Fig. 12, left).

382 Prokaryotic abundances in the sediment showed a great variability among stations,
383 particularly along the Angitola channel (Fig. 12, right). The lowest prokaryotic valuedensity was
384 measured at St. 11 ($0.70 \pm 0.05 \text{ } 10^8 \text{ cells g}_{\text{dry}}^{-1}$), whereas the maximum at St. 7 ($2.94 \pm 0.38 \text{ } 10^8$
385 $\text{cells g}_{\text{dry}}^{-1}$). A strong variability was also observed along the northern sector, where a strong
386 increase of the prokaryotic abundance was recognized at St. 12.

387

388 4.4 Physical parameters of CTD measurements

389 CTD profiles were analyzed focusing on the temperature close to the bottom of each profile, i.e.
390 looking for signals of geothermal activities. The standard deviation evaluated for each profile at its

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391 bottom and 5 m above gives no evident anomalous signal – thus ~~they sitranging~~ within the
392 variability ~~range~~ of a significant statistical test. ~~The lack of variability in temperature detection~~
393 ~~close the seafloor could be partially justified by the distance of the CTD measurement, from the~~
394 ~~seafloor (at least 10 m).~~

395

396

397 5. Discussions

398 The aim of this paper is to contribute with sub-surface offshore data and interpretations to ~~a) tackle~~
399 ~~some seismotectonic issues of this sector of the Calabrian Arc, and b) the identification of the~~
400 ~~potential-possible~~ seismogenic source of the 8 September 1905 earthquake, ~~contributing to better~~
401 ~~constrain its location and M_w , using a unique approach, which despite several studies and~~
402 ~~methodologies already applied in the literature, remains a debated earthquake from its very~~
403 ~~epicentral location and M_w .~~

404 Evidence from MCS data analysis (Figs. 6 and 94) allowed us to identify ~~mainly~~ three faults
405 that ~~affect deform sediments the deposits~~ of the S. ant'Eufemia ~~sub~~ basin, ~~that are~~: 1) the Angitola
406 Fault (AF; Fig. 6, Box); 2) ~~the~~ Polyphased Fault (PF) ~~confined~~ in the central part of the gulf (Fig.
407 6); and 3) ~~a major normal fault~~, the S. Eufemia Fault (Fig. 9).

408 ~~The Angitola fault~~ is ~~characterized identifiable~~ by ~~the its~~ tectonic control ~~it exerts~~ on the
409 straight trend of ~~the internal segment of~~ the Angitola Channel, and by the steep and deep levees
410 associated with a ~~bathymetric offset higher than~~ ≥ -150 m ~~bathymetric offset~~ (Fig. 6, Box).
411 ~~Nevertheless, d~~Deformation rapidly decreases with depth and fades out before reaching the
412 ~~undisturbed~~ Messinian top (Fig. 6). AF, therefore, is a shallow (if long) structural feature with no
413 basin-wide tectonic role. ~~This allows us to consider AF as a local structure, possibly resulting from~~
414 ~~the geometry of the basin development. All these elements show that AF showing that it has bears~~
415 ~~neither role~~ nor ~~causative~~ relationship with the 1905 earthquake or any earthquake at all.

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416 ~~The Polyphased Fault PF is characterized by the main fault that strongly affects~~deforms the
417 deeper sedimentary stack and the Messinian top, clearly showing positive inversion features ~~likely~~
418 ~~accompanied by oblique motion~~ (Fig. 6). In the shallower stack, ~~this PF system fault shows is~~
419 ~~associated with~~ anticlines ~~– folds~~, and deformation is accommodated along several sub-parallel
420 ~~secondary~~ faults buried below a thick ~~layer of~~ chaotic ~~sediments body~~ (Fig. 8). This fault system is
421 long-lived, well organized through the pre-Messinian sequence and ~~has had clearly~~ affected a broad
422 ~~region~~ the central part of the S. Eufemia basin. Its spatial extents lend an intuitive hint at the tectonic
423 ~~fabric of this sector of the back arc basin.~~ However, ~~it PF is sealed~~ does not extend through ~~by~~ the
424 upper part of the Plio-Quaternary deposits, ~~likely Pleistocene in age, and therefore has thus making~~
425 ~~it incompatible with any~~ present-day tectonic activity. ~~As Like~~ with the ~~AF Angitola Fault~~ east
426 ~~above~~, no relationship can be established between ~~the Polyphased Fault PF~~ and the 1905
427 earthquake.

428 The ~~third fault~~, S. Eufemia Fault, is an active ~~major~~ normal fault, sub-parallel to the large
429 ~~normal faults that control the~~ basins ~~known~~ in the western Calabrian ~~mainland, such as the (i.e., the~~
430 Mesima and the Gioia Tauro ~~b~~Basins). Its ~~dip-slip~~ kinematics appears to ~~have been~~ consistent at
431 least since ~~the~~ late Miocene ~~times up to today~~, as ~~confirmed shown~~ by the MCS profiles for the full
432 sedimentary stack (Fig. 9, Box) and by Chirp data for its shallower section (Fig. 10). The S.
433 Eufemia Fault is ~~in agreement~~ properly oriented with (1) fault plane solutions derived for ~~the other~~
434 earthquakes ~~that have~~ occurred offshore to the NW ~~of our study area~~ (Mulargia et al., 1984), and
435 (2) current extensional tectonics ~~that interacts with regional uplift of the western~~ Calabrian Are
436 (Westaway, 1993; Bordoni and Valensise, 1998; Monaco and Tortorici, 2000; Catalano et al., 2003;
437 Pizzino et al., 2004; Ferranti et al., 2007). Moreover, ~~our high resolution morpho-bathymetric data~~
438 ~~highlighted a straight~~ this fault shows a 8-km-long and up to 3-m-high ~~morphological~~
439 ~~escarpment~~ scarp (Fig. 5) associated with the cut-off of the fault plane rupture, located near shore.
440 Such scarp occurs close to (1) the maximum damage area of the 1905 earthquake, and to (2) the
441 coastal strip between Vibo Marina and Tropea, inundated by the tsunami associated with the 1905

442 earthquake (Guidoboni et al., 2007; Fig. 2). ~~close to. Although such seafloor rupture may not~~
443 ~~necessarily be the direct trigger of the tsunami associated with this event, — a feature which makes~~
444 ~~this rupture it is possibly consistent in agreement a favorable factor with (NGDC/WDC, 2012) the~~
445 ~~occurrence of the recorded tsunami. The discontinuities and folding affecting very recent sediments~~
446 ~~imaged in the Chirp profile (Fig. 10, right) confirm this hypothesis, bridging the gap between low~~
447 ~~and very high resolution seismic reflection data (Fig. 9, Box).~~

448 A further proof of the Biological data analysis provides some indications about the recent
449 activity of the S. Eufemia Fault in terms of seafloor heterogeneity and fluids circulation can also be
450 provided by the biological data analysis. The variability of biopolymeric C content, influenced by
451 channels and water currents, and the prokaryotic abundance in the studied area also supplies
452 indications about the seafloor heterogeneity, which can could be associated with the fluid escape
453 up-welling features at the seafloor from deep sediments. The presence of active faulting could
454 influence the water currents at a local scale, favoring the accumulation of organic matter at the
455 seafloor (Danovaro et al., 2010 and references therein). Data from sShallower stations could
456 show characterized by more labile compounds (Danovaro et al., 1998), as colloidal
457 carbohydrates, which promote microbial activities, thus supporting high abundances as those
458 observed at St. 7 and St. 8 (Fig. 12, left; de Brouwer and Stal, 2001). On the other hand, moving
459 offshore along the Angitola channel, the presence of the labile compounds probably decreases due to
460 preferentially used by prokaryotes. Although available, the prokaryotic community could be less
461 supported by the refractory organic fraction, harder to degrade, and this could partially explain the
462 limited prokaryotic concentrations abundances at the offshore stations. An exception is represented
463 by St. 4, characterized by high prokaryotic abundance density not supported by the high
464 biopolymeric C content (Fig. 12). Such This anomaly could be explained considering that St. 4 is
465 located at the border of the Angitola channel (Figs. 4 and 11), from along which water enriched by
466 organic matter can flow.

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467 Along the southern transect, ~~the high chemical-organic content values along the stations and~~
468 ~~depth of sampling at St. 8 suggests allow us to infer that the presence of the fluids and gases escape~~
469 ~~at the seafloor up-welling fluids, which~~ could represent ~~an~~ alternative sources of carbon and energy
470 for ~~the~~ microbial ~~activity community~~. As a consequence, ~~Prokaryotes concentration of microbes~~
471 with particular metabolisms (as chemiosynthetic ones) could ~~rise in fact be enhanced~~ and their
472 proliferation could support the other trophic levels, ~~explaining in partially~~ the high ~~biopolymeric~~
473 ~~BPC content values observed detected~~ (Fig. 12, left). ~~Even if not supported by the low organic~~
474 ~~matter content. Moreover, also~~ the high prokaryotic abundance ~~detected in at~~ St. 12 (Fig. 12, right),
475 located along the seafloor trace of the S. Eufemia Fault (Figs. 4 and 10, left), ~~could be explained in~~
476 ~~part by the presence of deep fluids, not necessarily warm, up-welling along the fault plane, which~~
477 ~~act as a source of carbon and the low biopolymeric C content~~ (Fig. 12, left) ~~could be partially~~
478 ~~explained by the presence of deep fluids, up-welling along the fault plane, acting as source of~~
479 ~~carbon~~. Such hypothesis is in agreement with the small fluid escape detected on the Chirp profile
480 (Fig. 10B, right).

481 Thus, the prokaryotic abundance detected at St. 12 could indicate hydrothermal fluid activity
482 ~~if modest~~ along the S. Eufemia Fault.

483 As per the ~~geometrical parameters of the S. Eufemia Fault, the seismic grid acquisition~~
484 ~~restricted by the physiography of the Gulf did not allow us to constrain the real lateral extents of the~~
485 ~~S. Eufemia Fault. Its length measured on the morpho bathymetric data (8 km; Fig. 10, left) is~~
486 ~~tentatively estimated to be 25 km sensu Walsh and Watterson (1988); it is therefore associated with~~
487 ~~a M_w ranging from 6.5 to 6.8, based on formulations by Wells and Coppersmith (1994) and by~~
488 ~~Kanamori and Anderson (1975; Table 2) respectively. The latter estimate is directly influenced by~~
489 ~~the amount of slip per event. Based on data from comparable Italian earthquakes with normal~~
490 ~~faulting mechanism like the 1908 Messina Reggio Calabria one (Valensise, 1988; Amoroso et al.,~~
491 ~~2002), we infer 2 m to be a credible slip amount, which therefore leads us to tentatively adopt a 6.8~~
492 ~~M_w .~~

493 Concerning the geometrical parameters of the S. Eufemia Fault, its measured~~A seafloor~~
494 ~~rupture associated with the S. Eufemia Fault only~~ length of only 138 km (Fig. 10A) and its total
495 ~~displacement of 460 m long (Fig. 10, left) does not prevent~~ lead us ~~a fault with the displacement we~~
496 ~~measured to be~~ infer a (much) longer fault than its outcropping rupture, at least for two simple
497 reasons:

498 -a) a stratigraphic one: the ~~northeasterly-southwesterly~~ strand of the S. Eufemia fault is
499 ~~closer buried below the Angitola channel system that completely masks any fault deformation~~
500 ~~clues to the sediment supply of the coastline, i.e. it may lie confined below recent sediments~~
501 ~~(sedimentation rate may be higher than displacement rate); and~~

502 b) a tectonic one: all field and experimental observation of normal faults consistently show
503 decreasing throw towards fault tips (for a reference: Ramsay and Huber, 1987), ~~as suggested by the~~
504 ~~decreasing deformation toward the northeast (Figs. 10B, C, and D).~~

505 ~~If we consider the~~ From the macroseismic M_w estimates M_w derived from macroseismic
506 ~~data~~ ranging between 6.7 and 7.0 (Gruppo di Lavoro CPTI04, 2004; Guidoboni et al., 2007; Rovida
507 et al., 2011), the expected fault length derived using empirical relationships by Wells and
508 Coppersmith (1994) and Kanamori and Anderson (1975) would should be exceed our estimated
509 2530 km or more, as ~~confirmed suggested~~ by field evidence for other ~~major~~ Italian earthquakes of
510 the same M_w range (~~for a summary: see Basili et al., 2008 and references therein see: Ward and~~
511 Valensise, 1989; Pantosti and Valensise, 1990; Burrato and Valensise, 2008; Pino et al., 2009). It
512 would, however, be close to the 20 to 30 km range inferred using Walsh and Watterson (1988)
513 formulations (see em20 and em30 in Fig. 13A). On the other hand, instrumental estimates ranging
514 from M 7.03 by (Mulargia et al., (1984) to M 7.5 by (Michelini et al., (2006) require up to a
515 >>50 km expected fault length by the same empirical relationships. Given the epicentral locations
516 proposed by these authors and by Ruscetti and Schick (1975), such fault ~~sh~~ would be lie entirely
517 ~~located~~ offshore, west of Capo Vaticano. ~~Regardless of its physical and geometrical constraints,~~
518 ~~such hypothetic fault should be associated causing with aa longer-wave and;~~ long-term imprint on

519 the geology ~~and the landscape of offshore~~ central Calabria, to-date ~~neither inferred nor~~ recognized
520 on data.

521 Based on the current set of knowledge and on the geological ~~constraints—evidence~~
522 ~~highlighted by in~~ our data, we prefer a conservative approach, considering 6.8 to 7.0 as a fairly
523 reliable estimate range (Fig. 13; Table 2). In fact, it is certainly true that ~~poorly located~~ moderate-
524 size earthquakes ~~with dubious location may show are associated with~~ uncertain M_w estimates,
525 especially when ~~such a novel~~ location can be constrained offshore by geological means (see an
526 example in Fracassi et al., 2012).

527 Finally, although our data cover only the marine sector of the S. Eufemia Gulf, they fall in a
528 broader seismotectonic context (Fig. 13) and shed some light on ~~comparisons,~~ possible
529 contradictions ~~and roles~~ among the various seismogenic faults / source models ~~previously~~ proposed
530 ~~by previous authors,~~ so different ~~among from~~ one another (Fig. 3, Table 1).

531 In chronological order, ~~length (22 km) and dip direction (SE) of PE, the seismogenic source~~
532 ~~by (Peruzza et al.; (1997), lies outside the physical range of our survey, being essentially onland.~~
533 ~~However, size (22 km long) and dip direction (SE) is are~~ consistent with our data, thus making PE
534 an interesting source model, ~~although lying —essentially onland, also because it derives from a~~
535 ~~regional segmentation model. MT, derived from a fault in a regional interpretive model of the~~
536 ~~Calabrian Arc by (Monaco and Tortorici; (2000), dips to the NW and lies in part within our~~
537 ~~survey's boundaries but is not shown on our data —possibly due to the geometry of the acquisition~~
538 ~~grid within and nearby the S. Eufemia Gulf. Therefore, MT Such negative evidence, however, can~~
539 ~~only suggest that MT~~ is not likely to affect the inner Gulf, while it could affect the NW flank of the
540 Capo Vaticano ~~Promontory promontory, and .~~ However, due to its location and dip direction, MT
541 would belong to an entirely distinct fault system ~~from that including SE dipping structures.~~ VP,
542 ~~based on a regional model by (Valensise and Pantosti; (2001b), is the longest one possible source in~~
543 the literature (40 km). Our data show no evidence of this source, which however is interestingly
544 sub-parallel to the S. Eufemia Fault, with same dip direction, like PE.

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545 ~~Using data by Monaco and Tortorici (2000), Piatanesi and Tinti (2002) proposed two~~
546 ~~possible solutions for their tsunami inversion: CV and VV. CV (Piatanesi and Tinti, 2002) is~~
547 essentially MT, although dipping at very high angle; given its location, same considerations done
548 for MT apply for CV. VV (Piatanesi and Tinti, 2002), ~~another very a high angle~~ NW-dipping high-
549 angle normal fault, lies outside our survey's boundaries, ~~nearby the city of Vibo Valentia,~~ and we
550 therefore cannot ~~ascertain-verify~~ its geometry and role, ~~if any~~. However, since its rupture ~~-~~ would
551 occur onland, one would likely need to invoke other nearby phenomena to account for the tsunami,
552 such as large submarine slides ~~or slumps~~, which our marine data do not show. We therefore doubt
553 that VV can be considered as a viable seismogenic source for the 1905 earthquake. On the other
554 hand, MT/CV's location and geometry seems to conflict with the S. Eufemia Fault, for which we
555 gathered positive evidence from our data.

556 ~~The most recent source model, CT (is based on a model by Cucci and Tertulliani, (2010), is~~
557 located ~~whose location~~ away from the area of maximum damage of the 1905 earthquake, along a
558 regional transverse structure, ~~and size, similar to that of MT, lead us to compare its role and~~
559 ~~hierarchy with MT/CV and, ultimately, with the S. Eufemia Fault.~~ Maximum damage is expected to
560 occur in and near the hanging-wall of CT, which however is not the case here (major damage is
561 located way north of CT's foot-wall). Therefore, while we clearly have no geological data to
562 discuss CT, we doubt it can be associated with the 1905 earthquake. On the other hand, MT/CV's
563 location and geometry seems to conflict with the S. Eufemia Fault, for which we gathered positive
564 evidence from our data.

565 Based on the above considerations, we believe that the S. Eufemia Fault redraws the
566 seismotectonic understanding of this sector of western Calabria (Fig. 13), and that it proves to be a
567 credible candidate as a ~~potential~~ seismogenic source model for the 1905 earthquake.

568

569

570 **6. Conclusions**

571 Uncertain epicentral location and M estimate of large historical earthquakes that have occurred at
572 sea yet caused major damage on-land often hamper the correct understanding of such destructive
573 events.

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574 In a region such as Calabria, with its numerous seismic crises and puzzling catastrophic earthquakes
575 that have occurred in a relatively narrow landmass, identifying the likely seismogenic source that
576 could be associated with the 8 September 1905 ~~earthquake event~~ is of key relevance to correctly
577 evaluate the seismogenic potential of this area and its seismic hazard. To contribute to this
578 ~~purposegoal~~, we present a multidisciplinary study that brings together evidence from our ~~new~~
579 ~~multidisciplinary surveydata to~~ ~~with open seismological issues of this area.~~ Our data highlighted
580 ~~new geological and geo-biological features that~~ shed new light on the seismo-tectonics of ~~the S.~~
581 Eufemia Gulfcentral-western Calabria.

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582 Our geophysical data allowed us to identify three tectonic features affecting-in the Gulf: 1) ~~a~~
583 ~~likelythe~~ Angitola Fault, ~~affecting-which deforms~~ only shallower sediments; 2) ~~thea~~ Polyphased
584 Fault system, ~~currently buried below a thick chaotic body,-affecting the upper part of Miocene units~~
585 ~~and deeper part of Plio-Quaternary deposits, buried below a thick chaotic layer;~~ and 3) ~~thea~~ N31°-
586 ~~striking normal-S. Eufemia normal Ffault,~~ rupturing the shallow deposits for -13- km along-strike,
587 N31° oriented, that dips to the southeast and extends through, SE dipping, rupturing the whole
588 sedimentary stack up to the seabed, ~~located offshore between the towns of Briatico and Lamezia~~
589 ~~Terme.~~ Among these structures, the ~~normal-S. Eufemia Ffault~~ is the only active one and compatible
590 ~~with shows several elements that strongly agree with most of~~ the 1905 earthquake required features,
591 ~~like i.e.; a1) expected fault size compatible-suitable with for the macroseismic M_w range, 2b) a 8-~~
592 ~~km-long seabed rupture-, corresponding to the up-ward prolongation of the fault plane,~~ compatible
593 with the ~~recorded occurrence of a~~ tsunami, ~~and-3e) location compatible-fitting with the~~ distribution
594 of the maximum damage area, and 4) geometry in agreement with the regional seismotectonic
595 model of the Calabria block. In light of these factors, we maintain that the S. Eufemia Fault is the
596 most credible seismogenic source for the 1905 earthquake, also against the critical review of source

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597 ~~models proposed in the literature. The normal fault, here called S. Eufemia Fault, ruptures the~~
598 ~~seafloor as revealed by the 8 km long morphological escarpment, corresponding to the cut off of the~~
599 ~~fault plane.~~

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600 A critical review of previous seismogenic source models allowed us to compare and contrast
601 characteristics and constraints of these models against the S. Eufemia Fault.

602 Recent activity of the S. Eufemia Fault is also witnessed by ~~i) discontinuities and~~
603 ~~deformation affecting shallow sediments in the overburden, and ii) the likely~~ fluid escapes detected
604 close to the seafloor. Such evidence is also confirmed by the high ~~Prokaryotes abundance and~~
605 ~~biopolymeric C content distribution that we tentatively explain with deep fluids, locally up-welling~~
606 ~~along the fault plane, acting as source of carbon.~~

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607 Despite the undersized length of the ~~seafloor~~ rupture associated with the S. Eufemia Fault,
608 cumulative displacement indicates that this fault is likely at least as long as the basin itself and
609 spans along-strike the whole Gulf - possibly beyond into the mainland. Geomorphological survey,
610 drainage basin evolution and displacement modeling are the premier tools of another on-going
611 study to test our hypothesis against field and regional evidence, to understand ~~i) how this major~~
612 ~~tectonic feature falls within the fault network that described in previous studies depicted, and ii)~~
613 ~~what is the seismotectonic model that best fits onshore to offshore geological evidence, fault~~
614 ~~hierarchy and kinematic relationships.~~

615

616

617 Captions:

618 **Figure 1** - A) Structural sketch ~~map~~ of the Southern Apennines and Calabrian Arc, simplified by
619 Catalano and Sulli (2006) and ~~y~~van Dijk et al. (2000); slip vectors ~~derived~~ from D'Agostino and
620 Selvaggi (2004). Shaded relief modified ~~by~~ © Google Earth, using data ~~by~~ SIO, NOAA, U.S, Navy,
621 NGA, ~~and~~ GEBCO. Small red dots represent ~~M_w>3~~ instrumental earthquakes recorded since 2000
622 up to ~~date, day with M_w>3~~ from ~~INGV Seismic Bulletin (ISIDe Working Group (INGV, 201:0),~~

623 ~~Italian Seismological Instrumental and parametric database: <http://iside.rm.ingv.it>).~~ ~~GTB = Gioia~~
624 ~~Tauro Basin; PB = Paola Basin; CPT = Calabrian Peloritani Terranes; SM = Sila Massif; SM =~~
625 ~~Strait of Messina; ME = Malta Escarpment; TF = Tindari Fault; CBF = Cirò-Benevento Fault. The~~
626 ~~transparent gray box includes the S. Eufemia Gulf.~~

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627
628 **Figure 2** - Morpho-bathymetric map of the studied area, ~~derived by~~ ~~(from~~ NOAA satellite data
629 ~~(http://topex.ucsd.edu/WWW_html/mar_topo.html;~~ ~~contour interval: 50 m)~~, showing ~~intensities~~
630 ~~distribution (Mercalli-Cancani-Sieberg scale) caused by the 1905 earthquake and the the~~
631 ~~mainhypothetical~~ seismogenic faults associated with ~~it in the literature the 1905 event~~: 1) Capo

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632 Vaticano Fault (Monaco and Tortorici, 2000); 2) Vibo Valentia Fault (Piatanesi and Tinti, 2002); 3)
633 Coccorino Fault Zone (Cucci and Tertulliani, 2006; ~~Cucci and Tertulliani~~, 2010); 4) Angitola Fault
634 (Peruzza et al., 1997; Valensise and Pantosti, 2001a); ~~5) Angitola Fault (Valensise and Pantosti,~~
635 ~~2001b).~~ ~~Notice that the highest damage was reported on the northern flank of the Capo Vaticano~~

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636 ~~Promontory. The~~ yellow stars indicated the 1905 earthquake epicentral locations proposed by (S1)
637 Ruscetti and Schick (1975), (S2) Camassi and Stucchi (1997), (S3) Boschi et al. (2000) and
638 Guidoboni et al. (2007), (S4) Rizzo (1906), and (S5) Michelini et al. (2006). ~~Br. = Briatico. Blue~~
639 ~~waves indicate the tsunami effects recorded by contemporary observers (data from Tinti and~~
640 ~~Maramai, 1996).~~

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641
642
643 **Figure 3** ~~.- Possible~~ ~~SS~~ Source models ~~causative~~ of the 8 September 1905 earthquake ~~derived~~
644 ~~available in the literature~~ ~~from published sources~~ the literature, based on seismogenic faults in Fig. 2
645 (data in Tab. 1). ~~Inset 1: conceptual model of geometry and parameters. Inset 2: list of IDs~~
646 ~~identifysource models are listedand associated studies within the inset 2.~~

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647 ~~taken from the following papers: PE: Peruzza et al. (1997); VP, Valensise and Pantosti (2001b);~~
648 ~~MT = Monaco and Tortorici (2000); CV, Capo Vaticano Fault, in Monaco and Tortorici (2000).~~

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649 ~~parameters by Piatanesi and Tinti (2002); VV = Vibo Valentia Fault, in Monaco and Tortorici,~~
650 ~~2000), parameters by Piatanesi and Tinti (2002); CT, Cucci and Tertulliani (2010). Inset: visual~~
651 ~~representation of source geometry model and parameters.~~

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652
653
654 **Figure 4** - Image of the high-resolution morpho-bathymetric map. Thin yellow lines indicate the
655 newly-acquired seismic dataset; white triangles show locations of the oceanographic and geo-
656 biological measurements; the blue circle show location of the industrial Marisa well. The ~~two~~
657 seismic profiles described later ~~on are indicated~~are shown by thick yellow lines. Grey shade:
658 mainland

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659
660 **Figure 5** - High resolution morpho-bathymetric map, with a detail (inset). The white dashed line
661 underlines the Angitola Channel (AC) trend; thick white arrows highlight the several minor
662 incisions and slide. LMT ~~=~~ Lametia Terme; Br. ~~=~~ Briatico.

663
664 **Figure 6** – Time migrated seismic profile GSE10_05 located in the central part of the S. Eufemia
665 Gulf; ~~hypothesized interpreted~~ faults are indicated with dashed black lines; ~~within the~~ Box (left);
666 the likely dip-slip fault affecting the Angitola channel is indicated as AF ? = Angitola Fault; the ~~null~~
667 point where fault offsets is null (null point) is indicated with a black dot; SL indicates the southern
668 levee. Inset: bathymetric map showing a sketch of the two faults location.

669
670 **Figure 7** - Marisa well plotted on the nearest seismic profile, GSE10_02 (location in Fig. 4),
671 running parallel to the morphological escarpment fault plane.

672

673 **Figure 8** — Left: high resolution morpho-bathymetry of the area surrounding the Polyphased Fault
674 (thick red line). On the right:, a detail of the upper part of the Ppolyphased Ffault system affecting
675 deforming the central part of the S. Eufemia sedimentary bBasin (Fig. 6). ~~On the left, the high~~
676 ~~resolution morpho-bathymetry of the area surrounding the polyphased fault (thick red line).~~

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677
678 **Figure 9** - Time migrated seismic profile GSE10-07 located close to the continental shelf (see
679 location in Fig. 42). Faults are shown as dashed black lines; AC = Angitola Channel; P-Q Dep.
680 indicates the Plio-Quaternary deposits are; white thick arrows indicate gentle folds, while the black
681 one indicates the drag fold. Inset: bathymetric map showing a sketch of the normal fault location.

682
683 **Figure 10** - ~~Left: A)~~ High resolution morpho-bathymetric map showing the location of the S.
684 Eufemia Fault, which includes the segment recognized on the seismic-geophysical data (thick
685 black line encircled by a thin rectangle around the seafloor rupture) and the one derived from
686 analytical relationships (dashed black line). RightB): Ppart of Chirp profile 39 crossing the
687 outcropping out-fault plane. C) part of Chirp profile 52 crossing the fault plane and shallow
688 sediments deformation. D) part of Chirp profile 71 crossing the fault plane deforming shallow
689 sediments without reaching the seafloor.

690
691 **Figure 11** - Location map of biological samples (white triangles), whose analysis results are listed
692 in table 3. N tran. = Northern transect; AC tran. = Angitola Channel transect; S tran. = Southern
693 transect.

694
695 **Figure 12** — Left: Biopolymeric C content and its composition measured at the twelve stations,
696 grouped in the three transects (left). The arrows indicate the near shore to offshore direction: from
697 inshore to offshore. CHO-EDTA = carbohydrates extracted in EDTA; CHO-H2O = colloidal
698 carbohydrates. On the right:, prokaryotic abundances measured at the twelve stations grouped in

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699 the three transects. The arrows indicate the near shore to offshore direction: ~~from inshore to~~
700 ~~offshore~~.

702 **Figure 13** – A) sketch map including the Sant’Eufemia Fault (thick red box) seismogenic source
703 ~~model~~ against: a) sesource models based on causative faults ~~causative~~ of the 8 September 1905
704 earthquake available in the literature (see Fig. 2 and 3; Table 1), and b) Individual Seismogenic
705 Sources from DISS 3.1.1 (DISS Working Group, 2010). The length of the two end members (em20
706 and em30) derived from the Walsh and Watterson (1988) empirical relationship (20 and 30 km fault
707 length, respectively). Notice that em30 reaches into the mainland beyond the Gulf’s extents. Among
708 em20 and em30, we adopted a conservative median length of 25 km. We adopted a conservative
709 fault length (and, therefore, M_w : 6.8) of 25 km using analytical relationships by Walsh and
710 Watterson (1988). See parameters and explanations in Table 2. B) morpho-structural map
711 combining the satellite-derived bathymetry (http://topex.ucsd.edu/WWW_html/mar_topo.html;
712 contour interval: 50 m) and the main on-land faults (modified after Monaco and Tortorici, 2000;
713 Pizzino et al., 2004; Tansi et al., 2007) and the offshore faults identified on our geophysical dataset.
714 Inset: visual representation of source geometry model and parameters.

715
716 **Table 1** - Parameters for the source models causative of the 8 September 1905 earthquake available
717 in the literature (see also Fig. 2).

718 IDs identify models taken from the following papers: PE ~~=~~ Peruzza et al. (1997); VP = Valensise
719 and Pantosti (2001b); MT = Monaco and Tortorici (2000); CV = Capo Vaticano Fault, in Monaco
720 and Tortorici (2000), parameters by Piatanesi and Tinti (2002); VV = Vibo Valentia Fault, in
721 Monaco and Tortorici, (2000), parameters by Piatanesi and Tinti (2002); CT = Cucci and Tertulliani
722 (2010). Note that source model parameters were available only for Peruzza et al. (1997) and for
723 Piatanesi and Tinti (2002), while in most cases L (Length) was deduced from mapped fault trace;
724 we computed W (Width) and the remaining parameters using empirical and analytical relationships.

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725 TD and BD are top and bottom depth, respectively; M_w (W&C) and M_w (K&A) are
726 computed using formulations by Wells and Coppersmith (1994) and Kanamori and Anderson
727 (1975), respectively.

728

729 **Table 2** - Parameters for the source model deduced from the SE (S. Eufemia) Fault. First and
730 second row list the two end-members (20 and 30 km length, respectively); third row lists the source
731 with the median length (25 km), that we adopted in this study.

732 ID identifies the source model. TD and BD are top and bottom depth, respectively; SI is Slip; M_w
733 (W&C) and M_w (K&A) are computed using formulations by Wells and Coppersmith (1994) and
734 Kanamori and Anderson (1975), respectively. L is Length inferred using cumulative displacement
735 of the Miocene reflector, *sensu* Walsh and Watterson (1988); W is Width computed using empirical
736 and analytical relationships. Dip is constrained using averaged Vp velocity and adjacent wells.

737

738 Table 3 - Values and standard deviation (SD) of the chemical and biological parameters. TN =
739 Total Nitrogen; TC = Total Carbon; TOC = Total Organic Carbon; CHO-H₂O = colloidal
740 carbohydrates; CHO-EDTA = carbohydrates extracted in EDTA.

741

742

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746 Sant'Eufemia - offshore tirrenico calabrese) project. Special thanks are due to Drs. Vedrana
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751 [manuscript](#). Seismic data interpretation was managed using the Kingdom software (IHS, Global
752 Inc.). [This paper is ISMAR-CNR contribution.](#)

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*Highlights (for review)

- We analysed a multidisciplinary data set to identify the source of the 1905 earthquake
- Our data reveals a NE-trending SE-dipping normal fault (S. Eufemia Fault) displacing modern sediments
- Prokaryotes abundance distribution agree with fluid up-welling along the fault
- We evaluate previous seismogenic source models for the 1905 event in light of this new data
- kinematics , orientation and location of the S. Eufemia Fault satisfies the historical record of the 1905 earthquake required features

1 **Approaching the seismogenic source of the Calabria 8 September 1905 earthquake: New**
2 **geophysical, geological and biochemical data from the S. Eufemia Gulf (S Italy)**

3

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15

16

17 **Abstract**

18 Recognizing the seismogenic source of major historical earthquakes, particularly when these have
19 occurred offshore, is a long-standing issue across the Mediterranean Sea and elsewhere. The
20 destructive earthquake (M ~7) that struck western Calabria (southern Italy) on the night of 8
21 September 1905 is one such case. having various authors proposed a seismogenic source, with
22 apparently diverse hypotheses and without achieving a unique solution. To gain novel insight into
23 the crustal volume where the 1905 earthquake took place and to seek a more robust solution for the
24 seismogenic source associated with this destructive event, we carried out a well-targeted
25 multidisciplinary survey within the Gulf of S. Eufemia (SE Tyrrhenian Sea), collecting geophysical
26 data, oceanographic measurements, and biological, chemical and sedimentary samples.

27 We identified three main tectonic features affecting the sedimentary basin in the Gulf of S.

28 Eufemia : 1) a NE-SW striking, ca. 13-km-long, normal fault, here named S. Eufemia Fault; 2) a
29 WNW-striking polyphased fault system; and 3) a likely E-W trending lineament. Among these, the
30 normal fault shows evidence of activity witnessed by the deformed recent sediments and by its
31 seabed rupture along which, locally, fluid leakage occurs. Features in agreement with the
32 anomalous distribution of prokaryotic abundance and biopolymeric C content, resulted from the
33 shallow sediments analyses.

34 The numerous seismogenic sources proposed in the literature during the past 15 years make
35 up a composite framework of this sector of western Calabria, that we tested against a) the
36 geological evidence from the newly acquired dataset, and b) the regional seismotectonic models.
37 Such assessment allows us to propose the NE-SW striking normal fault as the most probable
38 candidate for the seismogenic source of the 1905 earthquake. Re-appraising a major historical
39 earthquake as the 1905 one enhances the seismotectonic picture of western Calabria. Further
40 understanding of the region and better constraining the location of the seismogenic source may be
41 attained through integrated interpretation of our data together with a) on-land field evidence, and b)
42 seismological modeling.

43

44 **Keywords:** seismogenic source, earthquake, seismotectonics, prokaryotes, Calabrian Arc

45

46

47 **1. Introduction**

48 Calabria is one of the Italian regions with the largest concentration of seismic moment release (Fig.
49 1; Gasparini et al., 1982; Westaway, 1992; Castello et al., 2006; Calò et al., 2012) and highest
50 probability of occurrence of major earthquakes (Rotondi, 2010), mainly located between two main
51 shear zones, the Tindari Fault to the south-west, and the Cirò-Benevento Fault to the north. Most
52 earthquakes affecting Calabria and its western offshore are characterized by a normal fault plane

53 solution (D'Agostino and Selvaggi, 2004; Vannucci and Gasperini, 2004), confined within a
54 continuous extensional belt parallel to the Calabrian Arc.

55 The earthquake that struck western Calabria on the night of 8 September 1905 is one of the
56 strongest events in the Italian catalogue (M_w up to 7.5, according to Michelini et al., 2006), besides
57 the 28 December 1908 earthquake (M_w 7.1), that struck southern Calabria and the Messina Straits,
58 and the numerous ones occurred in the 17th and 18th century, that severely hit large parts of the
59 region (Postpischl, 1985; Boschi et al., 2000; Guidoboni et al., 2007). The 1905 earthquake caused
60 557 deaths (Baratta, 1906), most of them around the Capo Vaticano promontory, with the highest
61 intensity values (Mercalli-Cancani-Sieberg = XI) recorded between the towns of Tropea, to the
62 west, and Vibo Valentia, to the east (Fig. 2; Tiberti et al., 2006). Historical documents reported
63 several triggered ground failures (landslides, rock falls and lateral spreads), hydrological changes
64 (stream-flow variations, liquefaction, rise of water temperature and turbidity), and earthquake
65 “lights” and “sounds” (Guidoboni et al., 2007; Tertulliani and Cucci, 2008, 2009). Finally, a
66 tsunami, albeit modest, was reported by contemporary observers both in the open sea and along the
67 coast of the S. Eufemia Gulf (see blue small waves in Fig. 2), with few meters of maximum run-up
68 and sea flooding in some beaches up to 30 m (Tinti and Maramai, 1996 and references therein;
69 Guidoboni and Ebel, 2009; NGDC/WDC, 2012).

70 Although this earthquake is one of the most catastrophic ones recorded in the region, poor
71 documentation resulting from this early 20th century event has caused it to go relatively overlooked
72 and not fully understood in terms of magnitude and epicentral location. Uncertain M estimates,
73 particularly when so diverging among each other, and dubious location, especially when the latter is
74 at sea, make earthquake assessment all the more problematic. Together with the underlying
75 geology, these are among the primary ingredients to search the seismogenic source (i.e., the
76 causative fault) of a damaging earthquake, to ultimately enhance the seismic hazard pattern of a
77 given region. To address these issues and to build on the knowledge of the seismotectonic
78 framework and the seismogenic potential of western Calabria, we performed a well-targeted

79 multidisciplinary survey during the summer of 2010 in the S. Eufemia Gulf (gray transparent square
80 in Fig. 1) aboard the R/V OGS-*Explora*. Biological and geochemical data, collected to detect
81 hydrothermal activity of potential seismotectonic relevance, and evidence stemming from the
82 analysis of geophysical data (multichannel seismic - MCS, sub-bottom profiles - Chirp and high
83 resolution morpho-bathymetry) allowed us to propose a causative source for the 1905 earthquake,
84 while reappraising previously proposed solutions in the light of the new geological evidence.

85

86

87 **2. Geological and seismotectonic framework**

88

89 *2.1 Geological Setting*

90 The S. Eufemia Gulf lies between the Calabrian Arc and the SE Tyrrhenian Basin (Fig. 1), which is
91 the Neogene back-arc basin of the Apennines subduction system (Patacca et al., 1990, 1993, 2004,
92 and references therein). Subduction migrated eastward from the Tortonian to Early Pliocene, and
93 south-eastward from the Late Pliocene to Early Pleistocene (Patacca et al., 1990; Sartori, 2003).

94 The Calabrian arc (Fig. 1) is an independent arcuate continental block (Bonardi et al., 2001)
95 that bridges the NW-SE trending southern Apennines with the SSW-NNE trending Apennines in
96 Sicily. Several authors have considered the Calabrian arc as an uprooted fragment of the Alpine belt
97 (e.g., Amodio-Morelli et al., 1976; Malinverno and Ryan, 1986; van Dijk et al., 2000 and references
98 therein). Its arcuate shape can be attributed to the diachronous collision of the Apennine chain with
99 the Apulian foreland, to the north, and with the Hyblean foreland, to the south (Malinverno and
100 Ryan, 1986; van Dijk et al., 2000). Such collision also controlled (1) the clockwise rotation of
101 Sicily and Calabria, (2) the counter-clockwise rotation of the southern Apennines (Cifelli et al.,
102 2007), that ceased at the end of the Pleistocene (Mattei et al., 2007), and (3) the intense
103 fragmentation of the Calabrian Arc in NW-SE striking blocks (Knott and Turco, 1991; van Dijk,
104 1991, 1992; Del Ben et al., 2008; Barone et al., 2008). Since the Middle Pleistocene, the Calabrian

105 Arc experienced rapid uplift of up to ca. 1 mm/y (Westaway, 1993; Bordoni and Valensise, 1998;
106 Anzidei et al., 2012) and a ESE-trending forearc advancement, shown by GPS data (D'Agostino et
107 al., 2011; Devoti et al., 2011). Uplift was in part accommodated by major normal faults (Monaco
108 and Tortorici, 2000; Catalano et al., 2003), frequently bounded by NW-SE striking shear zones
109 (Fig. 1; van Dijk, 1991; Tansi et al., 2007).

110 The sedimentary basin hosted by the S. Eufemia Gulf is bounded by the Capo Vaticano
111 promontory to the south, by the Calabrian landmass to the east, and by the steep submarine slope
112 extending to the Marsili abyssal plain to the west (Figs. 1 and 2). The S. Eufemia basin is filled by a
113 ca. 2-km-thick, Plio-Quaternary sequence, overlying intensely deformed Miocene units (Argnani
114 and Trincardi, 1993; Milia et al., 2009; Loreto et al., 2012). The S. Eufemia slope basin (Argnani
115 and Trincardi; 1993) includes several turbiditic, large mass-failure and drape deposits (Trincardi et
116 al., 1995). Finally, Milia et al. (2009) identified a sub-vertical fault system showing a polyphased
117 history, coeval with the early N-S extensional phase.

118

119 *2.2 Seismogenic source models of the 1905 earthquake*

120 Numerous epicentral locations and M_w estimates of the 8 September 1905 earthquake have been
121 proposed in the literature. According to Rizzo (1906), Boschi et al. (2000), and Guidoboni et al.
122 (2007), the epicenter of the earthquake was onshore (Fig. 2), whereas Riuscetti and Schick (1975),
123 Camassi and Stucchi (1997), Michelini et al. (2006), and a recent macroseismic study by Rovida et
124 al. (2011) all place the epicenter offshore (Fig. 2). Assigned magnitudes range from instrumental
125 estimates of M 7.0 (Martini and Scarpa, 1982) and M 7.5 (Michelini et al., 2006), to the
126 macroseismic ones of M 6.7 (Guidoboni et al., 2007), M 7.0 (Gruppo di Lavoro CPTI04, 2004;
127 Rovida et al., 2011) and M 7.1 (Postpischl, 1985).

128 Over the past 15 years, various researchers hypothesized a possible seismogenic source
129 responsible for the 1905 earthquake (see Table 1, Fig. 3). Peruzza et al. (1997) presented the first
130 seismotectonic model for the largest Calabrian earthquakes, proposing a segmentation model with

131 large normal faults sub-parallel to the extensional axis of western Calabria. For the 1905 earthquake
132 case, these authors maintained an E-dipping, NNE-SSW striking source (PE in Fig. 3), based on an
133 onshore epicenter. Monaco and Tortorici (2000) presented a seismotectonic model of the Calabrian
134 Arc and eastern Sicily and proposed causative faults for key destructive earthquakes. For the 1905
135 event, these authors hypothesized the Capo Vaticano Fault, a NW-dipping, NE-SW striking normal
136 fault (MT in Fig. 3), with an offshore epicenter.

137 Valensise and Pantosti (2001b) presented a regional seismogenic source model and proposed
138 a 40-km-long, SE-dipping, NE-striking normal fault near the edge of the S. Eufemia Gulf (VP in
139 Fig. 3), and extending on land. Searching for an explanatory source of the tsunami associated with
140 the 1905 earthquake, Piatanesi and Tinti (2002) parameterized the Capo Vaticano and the Vibo
141 Valentia faults (Monaco and Tortorici, 2000), two NW-dipping, NE-SW striking normal faults
142 straddling the northern shore of the Capo Vaticano promontory and the internal sector of the gulf
143 (CV and VV in Fig. 3; Table 1). Finally, Cucci and Tertulliani (2006; 2010) suggested the
144 Coccorino Fault, a 29-km-long S-dipping, WNW-ESE striking normal fault affecting the southern
145 sector of the Capo Vaticano promontory and the northern Gioia Tauro Plain (CT in Fig. 3).

146

147

148 **3. Data and Methods**

149 *3.1 Geophysical data*

150 Nine multichannel seismic profiles, organized in a tight grid (thin yellow lines in Fig. 4) were
151 acquired using a 1500-m-long streamer cable, with a 120-channels array and a 12.5 m trace interval.
152 The energy source consisted of two GI-guns with a total volume of 8 liters shot every 25 m, with a
153 resulting seismic coverage of 30 for each investigated depth point. The seismic data were processed
154 following a standard procedure, in order to get post-stack time migrated seismic sections. More
155 details about acquisition parameters and processing performed to improve Signal/Noise ratio can be
156 found in Loreto et al. (2012).

157 More than 2200 km of sub-bottom profiles (Chirp) were acquired using a Benthos CAP-
158 6600, consisting of 16 keel mounted transducers. Sweep ranges between 2 and 7 kHz, with the
159 resulting configuraton ensuring a full ocean depth investigation. Chirp data image in detail the
160 uppermost section of the sedimentary cover down to a ca. 75 m depth, assuming a constant 1550
161 m/s sound speed within the shallowest sediments.

162 The high resolution morpho-bathymetric map (Fig. 4) was obtained using two hull mounted
163 multibeam echosounders, a Reson Seabat 8111 (100 kHz) and 8150 (12 kHz). We employed the
164 Seabat 8111 up to 400 m depth (maximum swath width of 7.4 times the water depth), the Seabat
165 8150 for water depth >500 m (maximum swath width of 4.5 times the water depth), and both
166 echosounders for the 400-500 m depth range. The data were processed to remove spikes due to
167 navigation system problems and/or to the acquisition system.

168

169 *3.2 Chemical, biological and oceanographic data*

170 We collected 12 biological samples (white triangles in Figs. 4), at the top of gravity cores using a
171 sterile spoon and frozen at -20 °C, and performed 10 CTD (Conductivity-Temperature-Depth)
172 profile measurements in the sector near the tectonic features recognized in the multichannel data.
173 These samples were used to evaluate prokaryotic abundance, and to perform Total Carbon (TC),
174 Total Nitrogen (TN), and Total Organic Carbon (TOC) chemical analyses.

175 For TC, TN and TOC analyses, triplicate sub-samples of homogenized and freeze-dried
176 sediment (< 250 µm) were weighed directly in capsules (5x9 mm). Before the TOC determination,
177 sub-samples were treated with increasing concentrations of HCl (0.1N and 1N) to remove
178 carbonates, following the procedure by Nieuwenhuize et al. (1994). Carbon and nitrogen were
179 determined using a CHNO-S elemental analyzer according to the methods of Pella and Colombo
180 (1973) and Sharp (1974). Sub-samples of homogenized sediment were freeze-dried and processed
181 to determine carbohydrates, lipids, and proteins following the procedure described by Cibic et al.

182 (2008). The sum of carbohydrates, lipids and proteins carbon was referred to as Biopolymeric
183 Carbon (BPC).

184 Prokaryotic abundance was determined using the centrifugation method by Ravenschlag et
185 al. (2000) and a modified protocol by Lunau et al. (2005). Sediment samples were diluted to a final
186 concentration of 1:110 and filtered on black Nuclepore polycarbonate 0.2- μ m-pore-size filters.
187 Filters were mounted on microscope slides, stained with a SYBR Green I-mounting medium Mowiol
188 solution (1:15) and counted by epifluorescence microscopy (LEICA DM2500) at 1000 X
189 magnification under a blue filter set (BP 450-490 nm, BA 515). A minimum of 300 cells were
190 accounted for each filter in at least 40 randomly selected fields.

191 The CTD measurements are done using the sea-bird electronics (SBE) 911plus system with
192 sensors mounted on the Carousel SBE32 frame with 12 Niskin bottles. We measured: Pressure (db),
193 Conductivity (mS/cm), Temperature ($^{\circ}$ C), Oxygen (μ A0), Fluorescence (μ g/l), and optical
194 backscatter, with a 10^{-3} accuracy. Lacking a high accuracy altimeter, the last measurement was done
195 at ca. 10 m from the seafloor to avoid problems of interaction with the seafloor morphology.

196

197

198 **4. Results**

199 *4.1 Morpho-bathymetric features*

200 Our high resolution morpho-bathymetric data (Fig. 4) allowed us to identify some key features: 1) a
201 large submarine Angitola canyon, already shown by Argnani and Trincardi (1988), characterized in
202 the near-shore part of the gulf by an unusually straight trend, ca. ENE-WSW oriented for about 20
203 km, and in the distal part by a meandering trend; 2) a NW-SE oriented morpho-structural high
204 (hereafter: MS-High) offshore the town of Tropea, recognized as the seaward prolongation of the
205 Capo Vaticano promontory, surrounded by several slide scars (Loreto et al., 2012). However, a
206 more detailed analysis (Fig. 5) allowed us to identify other noteworthy features, between the
207 northern internal slope of the gulf and the Angitola Channel, such as small slides or slumps (see

208 white thick arrows) and a prominent N31°-trending, 3-m-high, 8-km-long scarp, well visible across
209 the 150-m contour line (i.e., the shelf break; see inset in Fig. 5).

210

211 *4.2 Tectonic features*

212 Seismic profile GSE10-05, NE-SW oriented (Fig. 4), shows a thick and well stratified
213 sedimentary sequence overlying a poorly reflective and poorly stratified sequence (Fig. 6). Based
214 on previous works (Argnani & Trincardi, 1993; Trincardi et al., 1995; Milia et al., 2009; Pepe et al.,
215 2010) and on evidence from the Marisa industrial well (Figs. 4 and 7; VI.D.E.PI. Project,
216 www.videpi.com), the imaged sequence probably is the Plio-Quaternary basin infill deposited on
217 top of the Miocene, which correspond to the Messinian units. Data from the Marisa well lack the
218 upper part from Pleistocene to present that could be associated with the uppermost, condensed
219 layer. The boundary between the Miocene and Pliocene generates a strong acoustic contrast, due to
220 lithology, seismically associated with a high amplitude horizon, here defined Top Horizon.

221 The southern levee of the Angitola Channel (SL; Fig. 6) shows a scarp 200 ms high, i.e. 150
222 m, assuming a fixed seismic water velocity of 1500 m/s. Sediments next to the levee show gentle
223 folding (see black thick arrow) involving only the well-stratified Plio-Quaternary sequence leaving
224 the Top Horizon undisturbed. Combined with these elements, the straight trend of the Angitola
225 Channel leads us to hypothesize that a shallow ca. E-W striking fault (see AF? in Fig. 6, box and
226 inset), with a likely strike-slip motion, passively controls the edge of the channel (Loreto et al.,
227 2012).

228 Plio-Quaternary sediments of the central basin (Fig. 6) are deformed by two gentle wide
229 anticlines, the main one controlled by the compressional phase of a SW-dipping fault. Folding
230 decreases with depth and fades out at mid-sequence (see black dot). The underlying sediments
231 thicken into a syn-rift sequence controlled by the extensional phase of the bordering fault.
232 Assuming a constant seismic velocity of 2200 m/s for Plio-Quaternary sediments (Pepe et al., 2010;
233 Marisa well), we estimate that the Top Horizon is offset ca. 350 m (see Trc num 6150 in Fig. 6). We

234 interpret such deformational style as due to a N93° striking Polyphased Fault (from here on, PF)
235 and 58° SSW-dipping (Fig. 6, inset), visible in two seismic profiles (GSE10_04A and GSE10_05).
236 Upward, contraction abruptly stops below a thick and chaotic body perching in stratigraphic
237 unconformity (dotted line; Fig. 8). There is no evidence of surface rupture, such as a scarp on the
238 seafloor (Fig. 8, left), confirming that PF is sealed by the upper section of the Plio-Quaternary
239 deposits.

240 The analysis of the E-W-striking GSE10_07 seismic profile (Figs. 4 and 9) allowed us to
241 identify two main features: 1) the Angitola Channel characterized by steep and deep levees, to the
242 west; and 2) a normal fault extending through the whole imaged sedimentary succession, to the east
243 (Fig. 9, Box). Discontinuities and deformations of the Plio-Quaternary sediments, expressed as
244 gentle folds in the foot-wall (thick white arrows) and small drag folds (thick black arrow) in the
245 hanging-wall, can be recognized within older and recent sediments (Fig. 9, Box). These folded and
246 faulted recent deposits are well imaged on Chirp profile CH_39 (Fig. 10B), acquired north of
247 seismic profile GSE10_07, that crosses the notable scarp on the high-resolution morpho-
248 bathymetric data (Fig 5). Northward over the seafloor scarp zone, the discontinuities and
249 deformations affect the shallow deposits without reaching the seafloor (see chirp profile CH_52 in
250 Fig. 10C); farther north, the deformation of the recent sediments strongly decreases and only a
251 weak, structurally-controlled offset is detectable (see chirp profile CH_71 in Fig. 10D). Combining
252 evidence from all geophysical data (MCS, Chirps, and bathymetry), we mapped a N31° trending,
253 38° ESE-dipping, ca. 13-km-long normal fault rupturing the seafloor for about 8 km along strike
254 (Figs. 9, Box and 10).

255 Assuming a constant seismic velocity of 2200 m/s for Plio-Quaternary sediments, the
256 normal fault, that here we call S. Eufemia Fault (Fig. 10), offsets the upper Miocene top about 460
257 m. Using fault scaling relationships by Walsh and Watterson (1988) to compute fault length from
258 cumulative offset, we estimate that the S. Eufemia Fault length ranges from 20 to 30 km, much
259 longer than the 13 km we measured on the geophysical data (see Fig 10). In other words, the S.

260 Eufemia Fault credibly propagates along-strike toward the mainland, to the north-east and to the
261 south-west. Considering an estimated median fault length of 25 km, and based on formulations by
262 Wells and Coppersmith (1994) and by Kanamori and Anderson (1975), we estimate a M_w ranging
263 from 6.5 to 6.8, respectively (Table 2) - the latter being directly influenced by the amount of slip per
264 event. Based on data from comparable Italian earthquakes with normal faulting mechanism, like the
265 1908 Messina-Reggio Calabria one (Valensise, 1988; Amoruso et al., 2002; Pino et al., 2009), we
266 infer 2 m to be a credible slip amount, which therefore leads us to tentatively adopt M_w 6.8 for this
267 fault.

268

269

270 *4.3 Chemical and biological analyses*

271 The stations (St.) sampled . for chemical and biological parameters in the sediments can be grouped
272 into three transects (see white triangles in Figs. 4 and 11), with inshore-offshore direction and
273 located a) north (N Tran. in Fig. 11), b) along (AC Tran. in Fig. 11), and c) south (S tran. in Fig. 11)
274 of the Angitola channel. Water temperature close to the sea-bottom was almost constant in all
275 stations and varied in a range of 13.97 °C (St. 3) - 14.18 °C (St. 12).

276 The results of both chemical and biological parameters are reported in Table 3. TN, TC and
277 TOC did not show any evident difference among stations, except for the southern transect, along
278 which we observed a small decreasing gradient from inshore to offshore. Proteins were the main
279 constituent of the BPC, followed by lipids and carbohydrates (Fig. 12, left). Their values did not
280 change remarkably among stations with the exception of St. 7, characterised by the highest proteins
281 content ($1623 \pm 25 \mu\text{g C g}_{\text{dry}}^{-1}$; Table 3). The other components of the BPC (lipids, CHO-H₂O and
282 CHO-EDTA) showed a slightly higher variability and no evident pattern was detected (Fig. 12,
283 left). Along the Angitola channel, carbohydrates extracted in EDTA were higher than in the other
284 stations (Table 3). Prokaryotic abundance in the sediment showed a great variability among
285 stations, particularly along the Angitola channel (Fig. 12, right). The lowest density was measured

286 at St. 11 ($0.70 \pm 0.05 \cdot 10^8$ cells g_{dry}⁻¹), whereas the maximum at St. 7 ($2.94 \pm 0.38 \cdot 10^8$ cells g_{dry}⁻¹).
287 A strong variability was also observed along the northern sector, where a strong increase of the
288 prokaryotic abundance was recognized at St. 12.

289

290 *4.4 Physical parameters of CTD measurements*

291 CTD profiles were analyzed focusing on the temperature close to the bottom of each profile, i.e.
292 looking for signals of geothermal activity. The standard deviation evaluated for each profile at its
293 bottom and 5 m above gives no evident anomalous signal – thus ranging within the variability of a
294 significant statistical test. The lack of variability in temperature detection close the seafloor could
295 be partially justified by the distance of the CTD measurement from the seafloor (at least 10 m).

296

297

298 **5. Discussions**

299 The aim of this paper is to contribute with sub-surface offshore data and interpretations to identify
300 the possible seismogenic source of the 8 September 1905 earthquake, contributing to better
301 constrain its location and M_w , using a unique approach.

302 Evidence from MCS data analysis (Figs. 6 and 9) allowed us to identify three faults that
303 deform the deposits of the S. Eufemia basin: 1) the Angitola Fault (Fig. 6, Box); 2) the Polyphased
304 Fault in the central part of the gulf (Fig. 6); and 3) the S. Eufemia Fault (Fig. 9).

305 The Angitola fault is identifiable by its tectonic control on the straight trend of the Angitola
306 Channel, and by the steep and deep levees associated with a >150 m bathymetric offset (Fig. 6,
307 Box). Deformation rapidly decreases with depth and fades out before reaching the Messinian top
308 (Fig. 6). AF, therefore, is a shallow (if long) structural feature with no basin-wide tectonic role,
309 showing that it has no causative relationship with the 1905 earthquake or any earthquake at all.

310 The Polyphased Fault deforms the deeper sedimentary stack and the Messinian top, clearly
311 showing positive inversion features (Fig. 6). In the shallower stack, this fault is associated with

312 anticlines, and deformation is accommodated along several sub-parallel secondary faults buried
313 below a thick chaotic body (Fig. 8). This fault system is long-lived, well organized through the pre-
314 Messinian sequence and has affected the central part of the S. Eufemia basin. However, it does not
315 extend through the upper part of the Plio-Quaternary deposits and therefore has no present-day
316 tectonic activity. Like with the Angitola Fault, no relationship can be established between the
317 Polyphased Fault and the 1905 earthquake.

318 The S. Eufemia Fault is an active normal fault, sub-parallel to the large normal faults that
319 control the basins in the western Calabrian mainland (i.e., the Mesima and the Gioia Tauro basins).
320 Its dip-slip kinematics appears to have been consistent at least since the late Miocene, as shown by
321 the MCS profiles for the full sedimentary stack (Fig. 9, Box) and by Chirp data for its shallower
322 section (Fig. 10). The S. Eufemia Fault is properly oriented with (1) fault plane solutions derived
323 for earthquakes occurred offshore to the NW (Mulargia et al., 1984), and (2) current extensional
324 tectonics of western Calabria (Westaway, 1993; Bordoni and Valensise, 1998; Monaco and
325 Tortorici, 2000; Catalano et al., 2003; Pizzino et al., 2004; Ferranti et al., 2007). Moreover, this
326 fault shows a 8-km-long and up to 3-m-high scarp (Fig. 5) associated with the cut-off of the fault
327 plane rupture, located near shore. Such scarp occurs close to (1) the maximum damage area of the
328 1905 earthquake, and to (2) the coastal strip between Vibo Marina and Tropea, inundated by the
329 tsunami associated with the 1905 earthquake (Guidoboni et al., 2007; Fig. 2). Although such
330 seafloor rupture may not necessarily be the direct trigger of the tsunami associated with this event,
331 it is possibly a favorable factor (NGDC/WDC, 2012). Biological data analysis provides some
332 indications about the recent activity of the S. Eufemia Fault in terms of seafloor heterogeneity and
333 fluids circulation, which could be associated with the fluid up-welling from deep sediments. The
334 presence of active faulting could influence the water currents at a local scale, favoring the
335 accumulation of organic matter at the seafloor (Danovaro et al., 2010 and references therein). Data
336 from shallower stations show more labile compounds (Danovaro et al., 1998) as colloidal
337 carbohydrates, which promote microbial activities, thus supporting high abundances as those

338 observed at St. 7 and St. 8 (Fig. 12, left; de Brouwer and Stal, 2001). On the other hand, moving
339 offshore along the Angitola channel, the labile compounds probably decrease due to preferential use
340 by prokaryotes. Although available, the prokaryotic community could be less supported by the
341 refractory organic fraction, harder to degrade, and this could partially explain the limited
342 abundances at the offshore stations. An exception is represented by St. 4, characterized by high
343 prokaryotic density not supported by the high biopolymeric C content (Fig. 12). This anomaly could
344 be explained considering that St. 4 is located at the border of the Angitola channel (Figs. 4 and 11),
345 along which water enriched by organic matter can flow.

346 Along the southern transect, the high organic content at St. 8 suggests the presence of up-
347 welling fluids, which could represent an alternative source of carbon and energy for the microbial
348 community. Prokaryotes with particular metabolisms (as chemiosynthetic ones) could in fact be
349 enhanced and their proliferation could support the other trophic levels explaining partially the high
350 biopolymeric C values observed (Fig. 12, left). Even if not supported by the low organic matter
351 content, also the high prokaryotic abundance at St. 12 (Fig. 12, right), located along the seafloor
352 trace of the S. Eufemia Fault (Figs. 4 and 10, left), could be explained in part by the presence of
353 deep fluids, not necessarily warm, up-welling along the fault plane, which act as a source of carbon
354 (Fig. 12, left). Such hypothesis is in agreement with the small fluid escape detected on the Chirp
355 profile (Fig. 10B).

356 Concerning the geometrical parameters of the S. Eufemia Fault, its measured length of only
357 13 km (Fig. 10A) and its total displacement of 460 m lead us to infer a (much) longer fault, at least
358 for two simple reasons:

359 a) a stratigraphic one: the southwesterly strand of the S. Eufemia fault is buried below the
360 Angitola channel system that completely masks any fault deformation clues; and

361 b) a tectonic one: all field and experimental observation of normal faults consistently show
362 decreasing throw towards fault tips (for a reference: Ramsay and Huber, 1987), as suggested by the
363 decreasing deformation toward the northeast (Figs. 10B, C, and D).

364 From the macroseismic M_w estimates ranging between 6.7 and 7.0 (Gruppo di Lavoro
365 CPTI04, 2004; Guidoboni et al., 2007; Rovida et al., 2011), the expected fault length derived using
366 empirical relationships by Wells and Coppersmith (1994) and Kanamori and Anderson (1975)
367 should exceed our estimated 25 km, as suggested by field evidence for other Italian earthquakes of
368 the same M_w range (see: Ward and Valensise, 1989; Pantosti and Valensise, 1990; Burrato and
369 Valensise, 2008; Pino et al., 2009). It would, however, be close to the 20 to 30 km range inferred
370 using Walsh and Watterson (1988) formulations (see em20 and em30 in Fig. 13A). On the other
371 hand, instrumental estimates ranging from M 7.0 (Mulargia et al., 1984) to M 7.5 (Michelini et al.,
372 2006) require up to a $\gg 50$ km expected fault length. Given the epicentral locations proposed by
373 these authors and by Riuscetti and Schick (1975), such fault should lie entirely offshore, west of
374 Capo Vaticano, causing a long-wave and long-term imprint on the geology offshore central
375 Calabria, to-date not recognized on data. Based on the current set of knowledge and on the
376 geological evidence in our data, we prefer a conservative approach, considering 6.8 to 7.0 as a fairly
377 reliable estimate range (Fig. 13; Table 2). In fact, it is certainly true that poorly located moderate-
378 size earthquakes are associated with uncertain M_w estimates, especially when a novel location can
379 be constrained offshore by geological means (see an example in Fracassi et al., 2012).

380 Finally, although our data cover only the marine sector of the S. Eufemia Gulf, they fall in a
381 broader seismotectonic context (Fig. 13) and shed some light on possible contradictions among the
382 various seismogenic faults / source models previously proposed, so different from one another (Fig.
383 3, Table 1).

384 In chronological order, length (22 km) and dip direction (SE) of PE (Peruzza et al.; 1997)
385 are consistent with our data, thus making PE an interesting source model, although lying essentially
386 onland. MT (Monaco and Tortorici; 2000) dips to the NW and lies in part within our survey's
387 boundaries but is not shown on our data. Therefore, MT is not likely to affect the inner Gulf, while
388 it could affect the NW flank of the Capo Vaticano promontory, and would belong to an entirely
389 distinct fault system. VP (Valensise and Pantosti; 2001b) is the longest possible source in the

390 literature (40 km). Our data show no evidence of this source, which however is interestingly sub-
391 parallel to the S. Eufemia Fault, with same dip direction, like PE.

392 CV (Piatanesi and Tinti, 2002) is essentially MT, although dipping at very high angle; given
393 its location, same considerations done for MT apply for CV. VV (Piatanesi and Tinti, 2002), a NW-
394 dipping high-angle normal fault, lies outside our survey's boundaries and we therefore cannot verify
395 its geometry and role. However, since its rupture would occur onland, one would likely need to
396 invoke other nearby phenomena to account for the tsunami, such as large submarine slides, which
397 our marine data do not show. We therefore doubt that VV can be considered as a viable
398 seismogenic source for the 1905 earthquake. On the other hand, MT/CV's location and geometry
399 seems to conflict with the S. Eufemia Fault, for which we gathered positive evidence from our data.

400 CT (Cucci and Tertulliani, 2010) is located away from the area of maximum damage of the
401 1905 earthquake, along a regional transverse structure. Maximum damage is expected to occur in
402 and near the hanging-wall of CT, which however is not the case here (major damage is located way
403 north of CT's foot-wall). Therefore, while we clearly have no geological data to discuss CT, we
404 doubt it can be associated with the 1905 earthquake.

405 Based on the above considerations, we believe that the S. Eufemia Fault redraws the
406 seismotectonic understanding of this sector of western Calabria (Fig. 13), and that it proves to be a
407 credible candidate as a seismogenic source model for the 1905 earthquake.

408

409

410 **6. Conclusions**

411 Uncertain epicentral location and M estimate of large historical earthquakes that have occurred at
412 sea yet caused major damage on-land often hamper the correct understanding of such destructive
413 events. In a region such as Calabria, with its numerous seismic crises and puzzling catastrophic
414 earthquakes that have occurred in a relatively narrow landmass, identifying the likely seismogenic
415 source that could be associated with the 8 September 1905 event is of key relevance to correctly

416 evaluate the seismogenic potential of this area and its seismic hazard. To contribute to this goal, we
417 present a multidisciplinary study that brings together evidence from our data to shed new light on
418 the seismo-tectonics of central-western Calabria.

419 Our geophysical data allowed us to identify three tectonic features in the Gulf: 1) the
420 Angitola Fault, which deforms only shallower sediments; 2) the Polyphased Fault system, currently
421 buried below a thick chaotic body; and 3) the N31°-striking S. Eufemia normal Fault, rupturing the
422 shallow deposits for 13 km along-strike, that dips to the southeast and extends through the whole
423 sedimentary stack up to the seabed. Among these structures, the S. Eufemia Fault is the only active
424 one and compatible with the 1905 earthquake required features, i.e.: 1) expected fault size suitable
425 for the macroseismic M_w range, 2) a 8-km-long seabed rupture, corresponding to the up-ward
426 prolongation of the fault plane, compatible with the occurrence of a tsunami, 3) location fitting the
427 distribution of the maximum damage area, and 4) geometry in agreement with the regional
428 seismotectonic model of the Calabria block. In light of these factors, we maintain that the S.
429 Eufemia Fault is the most credible seismogenic source for the 1905 earthquake, also against the
430 critical review of source models proposed in the literature.

431 Recent activity of the S. Eufemia Fault is also witnessed by the fluid escapes detected close
432 to the seafloor. Such evidence is also confirmed by the high Prokaryotes abundance and
433 biopolymeric C content distribution that we tentatively explain with deep fluids, locally up-welling
434 along the fault plane, acting as source of carbon.

435 Despite the undersized length of the rupture associated with the S. Eufemia Fault,
436 cumulative displacement indicates that this fault is likely at least as long as the basin itself and
437 spans along-strike the whole Gulf - possibly beyond into the mainland. Geomorphological survey,
438 drainage basin evolution and displacement modeling are the premier tools of another on-going
439 study to test our hypothesis against field and regional evidence, to understand how this major
440 tectonic feature falls within the fault network described in previous studies.

441

442

443 **Captions:**

444 **Figure 1** - A) Structural sketch of the Southern Apennines and Calabrian Arc, simplified by
445 Catalano and Sulli (2006) and van Dijk et al. (2000); slip vectors from D'Agostino and Selvaggi
446 (2004). Shaded relief modified © Google Earth, using data by SIO, NOAA, U.S, Navy, NGA, and
447 GEBCO. Small red dots represent $M_w > 3$ instrumental earthquakes recorded since 2000 up to-date,
448 from INGV Seismic Bulletin (ISIDE: <http://iside.rm.ingv.it>). SM = Strait of Messina. TF = Tindari
449 Fault; CBF = Cirò-Benevento Fault.

450

451 **Figure 2** - Morpho-bathymetric map of the study area (from NOAA satellite data
452 http://topex.ucsd.edu/WWW_html/mar_topo.html; contour interval: 50 m), showing intensities
453 distribution (Mercalli-Cancani-Sieberg scale) caused by the 1905 earthquake and the seismogenic
454 faults associated with it in the literature: 1) Capo Vaticano Fault (Monaco and Tortorici, 2000); 2)
455 Vibo Valentia Fault (Piatanesi and Tinti, 2002); 3) Coccorino Fault Zone (Cucci and Tertulliani,
456 2006, 2010); 4) Angitola Fault (Peruzza et al., 1997; Valensise and Pantosti, 2001a); 5) Angitola
457 Fault (Valensise and Pantosti, 2001b). Notice that the highest damage was reported on the northern
458 flank of the Capo Vaticano Promontory. Yellow stars indicate the 1905 epicentral locations
459 proposed by (S1) Riuscetti and Schick (1975), (S2) Camassi and Stucchi (1997), (S3) Boschi et al.
460 (2000) and Guidoboni et al. (2007), (S4) Rizzo (1906), and (S5) Michelini et al. (2006). Blue waves
461 indicate the tsunami effects recorded by contemporary observers (data from Tinti and Maramai,
462 1996).

463

464 **Figure 3** – Source models of the 8 September 1905 earthquake derived from the literature, based on
465 seismogenic faults in Fig. 2 (data in Tab. 1). Inset 1: conceptual model of geometry and parameters.
466 Inset 2: list of source models and associated studies.

467 **Figure 4** - Image of the high resolution morpho-bathymetric map. Thin yellow lines indicate the
468 newly-acquired seismic dataset; white triangles show locations of the oceanographic and geo-
469 biological measurements; the blue circle show location of the industrial Marisa well. The seismic
470 profiles described later are shown by thick yellow lines. Grey shade: mainland

471

472 **Figure 5** - High resolution morpho-bathymetric map, with a detail (inset). The white dashed line
473 underlines the Angitola Channel (AC) trend; thick white arrows highlight the several minor
474 incisions and slide. LMT, Lametia Terme; Br., Briatico.

475

476 **Figure 6** – Time migrated seismic profile GSE10_05 located in the central part of the S. Eufemia
477 Gulf; interpreted faults are indicated with dashed black lines. Box (left): the likely dip-slip fault
478 affecting the Angitola channel is indicated as AF ? = Angitola Fault; the point where fault offsets is
479 null (null point) is indicated with a black dot; SL indicates the southern levee. Inset: bathymetric
480 map showing a sketch of the two faults location.

481

482 **Figure 7** - Marisa well plotted on the nearest seismic profile, GSE10_02 (location in Fig. 4),
483 running parallel to the fault plane.

484

485 **Figure 8** — Left: high resolution morpho-bathymetry of the area surrounding the Polyphased Fault
486 (thick red line). Right: a detail of the upper part of the Polyphased Fault system deforming the
487 central part of the S. Eufemia sedimentary basin (Fig. 6).

488

489 **Figure 9** - Time migrated seismic profile GSE10-07 located close to the continental shelf (see
490 location in Fig. 4). Faults are shown as dashed black lines; AC = Angitola Channel; white thick

491 arrows indicate gentle folds, while the black one indicates the drag fold. Inset: bathymetric map
492 showing a sketch of the normal fault location.

493

494 **Figure 10** – A) high resolution morpho-bathymetric map showing the location of the S. Eufemia
495 Fault, including the segment recognized on the geophysical data (thick black line encircled by a thin
496 rectangle around the seafloor rupture) and the one derived from analytical relationships (dashed
497 black line). B) part of Chirp profile 39 crossing the outcropping fault plane. C) part of Chirp profile
498 52 crossing the fault plane and shallow sediments deformation. D) part of Chirp profile 71 crossing
499 the fault plane deforming shallow sediments without reaching the seafloor.

500

501 **Figure 11** - Location map of biological samples (white triangles), whose analysis results are listed
502 in table 3. N tran. = Northern transect; AC tran. = Angitola Channel transect; S tran. = Southern
503 transect.

504

505 **Figure 12** – Left: Biopolymeric C content and its composition measured at the twelve stations,
506 grouped in the three transects. The arrows indicate the near shore to offshore direction. CHO-EDTA
507 = carbohydrates extracted in EDTA; CHO-H₂O = colloidal carbohydrates. Right: prokaryotic
508 abundances measured at the twelve stations grouped in the three transects. The arrows indicate the
509 near shore to offshore direction.

510

511 **Figure 13** – A) sketch map including the Sant'Eufemia Fault (thick red box) seismogenic source
512 against: a) source models based on causative faults of the 8 September 1905 earthquake available in
513 the literature (see Fig. 2 and 3; Table 1), and b) Individual Seismogenic Sources from DISS 3.1.1
514 (DISS Working Group, 2010). The length of the two end members (em20 and em30) derived from
515 the Walsh and Watterson (1988) empirical relationship (20 and 30 km fault length, respectively).
516 Notice that em30 reaches into the mainland beyond the Gulf's extents. Among em20 and em30, we

517 adopted a conservative median length of 25 km. See parameters and explanations in Table 2. B)
518 morpho-structural map combining the satellite-derived bathymetry
519 (http://topex.ucsd.edu/WWW_html/mar_topo.html; contour interval: 50 m) and the main on-land
520 faults (modified after Monaco and Tortorici, 2000; Pizzino et al., 2004; Tansi et al., 2007) and the
521 offshore faults identified on our geophysical dataset.

522

523 **Table 1** - Parameters for the source models causative of the 8 September 1905 earthquake available
524 in the literature (see also Fig. 2). IDs identify models taken from the following papers: PE =
525 Peruzza et al. (1997); VP = Valensise and Pantosti (2001b); MT = Monaco and Tortorici (2000);
526 CV = Capo Vaticano Fault, in Monaco and Tortorici (2000), parameters by Piatanesi and Tinti
527 (2002); VV = Vibo Valentia Fault, in Monaco and Tortorici (2000), parameters by Piatanesi and
528 Tinti (2002); CT = Cucci and Tertulliani (2010). Note that source model parameters were available
529 only for Peruzza et al. (1997) and for Piatanesi and Tinti (2002), while in most cases L (Length)
530 was deduced from mapped fault trace; we computed W (Width) and the remaining parameters using
531 empirical and analytical relationships. TD and BD are top and bottom depth, respectively; Sl is slip;
532 M_w (W&C) and M_w (K&A) are computed using formulations by Wells and Coppersmith (1994) and
533 Kanamori and Anderson (1975), respectively.

534

535 **Table 2** - Parameters for the source model deduced from the SE (S. Eufemia) Fault. First and
536 second row list the two end-members (20 and 30 km length, respectively); third row lists the source
537 with the median length (25 km), that we adopted in this study. ID identifies the source model. TD
538 and BD are top and bottom depth, respectively; Sl is Slip; M_w (W&C) and M_w (K&A) are computed
539 using formulations by Wells and Coppersmith (1994) and Kanamori and Anderson (1975),
540 respectively. L is Length inferred using cumulative displacement of the Miocene reflector, *sensu*
541 Walsh and Watterson (1988); W is Width computed using empirical and analytical relationships.
542 Dip is constrained using averaged V_p velocity and adjacent wells.

543

544 **Table 3** - Values and standard deviation (SD) of the chemical and biological parameters. TN =
545 Total Nitrogen; TC = Total Carbon; TOC = Total Organic Carbon; CHO-H₂O = colloidal
546 carbohydrates; CHO-EDTA = carbohydrates extracted in EDTA.

547

548

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559

560

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Figure 1
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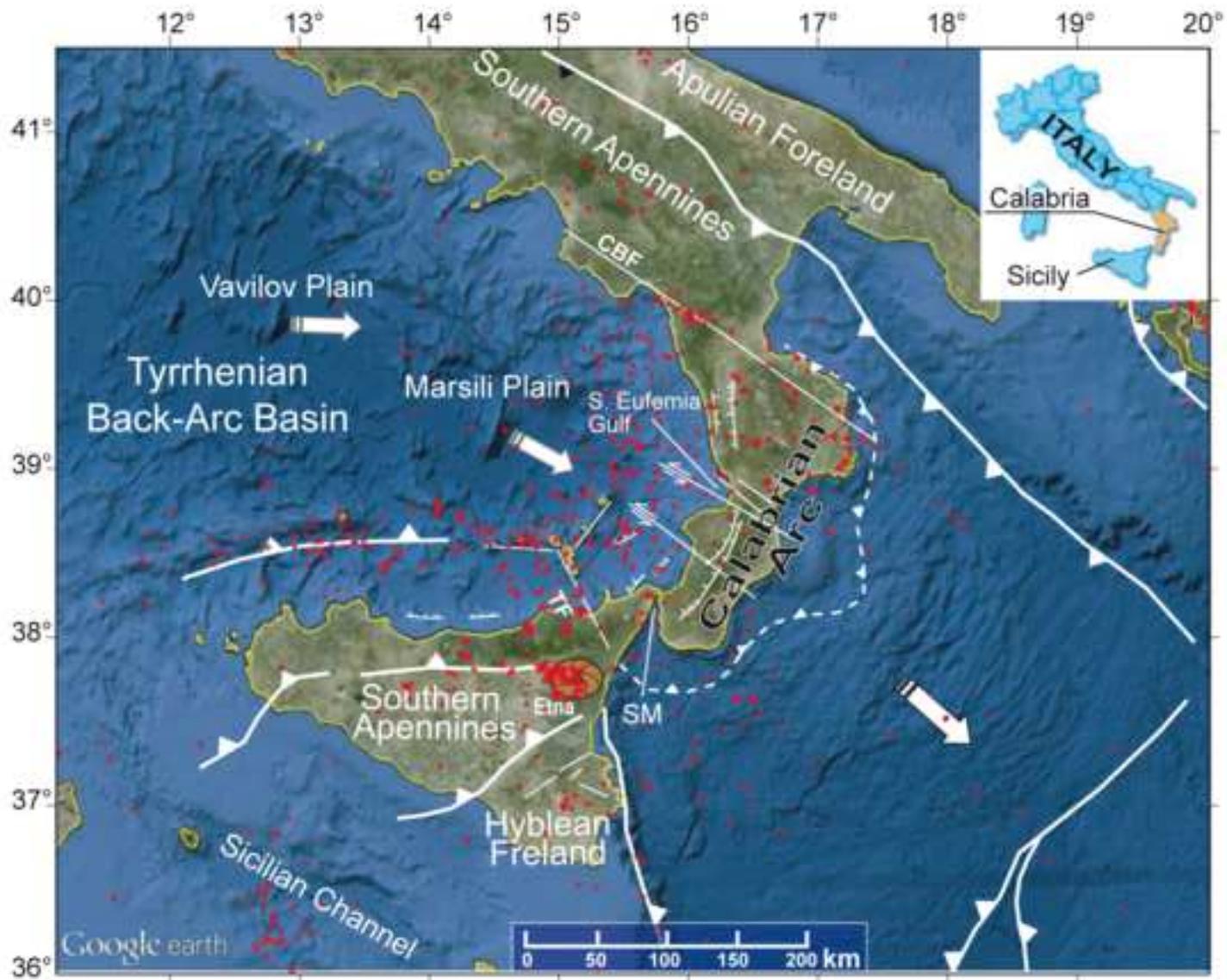


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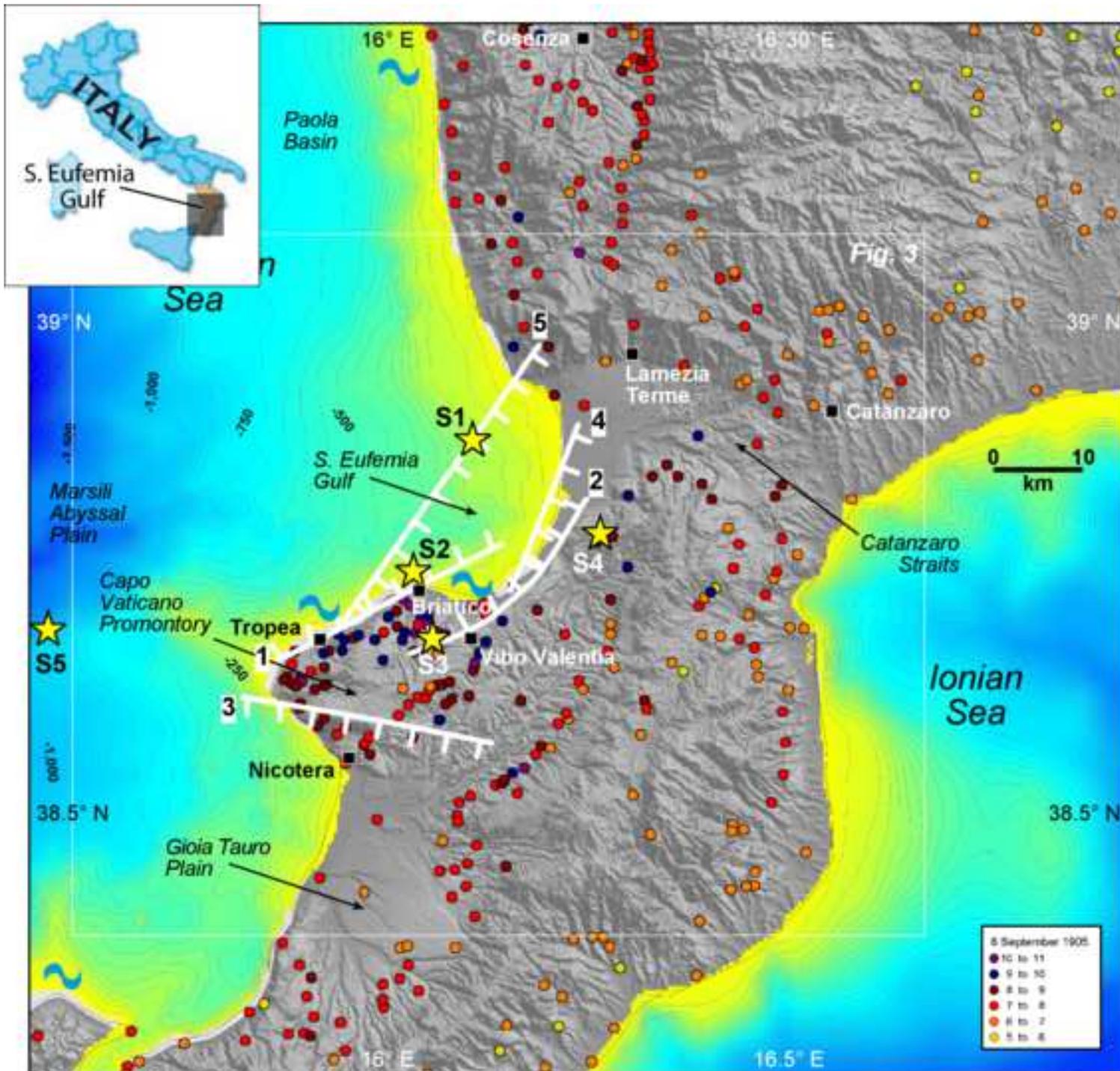


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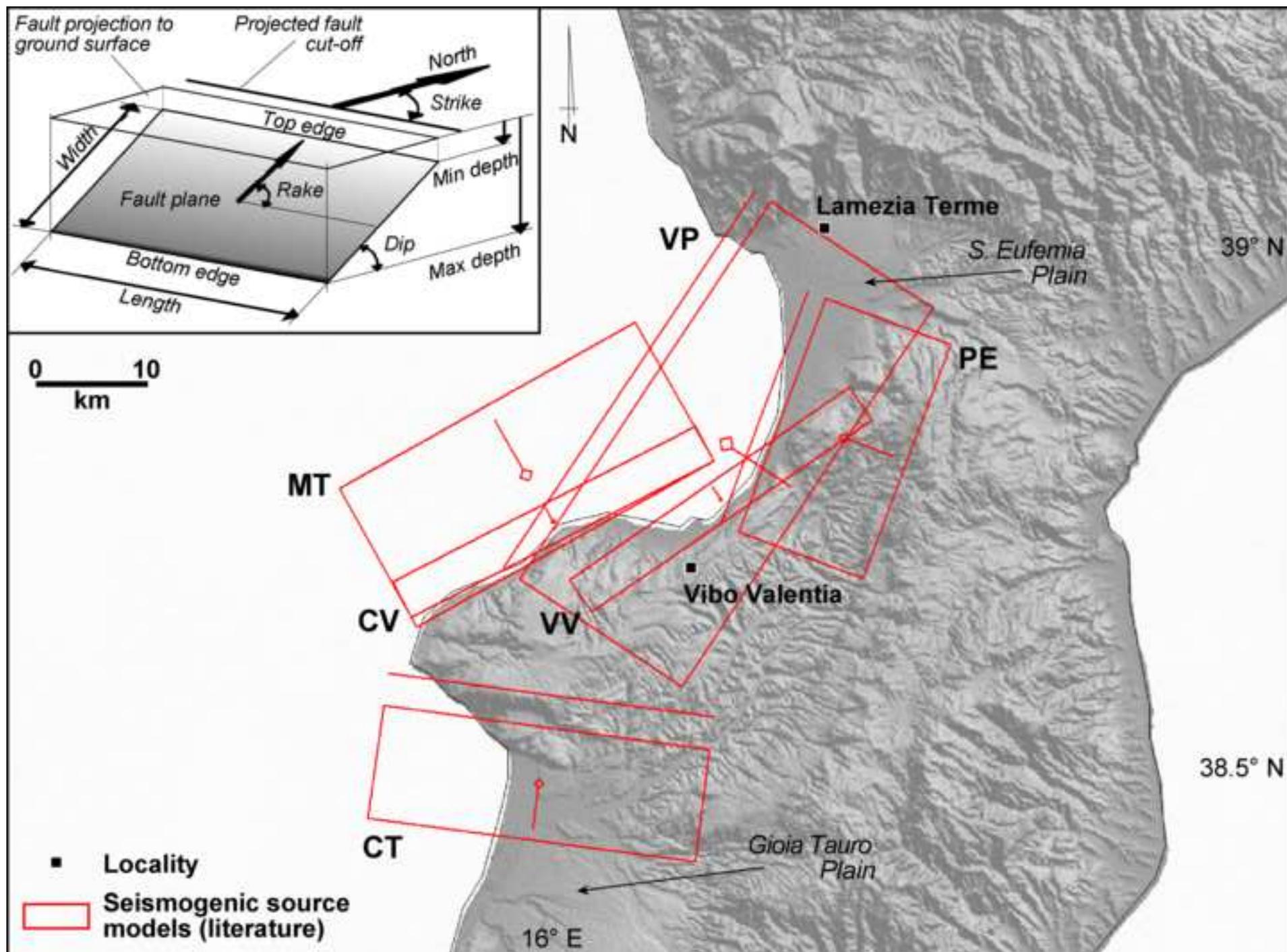


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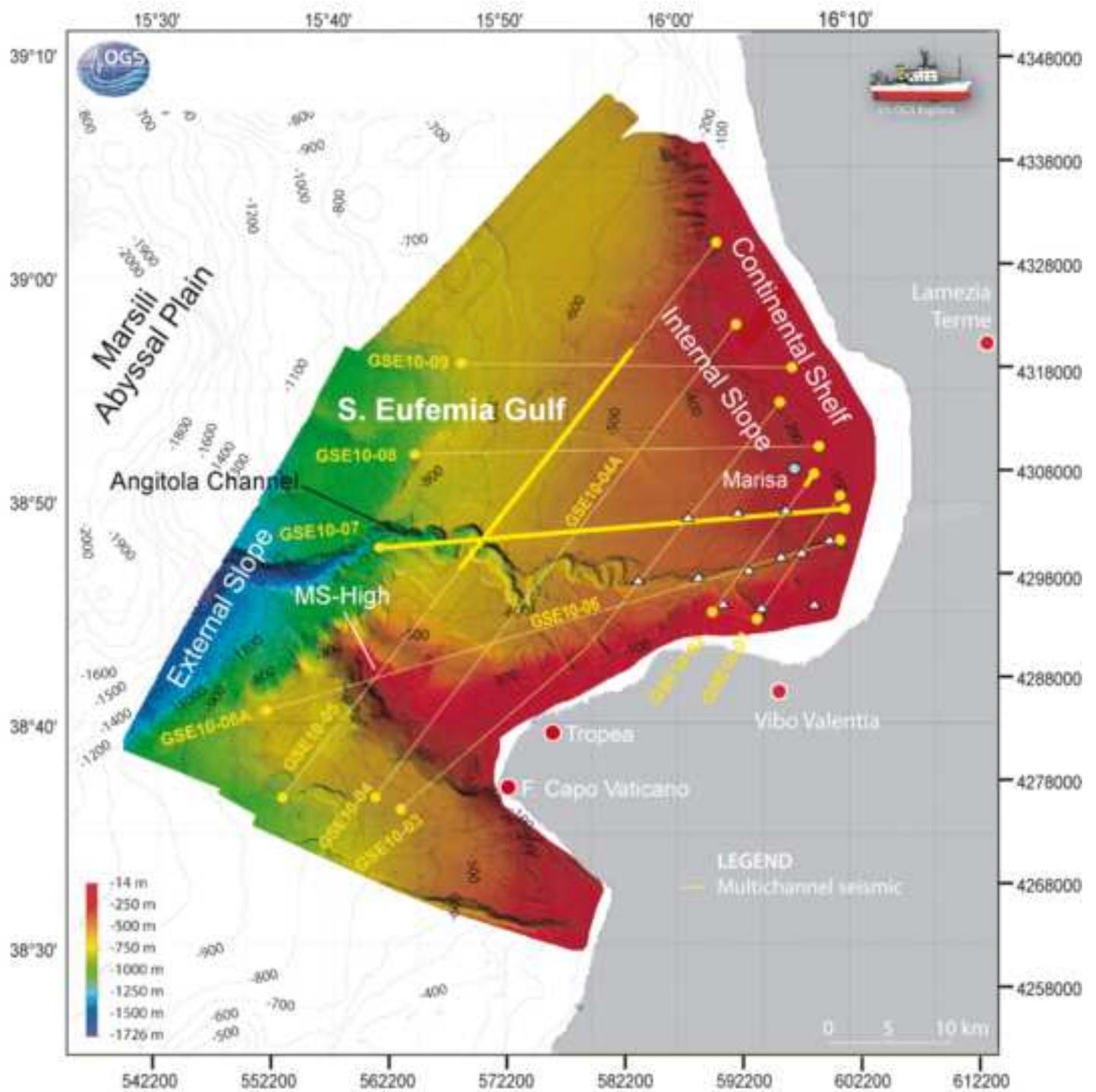


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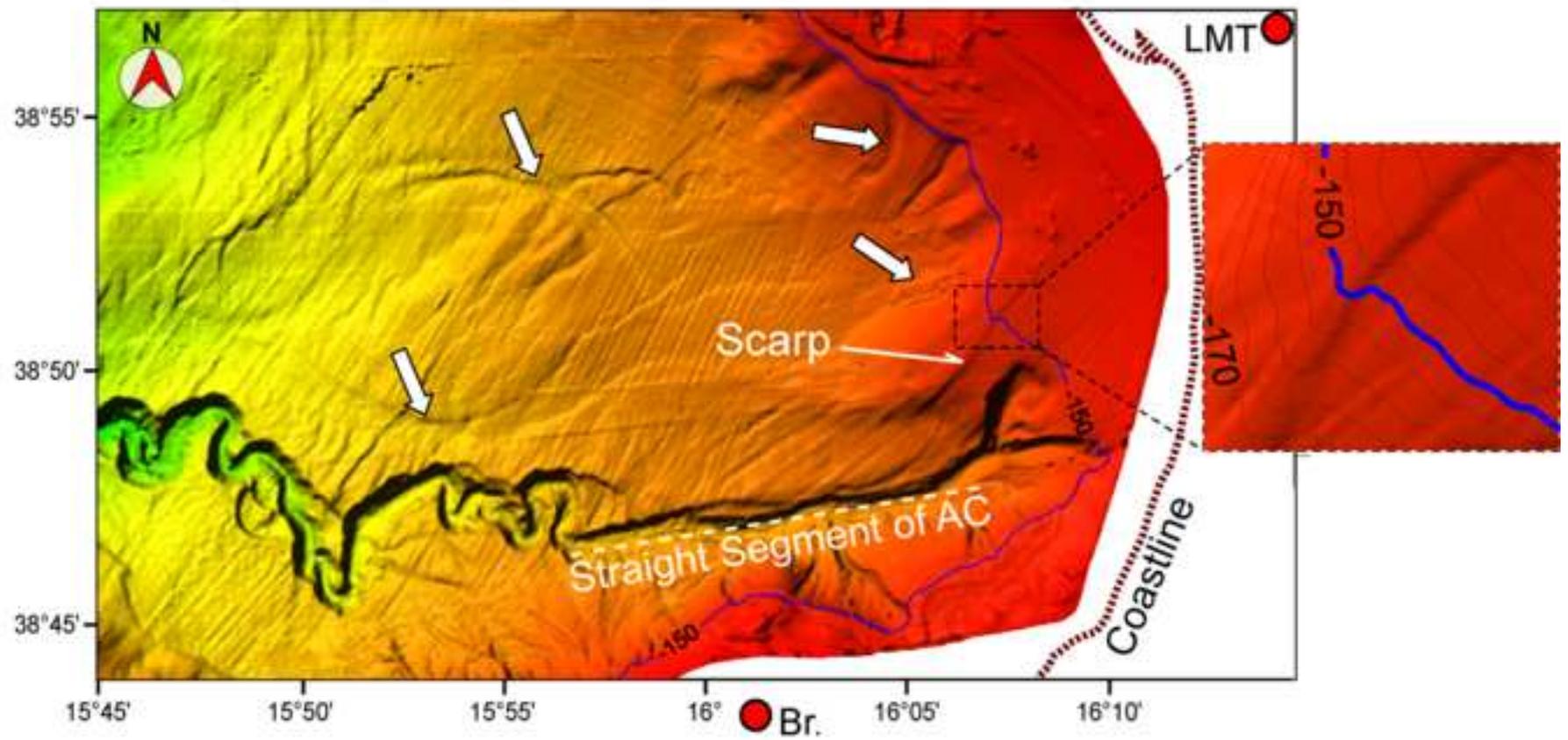
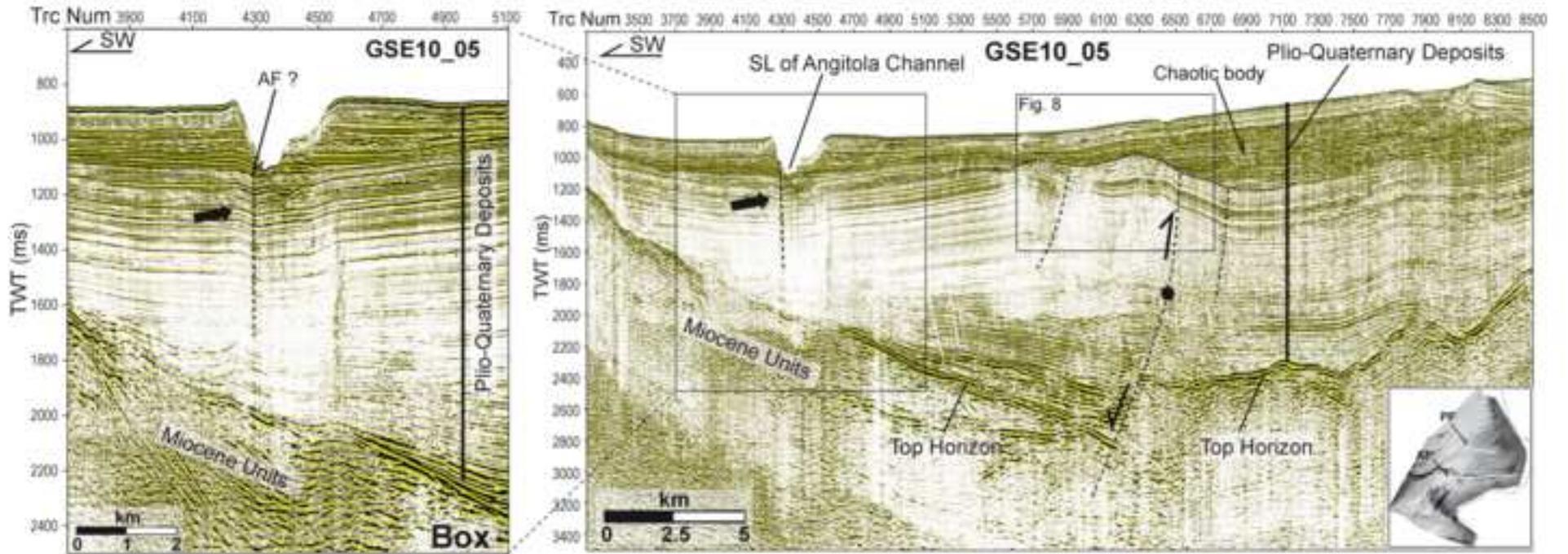


Figure 6 TIFF format
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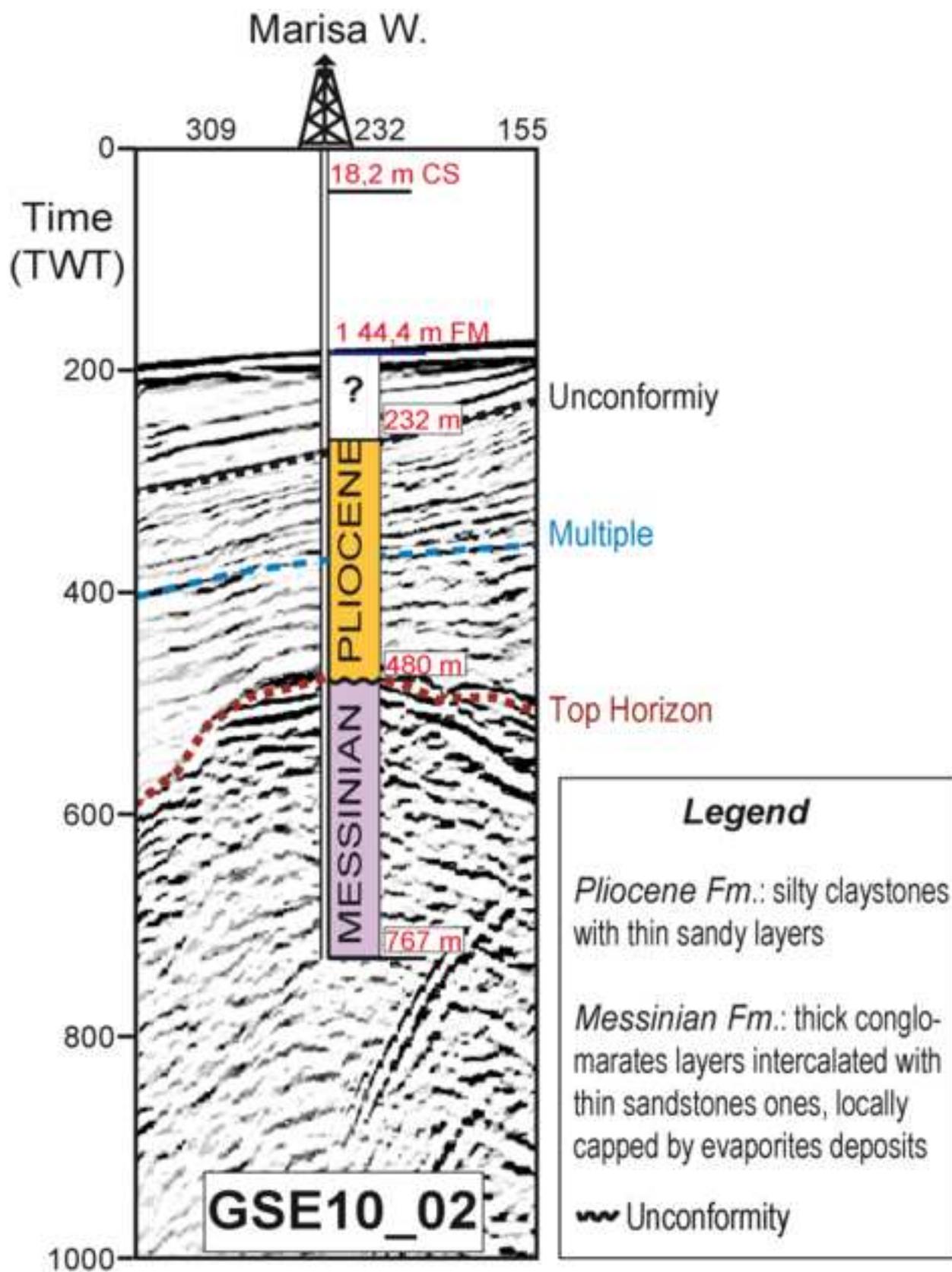


Figure 8 TIFF format
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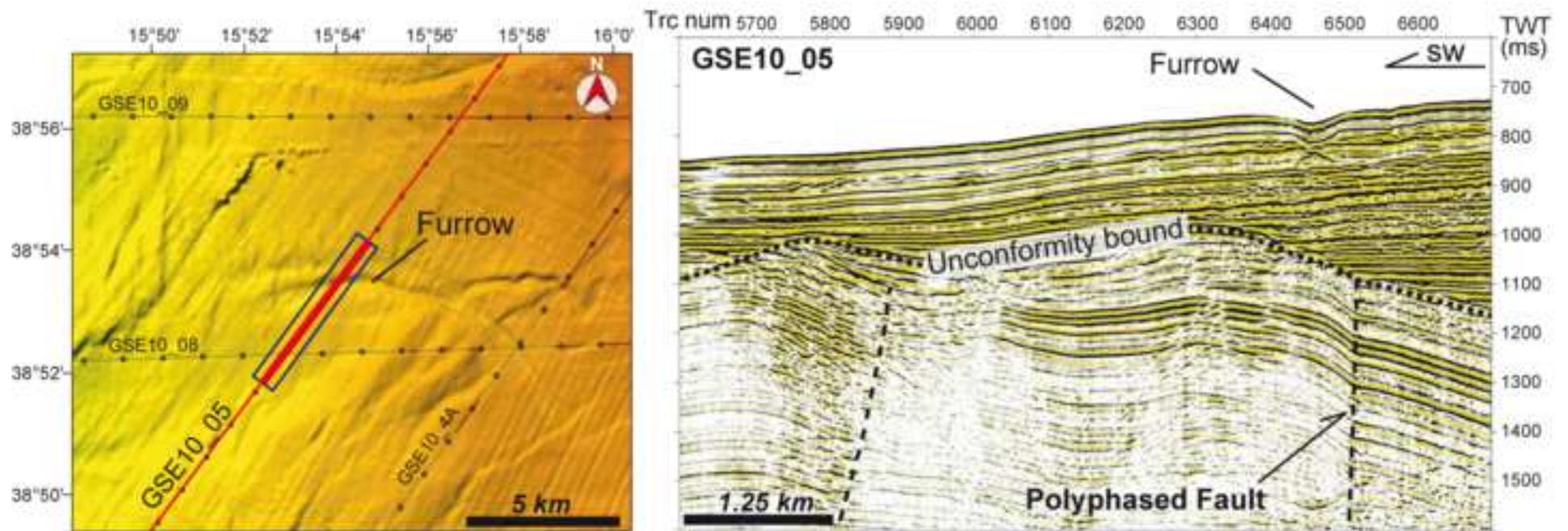


Figure 9 TIFF format
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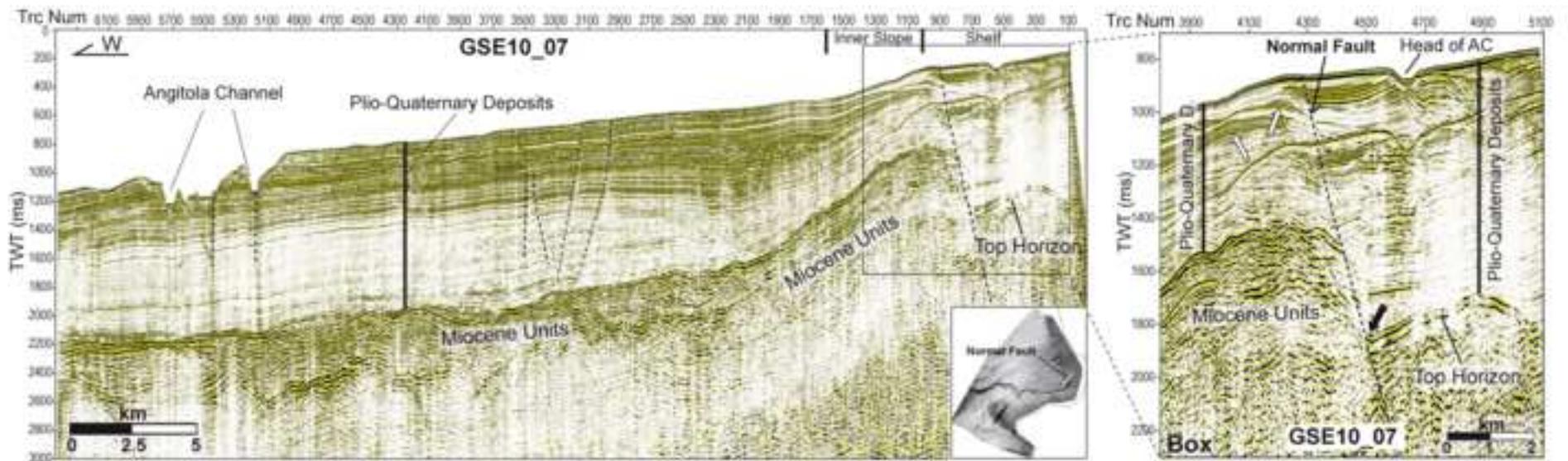


Figure 10 TIFF format
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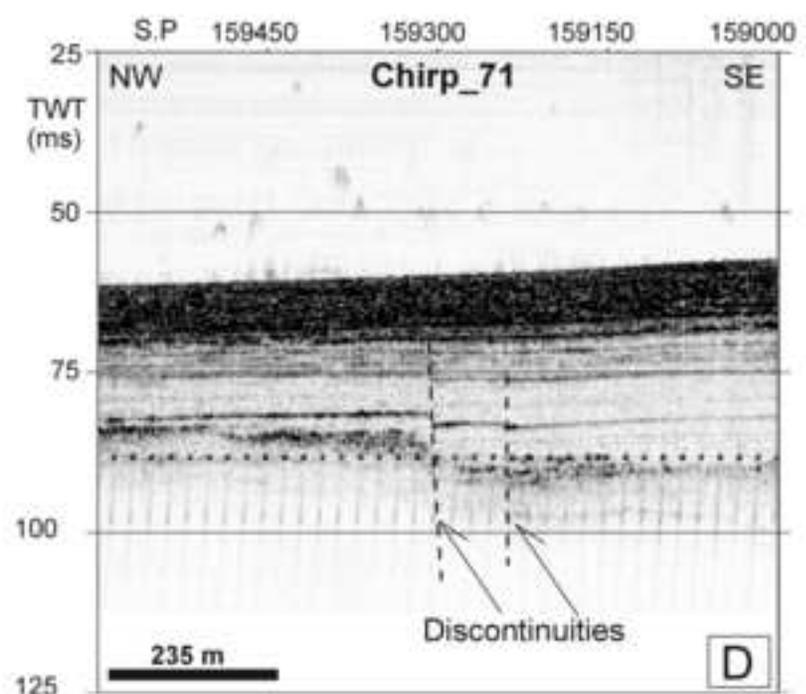
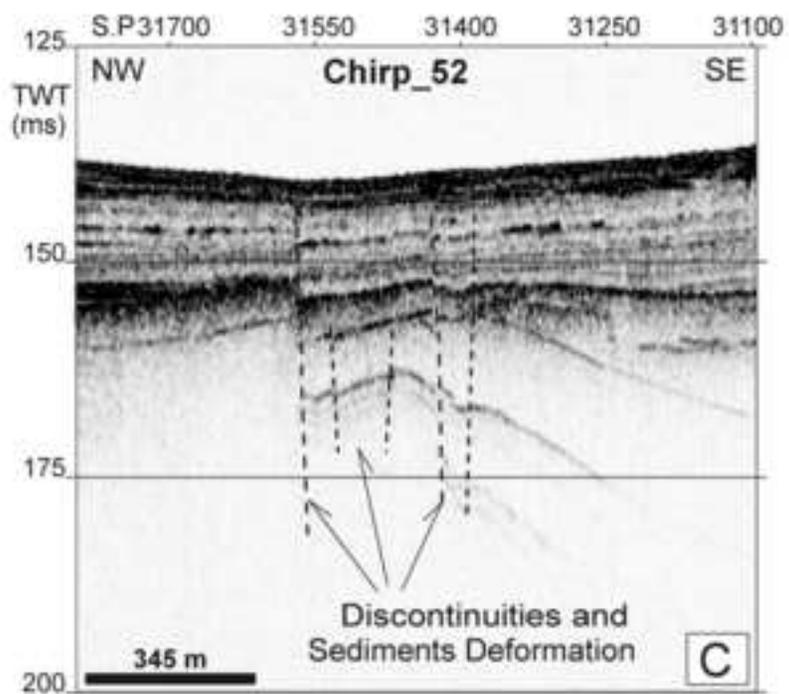
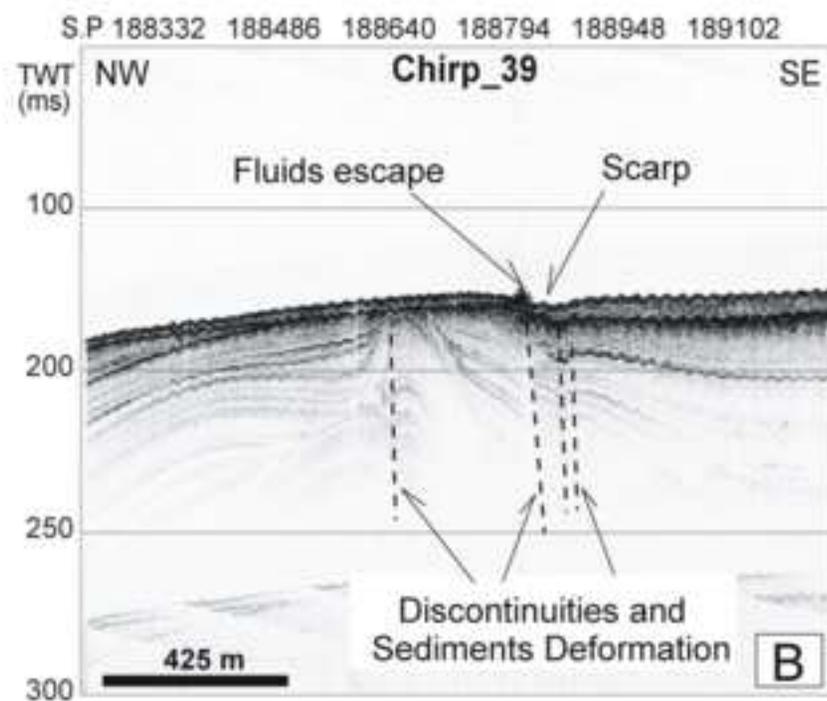
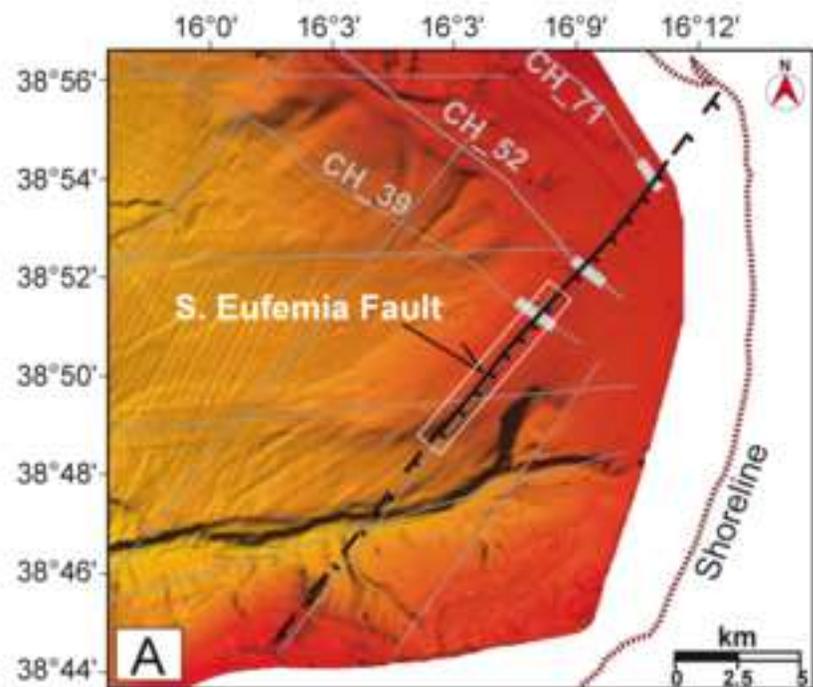


Figure 11 TIFF format
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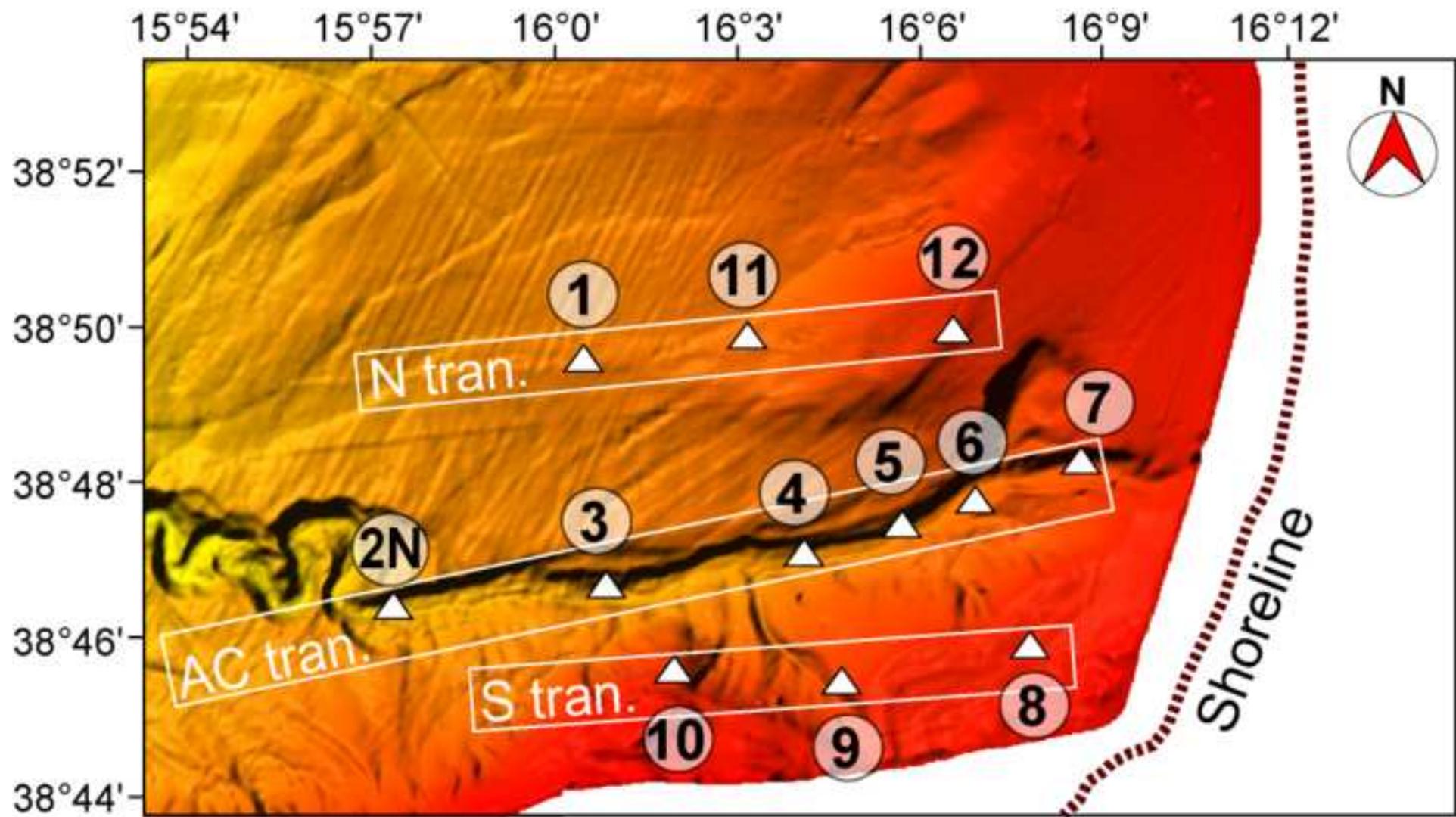


Figure 12 TIFF format
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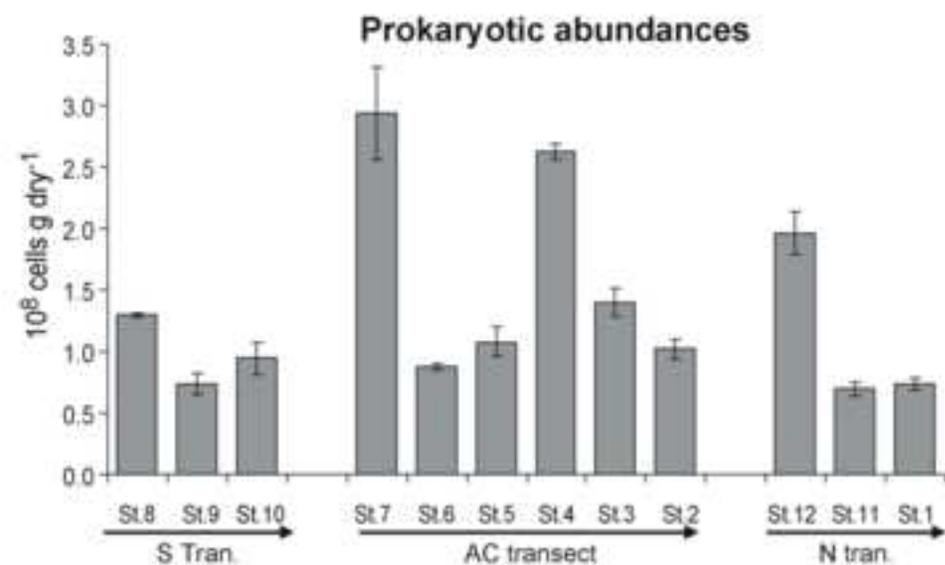
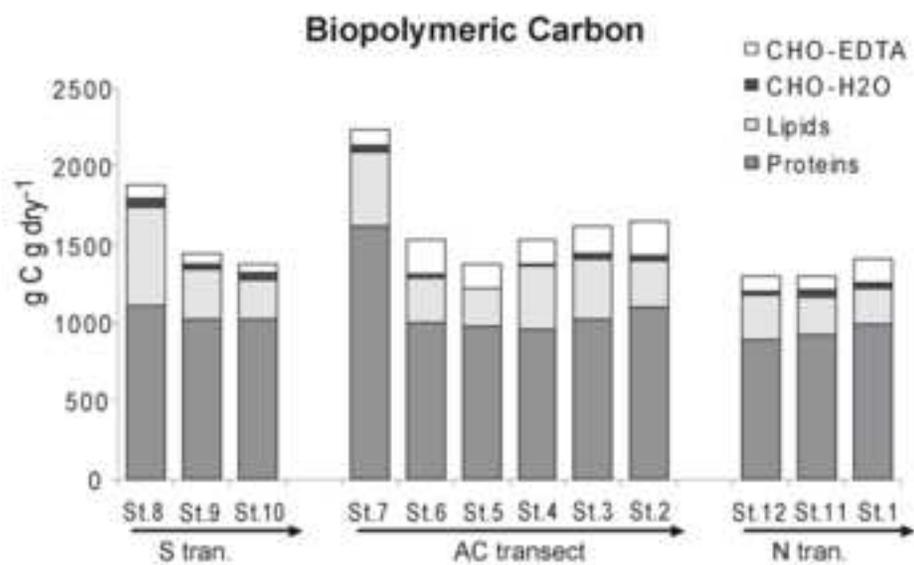


Figure 13 TIFF format

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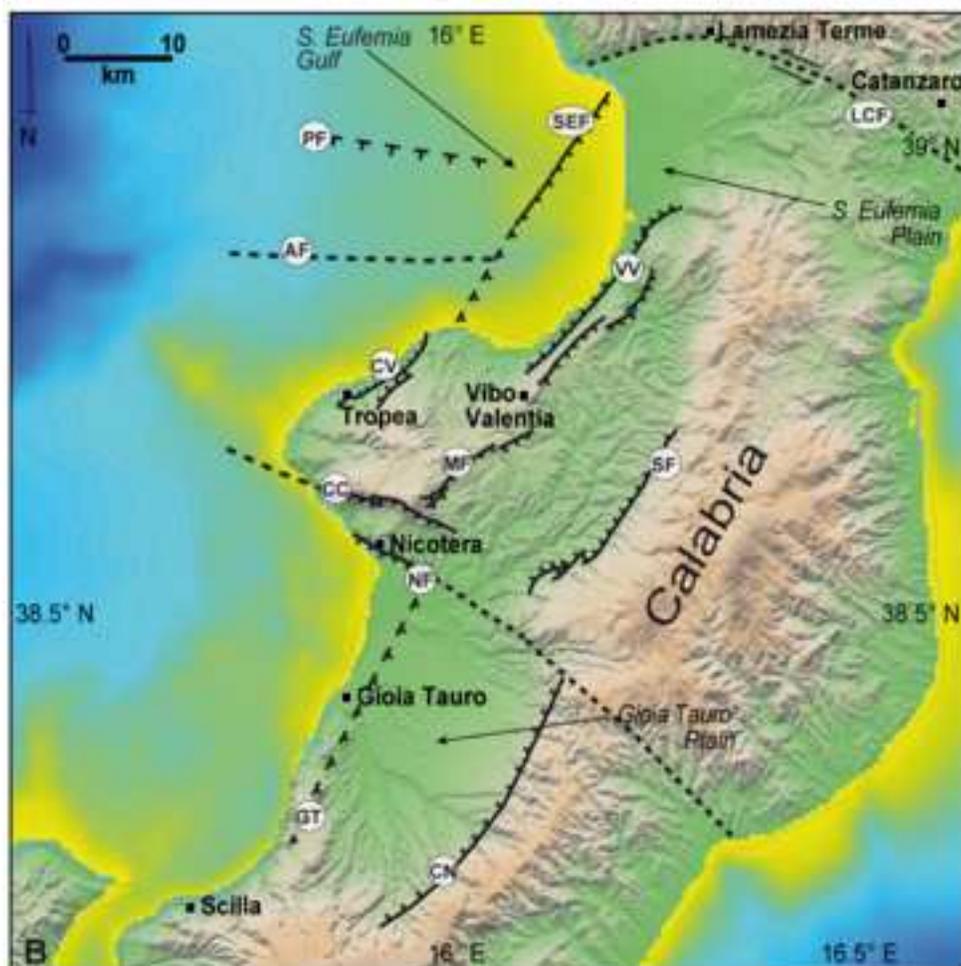
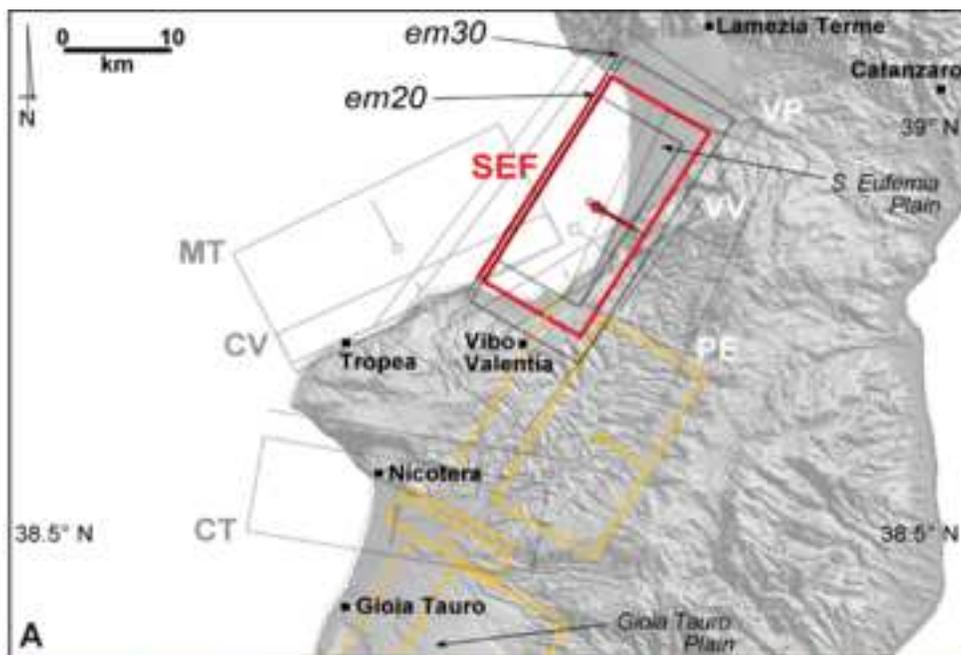


Table 1 format TIFF

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ID	Strike	Dip	Rake	L (km)	W (km)	TD (km)	BD (km)	SI (m)	M _w (W&C)	M _w (K&A)	M _s (Nm)
PE	23	30	270	22	13.5	1	7.8	1	6.5	6.6	8.91E+18
VP	36	30	270	40	19.8	1	10.9	2	6.9	7.1	4.75E+19
MT	243	30	270	30	16.2	0	8.1	1.5	6.7	6.8	2.19E+19
CV	245	80	270	30	20	0	19.7	2.5	6.8	7.0	4.50E+19
VV	238	80	270	30	20	0	19.7	2.5	6.8	7.0	4.50E+19
CT	100	60	270	29	20	5	22.3	0.84	6.7	6.7	1.46E+19

Table 2 TIFF format

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ID	Strike	Dip	Rake	L (km)	W (km)	TD (km)	BD (km)	SI (m)	M ₀ (W&C)	M ₀ (K&A)	M ₀ (Nm)
em20	31	38	270	20	12.2	0.5	8	1.5	6.4	6.6	1.10E+19
em30	31	38	270	30	16.2	0.5	10.5	2.5	6.7	7	3.65E+19
SEF	31	38	270	25	14.4	0.5	11.2	2	6.5	6.8	2.16E+19

Table 3 TIFF format

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St.	TN mg N g ⁻¹	TC mg C g ⁻¹	TOC mg C g ⁻¹	Proteins µg C g _{dry} ⁻¹	Lipids µg C g _{dry} ⁻¹	CHO-H ₂ O µg C g _{dry} ⁻¹	CHO-EDTA µg C g _{dry} ⁻¹	Picobenthos *10 ⁸ cells g _{dry} ⁻¹
8	0.89 ± 0.04	21.16 ± 0.08	8.20 ± 0.09	1112.83 ± 28.43	625.72 ± 78.20	54.90 ± 1.52	81.86 ± 5.22	1.30 ± 0.02
9	0.82 ± 0.02	20.96 ± 0.25	7.71 ± 0.02	1021.28 ± 32.19	320.83 ± 20.44	33.72 ± 1.17	66.85 ± 3.46	0.74 ± 0.08
10	0.66 ± 0.01	18.13 ± 0.18	6.55 ± 0.22	1026.82 ± 21.29	251.23 ± 15.47	43.42 ± 1.29	60.69 ± 5.75	0.95 ± 0.13
7	0.85 ± 0.01	20.40 ± 0.04	7.56 ± 0.04	1623.05 ± 24.91	467.62 ± 19.68	45.02 ± 1.29	101.66 ± 1.97	2.94 ± 0.38
6	0.74 ± 0.03	18.74 ± 0.06	6.80 ± 0.07	997.54 ± 49.35	289.27 ± 11.97	22.19 ± 1.31	214.42 ± 3.56	0.87 ± 0.02
5	0.68 ± 0.01	18.21 ± 0.04	6.84 ± 0.16	982.58 ± 11.32	228.88 ± 24.30	14.25 ± 1.26	146.53 ± 8.31	1.08 ± 0.12
4	0.83 ± 0.04	20.83 ± 0.14	7.24 ± 0.09	959.87 ± 4.58	403.76 ± 14.62	13.63 ± 1.46	144.48 ± 7.54	2.62 ± 0.06
3	0.73 ± 0.02	20.66 ± 0.08	6.66 ± 0.13	1024.25 ± 28.74	391.54 ± 7.87	25.83 ± 2.42	180.17 ± 6.01	1.40 ± 0.12
2N	0.77 ± 0.02	20.18 ± 0.07	6.78 ± 0.04	1094.89 ± 19.82	298.75 ± 7.86	35.12 ± 4.05	217.77 ± 12.13	1.02 ± 0.08
12	0.79 ± 0.01	19.91 ± 0.09	6.19 ± 0.12	887.88 ± 18.21	285.75 ± 20.10	28.27 ± 2.38	102.24 ± 1.42	1.96 ± 0.18
11	0.78 ± 0.04	19.32 ± 0.07	6.22 ± 0.03	919.75 ± 17.41	242.34 ± 3.67	46.03 ± 2.24	97.63 ± 2.36	0.70 ± 0.05
1	0.74 ± 0.01	19.58 ± 0.03	6.20 ± 0.06	992.99 ± 6.73	229.93 ± 13.48	23.75 ± 1.39	160.26 ± 11.72	0.73 ± 0.05

Values and standard deviation (SD) of the chemical and biological parameters. TN = Total Nitrogen; TC = Total Carbon; TOC = Total Organic Carbon; CHO-H₂O = colloidal carbohydrates; CHO-EDTA = carbohydrates extracted in EDTA.