Evidence of active deformation in the Adriatic foreland (southern Italy): integration of on- and off-shore seismotectonic and stratigraphic data along the Molise-Gondola shear zone

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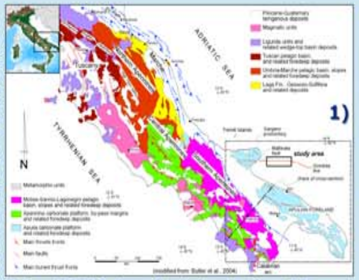
1. Introduction

The active tectonics of the Southern Apennines of Italy (Calabrian Arc excluded; **Fig. 1**) is mainly characterized by SW-NE extension, which accounts for large earthquakes generated by NW-SE striking normal faults. However, the 2002 Molise earthquakes (**Fig. 2**) occurred along an E-W striking right-lateral seismogenic structure located to the NE of the Southern Apennines axis. This and other lines of evidence suggested that the frontal part of the chain and the adjacent foreland are affected by E-W striking, right-lateral active faults systems. The 2002 Molise seismic sources, in particular, are located along the western part of a regional fault system, the Molise-Gondola shear zone (MGsz). On land, this system is mainly represented by the Mattinata Fault, an important structure of the foreland that has already been intensely investigated from a regional, structural and seismotectonic point of view. A polyphase activity (since Mesozoic times) has been recognized by several Authors, and the complex fault kinematics is still matter of debate. Nevertheless, most investigators agree on a present-day activity with right-lateral sense of motion, as confirmed by the focal mechanism of the 19 June 1975 earthquake, GPS data, geomorphological and paleoseismological investigations.

Indeed, the Mattinata Fault has already been interpreted as the source of historical earthquakes (e.g., 493 AD, 1875), and instrumental seismicity is normally recorded within the first 25 km of the crust of the Gargano area. These data indicate that inherited E-W striking high-angle fault systems are solicited under the present-day stress field.

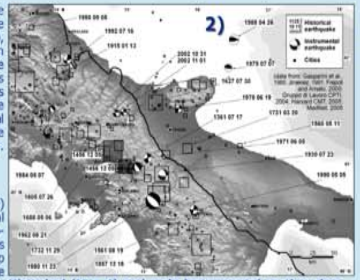
Off-shore the Gargano Promontory, the Mattinata Fault seems to be aligned with a regional (ca. 150 km in extent) E-W to NW-SE oriented deformation belt (known in the literature as Gondola Line), including a main fault and fold system known as Gondola Fault and Gondola Ridge, respectively (**Fig. 3**). In the past, this structure has been investigated using multi-channel seismic reflection profiles and well-log data. Several investigators proposed a Mesozoic origin for the Gondola Line, followed by a complex pattern of repeated re-activation during the Cenozoic. Kinematics and timing of post-Mesozoic re-activation are still debated; however, most investigators agree that only deposits older than Miocene appear severely deformed, whereas Plio-Pleistocene units yield little or no deformation at all. This multi-history deformation pattern shown along the Gondola Line closely resembles the long-term complex evolution recorded along the Mattinata Fault, except for the lack of significant seismicity. Therefore, although one could expect the Gondola Line to be subjected to the same stress field responsible for recent re-activation of the Mattinata Fault, direct evidence is not available from historical and present-day seismicity.

We present evidence of recent tectonic deformation off-shore Gargano based on a dense network of very-high resolution seismic lines (**Fig. 4**).



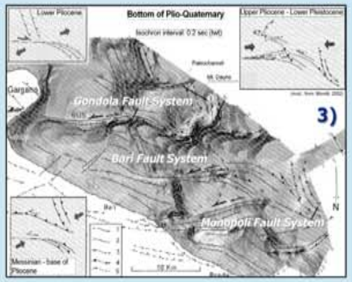
Main geological features of central and southern Italy.

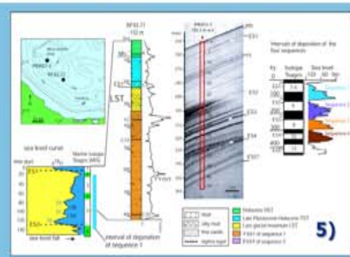
1) The main tectonic units in the dotted drame are (from west to east): the Mesozoic-Paleogene Apennines inner carbonate platform (hinterland), the Mesozoic-Neogene Lagonegro pelagic basin and the Mesozoic-Paleogene Apulian carbonate platform (foreland). East of the outer Apennines front, the Bradano-Candela Foredeep hosts Plio-Quaternary terrigenous deposits on the Apulian platform dissected by SW-dipping normal faults. Jurassic-Oligocene Liguride units can be found southwest of the studied area.



2) Black squares (proportional to magnitude) are events from Italy's current historical catalogue. Notice the predominance of (a) dip-slip focal mechanisms on NW-SE trending planes in the core of the thrustbelt and (b) strike-slip mechanisms in the eastern sector of the Apennines and in the Apulian foreland. **Historical (M > 4) and main instrumental earthquakes**

3) Existing medium-resolution seismic reflection lines allowed investigators to reconstruct the Gondola Ridge and other regional tectonic discontinuities affecting the Southern Adriatic basin





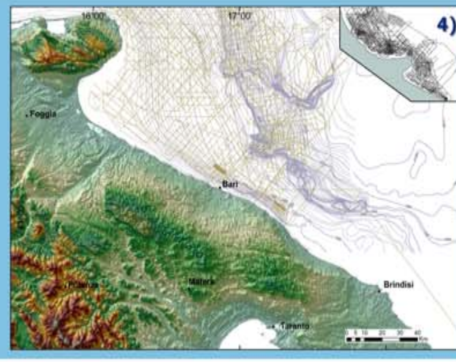
Sequence	Oxygen Isotope Stage	Age (ka)	Erosional Surface
		Present-day – 20/30	
			ES1
Sequence 1	OIS 2-6	20/30 – 130/140	
			ES2
Sequence 2	OIS 6-8	130/140 – 230/250	
			ES3
Sequence 3	OIS 8-10	230/250 – 330/350	
			ES4
Sequence 4	OIS 10-12	330/350 – 430/450	
			ES5

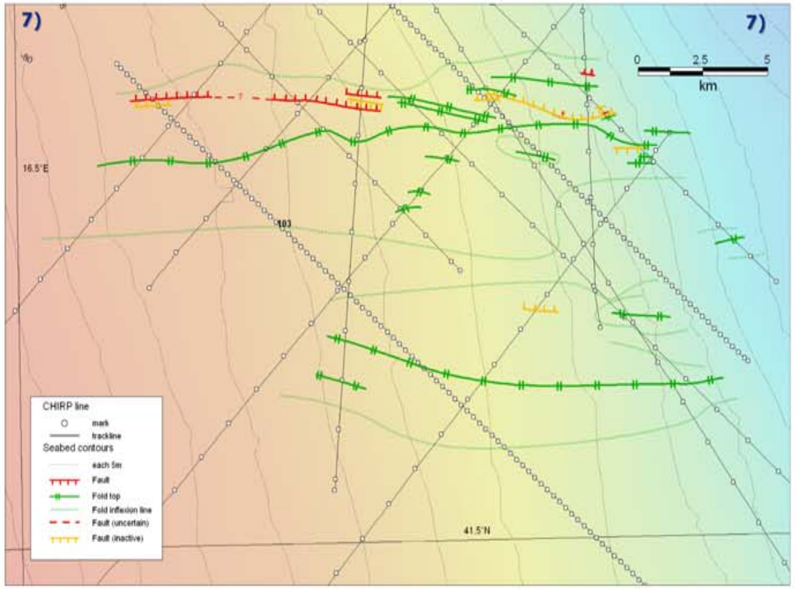
Table 1

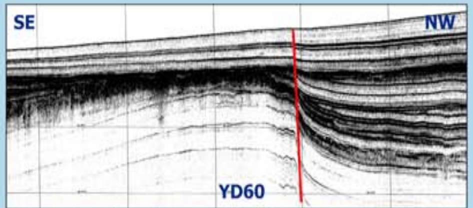
2. Dataset

The data set for this study belongs to a dense network (more than 25.000 km) of high-resolution seismic profiles (2-7 kHz Chirp-Sonar, 3.5 kHz Sub-bottom, 500 joule Uniboom, 1 kjoule Sparker; see box in Fig. 4) and extensive core data. The lines we show are Chirp-Sonar, characterised by very high vertical resolution (in the order of 50 cm) and vertical exaggeration up to 100 times. Conventional sediment cores and borehole PRAD 1-2 (**Fig. 5**) provided sedimentological and chrono-stratigraphic constraints. This dataset allows us to investigate the upper 80-100 m of the Quaternary succession in the Adriatic Sea, that correspond to the middle-late Pleistocene and Holocene interval.

The analysed succession is composed by four depositional sequences, each recording 100 ka climatically-driven eustatic cycles, formed between 450 and 20 ka B.P. These sequences are overlain by deposits formed during the last ca. 20 ka, when a rapid sea level rise (in the order of ca. 120 m in ca. 15 ka) shifted the shoreline to its present highstand position (**Tab. 1**). Lithologic data indicate a dominant muddy composition of the four regressive sequences, with thin beds of silt and fine sand occasionally occurring just above and/or below the sequence boundaries (erosion surfaces ES in the figures).

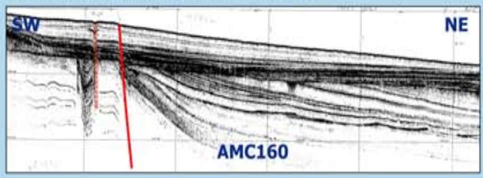






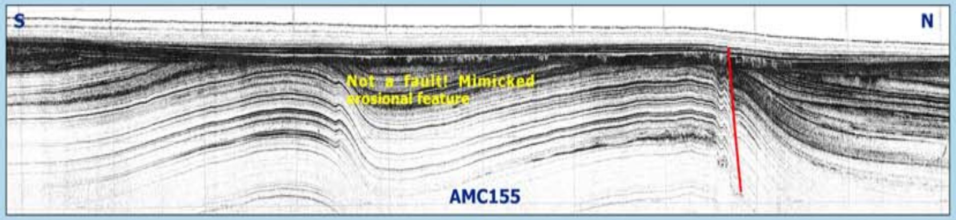
Fault dissecting all sections and seabed

Evidence of active faulting to the west of the area analysed in Fig. 7



Fault dissecting all sections and seabed

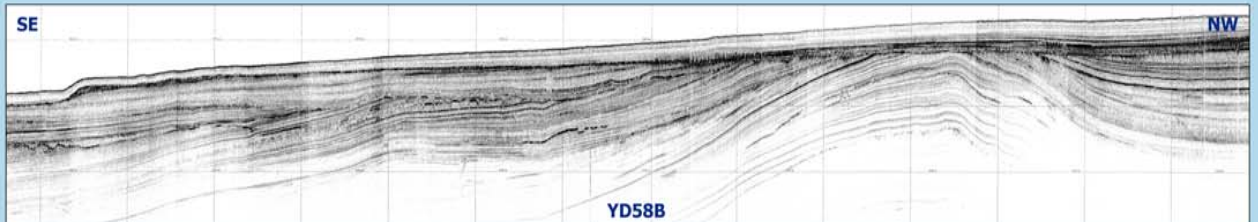
Gas pipe on footwall of fault



Fault on N (steeper) slope of main fold

Two folds visible

Only main fold, no faulting



4. Interpretation

The deformation pattern as a whole encompasses two main asymmetric similar folds characterised by E-W-oriented ~14 km-long parallel crest lines, and by wavelength of ~7 km and amplitude of ~15 m (**Fig. 7**). These north-verging gentle folds show an interlimb angle very close to 180°, being 1° the maximum real dip of the limbs (in particular of the northern ones). The limbs of both anticlines are affected by minor undulations. Moreover the northern limbs, i.e. those slightly more inclined, are also affected by faults.

In particular, the northern anticline is more developed, and the deformation affecting its northern limb consists of a set of left-stepping, alternating faults and undulations, each of them developing for a maximum length of ~5 km and striking N270°-285°. Faults exhibit very steeply dip and a normal component of motion that causes their northern side to be downthrown of metres to about one ten of metres. The mean vertical slip rate for the late Pleistocene and Holocene is of the order of 0.05 mm/a. Moreover, the comparison of the length of these faults with their limited vertical displacement suggests the possible occurrence of a significant horizontal component of motion not directly detectable on the seismic lines.

In all the interpreted lines, the observed deformation pattern as a whole affects the middle and late Pleistocene deposits; moreover, in some places faults also displace Holocene deposits (particularly a layer referred to 5.5 ka quite in the middle of the youngest succession) and the seabed.

The two main fold show comparable shape, wavelength, amplitude, faulted northern limb, and this leads to interpret them jointly as evidence of one deformation system. Therefore, being the Gondola Line located below the analysed deposits in correspondence with the detected structures, we interpret the observed deformation pattern as due to the reactivation of this major inherited lineament (see the E-W elongation and the precise superposition of the deformation pattern as a whole) caused by a compressional component of the stress field from the southern quadrants to the northern ones (see the folds asymmetry).

5. Final remarks

Altogether, both recent seismicity related to E-W dextral strike-slip tectonics along the westernmost part of the MGsz and along the Mattinata Fault, and very recent (< 5.5 ka) deformation features along the Gondola Line, suggest that the MGsz as a whole is being actively deformed, although variably along-strike.

It is noteworthy that the Gondola Line shows close affinities with the other parts of the MGsz on-shore. It is an E-W oriented inherited structure, reactivated during the late Pleistocene and Holocene. A strike-slip component of motion, coupled with a minor dip-slip component, can be associated to this structure. Above mentioned data suggest the Gondola activity as due to a stress field that, like in the case of the Mattinata fault and 2002 Molise earthquakes sources, is compatible with the NW-SE-oriented Africa-Europe convergence. Therefore, considering the seismogenic nature of the other parts of the MGsz, one can hypothesize the same behaviour also for the Gondola Line. The in-depth analysis of this hypothesis, still in need of investigations, marks the starting point for our ongoing studies on this structure.

Selected references

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