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A study to constrain the geometry of an active fault in southern Italy through borehole breakouts and downhole logs

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ABSTRACT

Identification of an active fault and the local versus regional present-day stress field in the Irpinia region (southern Apennines) have been performed along a 5900 m deep well (San Gregorio Magno 1) by a detailed breakout and geophysical log analysis. The selected area is characterized by diffuse low magnitude seismicity, although in historical times moderate to large earthquakes have repeatedly struck it. On 23rd November 1980 a strong earthquake (M = 6.9) nucleated on a 38-km long normal fault, named Irpinia fault, producing the first unequivocal historical surface faulting ever documented in Italy. The analysis of stress-induced wellbore breakouts shows a direction of minimum horizontal stress N18°±24°, fairly consistent with the regional stress trend (N44°±20°). The small discrepancy between our result and the regional stress orientation might be related to the influence of local stress sources such as variations of the Irpinia fault plane orientation and the presence of differently oriented active shear zones. This paper shows for the first time a detailed analysis on the present-day stress along a well to identify the Irpinia fault at depth and constrain its geometry.

1. Introduction

This paper is mainly devoted to the present-day stress field study performed in a high seismic hazard area of southern Italy (Cinti et al., 2004; Faenza and Pierdominici, 2007) in order to assess a methodology to identify and constrain active faults at depth along deep wells.

The present-day stress state can be assessed by different techniques, including the analysis of: (i) borehole breakouts, (ii) focal mechanism solutions, (iii) exposed active fault segments, (iv) well cores, and (v) crustal deformation and differential strain (Ding and Zhang, 1991; Zoback, 1992; Seto et al., 1998). Breakouts are used as indicators of the direction of maximum and minimum horizontal stress (S_{Hmax} and S_{hmin}, respectively) and correspond to observation points along deep wells (Bell and Gough, 1979; Zoback et al., 1985). Many studies have shown that the present-day stress orientation in a region is quite homogeneous and independent of the stratigraphy and depth (e.g., Plumb and Cox, 1987; Castillo and Zoback, 1994), whereas along a borehole the breakout orientations can change due to the presence of active faults (Barton and Zoback, 1994; Wu et al., 2007). As reported by several authors stress perturbations have been associated to open fractures and to active faults which have slipped recently (Bell et al., 1992; Shamir and Zoback, 1992; Barton and Zoback, 1994; Mariucci et al., 2002; Wu et al., 2007). Moreover, shear zones at depth usually show physical properties different from the nearby undamaged rock and downhole logs can record these features.

In this paper we have analysed the present-day stress along and around a deep well and tried to identify at depth some shear zones and the seismogenic fault, named Irpinia, located in the southern Apennines. This fault is related to the 1980 Ms = 6.9 Irpinia earthquake, and represents the first unequivocal surface faulting ever documented in Italy. Its geometry is not well constrained by geophysical exploration and aftershock data analysis because this tectonic structure is relatively a young fault that has not yet developed enough cumulated vertical slip to be clearly resolved by seismic reflection profiles (Pantosti and Valensise, 1993; Improta et al., 2003; Cippitelli, 2007; Patacca, 2007; Fig. 1). This paper shows for the first time a detailed analysis on the present-day stress nearby the seismogenic fault in the context of the overall setting. The Irpinia fault trace is located ~1.3 km westward from the well San Gregorio Magno 1 (herein named SGM1), and according to its geometry, the well should cut off it. If this is true, the main observation of Barton and Zoback (1994) that stresses reorient close to faults should be verified. The idea is to study the present-day stress in the SGM1 well to identify the possible stress perturbations close to the Irpinia fault. Then, borehole breakouts, downhole log data and tectonic structures along the deep well SGM1 have been analysed.

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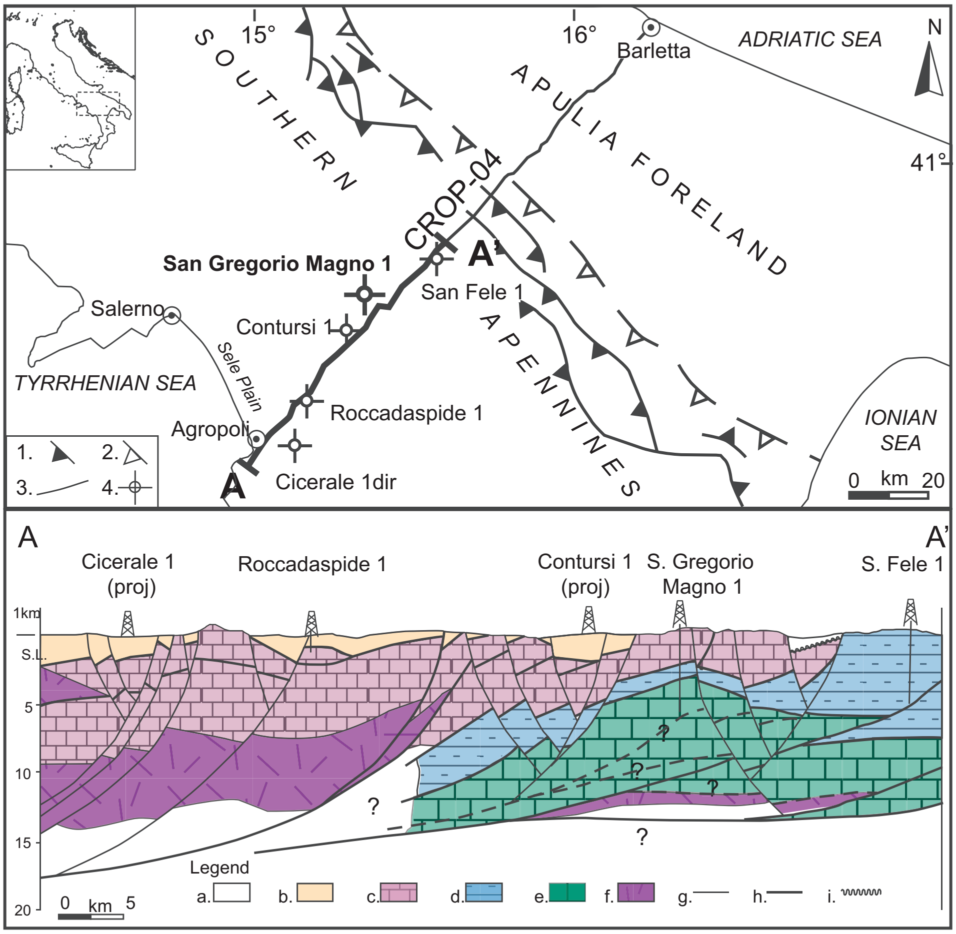

Fig. 1. Above: schematic structural map (modified after Scrocca et al., 2007): (1) main out of sequence thrust; (2) buried Apenninic thrust front; (3) CROP-04 seismic line; (4) Wells. Below: part of CROP-04 cross-section (section A-A′; modified after Cippitelli, 2007 according to the stratigraphic description of Patacca, 2007 from c. to e. deposits). Legend: a. Castelgrande Sandstone (Miocene); b. Cilento Flysch and Liguride-Sicilide complex (Cretaceous-Paleogene); c. Apenninic carbonate Platform (Alburno-Cervati; late Triassic); d. Lagonegro II unit (early Triassic-early Cretaceous); e. Apulian carbonate Platform (Dogger-early Pliocene); f. Permo-Triassic substratum; g. normal fault; h. reverse fault-overthrust plane; i. unconformity.

2. Geological-structural setting and regional seismicity

The southern Apennine belt is part of the Alpine orogens of the Mediterranean area, developing from the interaction between the converging Africa-Apulian and European plates since Late Cretaceous time, (e.g., D'Argenio et al., 1973; Dewey et al., 1989; Mazzoli and Helman, 1994 and references therein; Butler et al., 2004). The southern Apennines are a NE-verging fold-and-thrust belt that began to grow mainly since the lower Miocene (Bonardi et al., 1988; Patacca et al., 1990) due to deformation of the Adriatic subducting margin. The thrust belt is characterized by allochthonous units derived from both carbonate platform and pelagic basin successions (Apenninic Platform and Lagonegro Basin, respectively), which are stratigraphically overlain by Neogene foredeep and wedge-basin deposits (Miocene and Pliocene successions). These units are completely detached from their original substratum and transported onto the foreland sequence of the Apulian carbonate Platform (e.g., Doglioni et al., 1996; Mazzoli et al., 2004).

In the early Pliocene (Scandone et al., 2003), the entire pile of nappes overthrusts the Apulian carbonate platform giving rise to a complex duplex system (e.g., Mostardini and Merlini, 1986; Cello et al., 1987, 1989; Casero et al., 1988; Ascione et al., 2003; Patacca and Scandone, 2007). In this tectonic context, the thrust sheet emplacement moved following the opening of the Tyrrhenian back-arc basin (Patacca et al., 1990) as a consequence of the roll-back of the subducting Adriatic plate (Malinverno and Ryan, 1986; Doglioni, 1991). Only in the middle-late Pliocene, the Apulia Platform underwent shortening processes that created duplexing in the deep-seated carbonates and displacement of the overlying allochthonous sheets (Patacca and Scandone, 2007). The processes of thrusting and Adriatic-verging nappe transport have been active on the eastern side until the lower part of middle Pleistocene (Casero et al., 1988; Patacca et al., 1990; Roure et al., 1991; Cinque et al., 1993; Pieri et al., 1997; Patacca and Scandone, 2001), when the flexure-hinge retreat in the Adriatic plate suddenly stopped (Patacca and Scandone, 2007).

For further information on the geological and structural setting, the reader is referred to the wide existing literature (e.g., Casero et al., 1991; Patacca and Scandone, 1989, 2004; Lavecchia, 1988; Pescatore et al., 1999; Galadini et al., 2000; Giano et al., 2000; Lentini et al., 2002; Valensise and Pantosti, 2001; Schiattarella et al., 2003; Scrocca et al., 2007).

Concerning the seismicity, the southern Apennines are characterized by recent low magnitude seismic events, punctuated by large historical earthquakes that shook the area in the past (CPTI Working Group, 2004) (Fig. 2). Strong historical events (Io = IX–X) have been well documented since 1500: 1561-Vallo di Diano; 1694-Irpinia; 1826-Tito; 1831-Rivello; 1836-Lagonegro; 1851-Basilicata; 1857-Val d'Agri; 1930-Irpinia; 1980-Irpinia (Esposito et al., 1988; Marturano et al., 1988; Porfido et al., 1988; CPTI Working Group, 2004).