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Imaging the Crust in the Northern Sector of the 2009 L'Aquila Seismic Sequence through Oil Exploration Data Interpretation

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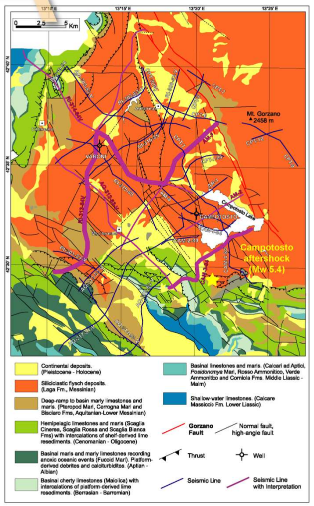
A — Geological Setting



INTRODUCTION

The 2009 L'Aquila seismic sequence activated a complex, 40 km long, NW-trending, SW-dipping extensional fault-system, consisting of three main right-stepping fault segments. The central segment, 15-18 km long and dipping ~45° to the SW, was responsible for the nucleation of the 6th April 2009 mainshock (Mw6.3). Along the northwestern fault segment, which is ~ 10 km apart from the previous one, a strong aftershock occurred on the 9th April 2009 (**Campotosto Aftershock**; Mw5.4, yellow star in the geologic map).
While seismicity surrounding the 6th April fault spans 2-12 km depth and geological evidence of coseismic deformation are widespread along its surface projection (i.e.: Paganica Fault), in the northern sector aftershocks are confined between 5 and 13 km depth.
The northern sector of the epicentral area has been deeply investigated by oil industry. Conversely, only a few scattered, poor-quality seismic commercial profiles are located in the central and southern sectors.

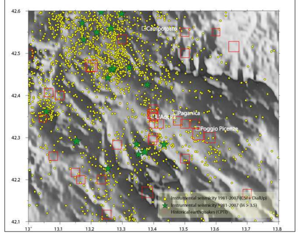
In this study we interpret seismic reflection and well data from the northern sector of the L'Aquila seismic sequence. Our goals are:
(1) to define a reliable framework of the upper crust structure;
(2) to investigate how the intense aftershock activity relates to preexisting structures inherited from the Neogene contractional tectonics and to Quaternary extensional faults.

Geological Setting.

The investigated area is sited in the axial portion of the Central Apennines fold-and-thrust belt. It mainly consists of sedimentary thrust-sheets derived from Mesozoic-Tertiary pelagic and transitional sequences of the Adria margin ("Umbria-Marche" pelagic domain), covered by a thick (up to 4 km) pile of late Miocene – early Pliocene siliciclastics. In the northern sector of the L'Aquila seismic sequence, the pre-orogenic stratigraphic sequence is characterized by Triassic evaporites and dolomites (Burano Fm.), followed by liassic platform carbonates (Calcare Massiccio Fm.) and then by a middle Lias – lower Miocene pelagic succession of marly limestones cherty limestones and marls (Corniola Fm., Rosso Ammonitico Fm., Scisti ad Aptici Fm., Maiolica Fm., Marne a Fucoidi Fm., Scaglia Fm., Bisciaro Fm., Marne a Cerrogna Fm.). The syn-orogenic succession (Laga Flysch) consists of a thick sequence of foredeep turbiditic sandstones, channelized conglomerates and gypsumarenite turbidites, and it covers most of the investigated area.
This portion of the Apennines underwent contractional tectonics between early Miocene and early Pliocene. Compressive structures are mainly characterized by NW-trending, NE-vergent thrusts and folds. Out-of-sequence thrusting gave rise to complex non-coaxial structures, which are typically N-S trending in the western part ("Olveano-Antrodoco" thrust) and E-W trending in the eastern part of the investigated area (Gran Sasso thrust).
Superimposed on this Miocene-Pliocene compressive architecture, a dense network of high-angle Quaternary normal faults is present. They are typically NW-trending, showing at places N-S transfer structures at their edges. The main Quaternary normal fault in the study area is the NNW-trending, SW-dipping Mt. Gorzano fault. It cumulated ~1500 m normal displacement.
This study focuses on the Mt. Gorzano fault because it is a potential source of the Campotosto Aftershock.

B — Seismological Setting

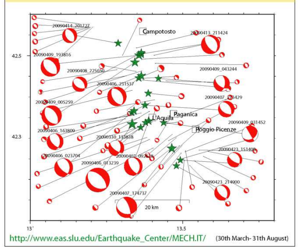
1981-2007 Seismicity



The map of instrumental seismicity in the period 1981-2007 (from CSI catalogue, Castello et al., 2006) shows that the 6th April L'Aquila earthquake occurred in a silent region. However, the high seismogenetic potential of the area is documented by large destructive earthquakes (M>6.5 and I>10, CPTI Working Group, 2004). Conversely, instrumental seismicity in the Campotosto area appears quite frequent.

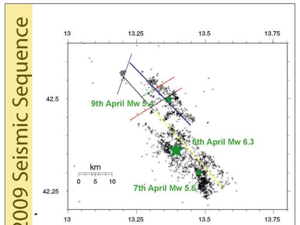
The moment tensor solutions are computed using regional waveforms from the Italian Broadband Network (ISIDE - Italian Seismological Instrumental and Parametric Data-Base by INGV).
The seismic sequence is dominated by normal-faulting mechanisms, with NW-trending nodal planes. Some events having a not negligible strike slip component occur in the southern portion of the seismic sequence.

Moment Tensor Solutions



http://www.eas.slu.edu/Earthquake_Center/MECH.IT/ (30th March - 31th August)

The 2009 Seismic Sequence



1D hypocentral locations (HypoEllipse) with outlined the 6th April mainshock and the two strongest aftershocks

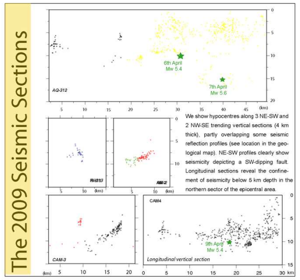
The 2009 L'Aquila seismic sequence activated a 40 km long NW-trending SW-dipping extensional fault system, consisting of three main right-stepping fault segments. The mainshock nucleated at 9.5 km depth and activated a 15-18 km long fault segment that dips 45° to the SW, between 10 and 2 km depth. Hypocentres are up to 18 km deep in the southern portion of the seismic sequence, where the strong Mw 5.6 earthquake occurred on 7th April at 15 km depth.
Conversely, in the northern portion, where the Campotosto aftershock occurred at about 11 km depth, seismicity is mainly confined beneath 5 km depth. Hypocentres alignment defines a SW-dipping fault plane, whose surface projection matches the Mt. Gorzano fault (Chiarabba et al., 2009).

Gruppo di Lavoro CPTI (2004), Catalogo Parametrico dei Terremoti Italiani, versione 2004, Rep. CPTI04, Ist. Naz. di Geofis. e Vulcanol., Bologna, Italy.

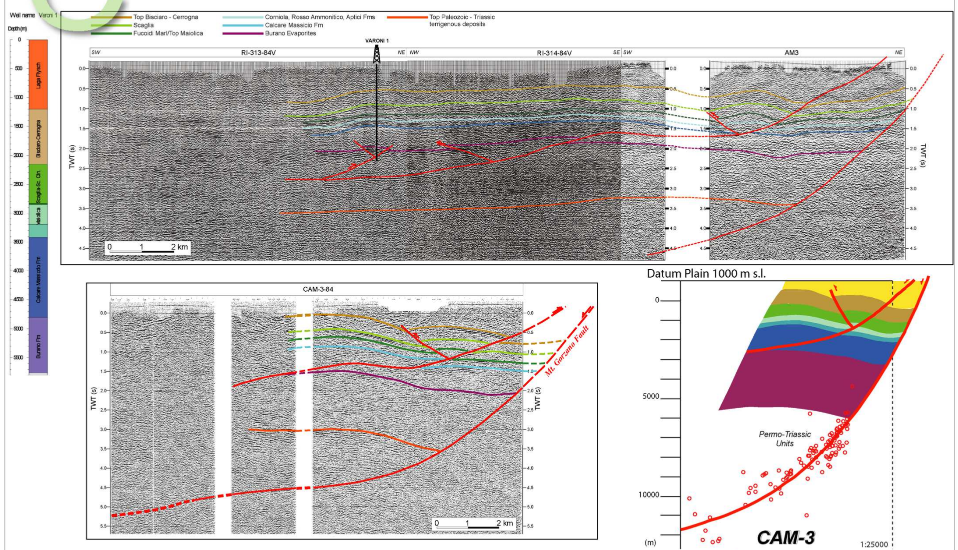
Castello B., Selvaggi G., Chiarabba C., Amato A. (2006). CSI Catalogo della sismicità italiana 1981-2002, vers. 1.1. INGV-CNT, Roma http://www.ingv.it/CSI/

Chiarabba, C., et al. (2009), The 2009 L'Aquila (central Italy) Mw6.3 earthquake: Main shock and aftershocks, Geophys. Res. Lett., 36, L18308, doi:10.1029/2009GL039627.

The 2009 Seismic Sections



C — Seismic Reflection Lines



Data and Results.

We have intepreted several confidential seismic reflection profiles mostly acquired by ENI oil company to the SW of the Mt. Gorzano ridge. Seismic lines are tied to a public well (Varoni 1) 5700 m deep (see the geologic map for location). Quality of the reflection imag is highly variable, but it is usually poor below 2.0-2.5 s. Nevertheless, a few good quality stack sections contains interpretable events down to 3.0 s TWT, corresponding to 7-8 km depth, thus allowing the crustal imaging at seismogenic depths.
We show two representative seismic sections. The first one is a merged line (comprising sections RI-313-84, RI-314-84 and AM3), tied to Varoni 1 well. The second one, striking SW-NE, is the CAM3 line, which, together with AM3 line, illuminates the hanging-wall of Gorzano fault and is very close to the Campotosto aftershock epicenter (see geological map for location). Key-reflectors for our structural interpretations correspond to: (1) the top of the Cerrogna Fm.; (2) the top of the Scaglia Group (Albian – Oligocene); (3) the late rassic - lower Cretaceous carbonate multilayer (Maiolica Fm.); (5) the top of the Calcare Massiccio Fm. (6) the Triassic evaporites (Burano Fm.). Strong but discontinuous deeper events can be reasonably interpreted as the boundary between Triassic evaporites and Trassic clastic sequences. From our interpretation, it comes out that Neogene compression was responsible for the development of evident ramp-flat structures along WNW- to NNW-thrusts and back-thrusts involving the whole Umbria-Marche succession. Fault propagation folding is the surface expression of a complex deep architecture, mainly related to thin-skinned tectonics. Thrusting and folding also involves the deep Triassic evaporites and the underlying Permo-Triassic sequences imaged between 2.0-3.0 s TWT, cor sponding to 5-8 km depth.
Extensional structures in the subsurface are much less widespread.
The CAM3-84 and AM3 sections anyway reveal an important SW-dipping normal fault, which we relate to the Mt. Gorzano structure. In the hangingwall of this normal fault a low-angle thrust with an associated small back-thrust are present. Time-depth conversion o CAM3-84 section, constrained by Varoni 1 data (including a reliable sonic velocity log), indicates that this normal fault plane has a listric geometry, with high angle at shallower depths and decreasing dip below 8-9 km depth. Hypocentral locations of aftershocks clos the CAM3 line has been projected on the time-depth converted section. Hypocentres distribution indicates that aftershock activity is mainly confined between the Trassic evaporites and the underlying Paleozoic-Triassic units, without affecting the upper structural levels.
Aftershocks alignment suggests that the Mw5.4 aftershock ruptured a fault segment between 5 and 10 km depth. The inferred fault segment is compatible with the fault imaged by the CAM-3 profile down to 4.5 s TWT, that dips 45°-50° to the SW. Therefore, oil explo tion data indicate that the Campotosto strong aftershock can be reasonably related to the activation of the deeper portion of the Mt. Gorzano Fault. Our future efforts will focus on the reconstruction of the 3D geometry of the Mt. Gorzano Fault and on the comparison with more accurate 3D aftershock locations from Local Earthquake Tomography.

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