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T40-4 Orale Caporali, Alessandro

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GEODESY AND SEISMICITY IN THE EASTERN ALPS

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Key terms: Geodesy; Seismicity; GPS; Neotectonics

Combination of weekly solutions of the EUREF permanent GPS network (EPN) with similar solutions for national networks of permanent stations enables velocities to be reliably computed for a locally denser network than the EPN, while maintaining proper alignment and scale. Scattered velocities can be further analyzed by suitable algorithms, such as Least Squares Collocation, to yield estimates of the horizontal velocity gradient, and hence the eigenvectors of the strain rate tensor. If such estimates are done at locations with a distribution of neighbor velocities sufficiently dense and homogeneous, the principal directions of strain rate are affected by uncertainties sufficiently small that they provide a geophysically meaningful estimate of the average surface strain rate in the area. If a seismic catalogue is also available, a number of important questions can be addressed, such as a) how does the strain rate released seismically relate to geodetic strain rate? b) what is the maximum earthquake magnitude expected in a seismic province of known Gutenberg -Richter 'a' and 'b' parameters and geodetic strain rate? c) how does failure on a fault at depth relate to strain measured geodetically on the surface?
The area of the Eastern Alps is covered by several Austrian and Italian permanent GPS stations, in additions to those contributing to the EPN, and has an excellent catalogue of historical earthquakes. Based on available strain rate maps, we show that a) the strain rate which, according to the Kostrov formula, has been released in the past 30 years is typically one order of magnitude larger than the strain rate measured geodetically, about 30 nanostrain/year. We show that the seismic moment of individual earthquakes must be integrated backwards in time for approximately 160 years for the seismically released strain rate to equal the geodetic strain rate; b) with the Gutenberg Richter's a and b parameters computed for events in the past 160 years we show that the equality between geodetic and seismic strain rates constrains the maximum earthquake magnitude to M=6.7; c) using a simple slider block model on an inclined plane, and the Coulomb Failure criterion to describe quantitatively the sliding instability, we estimate the pattern of strain rate which is expected to be measurable on the surface above a locked reverse fault, as a function of the locking depth, dip angle and coefficient of static friction. We use present-day slip profiles inferred by GPS to constrain such dynamical fault parameters.

T40-5 Orale Boncio, Paolo

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A HYPOTHESIS OF SEISMOGENIC SOURCES FOR THE 1920 EARTHQUAKE AND THE HISTORICAL SEISMICITY OF THE LUNIGIANA-GARFAGNANA AREA (NORTHERN APENNINES, ITALY)

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Key terms: Seismicity; Seismotectonics; Active faults; Extensional tectonics; Northern Apennines

The September 7, 1920 earthquake is the largest event of the Lunigiana-Garfagnana area (max. MCS intensity = X, epic. intensity = IX-X, estimated Mw = 6.48). The earthquake damaged a large area, from the northern Garfagnana to the southern Lunigiana. The seismogenic source of this earthquake is poorly constrained. In the database of seismogenic sources DISS 3 (DISS Working Group, 2006 at www.ingv.it/DISS) a source from macroseismic data and a source (the preferred one) from geological-geophysical data are proposed. The macroseismic source strikes N108° for a length of ~25 km. The geological-geophysical source (Garfagnana north) is a N305°-striking, 18 km-long NE-dipping blind normal fault. The emergence at surface of the geological structure nearly corresponds to the Minucciano fault. A number of important questions are left open, such as the seismogenic role of the Minucciano fault, the causes of the divergence between the geological-geophysical and the intensity-based sources and, again, the possible role of the April 11, 1837 earthquake (I=IX-X, Mw=5.65) compared to the 1920 source.
In this work, we try to answer the open questions and to propose a more constrained model of seismogenic sources on the basis of geological and geophysical data, including: a) photo-geologic analysis, integrated with field data, of the Lunigiana area; b) field mapping (1:25.000 scale) of the Garfagnana area, from Minucciano to the Barga graben; c) detailed DEM of the Lunigiana-Garfagnana; d) subsurface geological data from seismic reflection profiles; e) detailed seismicity data recorded by the Lunigiana-Garfagnana Seismic Network; and f) seismological data from earthquake catalogues and intensity databases.
The Lunigiana and Garfagnana basins are asymmetric grabens controlled by NE-dipping master faults soling on a low-angle extensional detachment which deepens beneath the Apennines up to depths of ~13 km. The normal fault system includes synthetic (NE-dipping) and antithetic (SW-dipping) faults. The NE-dipping faults with strongest geomorphic signature (i.e. most likely active faults) are the Mulazzo and Olivola-Soliera faults in the Lunigiana and the Casciana-Sillicano and Bolognana-Gioviana faults in the Garfagnana. These faults dip at 30-35° up to depths of ~5 km before soling onto the low-angle detachment (dip ~20°). The Minucciano fault, belonging to the NE-dipping system, is characterized by scarce geomorphic evidence or "counter-evidence" of recent activity such as the higher elevation of the hanging wall block (Macigno turbidites) compared to the footwall block (carbonates) near Minucciano. The most important SW-dipping splays, in terms of geomorphic evidence, surface length and depth of the detachment, are the Groppodalosio and Compione-Comano faults in the Lunigiana and the faults along the M.Prato-Colle Uccelliera-M.Mosca alignment in the Garfagnana. A N-dipping E-W-striking fault zone, delimiting at the footwall the Apuane Alps, is highlighted by tectonic lineaments in aerial photographs and is well evident in seismic line. We interpret this fault zone as the right-lateral transfer of active extension between the Lunigiana and Garfagnana grabens (North-Apuane transfer fault-zone). We associate to the North-Apuane transfer a seismogenic role, as suggested by the October 1995 earthquake (M = 4.9) and its focal mechanism. We associate to the North-Apuane transfer also the 1837 earthquake plus a number of small-magnitude earthquakes ($4.5 \geq M \geq 5.2$) occurred in 1767, 1902, 1928 and 1962. The 1920 earthquake is associated to a complex rupture involving the entire Casciana-Sillicana fault plus the eastern portion of the North-Apuane transfer. Computations of the ruptured areas from the estimated Mw of the associated earthquakes suggest that the two faults were almost entirely activated in historical times.

T40-6 Orale Mirabella, Francesco

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SUBSURFACE AND SURFACE DATA IN THE SAN SEPOLCRO, CASENTINO AND MUGELLO BASINS (NORTHERN APENNINES OF ITALY): NEW CONSTRAINS ON THE ACTIVE TECTONICS OF THE AREA

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Key terms: northern Apennines; Seismic profiles; seismotectonics

The seismicity of the axial zone of the northern Apennines indicates that the present-day deformation is characterised by active extension oriented SW-NE occuring within the upper 12-15km of the crust at extending rates of about 2.5 mm/yr. In the area between Norcia to the SE and Pontremoli to the NW, several moderate magnitude events were recorded in recent and historical times. The southern area (Norcia-S.Sepolcro) was struck by destructive earthquakes in recent times (Norcia 1979 , Gubbio 1984 , Umbria-Marche 1997-98), while the northern part is apparently less active but with several historical moderate earthquakes. From a structural point of view, the moderate magnitude earthquakes of the southern area occur on SW-dipping normal faults which are antithetic to a low-angle normal fault interpreted as the regional detachment of the area (AltoTiberina fault).
In the northern Pontremoli area, an analogous low-angle East-dipping detachment has been described on the basis of seismic reflection data and some authors have suggested the continuity of such low-angle detachment from Pontremoli to the NW to the Umbria region to the SE (Etrurian fault system).
In this work we present seismic data in the San Sepolcro, Casentino and Mugello basins integrated with deep-wells, surface geological data aerial photo interpretation.
The San Sepolcro basin is about 22km-long and its age at least lower Pleistocene. Seismic data in the San Sepolcro area were calibrated with the Pieve S.Stefano well, and with the Crop03 seismic profile. On the basis of our interpretation the San Sepolcro basin is bordered to the West by two splays of the Altotiberina fault bordering the Anghiari ridge. Towards the East the basin is borderd by a SW-dipping normal fault antithetic to the Altotiberina fault.
The Casentino basin is a 15km-long depression infilled with fluvio-lacustrine deposits of late Pliocene-early Pleistocene age with a minimum thickness of about 60m. The seismic data in the Casentino basin allow us to trace two main NE-dipping reflectors the westernmost of which corresponds to a steep topographic signature which we interpret as the surface expression of a NE-dipping normal fault. The seismic signal in correspondance with the fault is also characterised by a set SW-dipping reflectors which can be an indication of fault growth. Its topographic signature and the basin shape and morphology let us suppose that this fault system is different in terms of offsets and geometry from the fault system which borders the San Sepolcro basin, the extensional structure being less outstanding. Also the existance of a low-angle detachment below the extensional fault system is still under investigation.
The Mugello basin is a 25km-long structure infilled with up to 600m of late Pliocene - early Pleistocene fluvio-lacustrine deposits. Though the tectonic history of the basin is debated, the Quaternary deformation of the basin is characterised by SW-NE trending extension. In the Mugello basin, where no seismic data are present, the aerial photo interpretation is particulary usefull for neotectonic purposes. On the basis of our data a large number of alignments with a prevalent NW-SE direction are recognizable. On the bedrock they are more evident in the southeastern border of the basin where many sets of river network anomalies, triangular facets and aligned peaks are recognizable, indicating the presence of a set of NW-SE-trending tectonic alignments. These are more frequent and evident moving toward the eastern side of the basin, mainly in the area between the Ensa River and Vicchio.

T40-7 Orale Messina, Paolo

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QUATERNARY TECTONICS OF THE ABRUZZI APENNINES (ITALY) INFERRED FROM INTEGRATED GEOMORPHOLOGICAL-STRATIGRAPHIC DATA

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Key terms: Quaternary; intermontane basins; uplift; extensional tectonics; Central Italy

The geomorphological setting of the Abruzzi Apennines is characterized by flat or gently rolling summit levels, representing the remnants of an ancient low relief landscape, and by a sequence of erosional/depositional surfaces, which testify the progressive sinking of tectonic intermontane basins. These surfaces

are embedded in the summit paleo-landscape and are placed at different elevation on the intermontane basins margins as well as on the slopes of their tributary valleys; geomorphological/stratigraphic evidence clearly indicates that, in their initial stages, the intermontane basins hosted closed lakes fed by a centripetal drainage network.
Thick sequences of tectonically deformed Pliocene-Quaternary lacustrine/alluvial deposits fill up the intermontane basins, testifying their complex tectonic-sedimentary evolution (Bosi et al., 2003). In some cases (e.g. Fucino and Sulmona basins) the spatial distribution of sediments indicates that the ancient lakes were topographically related to the present depressions; other basins (e.g. Salto and Turano basins) were definitely inconsistent with the modern landscape as a consequence of intense tectonic deformation and/or erosion.
The integrated geomorphological/stratigraphic analysis of the Abruzzi Apennines, indicates that the lacustrine basins were drained off by regressive erosion, induced in the effluent rivers by the large scale uplift which affected the Apennine during the Quaternary and the contemporaneous activity of west-dipping normal faults on the Tyrrhenian side (Dramis, 1992; D'Agostino et al., 2001; Galadini et al., 2003). In some cases, competition occurred between the backward fluvial erosion and the activity of normal faults, tending to close the basin again.
The extinction of the ancient lakes occurred earlier for the westernmost "Thyrrhenian" basins (e.g. Salto and Turano basins) and later for the easternmost "Adriatic" ones (e.g. Aterno and Sulmona basins). This evolutionary trend seems to be quite consistent with the eastward migration of extensional tectonics (Galadini & Messina, 2004) and may undertake a crucial importance for seismic hazard assessment in the Abruzzi Apennines.
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T40-8 Orale Gori, Stefano

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ACTIVE FAULTING ALONG THE MT. MORRONE SOUTH-WESTERN SLOPE (CENTRAL APENNINES, CENTRAL ITALY)

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Key terms: central Apennines; active faulting; earthquake; slip rate

Active normal faults and fault systems potentially responsible for earthquakes with Magnitude up to 7 have been detected in the central Apennines since the 90s of the last century. Strong historical earthquakes have been associated to some active faults by means of paleoseismological analysis or by the comparison between the damage distribution and the fault geometry. On the other hand, several faults showing evidence of Late Quaternary activity cannot be related to high-magnitude historical earthquakes and are therefore defined as silent. The level of hazard associated to these silent faults is commonly considered as high. Within this light, the fault affecting the south-western slope of Mt. Morrone, in the Abruzzi Apennines, can certainly be considered as silent. Indeed, this tectonic structure, made of two parallel, northwest-southeast

trending fault segments, is considered as potentially responsible for $M \leq 6.5$ earthquakes, but its last activation probably occurred about 1,800 years ago, in the 2nd century AD. Geological and geomorphological surveys have been performed along the Mt. Morrone south-western slope in order to achieve data useful for the definition of (i) the kinematics and (ii) the slip rate of the mentioned fault system. Our analyses allowed us to confirm that this tectonic structure is characterized by a mainly normal kinematics with a minor left-lateral oblique component, fitting an about N 20° trending extensional deformation. The slip rate of the westernmost fault segment has been estimated through the offset of three orders of alluvial fan deposits attributed to the late Pleistocene by means of radiocarbon dating and tephrochronological age determinations. The slip rate estimate ranges between 0.27 and 0.36 mm/yr. The lack of displaced deposits in the footwall of the fault has hindered the estimation of the slip rate related to the eastern fault segment. The geometry of the two fault segments allowed us to hypothesize that they probably represents the splaying at surface of the same deep-seated fault. Therefore, assuming an ditribution of the slip between the two fault segments, a total slip rate for the Mt. Morrone fault system ranging between 0.54 and 0.72 mm/yr may be defined. Moreover, our observations allowed us to confirm that the maximum expected magnitude of an earthquake which may originate along this ~21,5 km-long fault system, according to Wells and Coppersmith (1994), is ~ 6.6.

T40-9 Orale Pace, Bruno

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THE MAIELLA EARTHQUAKES (ABRUZZO, ITALY): SOME INSIGHTS INFERRED FROM GEOLOGICAL AND MACROSEISMIC DATA FOR SEISMOTECTONIC PURPOSE

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Key terms: seismotectonics; historical earthquakes; scenario; Maiella; central Italy

The nature and distribution of the seismicity and of the active structures in central Italy show that the active and seismogenic deformation field of central Italy is mainly characterised by extension in the axial zone of the Apennines and by co-axial contraction on the frontal part of the belt, close to the Adriatic sea border. In this tectonic context become crucial, from the seismic hazard point of view, the seismotectonic characterization of the major earthquake localised between the two seismotectonic provinces with different kinematics.
The major earthquakes of the Maiella region (Abruzzo, central Italy), like the 1706 (I=IX-X), the 1933 (I=VIII-IX) and the 1881 (I=VIII) events, are just localised in this intermediate position, outward of the easternmost active NNW-SSE normal fault alignment and inward of the N10°E striking thrust front of the Coastal-Adriatic contractional province. These earthquakes have been attributed by some Authors (e.g. Pace et al., 2006) to mid crust thrust faulting along the deep prosecution of the SW-dipping Adriatic Basal Thrust, but the discussion about a possible upper crust normal faulting is still open.
The analysis of the distribution of the macroseismic data of the Maiella earthquakes may greatly help to define the geometry and depth of the seismogenic source and, therefore, to discriminate between the different proposed interpretation of the potential seismogenic sources. For a well constrained seismotectonic interpretation of the intensity data field, the evaluation of the possible local effect from field data is necessary. Therefore, the present study will be developed following and integrating three essential steps: a) analysis of structural constraints for the definition of the three-dimensional geometry of the potential seismogenic sources; b) evaluation of the possible local effect from field data; c) estimation of the intensity data field.
The approach used to reproduce the macroseismic field associated to the Maiella earthquakes consists in calculating synthetic strong motion time histories from a geological source model, with a stochastic finite-fault modeling of ground motion. The method involves discretization of fault plane into smaller sub-faults and the contribution from all sub-faults is summed to produce the synthetic acceleration time history. For each point, peak ground acceleration is determined in order to calculate macroseismic intensities using Trifunac and Brady empirical relationships.
Evidently, the geological designation of some possible seismogenic sources is a very important aspect and can be used as constraining and discriminating factor among the different solutions. We consider this integrate methodology and the results of this study useful in terms of seismotectonic understanding and seismic hazard assessment.
Pace, B., Peruzza, L., Lavecchia, G., Boncio, P., 2006. Layered seismogenic source model and probabilistic seismic-hazard analyses in central Italy. Bull. Seism. Soc. Am., 96-1, 107-132.

T40-10 Orale Caputo, Riccardo

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IS THE OROGENIC ACTIVITY STILL ACTIVE IN THE EXTERNAL SOUTHERN APENNINES-

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Key terms: marine terraces; morphotectonics; Quaternary; seismic hazard; Structural Geology

Orogenic activity along the external Southern Apennines is well documented up to Middle Pleistocene p.p., when a major geodynamic re-arrangement is suggested for the Central Mediterranean, but in the external part of the orogenic wedge at the boundary with the Bradanic Foredeep, it is commonly assumed that thrust activity has completely ceased. To test this statement, we investigated the Ionian coastal sector characterised by an impressive flight of marine terraces (roughly parallel to the orogenic shortening direction), representing regional-scale Middle-Late Quaternary morphological markers.
We carried out systematic remote sensing and field-work analyses that allowed to map in detail more than 10 orders of marine terraces. The projection of their palaeoshorelines along a NE-SW profile shows a fan-shape geometry converging NE-wards, thus documenting the cumulative effects of the regional uplift as well as of the progressive NE-wards tilting. The areal and especially the vertical distribution of the terraces reveal the occurrence of three NW-SE trending zones with different geodynamic behaviours separated by two marked changes in both uplift- and tilting-rate.
Notwithstanding the uncertainties associated with the different dating techniques, the critical analysis of all absolute ages available in the literature constrain the first 3-4 orders to the Late Pleistocene. Based on several sealevel curves, we correlated the mapped terraces (at least the lower 7-8 orders) to the major marine highstand sealevels occurring during the last ca. 300 ka and calculated the associated long-term uplift-rates. Mean values for the three sectors are 0.6, 1.2 and 1.8 mm/a, from NE to SW respectively. The observed differences are far outside the degree of uncertainty of all parametres considered in the calculation.
The major geodynamic elements of the region are i) the subducting Adria Plate characterised by a flexed geometry; ii) the basal detachment running roughly on top of the Apulian succession and characterised by a convex-upward shape; iii) the external sector of the orogenic wedge largely affected by contractional structures. The two changes in behaviour that separate the three sectors occur just next to 1) the most external sub-emergent thrusts (between Sinni and Agri rivers) within the orogenic wedge and 2) the fault-tip of the most external blind thrust (between Cavone and Basento rivers) representing the basal detachment.
The differential uplift and tilt is likely due to the overlap of three major tectonic