Foreshock Sequence of September 26, 1997 Umbria-Marche Earthquakes.

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September 3, 1997 at 22.07 GMT a Ml 4.4 (M0=0.08*1017) earthquake struck the Colfiorito basin located in the Central Apeninnes between the Umbria and Marche regions. Two days after, September 5th a small network of 4 three-components digital stations were deployed by the Department of Earth Sciences of Camerino University in the epicentral area with the aim of recording the aftershock sequence. Seismic stations were located in a distance range of 3 and 22 km from the September 3th epicenter. However, in the same area 23 days after, September 26th, two main shocks at 00.33 and 09.40 GMT with magnitude Ml 5.6 and Ml 5.8, respectively, hit again the area. This has allowed us to record near the epicenter (3-5 Km) more than 700 events with magnitude between 3.2 ML and 1 ML, during three weeks preceedings the two main shocks of September 26th. This foreshock sequence showed up a very high seismicity rate, reaching about 100 earthquakes per day (September 11th) with magnitude less than 3.2 Ml. Localization of about 100 foreshocks by using different velocity models, indicates that seismicity was concentrated in an area of about 5-7 Km oriented 320 N along the NW-SE direction and dipping 50-60° SW. This cluster of seismicity is located between the two main shocks of September 26th and fills a seismic gap evidenciated by the seismicity in the area of the last 10 years. Focal plane solutions of 4 major events are in agreememt with the NW-SE epicentral distribution and give a fault direction of N140 . These results are coherent with the results obtained from the analysis of the two main shocks of the September 26th. The foreshocks sequence has been also analysed and compared to the aftershocks sequence in terms of distribution of number of events per day , Gutenberg-Richter distribution and variations of the Vp/Vs ratio.

LOW FREQUENCY INCLINOMETRIC REGISTRATION OF THE UMBRIA-MARCHE EARTHQUAKE SEQUENCE AT THE GRAN SASSO UNDERGROUND LABORATORY.

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An inclinometer with sensitivity better than $10^{-9} rad/\sqrt{Hz}$, in the range $dc - 1Hz$, is operating since several years in the underground laboratory of Gran Sasso, L'Aquila (Italy). This inclinometer developed at IFSI (Istituto di Fisica dello Spazio Interplanetario) of CNR (Consiglio Nazionale delle Ricerche) is of new concept. It is developed like an accelerometer for space use. The only chance to calibrate such accelerometer at low frequency and low signal level is offered by a place, like an underground laboratory, where vibrational and thermal influences are reduced.
Here we present the instrument and data recorded during the recent Umbria-Marche earthquake sequence. The inclinometric data, together with pressure and temperature, are acquired with sampling time of 10sec.
Even if the instrument is not the optimum to detect so high signals, our first evaluation indicates that the amplitudes recorded are connected with the earthquake magnitudes. Our magnitude seems in agreement with the data recorded by the Istituto Nazionale di Geofisica (ING).
At low frequency there is some evidence of local fault motion, connected with the shocks waves arrival.

ARE AFTERSHOCKS ON INDIVIDUALIZED FAULTS ?

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During the seismic Umbria-Marche 1997 sequence, aftershock clustering was observed in relation to some magnitude larger than 4 events, in particular in the central part of the active area, in the vicinity of the September 26 main events epicenters. In this part the global aftershock distribution is the more complex and shows the existence of parallel SW dipping normal faults in the upper crust. The sequence was well recorded by a dense seismological network of 25 digital stations from ING, Camerino University and CNRS. All time basis were controlled by GPS and 5 stations were telemetred and recorded with the same clock so that the uncertainties on time is less than .002 sec. In a data base of more than 2000 events, selection of families is performed on a criterion of waveform similarity at more than 4 selected stations. A precise location of events of a same family relatively to a master event is then possible, measuring time delays by crosscorrelation of the waveforms. We focuss our attention on some clusters related to the larger events as the October 16 event. The focal mechanism of this event show a left lateral strike slip motion and location of the corresponding aftershocks allows to select the NS nodal plane as fault plane. The extension of the reactivated area will be compared to the rupture extension as determined by waveform modeling. Application to adjacent clusters, corresponding to normal faults, provides a description of the faults complexity.

LONG-TERM TECTONIC EVOLUTION AND CHARACTERISTICS OF THE PRESENT TECTONIC REGIME IN THE AREA OF THE UMBRIA-MARCHE SEISMIC SEQUENCE (CENTRAL ITALY)

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The fieldwork performed during September-October 1997 was aimed at collecting data on the surface ruptures related to the main shocks of the Umbria-Marche sequence. Moreover, this work provided some hints for specific studies on the long-term tectonic behaviour of the area struck by the earthquakes (comprising the Colfiorito and Cesi-San Martino basins). In the following months, through geomorphological surveys it has been possible to identify the main Quaternary faults, while geological research consisted in: 1) checking the previous works on the Quaternary stratigraphy; 2) performing structural surveys in the Cesi-San Martino basin and in the easternmost sector of the Colfiorito basin in order to collect data on the deformative features affecting the Quaternary deposits; 3) reconstructing the top of the pre-Quaternary substratum in the Colfiorito basin mainly by means of borehole data and the geo-electrical surveys made in the Fifties. This basin is characterised by two structural lows in the inner part and does not present the geometries of other fault-bounded Quaternary basins of the central Apennines (typically half-graben basins). Tectonic history may be summarised as follows: 1) origin of the Quaternary fault-bounded Colfiorito and Cesi-San Martino basins; 2) strain change during the Middle Pleistocene. As a consequence, activity is no longer detectable through fault-related surficial displacements but only through "continuous" deformations spread over the basins, as occurred during the recent seismic sequence.

INTERSEISMIC STRESS ACCUMULATION IN CENTRAL ITALY: CONSTRAINTS AND MODELLING

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Earthquakes can be characterized in time by at least two scales: a short one associated with generation and propagation of elastic waves, and a long one associated with the stress build up due to geodynamic processes. We exploit wheather the processes controlling interseismic stress accumulation can be constrained on the basis of the seismicity and stress release pattern in the Umbria-Marche region. We develop a 2D viscoelastic dynamic model to calculate the stress distribution in central Italy induced by different geodynamic processes likely active in the region: Africa-Eurasia convergence, Adriatic underthrusting/subduction and asthenospheric upwelling underneath Tuscany. Model results are compared with the hypocentral distribution of earthquakes and with the orientation of P and T axes available for the region.
The first order characteristics of the seismotectonic observations in central Italy are: subcrustal seismicity, the pair extension-compression in Tuscany and in the outer Apennines, and the flexural behaviour evident in long wavelength orientation of T axes. These features are reproduced by the combination of two processes: underthrusting of the Adriatic plate under the Apennines and asthenospheric upwelling underneath Tuscany. The comparison with available data does not give insights about slab pull as an on going process.

RUPTURE DIRECTIVITY OF THE MAJOR SHOCKS IN THE 1997-1998 UMBRIA-MARCHE (CENTRAL ITALY) SEQUENCE FROM REGIONAL BROADBAND WAVEFORMS

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The 1997-1998 Umbria-Marche seismic sequence is characterized by the occurrence of several events with magnitude $M_w > 5.0$, all recorded at the stations of the MedNet broadband network. We compute the relative moment rate function of these shocks, by applying an empirical Green function method, for the three stations at which a good signal to noise ratio is available also for small events. The good azimuthal distribution of these stations allows the recognition of rupture directivity for all the events taken into account. By means of simple forward modeling of the source time function durations and amplitudes obtained from EGFs, we estimate fault length and average rupture velocity and direction. By assuming a simple Haskell source model, we also compute slip functions for the 97/9/26 00:33 ($M_w = 5.7$), 97/9/26 09:40 ($M_w = 6.0$) and 97/10/14 15:23 ($M_w = 5.6$) events, representing the major shocks in the whole sequence. Maximum slip of 52, 65, and 20 cm respectively result for the three events. The general picture resulting from our analysis displays a geometry consistent with a fault system in which each rupture breaks outward with respect to the epicentral area of the 97/9/3 foreshock sequence.