Giornale di Geologia Applicata 1 (2005) 147 –156, doi: 10.1474/GGA.2005-01.0-15.0015

The 1976 Friuli (NE Italy) earthquake

Giovanni Battista Carulli[1] & Dario Slejko[2]

[1] Dipartimento di Scienze Geologiche, Ambientali e Marine dell'Università di Trieste
[2] Istituto Nazionale di Oceanografia e di Geofisica Sperimentale - OGS, Trieste

ABSTRACT. On May 6, 1976 an M_L 6.4 earthquake caused about 1,000 casualties in central Friuli (where the hamlets of Gemona, Venzone, and Trasaghis suffered widespread destruction). Even though more than 25 years have passed since its occurrence, the 1976 Friuli event is still being studied. The reason for this is that it could represent the maximum possible quake in the Southern Alps and it was the first event that took place in Italy for which a large amount of seismological data were collected. Moreover, good geological and geophysical information is available for this region which also has a well-known seismological history. Nevertheless, some scientific aspects of the 1976 – 1977 seismic sequence are still under debate. This paper offers a general overview of the present knowledge about the earthquake and open the door to future investigations.

Key terms: Seismicity, Neotectonics, Southern Alps, Friuli, Italy

Introduction

The Friuli region, in NE Italy, and its surrounding areas were hit by several destructive earthquakes over the centuries, especially in the strip along the foothills (Cividale, Gemona, Tramonti, Belluno; locations shown in FIGS. 1 and 2), whereas the area of the plain and the Alps are less seismic. The seismic hazard of Friuli (REBEZ *et alii*, 2001) is conditioned by the lesser seismicity of the northern area on the border with Carinthia (Austria) and especially by that of the eastern area on the border with Slovenia.

Information about several earthquakes which occurred in the distant past is poor while some strong events of the 20th century (Tolmezzo 1928, Cansiglio 1936) are quite well reported because specific surveys were scientifically documented (GORTANI, 1928; CAVASINO, 1929; ANDREOTTI, 1937). The May 6, 1976 earthquake is probably the strongest event ever to have occurred in Friuli. It fostered geological and seismological studies aimed at giving a better understanding of the 1976 earthquake and, more generally, the regional seismicity (see references in SLEJKO, 2000) as well as the geodynamical and structural context (see references in CARULLI & PONTON, 1993 and POLI *et alii*, 2002). In this framework, several scientific activities were, and still are, financed by the regional government. Among many others, it is worth citing the regional seismometric network, which has been operating since May 1977, and the regional seismic risk map (CARULLI *et alii*, 2003), which is an important tool in urban planning and building retrofitting.

Geological Setting

The mountainous part of the Friuli Region comprises the eastern portion of the Southern Alps that in this area passes gradually towards the east into the Dinaric orogenic belt. The southern parts of these mountain chains (Carnian and Julian pre-Alps) face the Friuli plain to the south (the eastern part of the Po plain), which can be considered their foreland basin. The structural lineaments of the Dinaric orogenic belt have a SW vergence, while the Alpine ones have a S-SE one.

The stratigraphic succession cropping out in Friuli (Middle Ordovician to Recent) attains a total thickness of 20 km and can be considered unique in Italy for its geological time span and continuity. It is made mostly of sedimentary rocks that belong to the Adriatic microplate, today cropping out in E-W oriented structural domains, a consequence of the Hercynic, eo-Alpine, Dinaric and neo-Alpine orogenic events. In these structural compartments, the terrains become younger moving southwards from the Italian-Austrian border, in proximity to the Periadriatic Lineament, to the Friuli plain, a poorly deformed edge of the Adriatic microplate.

The central and external parts of the Carnian and Julian mountain chains (neglecting the more internal part made up of the Hercynian Paleocarnic mountain belt) were emplaced in distinct tectonic phases during the Paleogene *p.p.* and, with associated maximum deformation, during the Late Miocene-Quaternary. The latter tectonic phase determined the highest crustal shortening of the entire Southern Alps in the Friuli region (up to 1/3 of the original terrain extension) (CASTELLARIN, 1979; CASTELLARIN & VAI, 1981). The orogenic belt is composed of closely-spaced, generally south-verging overthrusts that originate an embricated structure. The footwall of the southernmost overthrusts is made of Neogene and Pleistocene successions (CARULLI & PONTON, 1993), in the maximum shortening zone that developed in response to the more recent N-S oriented compressional stresses (ZANFERRARI *et alii*, 2000) (FIG. 1).

Modern and recent activity of these tectonic lines is amply documented by geological data (CARULLI *et alii*, 1980; ZANFERRARI *et alii*, 1982) and high-precision topographic measurements (TALAMO *et alii*, 1978) of the pre-Alpine area in particular. Here, this neotectonic activity finds its expression in the extremely high reliefs and in numerous fresh and evident surface ruptures.

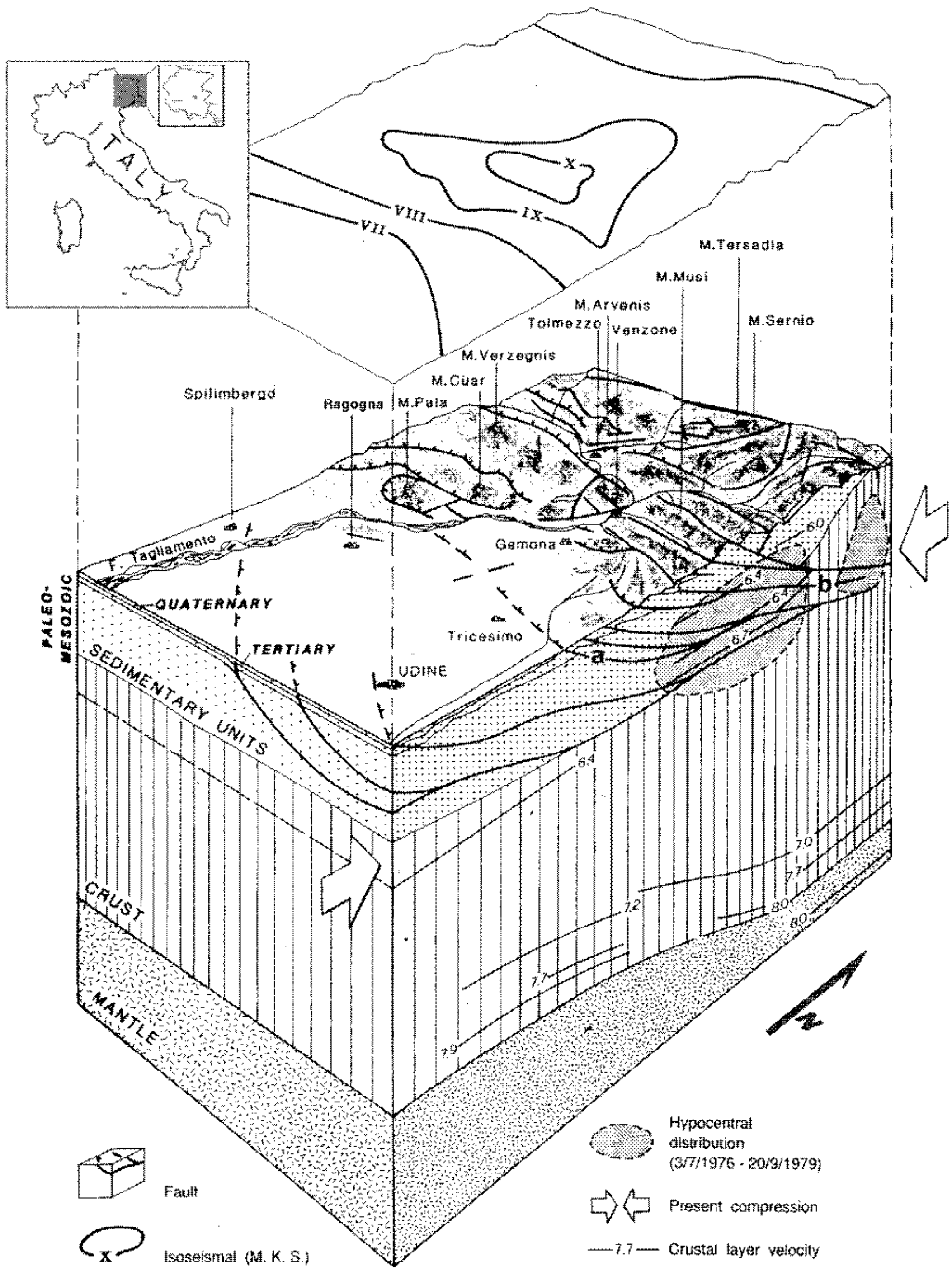

Fig. 1 - Sketch of the geological and seismological information for the epicentral area of the May 6, 1976 earthquake (partially modified from CAVALLIN *et alii*, 1990). The main causative faults of the 1976 sequence are indicated: a = Buja-Tricesimo line; b = Periadriatic overthrust.

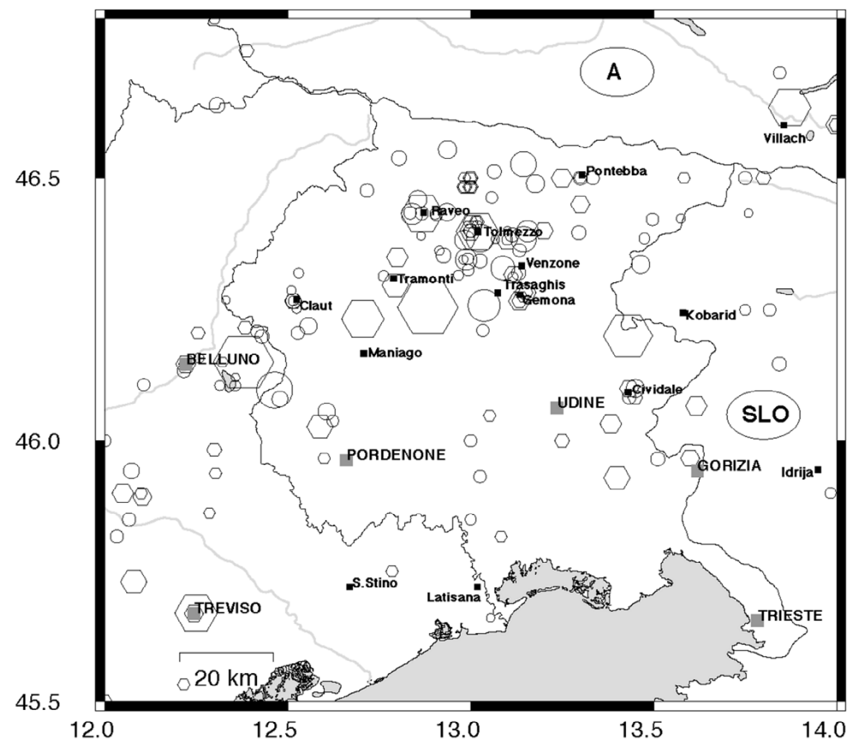

Fig. 2 - Epicenters of the earthquakes (mainshocks only) with magnitude larger than, or equal to, 3.5 from year 1000 to May 5, 1976. The circles indicate the events after 1894.

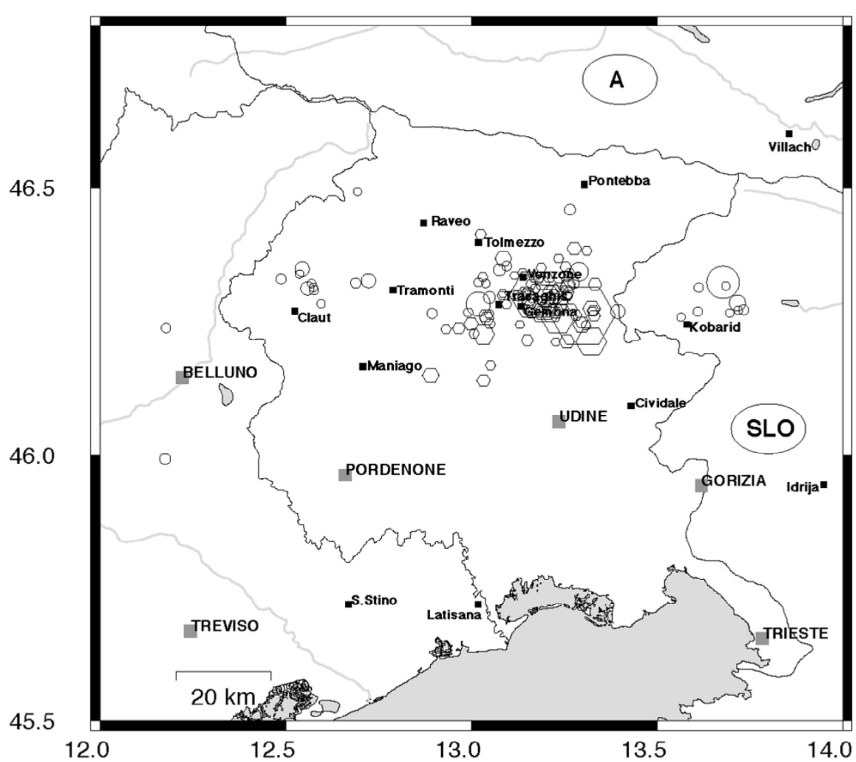

Fig. 3 - Epicenters of the earthquakes with magnitude larger than 3.4 from May 6, 1976 to December 31, 2001. The hexagons indicate the events of 1976.

The Regional Seismicity before 1976

The historical seismicity of Friuli and surrounding areas is rather well known (BONITO, 1691; BARATTA, 1901) because some settlements were already established in Roman times and developed during the Middle Ages (Belluno, Cividale, Trieste). The most recent earthquake catalogues of Italy (CAMASSI & STUCCHI, 1996; BOSCHI *et alii*, 1995, 1997; GRUPPO DI LAVORO CPTI, 1999) and some studies on the regional seismicity (e.g.: SLEJKO *et alii*, 1989) give a fairly precise view about the most seismically active areas.

The Friuli - Venezia Giulia region has a long history of instrumental data collection because the Osservatorio Marittimo seismographic station has been operating since 1906. Already in 1958, it became part of a public institution (Osservatorio Geofisico Sperimentale, the present-day Istituto Nazionale di Oceanografia e di Geofisica Sperimentale - OGS). In 1963, the seismographic station was moved from downtown Trieste (Campo Marzio) to a low-noise site (Grotta Gigante) and equipped with the instruments of the World Wide Standardized Seismographic Network, coordinated by the U. S. Geological Survey. Some other stations close-by (e.g.: Ljubljana, Pula, Padova, Venezia, Treviso) have contributed to the data collection of earthquakes in the eastern Alps since the beginning of the 20th century.

Figure 2 shows the epicenters of the earthquakes (mainshocks only) with magnitude larger than, or equal to, 3.5 which occurred from the year 1000 to May 5, 1976 (GRUPPO DI LAVORO CPTI, 1999). Different symbols show the accuracy of the locations: hexagons indicate post-1894 events, which are considered well located because regular seismological data reports have been available since then. The figure shows that the major seismicity occurred along the piedmont belt, from Cividale to Belluno, with its maximum in Friuli. The seismicity of eastern Veneto was particularly strong in the Belluno area, where large earthquakes occurred in 1873 (Io = IX-X Mercalli-Cancani-Sieberg, MCS), with damage in 50 villages of Alpago (BOSCHI *et alii*, 1995), and in 1936 (Io = IX MCS) with destruction in Cansiglio (ANDREOTTI, 1937). The most seismically active area in Friuli lies between Gemona and Tolmezzo: the return period of destructive earthquakes there is less than 100 years. Some strong events are associated with that area, like the 1389 (Io = VIII MCS), 1908 (Io = VIII MCS), and 1928 (Io = IX MCS; BOSCHI *et alii*, 1995) quakes. Another seismically active area is that of Tramonti, where the destructive quakes of 1776 (Io = VIII MCS) and 1794 (Io = IX MCS) occurred; an VIII - IX MCS event hit the neighboring village of Maniago in 1812. The Cividale area shows, on the contrary, a peculiar seismicity with some large earthquakes, like those of 1278 (Io = VIII MCS), 1279 (two quakes both with Io = VIII MCS), and 1898 (Io = VII-VIII MCS) but with only a few small-magnitude events. Furthermore, the quake that hit Raveo in 1700 (Io = X MCS), whose effects were relevant only in a very limited area (about 70 km^2) must also be mentioned.

A characteristic of the Friuli region is the mutual activation of some seismic sources. The most remarkable example is given by the seismic sequence which started in 1788 with an VIII MCS quake at Tolmezzo, followed by an VIII MCS event one year later at Tramonti and a IV-V MCS quake at Sutrio in 1790 (BOSCHI *et alii*, 1995). Another example is the 1511 event (RIBARIC, 1979; BOSCHI *et alii*, 1995), which destroyed Idria (X MCS) and Gemona (IX MCS) on March 26 and severely hit Cividale (IX MCS) on August 8 of the same year. Some other seismic areas are important for the Friuli seismic hazard, although they are located outside the present Italian borders. Southern Austria was affected by the large earthquake which destroyed Villach and many hamlets along the Gail valley in 1348 (Io = IX MCS) and was felt over the whole of Friuli (BORST, 1988; HAMMERL, 1994; BOSCHI *et alii*, 1995). Another destructive earthquake again hit Villach (Io = VIII-IX MCS) in 1690 (EISINGER & GUTDEUTSCH, 1994; BOSCHI *et alii*, 1995). Lower seismicity characterizes western Slovenia, especially the Mt. Sneznik area, SE of Trieste. Further eastwards, some large quakes hit Ljubljana (Io = VIII MCS in 1895; BOSCHI *et alii*, 1995) and the Croatian coastal area around Rijeka (Io = IX MCS in 1323, 1574, and 1721). In general, seismicity appears more uniform in Slovenia and in Croatia than in Veneto and Friuli (DEL BEN *et alii*, 1991).

The 1976 Earthquake and the Subsequent Seismicity

On May 6, 1976 a 6.4 local magnitude (M_L) hit a 5700 km^2 area in central Friuli, destroying several villages (AMBRASEYS, 1976) and causing 989 deaths and 4,500 billion Italian liras of damage (at the 1976 value; CAVALLIN *et alii*, 1990). The maximum intensity (X degree Medvedev-Sponheuer-Karnik, MSK) was reached at Gemona, Venzone and Trasaghis (GIORGETTI, 1976) and was felt as far as the Baltic coast and the Netherlands (KARNIK *et alii*, 1978). Several seismologists located the event (see more details in SLEJKO, 2000), the updated coordinates (SLEJKO *et alii*, 1999) are 46°15.8'N and 13°18.0'E, Gran Monte area, with a 6 km depth. CAPUTO (1976) computed a 10-13 bar stress drop, a $10^{25.9}$-$10^{26.1}$ dyne x cm seismic moment, an 800 km^2 fault area, and a 32-54 cm dislocation for the event. The fault-plane solution, computed by the first arrival onsets, as well as by waveform modeling (see more details in SLEJKO, 2000), is of reverse dip-slip type and refers to a gently north-dipping overthrust. The main shock was preceded one minute before by a 4.5 M_L magnitude event. Four small quakes occurred some months before May 6 much more to the south, around the mouth of the Tagliamento River, an almost aseismic area: they were interpreted as foreshocks of the May 6 main shock (FINETTI *et alii*, 1979). The May 6 main shock was followed by a long series of aftershocks, among which the

5.3 M_L event of May 9, which was the strongest. After a quiescence in August, two strong quakes occurred on September 11 (M_L 5.1 and 5.6) and a further two on September 15 (M_L 5.8 and 6.1), with additional deaths and damage especially in the Gemona area. FINETTI *et alii* (1976) studied the seismic sequence using the data of a temporary network installed after the May and September quakes. While the May seismicity remained concentrated in eastern Friuli, it propagated westwards in central Friuli during the month of September. All hypocenters were surficial, with a depth of less than 20 km. Different interpretations were given to the aftershock fault-plane solutions: reverse, normal, and transcurrent motions were proposed for the associated faults. The updated interpretation (SLEJKO *et alii*, 1999) suggests similar mechanisms for the majority of the events of reverse dip-slip type with a plane gently dipping N-NW, similar then to the mechanism of the main shock. Figure 3 shows the space distribution of the events of the seismic sequence: the concentration in central Friuli is evident although the epicenters spread from the Tagliamento River to the border with Slovenia. A few events can be seen in the Friuli plain and, as mentioned before, in the southernmost part of the Tagliamento River.

The OGS seismometric network of Friuli - Venezia Giulia started operating on May 6, 1977, exactly one year after the main shock: its goal, at this early stage, was to document the seismic sequence and, later, to collect data of

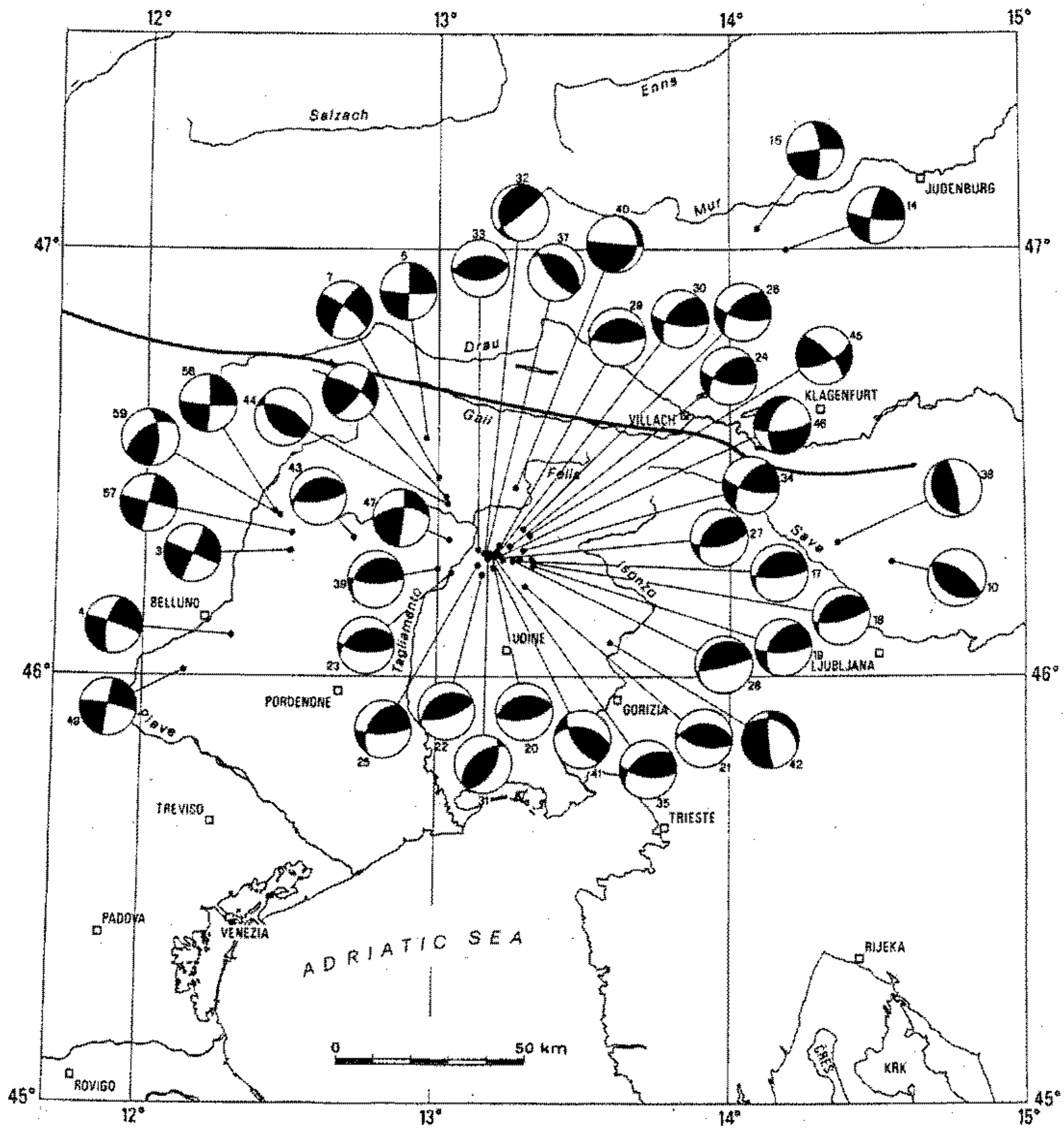

Fig. 4 – Fault-plane solutions of the main earthquakes which occurred from 1928 to 1986 (from SLEJKO *et alii*, 1989). Black sectors indicate compressions in the lower hemisphere of the stereographic projection. The numbers follow the chronological sequence and number 18 indicates the May 6, 1976 main shock.

the regional seismicity (OGS, 1977-1981, 1982-1990, 1991-2001). A new seismic phase started on September 16, 1977 with a 5.3 M_L event west of the Tagliamento River and, consequently, outside the bulk of the 1976 seismicity. According to FINETTI *et alii* (1976, 1979), the May 6, 1976 main shock was generated by the Buja-Tricesimo line (a in FIG. 1), a NW-SE (Dinaric) trending fault on the Friuli piedmont belt. From June onwards, the earthquakes affected Alpine faults as well, in particular the Periadriatic Overthrust (Barcis - Starasella line: b in FIG. 1): the main events of May and September 1976, and September 1977 identified a detachment plane, dipping about 40° north, related to the Periadriatic Overthrust.

The strong September aftershocks were due to the dynamic re-equilibrium following the decompression of the western rocky blocks caused by the main shock. Further studies suggested a model with asperities and barriers for the seismic sequence (LYON-CAEN, 1980) with a normal stress-drop in May and a larger one in September 1977 (SUHADOLC, 1981). A northward dipping plane, between a depth of 5 and 19 km, was identified for the September 1977 sequence. With the passing of time, the earthquakes affected an area which was vaster than the Gemona - Venzone epicentral area of the main events of 1976.

Figure 4 collects the fault-plane solutions of the principal events. They are rather similar to each other, representing a dip-slip mechanism in agreement with an E-W to NE-SW trending plane, gently dipping to the north. A link between earthquakes and surficial faults is very difficult to establish and a complex geometry of the faults in depth was proposed (SLEJKO *et alii*, 1989): faults could merge together upon contact with the crystalline basement at a depth of about 10 km, producing a detachment plane.

The surficial cracks (AMBRASEYS, 1976; BOSI *et alii*, 1976; PANIZZA, 1977; MARTINIS & CAVALLIN, 1978; CAVALLIN *et alii*, 1990) were not linked to any seismogenic fault because of the complexity of the regional tectonics and their long reactivation history, which is testified by the geometry of the structural elements. Only AOUDIA *et alii* (2000) related the ground cracks to a blind thrust buried under the Ragogna structure. It is proposed that this thrust is 19 km long, from Susàns to Mt. Bernadia (SE of Gemona) and it is considered the causative fault of the 1976 main shock. From geodetic data (TALAMO *et alii*, 1978), the maximum deformation caused by the earthquake was located around Venzone. The inversion of those data (ARCA *et alii*, 1985; BRIOLE *et alii*, 1986) suggested a fault-plane in agreement with that obtained from the seismological data with ruptures east and west of the Tagliamento River, the latter presenting also a strike-slip component. AMATO & MALAGNINI (1990) used tomographic inversion to identify a high-density south-verging body with a depth of 5 to 10 km, which was interpreted as being a wedge of the Paleocarnic Infrastructure (this feature was already suggested by CASTELLARIN *et alii*, 1979). This overthrust the crystalline basement and could have been the major cause of the seismicity in Friuli and, consequently, also of the 1976 earthquake.

A recent reconstruction, obtained by fault-plane solution inversion (SLEJKO *et alii*, 1999), of the stress field responsible for the sequence which started on May 6, 1976 shows that the stress field was not constant in time. After an initial phase, which lasted till mid-September, during which the stress field was homogeneous and coherent with the regional tectonics, a heterogeneous situation was reached. This heterogeneity started in July and increased after the middle of September and was probably caused by the superimposition of local responses to the regional field. The main quakes of September 1976 and September 1977 seem, anyway, again produced by the regional field.

As said before, the seismometric network of Friuli - Venezia Giulia has been operating since May 6, 1977. The number of stations has increased over the years from the initial 3 to the present-day 15. Considering also the data of the stations in the neighboring countries, most of the events with M_L larger than 1.0 have been located: 13,895 earthquakes were located between May 6, 1977 and December 31, 2001.

Using this huge data set, good information about the regional seismicity can be obtained. Figure 3 shows the epicenters of the events with magnitude larger than 3.5 which occurred from the installation of the seismometric network till December 2001. As can be seen, the seimicity is always located mainly along the Friuli foothills: the high density in its central sector is partly due to the coda of the May 6, 1976 sequence. Lower seismicity can be seen in the northernmost Alpine sector and in the Friuli plain. The NW-SE alignment in Slovenia refers to the 1998 Bovec sequence which started with the 5.6 M_L main shock of April 12, 1998 (an M_L=5.1 earthquake occurred in the same area on July 12, 2004). The general agreement between the space distribution of the historical seismicity in FIG. 2 and the present-day one in FIG. 3 is worth noting: almost all the zones which were active in the past are active nowadays with the major events occurring in the Gemona, Trasaghis, and Tolmezzo areas.

Seismotectonic Interpretation of the 1976 Earthquake and of the Present-day Regional Seismicity

The latest interpretation of the seismic sequence, which started on May 6, 1976, was recently proposed by POLI *et alii* (2002). On the basis of new geological data, they constructed a 2D structural model for the South-Alpine chain. According to the classical tectonic setting suggested for the eastern South-Alpine chain, the cross-section shows a south-verging thrust-belt arranged in an embricate fan geometry. At the Gemona latitude, at a depth of 5-8 km, a north-verging steep back-thrusting system becomes active: there seems to be a concentration of cracks in the carbonatic rocks. On the contrary, the 1977-1999 seismicity appears distributed in a larger crustal volume, with an evident westward shift of the maximum seismic activity. The stress redistribution caused by the 1976 sequence possibly produced a transfer of the deformation to the western sector. The main event of May 6, 1976 is associated with the Susans - Tricesimo fault, a new interpretation of the deep sector of the Buja-Tricesimo line of FINETTI *et alii* (1976) (a in FIG. 1) while the strong aftershock of September 15, 1976 is related to the buried Trasaghis fault (GALADINI *et alii*, 2002), lateral ramp of the Pozzuolo line. This regional overthrust (POLI *et alii*) crops out a few kilometers south of Udine.

The distribution of the present-day seismicity (FIGS 3 and 4) shows the clear alignment of epicenters along the pre-Alpine and Dinaric belts as far as the Croatian coast. The bulk of this active belt is located in Friuli. The seismicity in Slovenia is more diffuse and quite uniformly distributed from the surface to a 20 km depth, while in Friuli the foci mainly affect the surficial 12 km of depth, with the maximum concentration between 8 and 10 km. The space distribution of the recent seismicity suggests a link between the earthquakes and the Alpine overthrusts, which have sometimes reactivated older Dinaric structures (POLI *et alii*, 2002). The main seismic release occurs at the point of contact between the crystalline basement and the sedimentary cover (SIRO & SLEJKO, 1982), which must have been detached from the basement itself (BRESSAN *et alii*, 1992). CARULLI & PONTON (1993), in their structural interpretation of the crust in the central Friuli - Carnia sector, suggested that the south-verging overthrusts formed a progressive sequence towards the foreland. They linked, moreover, the earthquakes to the area of maximum crustal interference with the Dinaric structural system, not only inside the sedimentary cover, but also at the top of the Hercynic formations and of the magnetic basement (CATI *et alii*, 1989); the seismicity decreases abruptly below this zone. In the border area with Slovenia, the earthquakes testify the strike-slip activity of the Dinaric faults (see e. g.: the 1998 Bovec sequence; BERNARDIS *et alii*, 1998). The regional stress tensor, computed by inversion of the earthquake fault-plane solutions (BRESSAN *et alii*, 1998) indicates that seismicity refers both to the Alpine and Dinaric systems but a precise link between earthquake and fault was proposed only for the 1976 event (AMATO *et alii*, 1976; FINETTI *et alii*, 1979; AOUDIA *et alii*, 2000; GALADINI *et alii*, 2002) and for the two strong historical quakes of 1348 (GALADINI *et alii*, 2002) and 1511 (FITZKO *et alii*, 2001; GALADINI *et alii*, 2002). The high density of faults, with poorly known deep geometry, which belong to the two different tectonic systems and interfere with them does not help the detailed kinematic interpretation of the regional seismogenesis.

The global seismotectonic context (SLEJKO *et alii*, 1989; CARULLI *et alii*, 1990; DEL BEN *et alii*, 1991) points to the main seismic areas as being located between the presently active Alpine and Dinaric fronts and some vertical faults, which are supposed to act as disengaging elements (Fella - Sava and Idrija lines). These faults, which are seismically active and show recent vertical tectonic activity, seem to disengage the Adriatic microplate from the stable European plate kinematically.

On the basis of this general framework, the seismotectonic model of the eastern Alps (SLEJKO *et alii*, 1989) has recently been improved (REBEZ *et alii*, 2001) for seismic hazard purposes. The MELETTI et alii (2000)

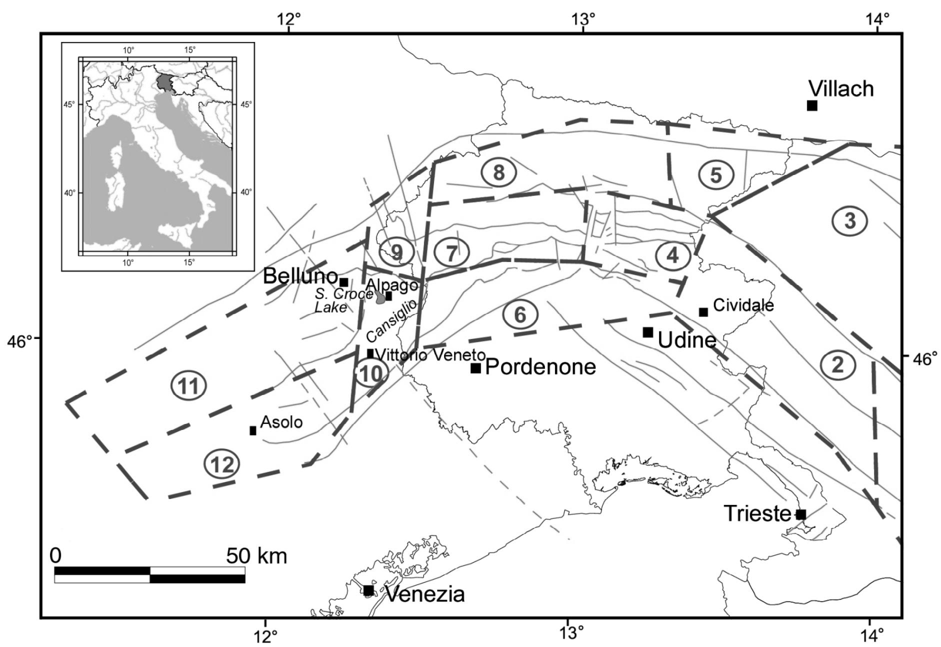

Fig. 5 - Seismogenic zones in the eastern Alps (modified from CARULLI *et alii*, 2002)

seismogenic zones, which were used for the seismic hazard assessment of Italy, were considered a starting point for the revision of the regional seismogenic zonation. This model defined only two seismogenic zones in Friuli. The detailed analysis of the regional seismicity, in terms of space distribution and focal mechanisms, within its geological context led to the identification of six seismogenic zones with different seismotectonic characteristics (FIG. 5).

This seismogenic zonation was recently used for the soil-dependent seismic hazard map of the Friuli - Venezia Giulia region (REBEZ *et alii*, 2001), where the horizontal peak ground acceleration with a 475-year return period was mapped, taking into account the specific soil typologies in the study area. This seismic hazard map contributed to the seismic risk assessment for the Friuli - Venezia Giulia region (CARULLI *et alii*, 2003), providing information of paramount importance for urban planning and building retrofitting.

Conclusions

Contrary to other earthquakes, the 1976 Friuli event is still being studied, regardless of the fact that 25 years have passed since its occurrence. This is because it is a complex phenomenon (the aftershocks lasted about 20 months, migrating northwestwards from the border with Slovenia to central Friuli) and a huge amount of seismological data was acquired, especially by temporary stations. This earthquake is surely a key element in understanding the seismogenesis of this region. Together with the data from recent seismicity, it is well documented because of the presence of the regional seismometric network, and thus it gives clear indications about the activity of the Alpine and Dinaric tectonic structures. This activity remains located inside the sedimentary cover with its maximum at the top of the crystalline basement.

Ten centuries of historical seismicity give quite a good vision of the active sources and this picture is coherent with that given by recent seismicity. The main seismic sources are: Belluno, Claut, Gemona-Trasaghis-Tolmezzo, Kobarid, and, to a lesser extent, Cividale. The seismotectonic characteristics of the region between Tarvisio and Villach are less evident, the occurrence there of some strong earthquakes of the past (1348 and 1690) is not supported by the very low recent seismicity. Furthermore, that region is far away from the external deformation front of the Alpine chain and does not show remarkable evidence of recent tectonic activity. The low magnitude earthquakes which occur in the vicinity of the Adriatic coast (Latisana and San Stino) are less important for the regional seismogenesis but are interesting because it is difficult to insert them into the regional geodynamical framework. To give a kinematic explanation of the mutual activation of neighboring sources is difficult as well.

The general structural-geological framework is also rather well known: the tectonic structures belong to a south-verging thrust belt arranged in a strictly embricate fan geometry. The seismicity is definitely connected with the Alpine faults or with faults with Dinaric orientation, which were re-activated during the neo-Alpine tectonic phase. This statement is supported by the fault-plane solutions available for Friuli. But it is not yet clear how the Alpine and Dinaric structures interfere or, better, how the presence in the Friuli region of the Dinaric structures, which are often reactivated by the present Alpine stress tensor, influences the present structural evolution. Furthermore, the relevance of the reactivation in a strike-slip fashion of the Mesozoic extensional paleostructures in the Tagliamento River gorge remains unclear.

Two different interpretations were proposed recently for the rupture model and the fault responsible for the 1976 seismic sequence. AOUDIA *et alii* (2000) suggested that the main active deformation was a fault-propagation fold associated with a blind thrust ramp. This model produces waveforms in agreement with the accelerograms recorded in the area. POLI *et alii* (2002) and GALADINI *et alii* (2002), updating the previous mainly cylindrical interpretations, presented a new picture of the Plio-Quaternary deformation front in Friuli: the Authors drew the deformation front segmented by a system of curved thrusts laterally piled by means of oblique ramps. The 1976 mainshocks and some large earthquakes which occurred during the past in Friuli (1348, 1511) are associated with some of these thrusts.

The very long duration of the seismic sequence which started on May 6, 1976 indicates that the energy was released progressively in time. A sudden energy release could have produced more severe effects and indicated the possibility of a larger maximum magnitude for the region. Evidence of this larger event is not documented in the earthquake catalogue, but doubts remain about the 1511 quake whose widely damaged area makes it difficult to identify its epicenter.

In conclusion, although the seismicity in Friuli is rather well documented in the literature, a huge amount of seismological data was collected for the 1976 earthquake sequence, good quality seismological data have been collected since 1977, geological surveys and studies were and are performed, nevertheless the regional seismogenesis still presents some cloudy aspects regarding the location and size of the maximum possible earthquake and its seismotectonic interpretation. Using the available seismotectonic knowledge, some specific studies were recently performed and some paramount results were obtained: the regional seismic hazard (REBEZ *et alii*, 2001) and seismic risk (CARULLI *et alii*, 2003) maps. Not only do these products have a scientific value but also a social relevance because they can be the bases for urban planning and building retrofitting.

Acknowledgements

The seismometric network of Friuli - Venezia Giulia is managed by OGS with financial support from the Regione

Autonoma Friuli - Venezia Giulia. The Civil Protection Direction of the same regional government financed the seismic risk map, which was produced by Trieste and Udine Universities and OGS.

References

AMATO A., BARNABA P.F., FINETTI I., GROPPI G., MARTINIS B. & MUZZIN A.(1976) - *Geodynamic outline and seismicity of Friuli Venetia Julia region.* Boll. Geof. Teor. Appl., **18**, 217-256.

AMATO A. & MALAGNINI L. (1990) - *A blind thrust beneath the Friuli region? Evidence from local earthquake tomography.* In: ROCA A. & MAYER-ROSA D. (eds), Proceedings ESC 22nd General Assembly, 121-126.

AMBRASEYS N.N.(1976) - *The Gemona di Friuli earthquake of 6 May 1976*. In: PICHARD P., AMBRASEYS N.N. & ZIOGAS G.N., Unesco Restricred Technical Report RP/1975-76 2.222.3., Paris, part 2.

ANDREOTTI G. (1937) - *Il terremoto del 18 ottobre 1936*. Mem. Regio Ist. Veneto Sc. Lett. Arti, **30** (3), 3-24.

AOUDIA A., SARAÒ A., BUKCHIN B. & SUHADOLC P. (2000) - *The 1976 Friuli (NE Italy) thrust faulting earthquake: a reappraisal 23 years later.* Geoph. Res. Lett., **27**, 573-576.

ARCA S., BONASIA V., DE NATALE G., PINGUE F. & SCARPA R. (1985) - *A multiple fault system as the fracture mechanism for the 1976-1977 Friuli earthquakes, from inversion of geodetic data.* Boll. Geod. Scienze Aff., **44**, 101-124.

BARATTA M. (1901) - *I terremoti d'Italia*. Fratelli Bocca, Torino, 951 pp.

BERNARDIS G., POLI M.E., SNIDARCIG A. & ZANFERRARI A. (1998) - *Il terremoto di Bovec (Slovenia NW) del 12 aprile 1998*. In: 17° Conv. Naz. GNGTS, Riassunti Estesi delle Comunicazioni, ESA, Roma, 137-138.

BONITO M. (1691) - *Terra tremante*. Parrino - Muti, 822 pp., Napoli

BORST A. (1988) - *Il terremoto del 1348.* Laveglia, 64 pp., Salerno

BOSCHI E., FERRARI G., GASPERINI P., GUIDOBONI E., SMRIGLIO G. & VALENSISE G. (1995) - *Catalogo dei forti terremoti italiani dal 461 a. C. al 1980*. Istituto Nazionale di Geofisica, SGA storia geofisica ambiente, 973 pp., Roma

BOSI C., CAMPONESCHI B., & GIGLIO G. (1976) - *Indizi di possibili movimenti lungo faglie in occasione del terremoto del Friuli del 6 maggio 1976.* Boll. Soc. Geol. It., **95**, 803-830.

BRESSAN G., DE FRANCO R. & GENTILE F. (1992) - *Seismotectonic study of the Friuli (Italy) area based on tomographic inversion and geophysical data.* Tectonophysics, **207**, 383-400.

BRESSAN G., SNIDARCIG A. & VENTURINI C. (1998) - *Present state of tectonic stress of the Friuli area (eastern Southern Alps).* Tectonophysics, **292**, 211-227.

BRIOLE P., DE NATALE G., GAULON R., PINGUE F., & SCARPA R. (1986) - *Inversion of geodetic data & seismicity associated with the Friuli earthquake sequence (1976-1977).* Ann. Geofis., **4** , B4, 481-492.

CAPUTO M. (1976) - *The area of the fault, the dislocation, the stress-drop & the seismic moment of the Friuli earthquake of May 6th 1976*. Boll. Geof. Teor. Appl., **18**, 405-409.

CARULLI G.B., CAROBENE L., CAVALLIN A., MARTINIS B. & ONOFRI R. (1980) - *Evoluzione strutturale Plio-quaternaria del Friuli e della Venezia Giulia.* Contrib. prelim. alla realizzazione della Carta Neotettonica d'Italia, Pubbl. n.265, P.F. Geodinamica, 487-532, Napoli.

CARULLI G.B., NICOLICH R., REBEZ A. & SLEJKO,D. (1990) - *Seismotectonics of the Northwest External Dinarides.* Tectonophysics, **179**, 11-25.

CARULLI G.B. & PONTON M. (1993) - *Interpretazione strutturale profonda del settore centrale carnico - friulano*. Studi Geol. Camerti, vol. spec. 1992/2 CROP 1 - 1A, 275-284.

CARULLI G.B., RIUSCETTI M. & SLEJKO D. (2003)

CARULLI G.B., CUCCHI F., REBEZ A., PERUZZA L, SLEJKO D. & CODEMATZ R. (2002) – *Seismic hazard in the Friuli-Venezia Giulia region (NE Italy) considering different soil typologies.* Mem. Soc. Geol. It., **57**, 401-408.

CASTELLARIN A. (1979) - *Il problema dei raccorciamenti crostali del Sudalpino.* Rend. Soc. Geol. It, **1**, 21-33,

CASTELLARIN A., FRASCARI F. & VAI G.B. (1979) - *Problemi di interpretazione geologica profonda del Sudalpino orientale.* Rend. Soc. Geol. It., **2**, 55-60.

CASTELLARIN A. & VAI G.B. (1981) - *Importance of the Hercynian tectonics within the frame of the Southern Alps.* Journ. Struct. Geol., **3** (4), 477-486.

CATI A., FICHERA R. & CAPPELLI V. (1989) – *Northeastern Italy, integrated processing of geophysical and geological data.* Mem. Soc. Geol. It., **40** (1987), 273-288.

CAVALLIN A., BROILI L., CARULLI G.B., MARTINIS B., MELE M., SIRO L. & SLEJKO D. (1990) - *Case history: Friuli earthquake, 1976.* In: COTECCHIA V. (ed), Proceedings of the international symposium on Engineering Geology Problems in Seismic Areas, Bari 13-19 April 1986, Geologia Applicata ed Idrogeologia, Bari, **6**, 1-82.

CAVASINO A. (1929) - *Il terremoto nelle Prealpi Carniche orientali del 27 marzo 1928*. Boll. Soc. Sism. It., **28**, 77-100.

DEL BEN A., FINETTI I., REBEZ A., & SLEJKO D. (1991) - *Seismicity and seismotectonics at the Alps - Dinarides contact.* Boll. Geof. Teor. Appl., **33**, 155-176.

EISINGER U. & GUTDEUTSCH R.. (1994) - *The Villach earthquake of December 4th, 1690 in the German sources.* In: ALBINI P. & MORONI A. (eds), Historical investigation of European earthquakes 2, C.N.R. Ist. Ric. Rischio Sism., Milano, 133-137.

FINETTI I., GIORGETTI F., HAESSLER H., HOANG T.P., SLEJKO D. & WITTLINGER G. (1976) - *Time space epicenter and hypocenter distribution and focal mechanism of 1976 Friuli earthquakes.* Boll. Geof. Teor. Appl., **18**, 637-655.

FINETTI I., RUSSI M. & SLEJKO D. (1979) - *The Friuli earthquake (1976-1977).* Tectonophysics, **53**, 261-272.

FITZKO F., SUHADOLC P., AUDIA A. & PANZA G.F. (2001) - *Constrains on the location and mechanism of the 1511 western Slovenia earthquake from active-tectono studies and modelling of macroseismic data.* In: SLEJKO D. (a cura di), 20° Convegno Nazionale G.N.G.T.S. Riassunti estesi delle comunicazioni, Tipografia Mosetti, Trieste, pp. 233.

GALADINI F., POLI M.E. & ZANFERRARI A. (2002) - *Sorgenti sismogenetiche responsabili di terremoti distruttivi nell'Italia nord-orientale.* In: SLEJKO D. & REBEZ A. (a cura di), G.N.G.T.S. 21° Convegno Nazionale - Riassunti estesi delle comunicazioni, Tip. Mosetti, 27-30, Trieste.

GIORGETTI F. (1976) - *Isoseismal map of the May 6, 1976 Friuli earthquake*. Boll. Geof. Teor. Appl., **18**, 707-714.

GORTANI N. (1928) - *Il terremoto del 27 marzo 1928 nelle Prealpi dell'Arzino (Friuli)*. Note geologiche. L'Universo, **9**, 1155-1210.

GRUPPO DI LAVORO CPTI (BOSCHI E., GASPERINI P., VALENSISE G., CAMASSI R., CASTELLI V., STUCCHI M., REBEZ A., MONACHESI G., BARBANO M.S., ALBINI P., GUIDOBONI E., FERRARI G., MARIOTTI D., COMASTRI A. & MOLIN D.) (1999) - *Catalogo Parametrico dei Terremoti Italiani*. ING, GNDT, SGA, 92 pp., Bologna.

HAMMERL C. (1994) - *The earthquake of January 25th, 1348: discussion of sources*. In: ALBINI P. & MORONI A. (eds), Historical investigation of European earthquakes 2, C.N.R. Ist. Ric. Rischio Sism., Milano, 225-240.

KARNIK V., PROCHAZKOVA, SCHENKOVA Z., RUPRECHTOVA L., DUDEK A., DRIMMEL J., SCHMEDES E., LEYDECKER G., ROTHE' J.P., GUTERCH B., LEWANDOWSKA H., MAYER-ROSA D., CVIJANOVIC D., KUK V., GIORGETTI F., GRUNTHAL G. & HURTIG E. (1978) - *Map of isoseismals of the main Friuli earthquake of 6 May 1976.* Pageoph, **116**, 1307-1313.

LYON-CAEN H. (1980) - *Séismes du Frioul (1976): modèles de source à l'aide de sismogrammes synthetiques d'ondes de volume.* Thèse dipl. doct. 3e cycle, Univ. Paris, 113 pp.

MARTINIS B. & CAVALLIN A. (1978) - *Ground cracks caused by the Friuli earthquake, 1976 from M. Cuarnan and Tremugna valley.* In: Proceedings Spec. Meet. on the 1976 Friuli earthquake & the antiseismic design of nuclear installation, CNEN, Roma, pp. 87-102.

MELETTI C., PATACCA E. & SCANDONE P. (2000) - *Construction of a seismotectonic model : the case of Italy.* Pure Appl. Geophys., **157**, 11-35.

OGS (1977-1981) - *Bollettino della Rete Sismologica del Friuli-Venezia Giulia.* OGS, Trieste.

OGS (1982-1990) - *Bollettino della Rete Sismometrica dell'Italia Nord Orientale*. OGS, Trieste.

OGS (1991-2001) - *Bollettino della Rete Sismometrica del Friuli - Venezia Giulia*. OGS, Trieste.

PANIZZA M. (1977) - *Geologia dei depositi superficiali: settore intravallivo.* In: Martinis B. (ed.), Studio geologico dell'area maggiormente colpita dal terremoto friulano del 1976. C. N. R. P. F. Geodinamica, Milano, 269-273.

POLI M.E., PERUZZA L., REBEZ A., RENNER G., SLEJKO D. & ZANFERRARI A. (2002) - *New seismotectonic evidence from the analysis of the 1976-1977 and 1977-1999 seismicity in Friuli (NE Italy).* Boll. Geof. Teor. Appl., **43**, 53-78.

REBEZ A., CARULLI G.B., CODERMATZ R., CUCCHI F., PERUZZA L. & SLEJKO D. (2001) - *Soil type dependent spectral seismic hazard in Friuli - Venezia Giulia (NE Italy).* Boll. Geof. Teor. Appl., **42**, 121-138.

RIBARIC V. (1979) - *Idrija earthquake of March 26, 1511: a reconstruction of some seismological parameters.* Tectonophysics, **53**, 315-324.

SIRO L. & SLEJKO D. (1982) - *Space-time evolution of the 1977-1980 seismicity in the Friuli area & its seismotectonic implications.* Boll. Geof. Teor. Appl., **24**, 67-77.

SLEJKO D. (2000) - *Sosta 1.1.1 - Il terremoto del Friuli del 6 maggio 1976 nel contesto della sismicità regionale.* In: CARULLI G.B. (ed.), 80° Riunione Estiva Soc. Geol. It. Guida alle Escursioni, Ediz. Università di Trieste, 293-300.

SLEJKO D., CARULLI G.B., NICOLICH R., REBEZ A., ZANFERRARI A., CAVALLIN A., DOGLIONI C., CARRARO F., CASTALDINI D., ILICETO V., SEMENZA E. & ZANOLLA C. (1989) - *Seismotectonics of the eastern Southern-Alps: a review*. Boll. Geof. Teor. Appl., **31**, 109-136.

SLEJKO D., NERI G., OROZOVA I., RENNER G & WYSS M. (1999) - *Stress field in Friuli (NE Italy) from fault plane solutions of activity following the 1976 main shock*. Bull. Seism. Soc. Am., **89**, 1037-1052.

SUHADOLC P. (1981) - *Spatial distribution of the aftershock sequence relative to the September 16, 1977 Friuli earthquake.* Boll. Geof. Teor. Appl., **23**, 331-348.

TALAMO R., PAMPALONI M. & GRASSI S. (1978) - *Risultati delle misure di livellazione di alta precisione eseguite dall'Istituto Geografico Militare nelle zone del Friuli interessate dalle recenti attività sismiche*. Boll. Geod. Sc. Aff., **1**, 6-75.

ZANFERRARI A., BOLLETTINARI G., CAROBENE L., CARTON A., CARULLI G.B., CASTALDINI D., CAVALLIN A., PANIZZA M., PELLEGRINI G.B., PIANETTI F. & SAURO U. (1982) - *Evoluzione neotettonica dell'Italia Nord Orientale*. Mem. Sc. geol., **35**, 355-376, Padova.

ZANFERRARI A., ROGLEDI S. & POLI M.E. (2000) - *Il fronte della Catena Sudalpina orientale nelle Prealpi Carniche centro-orientali (Friuli): caratteri strutturali ed evoluzione pliocenico-quaternaria.* In: 80° Riunione Estiva S.G.I., Trieste 6-8 settembre 2000, Riassunti delle comunicazioni orali e dei poster. (CARULLI G.B. & LONGO SALVADOR G. Edts.), 467-468.