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SEISMICITY AND SEISMOTECTONICS AT THE ALPS-DINARIDES CONTACT

Abstract. All seismic event data collected in the Friuli and Slovenia regions have been carefully analysed and their correct 3-D space distribution correlated on the up-to-date structural and tectonic setting reconstructed from geological and geophysical exploration data. On the basis of the large amount of information obtained, it is possible to propose a kinematic and seismotectonic model which satisfactorily fits the whole distribution of seismic events and their distinct characteristics. The regional geodynamic activity is determined by a clear NNW motion of the Adria plate with overthrusting effects along the Southern Alps (Pordenone, Periadriatic and successive thrusts). New very active and important seismotectonic elements are now clearly identified and defined: the Rijeka and Idrija transpressive strike-slip faults. These faults disconnect the Adria plate, allowing its relative northward motion. Other active transpressive thrust-faults with transcurrent components are identified and examined (i.e. Gorizia, Rasa and Postojna faults). Trieste and Udine transpressive reverse faults were active in Paleocene times and reactivated during the Pliocene to late Quaternary, but are historically slightly to non-significantly active.

INTRODUCTION

For the Italian peninsula, there are organic seismotectonic studies that cover the entire territory (Gruppo Redazionale della Carta Sismotettonica del P.F. Geodinamica, 1982). Successively more detailed proposals of tectonic schemes have been formulated for the northeastern Italian regions (Slejko et al., 1987, 1989), with the partition of the territory between lake Garda and Slovenia into several different seismotectonic zones. In these tectonic schemes the Alpine system is generally examined, mentioning only in a marginal manner the seismotectonic problems connected with the Alps-Dinarides interaction. A preliminary investigation on the Dinaric territory was recently done from mainly the structural and geological points of view (Carulli et al., 1990).

The purpose of this study is to investigate from the seismotectonic point of view a specific area which covers the orogenic deformation at the contact between Alps and Dinarides and their underthrusting foreland (Adria Plate). This area includes the territories of northeastern Italy, Slovenia, northern Croatia and part of southern Austria (Fig. 1).

In literature there are several papers which examine separately data collected in one, or even two countries, but no studies of the whole area in question, with the seismological and tectonic data uniformly collected and analysed for the four countries. In this study all the significant seismic events recorded in history or instrumentally in the different territories were carefully re-analysed and investigated. Moreover, all structural and tectonic data available from the literature (or even non-published data) were assembled into an organic picture in order

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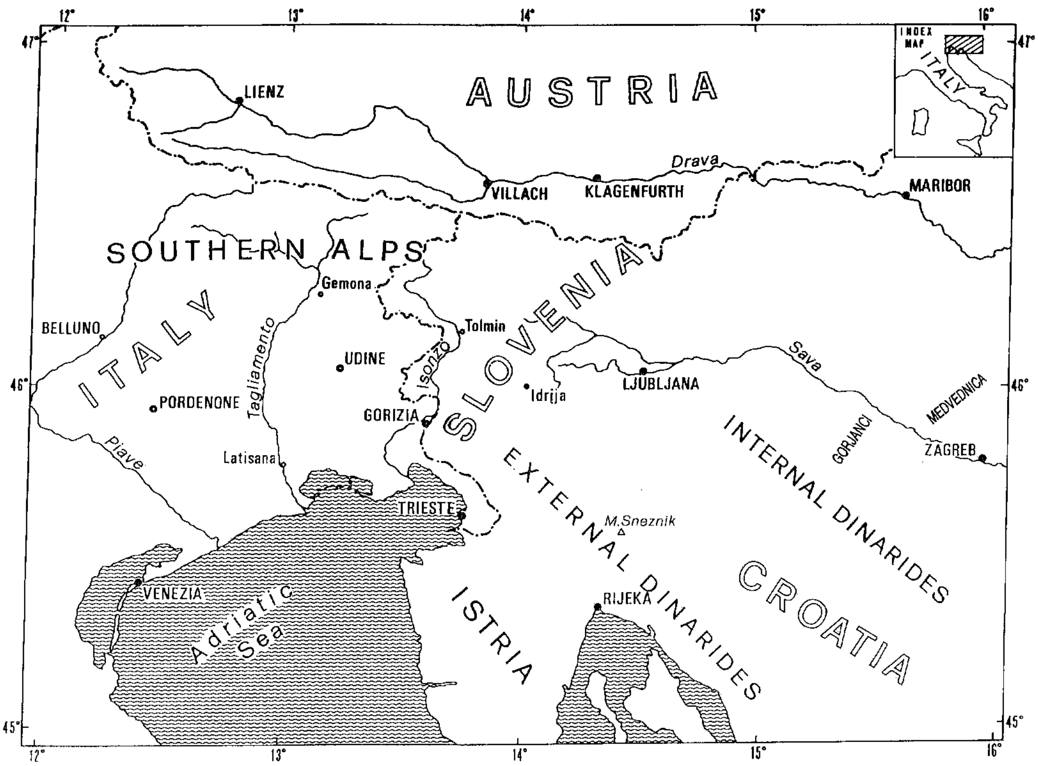


Fig. 1 - Index map of the study area.

to understand the seismotectonics of this Alpine-Dinarides region. An important contribution to the construction of the proposed seismotectonic model was furnished also by exploration geophysics (mainly by the seismic reflection data) of the northeastern Adria plate and surrounding deformed zones of the eastern Southern Alps and northwestern Dinarides.

HISTORICAL SEISMICITY

The area under study covers territories that presently belong to Italy, Slovenia, Croatia and Austria. The need for a new earthquake catalogue (OGS, 1987) thus arose and it has been prepared using the data contained in the existing catalogues for the eastern Alps (OGS, 1985), Slovenia (Ribarič, 1982) and Croatia (GIZ, 1986). The data were cross checked and homogenized (Rebez, 1987). The catalogue obtained contains the data for 7310 events which occurred in the area between 10° and 16° east longitude and between 45° and 47°30' north latitude in the period 238-1984. The epicentres of the quakes within the limits of the studied area (12°-16°E and 45°- 47°N) are reported in Fig. 2.

All intensities cited in the present study are in Mercalli-Cancani-Sieberg (MCS) scale. The largest event of this region occurred on January 25, 1348 and destroyed the town of Villach causing strong damage in a very wide area but especially along the Gail valley. Other strong quakes repeatedly damaged northern Friuli. The seismicity in the western sector is concentrated in the pre-Alpine strip, its maximum density being in the area of Gemona, to the north of Udine. Another centre of seismicity is located around the town of Belluno, where especially quakes of medium to large intensity have occurred. The seismicity appears to be more diffuse and of lower magnitude in Slovenia (especially along the Sava valley), nevertheless some alignments can be identified: the most evident is the one going from Idrija towards Rijeka. Some relevant earthquakes occurred along the Yugoslav coast, where the low level seismicity does

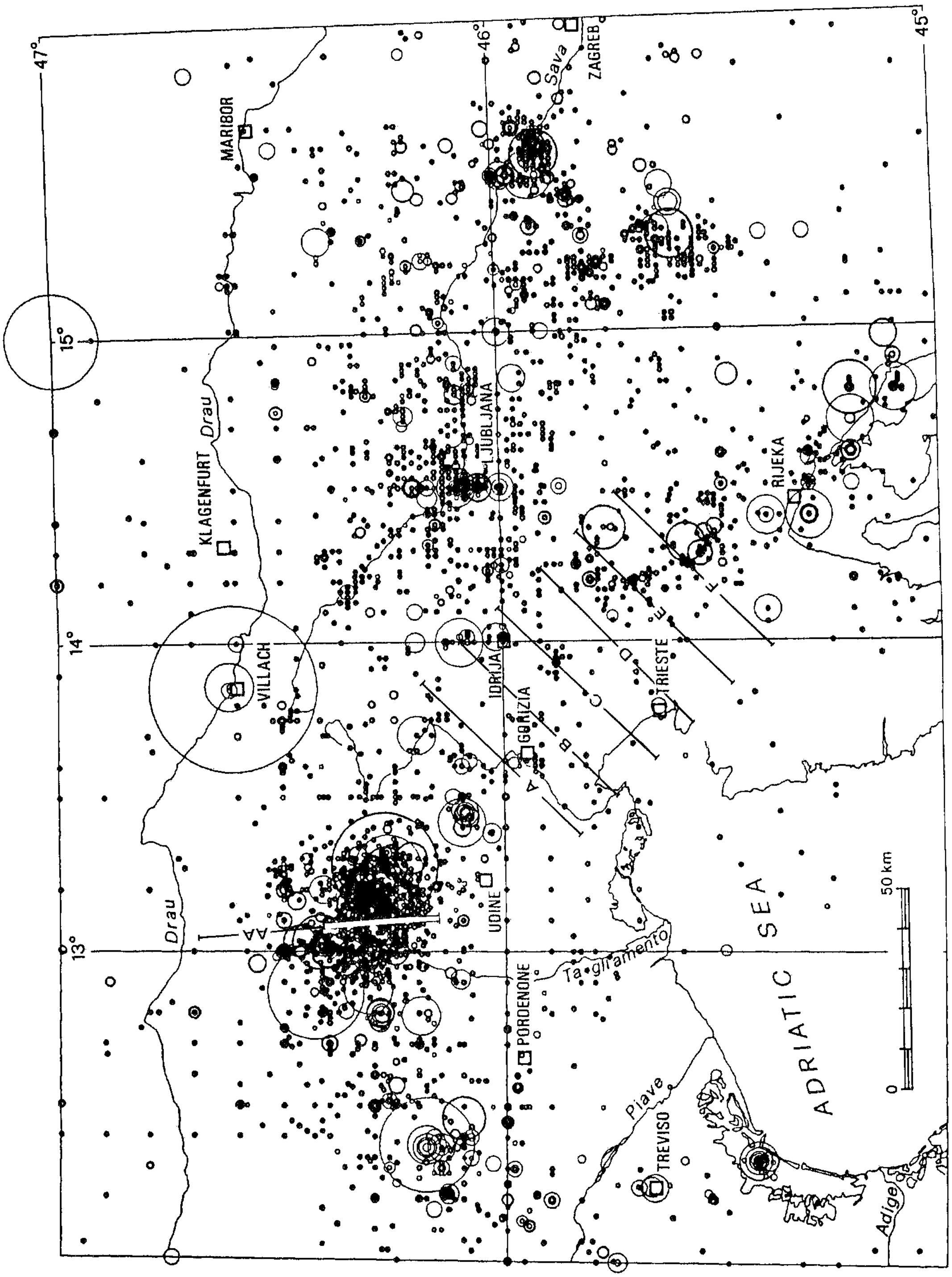


Fig. 2 - Map of the epicentres in focal volume (Båth and Duda, 1964) of the earthquakes for the period 238-1984 in the eastern Alps - northern Dinarides region with location of the seismotectonic cross-sections: AA crosses the Southern Alps and A, B, C, D, E, and F, the northern External Dinarides.

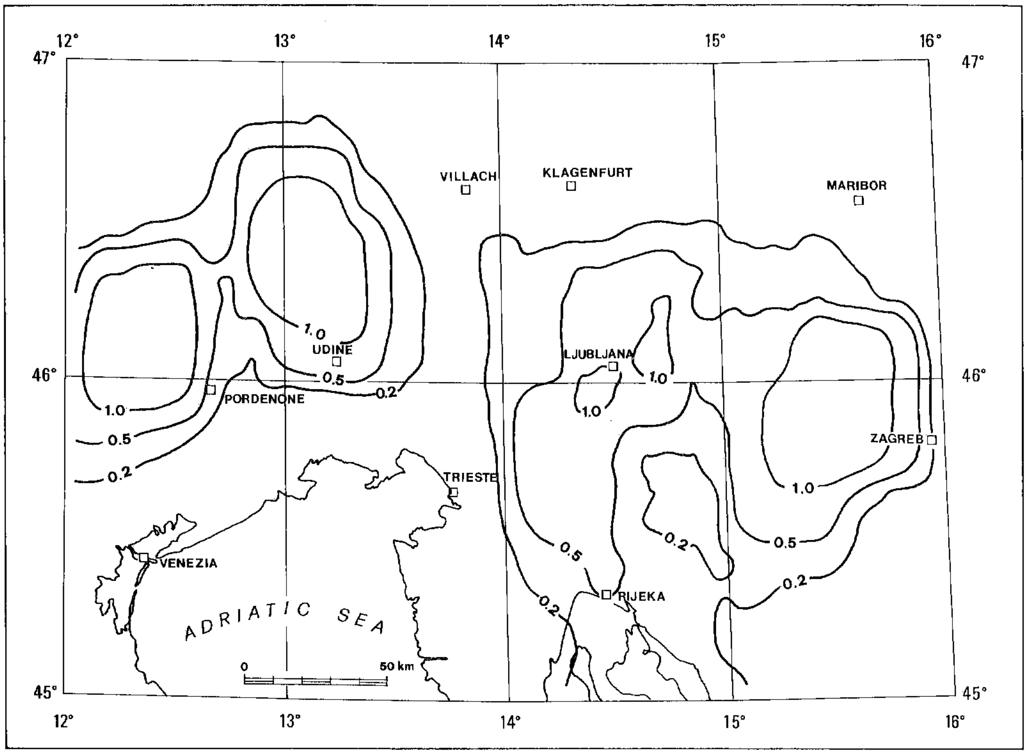


Fig. 3 - Map of the seismic activity according to Riznichenko (1959) of the eastern Alps - northern Dinarides region for magnitude 3.3 earthquakes, computed using the events of the period 1800 - 1984.

not seem to have been relevant in the past. It is noteworthy that the Alpine sector, the Veneto-Friuli plain and the Istria peninsula are pratically aseismic areas. A zone of lower activity than that of the neighbouring areas is situated around the 14°E meridian, if we ignore the three poorly located shocks of 1348 (Villach), 1511 (Idrija), and 1690 (Villach), and seems to separate two regions of seismicity.

To identify the low level (magnitude 3.3) seismicity, a map of the seismic activity according to Riznichenko (1959) was prepared (Fig. 3), the earthquakes of the period 1800-1984 being used to construct it. The seismic activity is computed statistically by extrapolating the medium-high level of seismicity down to the low values. It represents the expected number of 3.3 magnitude earthquakes per unit area (1000 km^2) and unit time interval (one year). The maximum values (1.0) are obtained in the Belluno-Cansiglio, Friuli and Zagreb areas. Two additional small maxima appear around Ljubljana. From Fig. 3, it can be seen that the seismicity is more concentrated in Italy than in Yugoslavia (compare the two areas of 0.2 activity in Fig. 3). A clear separation between the two zones can be noted approximately along the 14°E meridian, and confirms the conclusions based on the seismicity map (Fig. 2).

The focal mechanisms of the main earthquakes are key information for a better understanding the seismic behaviour in this complex region. In Fig. 4, selected solutions taken from the literature (Kunze, 1982; Skoko et al., 1982; Ribarič, 1986; Slejko et al., 1989) are reported together with seven new solutions (see the Table; the epicentres are marked by asterisks in the same Fig. 4) calculated for the Kozjansko sequence in 1974 and for some recent quakes in the External Dinarides. It can be seen that the general pattern is transcurrent in Veneto, of reverse dip-slip in Friuli and of all the types in the Dinaric province: some vertical movements are reported along the Sava line north of Ljubljana and normal dip-slip as well as strike slip motions in the Kozjansko area. Focal solutions for low magnitude present-day quakes in the External Dinarides show a general strike-slip pattern and a vertical movement north of Ri-

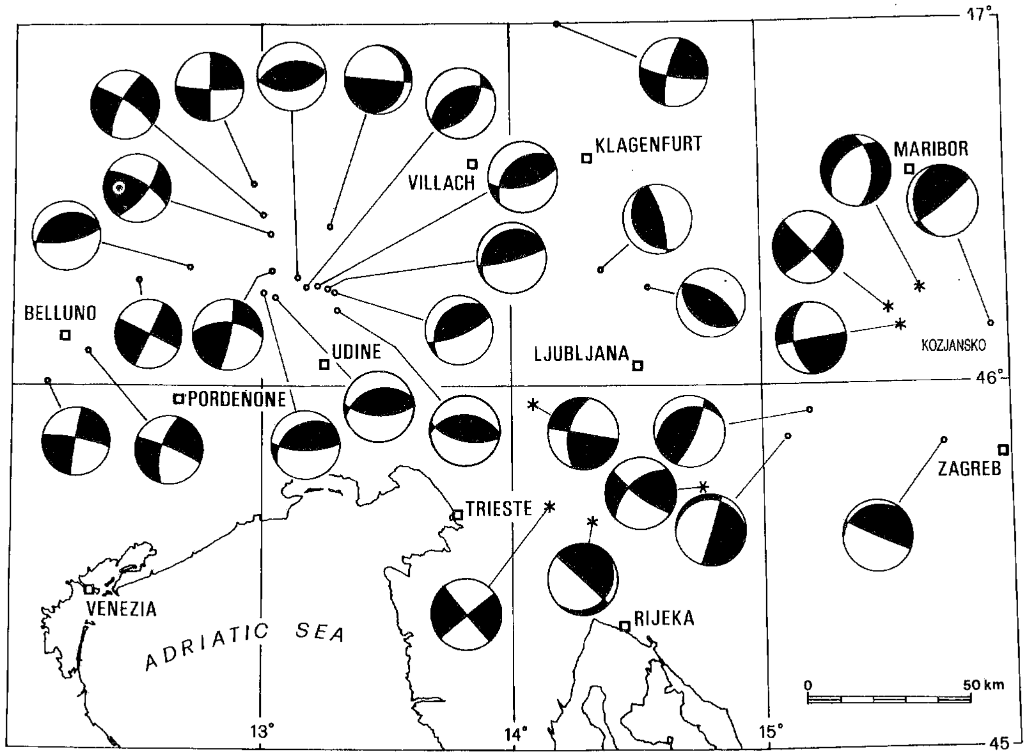


Fig. 4 - Map of the focal mechanisms of selected earthquakes in the study region. The asterisk indicates solutions calculated in the present study (see the Table).

jeka. One nodal plane maintains the Dinaric orientation and the compressional axis varies from N-S to NE-SW, in accordance with the stress pattern evidenced by the tectonic structures.

EASTERN ALPS AND NORTHERN DINARIDES SEISMIC SYSTEMS

As suggested by the regional tectonics and by the historical seismicity, the studied area can be initially divided into two different seismic macrozones, the Alps and Dinarides, by the 14°E meridian.

For the two regions, a statistical analysis of the seismicity was performed to check whether the difference in the seismic behaviour is significant (Figs. from 5 to 8).

Fig. 5 shows the intensities contained in the earthquake catalogue for the Alpine (Fig. 5a) and for the Dinaric (Fig. 5b) systems since 1200. This starting year was chosen as very few events are reported during the previous centuries. The time sampling chosen is ten years, and a very different quality of catalogue information in the two regions can be seen. In fact, while for the Alpine territory earthquakes with intensity V MCS or larger are reported since the beginning of the 16th century, the same quality of data is only reached more than one century later in the Dinaric area. It is also worth noting the lack of seismic information during the 17th century for the Alps, and during the 18th century for the Dinaric region. Both the regions show earthquakes of intensity III MCS or larger since the end of the 19th century. The presence of high intensities (IX MCS or larger) in the Dinaric region only before the 18th century creates the suspicion that those events were overestimated.

In Fig. 6a, the cumulative number of events is shown for the Alpine and the Dinaric regions. The period 1500-1984 has been used in the processing, because the information is very poor before the 16th century for both areas, and the events have been cumulated over ten

Table — Focal parameters of the studied earthquakes.

Date Year	Mo	Da	Time Hr	Mi	Sec	Coordinates Lat N	Long E	Depth (km)	Ml	Plane A dir(°)/inc(°)	Plane B dir(°)/inc(°)	Axis P dir(°)/inc(°)	Axis T dir(°)/inc(°)	Axis B dir(°)/inc(°)	Score
1974	06	20	17	08	28.2	46°09.5'	15°34.4'	17	4.5	173-50	80-90	29-26	134-28	260-50	12/16
1974	06	20	17	08	47.6	46°12.5'	15°55.0'	10	4.4	225-46	173-54	210-64	110-10	16-28	11/13
1974	06	20	22	26	31.5	46°11.7'	15°32.2'	4	4.2	246-50	96-44	169-7	273-70	80-16	22/24
1981	06	28	06	16	27.1	45°40.8'	16°08.8'	11	3.5	230-90	143-90	7-0	97-0	-90	23/28
1982	06	05	17	54	12.5	45°42.0'	16°47.2'	5	3.9	220-50	124-80	178-20	77-35	292-49	19/20
1983	08	05	15	50	50.6	45°57.3'	16°04.5'	1	3.7	184-50	95-90	42-26	147-26	275-50	15/15
1984	10	25	13	58	53.6	45°38.1'	16°20.2'	11	3.5	202-6	122-90	218-45	25-46	122-6	12/14

year intervals. The curve relative to the Alpine region shows a slight increase in the cumulative number of earthquakes starting from year 1790 and a marked change of slope around the year 1870. After this date, the slope of the curve remains constant (average increase: 155 events every ten years) up to the last period (1970-1984) characterized by a sharp increase in the cumulative number due to the Gemona seismic sequence which started in May 1976. The curve relative to the Dinaric region indicates a strong change in the cumulative number of earthquakes in the year 1895 when a VIII-IX MCS intensity quake hit Ljubljana; the cumulative number quantity increases very quickly until the year 1930 (average increase: 442 earthquakes every ten years), after which the increase becomes less evident (average increase 138 events). In the last decade, there is again an increase in the slope (238 events every ten years). It is intersting to note that the final cumulative number of earthquakes in the period 1500-1984 is quite similar in the two areas, although their pattern seems to be slightly different: more continuous in the Dinaric region and dominated by seismic episodes in the Alpine one.

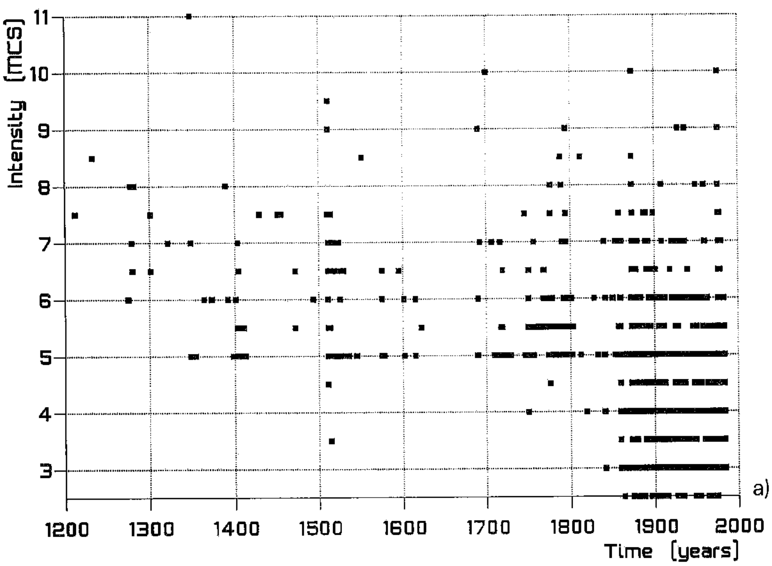
To investigate better this pattern, the Benioff graphs for the two regions have been constructed (Fig. 6b). While the Dinaric area releases seismic energy uniformely, with an obvious increase after 1900 due to the increase in the number of recording stations, the Alpine region is characterized by periodic strong seismic sequences. However, during the whole period, the total amount of energy released by the two zones appears to be approximately the same before the strong Gemona seismic sequence.

Analysing the number of events in each intensity class (Fig. 7), it is interesting to note that intensity III MCS is much more frequent in the Dinarides, but number of occurences of intensity IV MCS is quite similar in both regions. Intensity V MCS is much more frequent in the Alps, and from intensity VI MCS onwards the frequency is quite similar. More than describing the completness of the catalogue, this emphasizes the different pattern of the seismicity with frequent low intensity earthquakes in the Dinarides.

Furthermore, the Gutenberg-Richter relationship for the two systems has been assessed (Fig. 8) by considering the events of the period 1850-1984. The linear regression has a b-value (slope of the straight line) of 0.51 (+/- 0.01), in the intensity range IV-X MCS for the eastern Alps, and 0.57 (+/- 0.02), in the intensity range III/IV-IX MCS for the northern Dinarides. As the total number of considered events is 10% greater in the Dinaric than in the Alpine region, the difference in the seismic behaviour is once more detected: the earthquakes in the northern Dinarides are slightly more frequent than in the eastern Alps but have smaller magnitudes. The average return period for events of intensity VIII MCS in the Dinarides is, in fact, about double: 20 years with respect to 10 years in the Alps. However, the return period for the two regions becomes almost the same (0.1 years) for the intensity IV MCS.

REGIONAL ACTIVE SEISMICITY

On May 6, 1976 at 20:00 GMT, an earthquake of magnitude 6.4 occurred a few kilome-



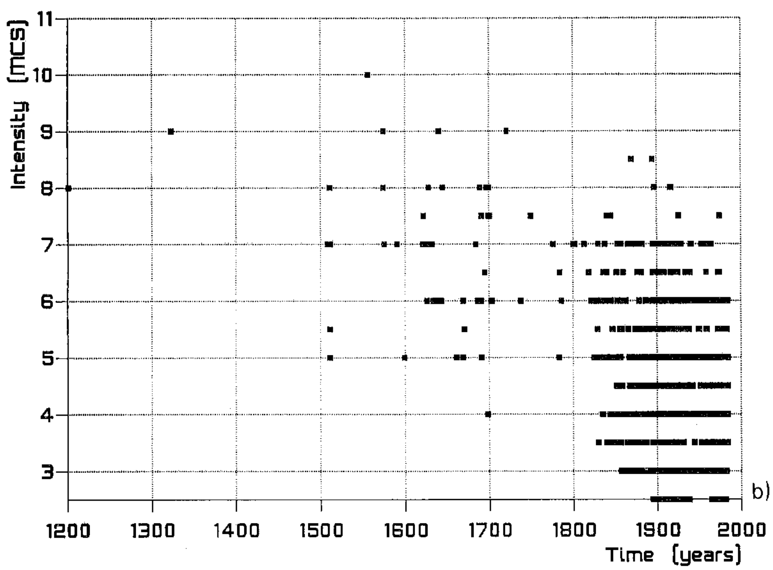


Fig. 5 - Intensity distribution over the last eight centuries: a) eastern Alps; b) northern Dinarides.

ters east of Gemona (Finetti et al., 1979) preceded one minute before by a 4.5 magnitude foreshock. During September 1976, four more events with magnitude larger than 5.0 occurred in the same area but shifted some kilometers westwards. A further seismic sequence, very probably connected with the 1976 earthquake, occurred one year later displaying its maximum magnitude (5.2) on September 16 (Cavallin et al., 1990). It is worth noting that some months before the 1976 main shock four earthquakes with magnitude between 2.5 and 3.5 occurred in the Latisana area, near the Tagliamento river mouth. This area is generally considered aseismic as only twelve events are reported in the catalogue (OGS, 1987) before 1975 and a further three of low magnitude after the Gemona earthquake. The Latisana quakes of 1975 - 1976 were interpreted as foreshocks of the May 6, 1976 main shock (Finetti et al., 1979). This interpretation is based on the time correlation of the events and on a fine analysis of the incipient

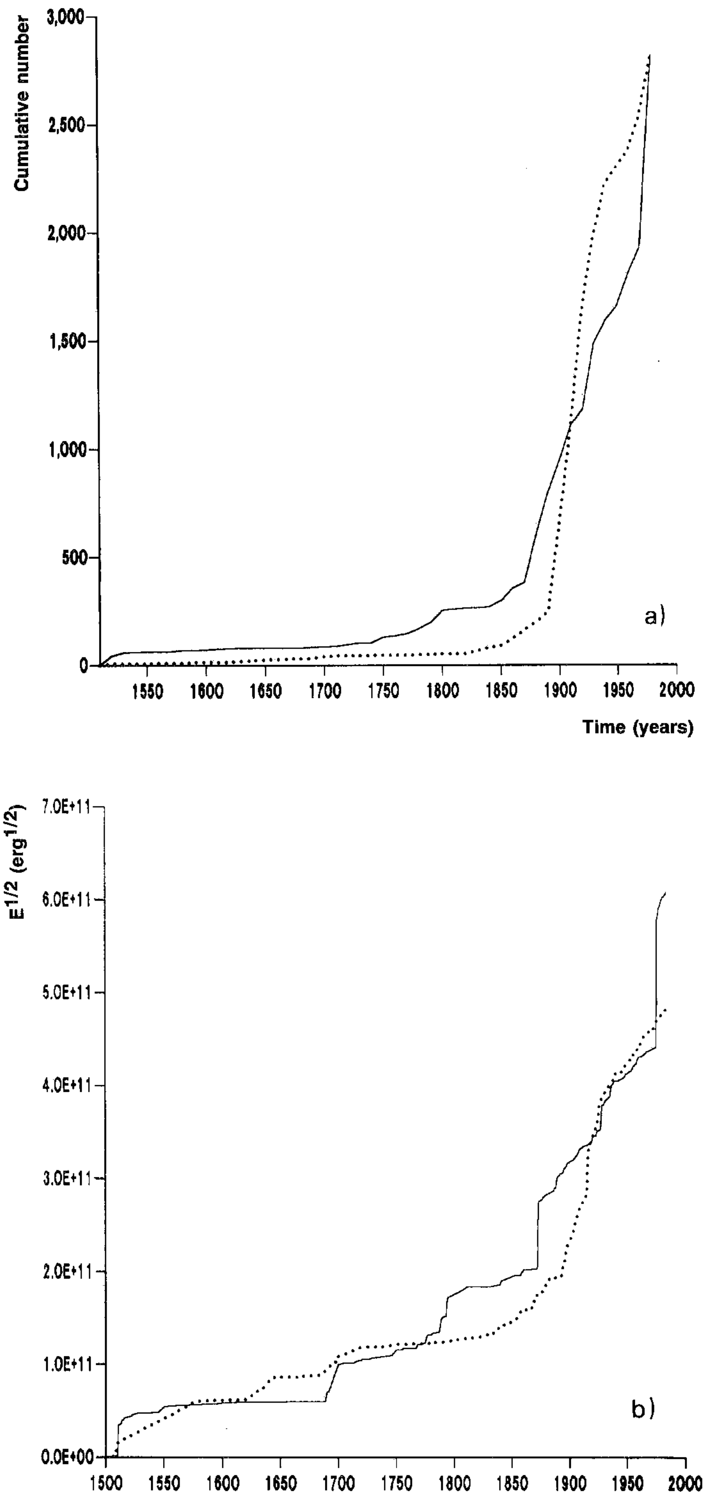


Fig. 6 - Statistics of the seismicity during the last five centuries in eastern Alps (solid line) and northern Dinarides (dotted line): a) cumulative number of events versus time; b) Benioff graph.

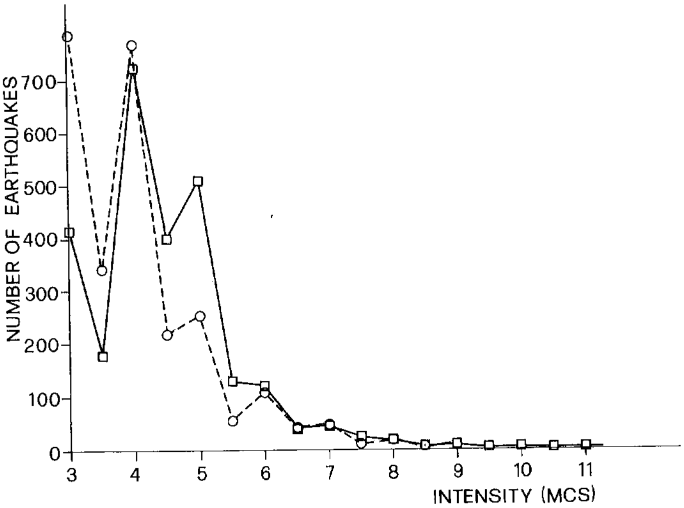


Fig. 7 - Number of earthquakes versus intensity during the last five centuries for the eastern Alps (solid line) and northern Dinarides (dotted line).

compressive deformation process in act at the Latisana epicentral zone.

The focal mechanism of the main event and of most of the aftershocks has been interpreted as due to a dip-slip movement with a more or less relevant strike slip component (Cipar, 1980, 1981; Slejko e Renner, 1984). The particular radiation with strong attenuation towards south and light attenuation towards SW, SE and NE (Giorgetti, 1976) is mainly due to the radiation pattern characteristics of the focal mechanism itself (Siro e Slejko, 1984).

A seismotectonic interpretation of the whole seismic sequence relates the main shock to the deep continuation of the Gorizia fault (which displays a Dinaric orientation), while the September 1976 sequence also affected Alpine structures (Finetti et al., 1976, 1979). Correlation between Dinaric surficial faulting and deep slip planes is not simple since the deformation pattern is composed of different tectonic elements such as thrust-faults, strike-slip faults and transpressive strike-slip faults with fault planes sometime complex and variable with depth.

On May 1977, a local seismometric network was installed in Friuli by the Osservatorio Geofisico Sperimentale of Trieste (OGS); in the following years, the number of stations was increased and now they cover the territory from lake Garda to the border with Slovenia. For earthquakes with epicentre determination to the east of the area covered by the network, data from Slovenian and Croatian stations are used in the processing.

Figs. 9 and 10 show the epicentres of the earthquakes located in the study area in the period 1977-1989. In the first figure (Fig. 9) the earthquakes having magnitude greater than 2.8 are reported, while in the second (Fig. 10) the events between the perceptibility threshold of the network (about 1.2) and magnitude 2.8 are shown. In the Friuli area more observations are reported than in the eastern areas and its high seismicity is also due to the well determined coda of the seismic sequence which started in May 1976. The maximum density of foci is located around Gemona (Friuli, Fig. 9). From this cluster two bands of epicentres emerge: one directed SW towards Belluno (Cansiglio), the other directed SE towards Rijeka (External Dinarides). Fig. 10 shows the same features as Fig. 9, but the low magnitude seismicity of the pre-Alpine belt is more continuous, and seems to define an active seismogenic belt going from Belluno to Gorizia and a less active portion, which comprises the seismicity of the Sneznik mountain area, to Rijeka. In both figures, the seismicity of the Internal Dinarides appears to be low and more diffuse, in agreement with data on the historical seismicity (Fig. 2), and it is mainly located along the Sava line. A group of epicentres around Idrija seems unconnected to the neighbouring seismicity. Very few shocks occurred north of the Insubric Lineament, in the Friulian plain, in Istria and in the Adriatic Sea. In the following years also, the areas around Ljubljana,

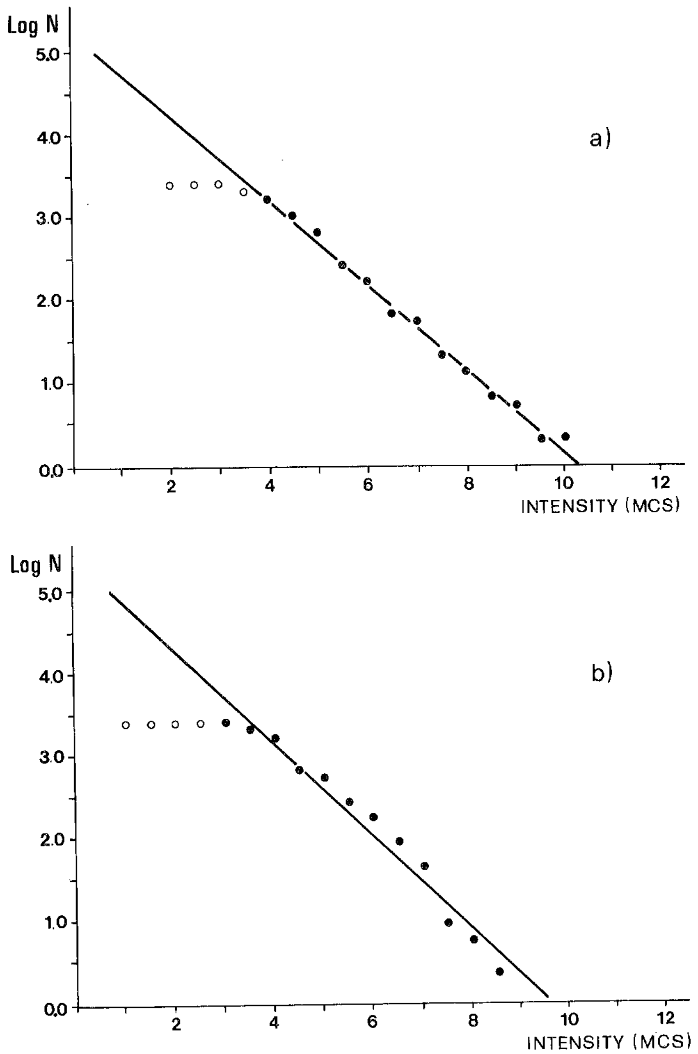


Fig. 8 - Gutenberg-Richter relationship for eastern Alps (a) and northern Dinarides (b), considering the quakes of the last five centuries.

Rijeka and SW of Zagreb (Gorjanci mountain) experienced the strongest seismicity in northwestern Yugoslavia (Markusic et al., 1990).

A further analysis consisted in the determination of the depth distribution of the foci. In Fig. 11, the smoothed distribution obtained by averaging the number of events in depth intervals of 1 km with a 3 sample mobile window are presented for the zones indicated by the epicentral distribution: Friuli, Internal Dinarides and External Dinarides (see location in Fig. 9). The separation of the Yugoslav seismicity is given by the front of the Internal Dinarides. The number of events in Friuli is different from the Yugoslavian areas due to the ability of the OGS network to detect small quakes. The different data sets are presented in percentage values in Fig. 11 for comparison. Friuli shows a slightly asymmetric distribution at around 9 km with more events having smaller depth (solid line in Fig. 11). The 7 km class is large in all three areas, since the starting value of depth for the computer hypocentral location is fixed at that value. The depth distribution for the External Dinaric events is different from those of the Internal Dinarides and Friuli: it is more evenly distributed over the whole 0-15 km range with

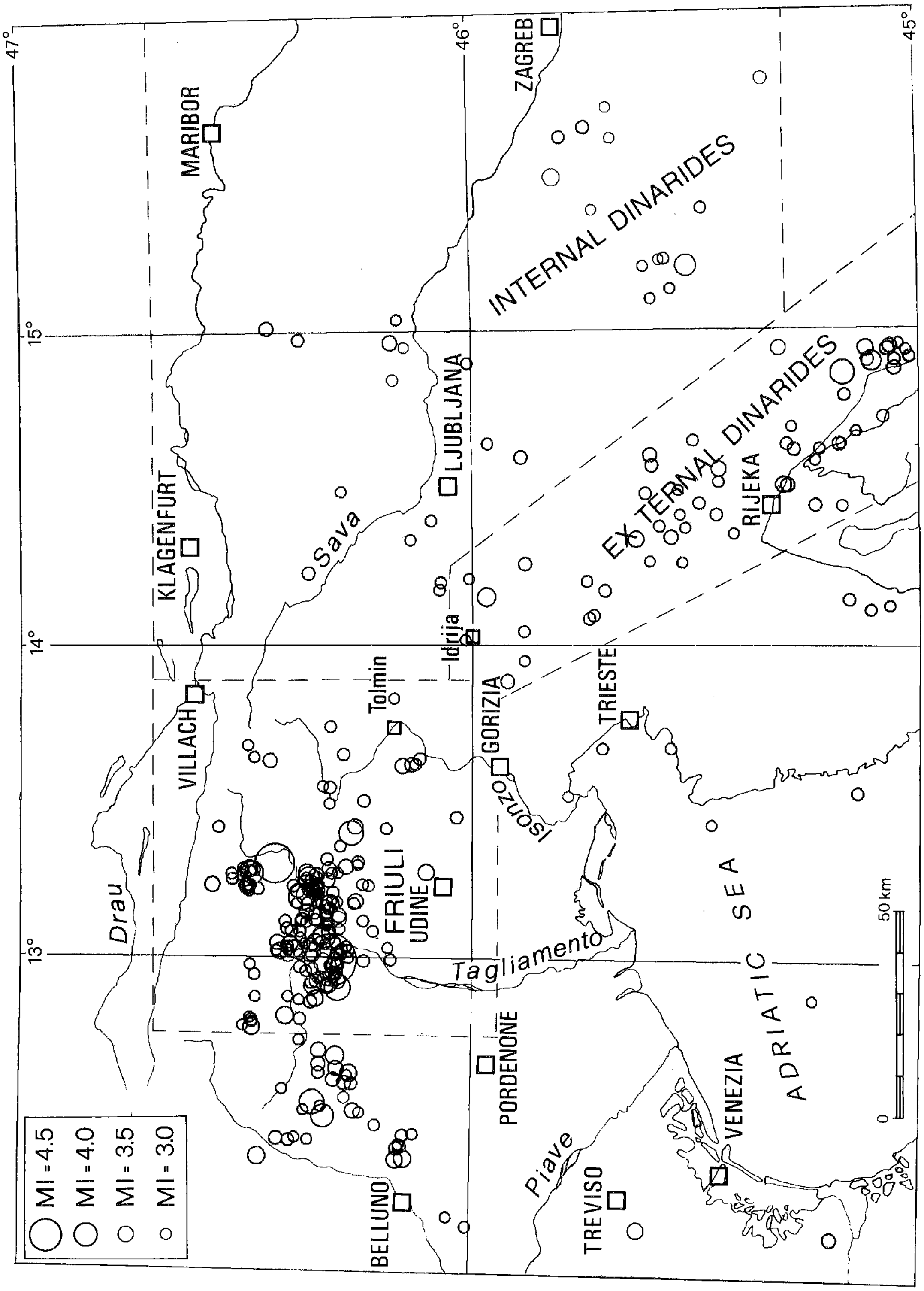


Fig. 9 - Map of the epicentres of the earthquakes with magnitude greater than, or equal to, 2.9 recorded by the OGS seismometric network in the period 1977-1989, and location map of the zones used in the depth distribution analysis of Fig. 11.

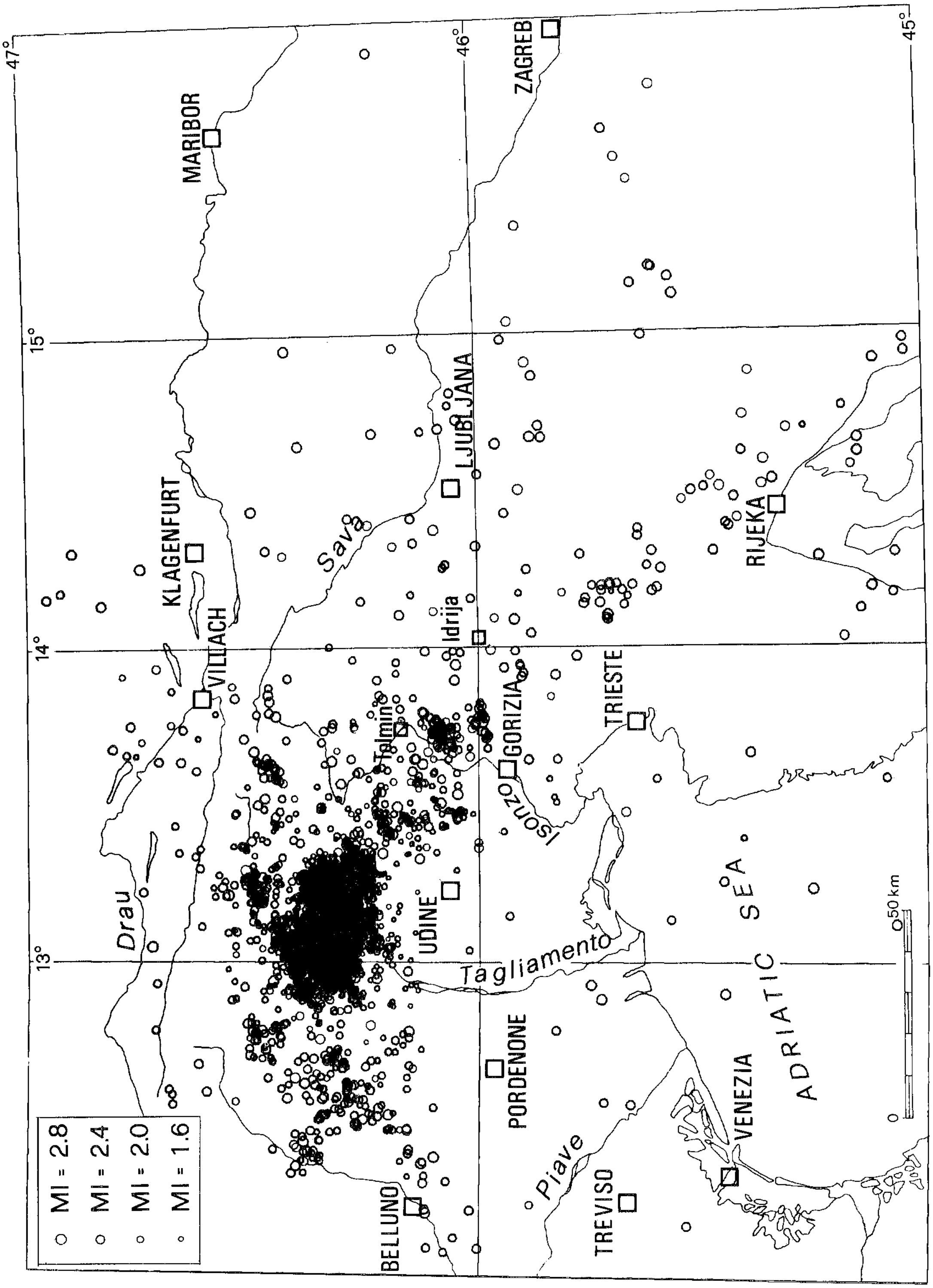


Fig. 10 - Map of the epicentres of the earthquakes with magnitude smaller than 2.9 recorded by the OGS seismometric network in the period 1977-1989.

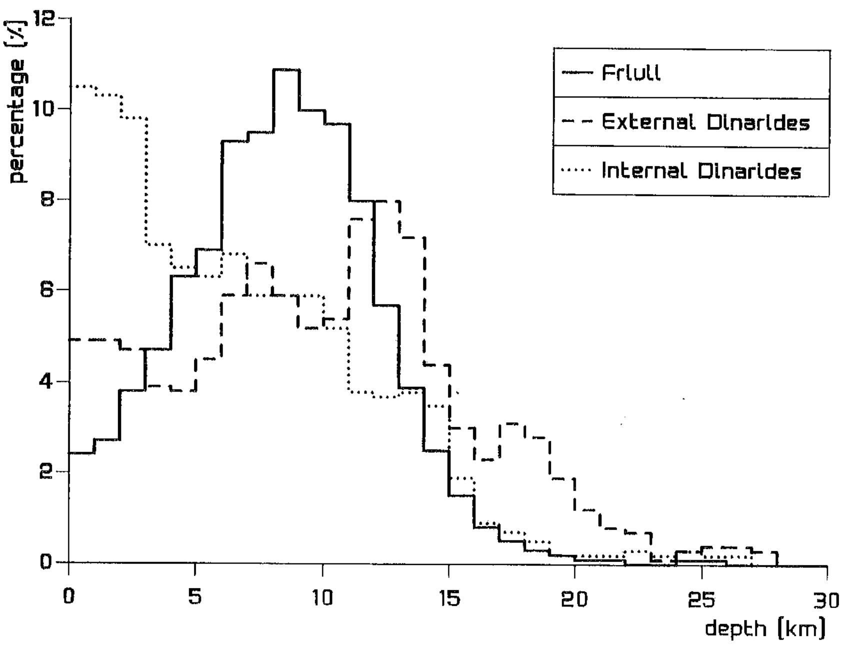


Fig. 11 - Depth distribution of the present-day seismicity in Friuli (solid line), External Dinarides (dashed line), and Internal Dinarides (dotted line).

maximum presence shifted to greater depths (dashed line in Fig. 11). The Internal Dinarides are characterized by very shallow quakes and a progressive decrease in number of events from the surface to 20 km depth (dotted line in Fig. 11). A further analysis for the three areas is shown in Fig. 12. Here the magnitude distribution in depth is given by different symbols which mark different numbers of earthquakes. It can be seen that in Friuli (Fig. 12a) the largest number of small quakes (magnitude between 1.5 and 2.0) occurs in the depth range 7-10 km, while the largest magnitudes (over 3.5) are slightly shifted to greater depths. The pattern is rather regular since around the maximum the seismicity gradually decreases, but less rapidly towards the surface as frequent events, also of important magnitude, can be found at very small depths. The distribution is less regular in the External Dinarides (Fig. 12b) where it is quite uniform from the surface to 20 km depth with largest number of events (between magnitude 2.3 and 2.7) in the depth range 5-13 km. The largest magnitudes seem located in the shallowest strata. In the Internal Dinarides, the maximum number of events is in the 2.6-2.9 magnitude range at very shallow depth. Considering the earthquakes which occurred from 1971 to 1988 further along the Yugoslav coast (Herak and Herak, 1990), the foci are located in the uppermost sedimentary layer of the crust, between the surface and 20 km depth, but with the strongest events at greater depths. The maximum hypocentral depth follows the shape of the sedimentary base with more quakes above where the Moho discontinuity is deeper. The same aseismicity in the lower crust and mantle, which is characteristic of intraplate and intracontinental seismicity, was also noted in Hungary (Zsiros et al., 1989).

The pattern of historical and present-day seismicity shows that the maximum seismic release remains concentrated in the same areas all times: first of all in northern Friuli, then along the belts towards the SW (Cansiglio) and towards the SE (Sneznik mountain and Rijeka area). The maximum seismicity is fairly well connected with the most evident and important young or reactivated tectonic structures. The epicentres are rather dispersed in northern Yugoslavia, where the major seismicity can be seen along the Sava river, especially around Ljubljana and Zagreb. This latter seismicity (only partly shown by Fig. 3 because the main events were NE of the town) has been related to the normal and reverse faults of the Sava depression in the area of the Medvednica mountain (Skoko et al., 1977).

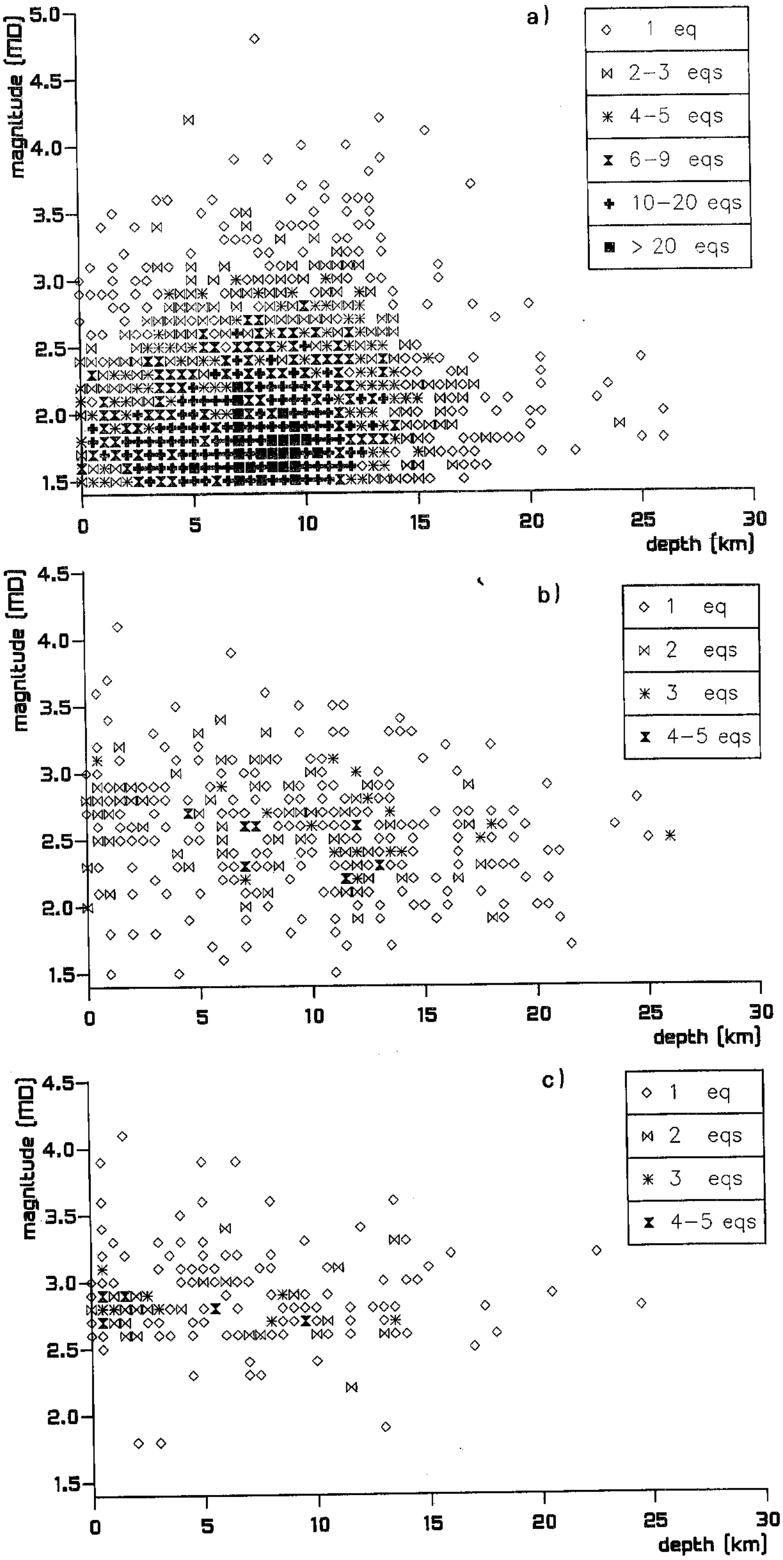


Fig. 12 - Number of earthquakes per magnitude and depth classes in Friuli (a), External Dinarides (b), Internal Dinarides (c).

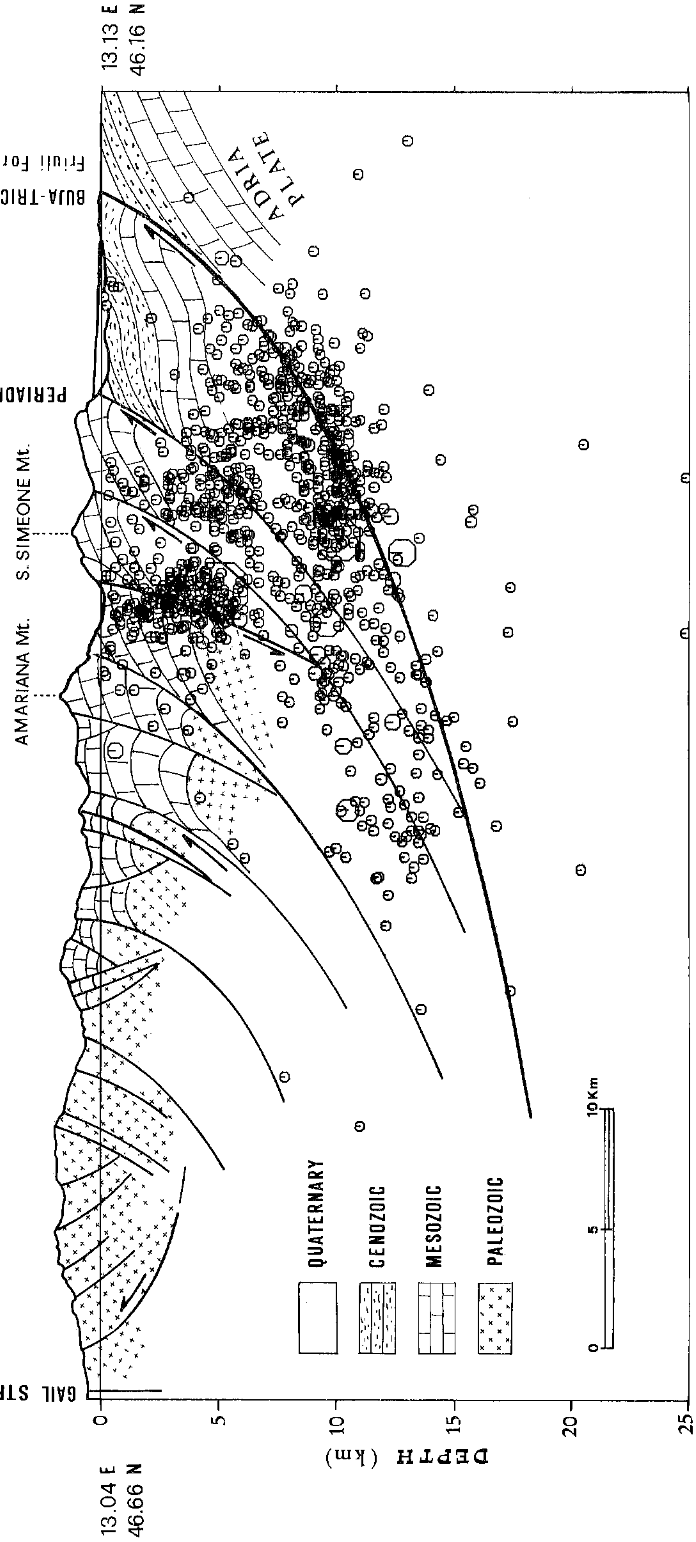


Fig. 13 - Seismotectonic cross-section (section AA: for location see Fig. 2) 12 km wide in the eastern Southern Alps (Friuli region) with the 1977-1989 seismicity. The tectonic deformation is here dominated by a pure, still very active thrusting process.

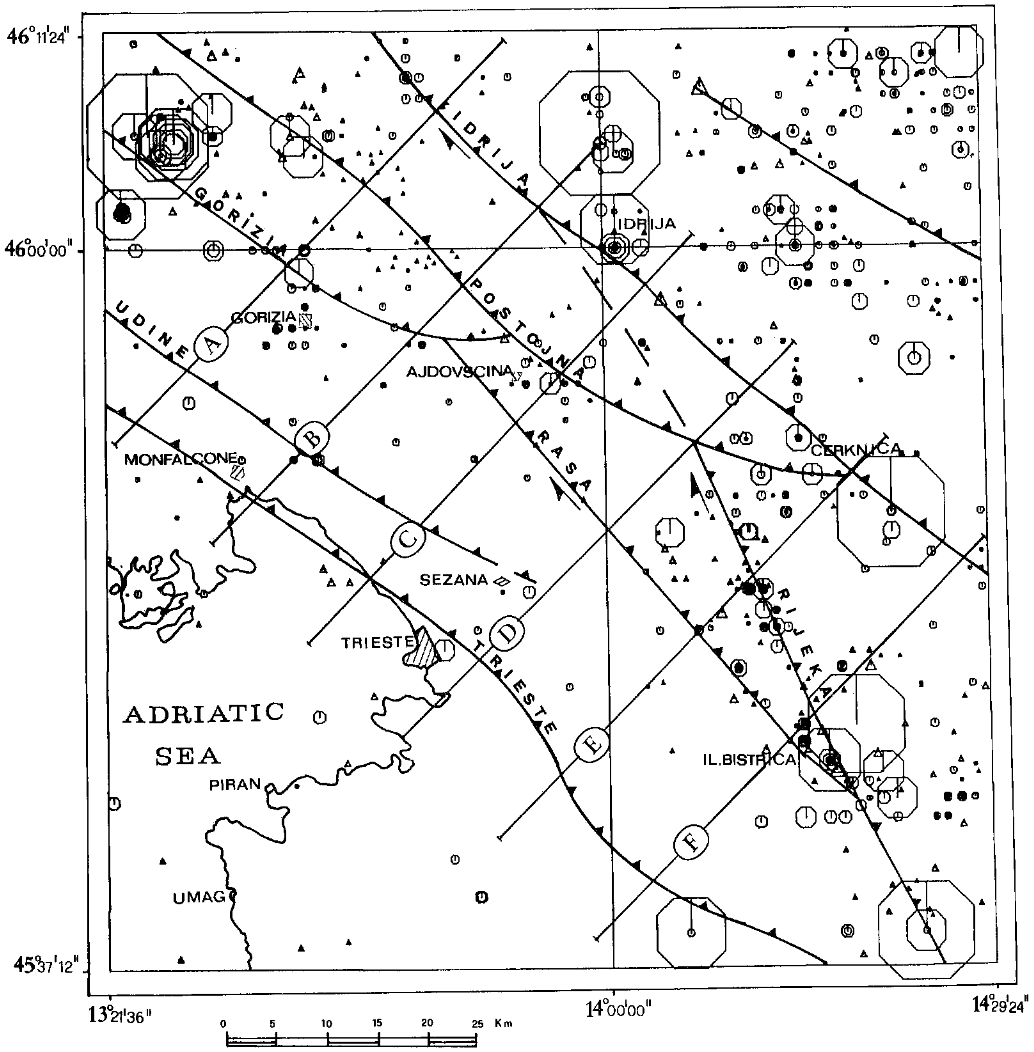


Fig. 14 - Seismicity and main regional tectonic elements of the Karst area (northern Dinarides). Epicenters are plotted with different symbols according to their age: octagons (from the beginning of the Christian era to 1976); triangles (from 1977 to 1989). Solid lines indicate the location of the vertical cross-sections (sections A, B, C, D, E, and F) shown in Figs. 15 to 20.

For northeastern Italy, correlations have been evidenced by analysing some vertical cross-sections of the present-day seismicity recorded by the OGS network and relating their trends to geological and geophysical data (Slejko et al., 1989). Summarizing the main results obtained for Friuli, we can say that the seismicity is connected to thrust faults (Fig. 13), is concentrated in the most superficial portion of the crust (sedimentary cover and upper crystalline layer), and that the maximum density of seismicity is at 10-12 km depth (Siro and Slejko, 1982) where a velocity horizon, probably identifying the top of the basement, has been revealed by refraction seismics. The most active area corresponds to a zone of maximum shortening in the Southern Alps and to the increase, from south to north, of the crustal thickness.

A preliminarly analysis of the stress diffusion in the study area (Rebez et al., 1987) has shown a transmission of stresses from west to east and, less clearly from north to south in the Dinaric region.

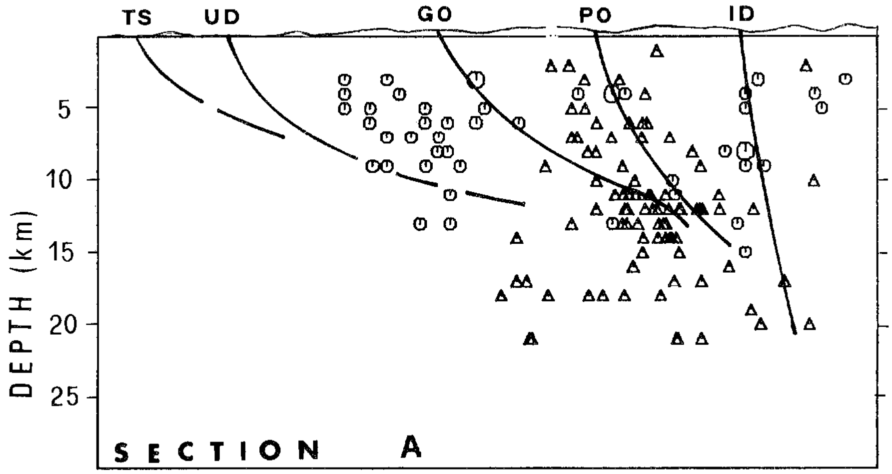


Fig. 15 - Seismotectonic cross-section A in northern External Dinarides (for location and symbol explanation see Fig. 14). It indicates very little to zero activity for the Trieste (TS) and Udine (UD) thrust-faults; these two faults, when active, very probably had a transpressive strike slip component. The Gorizia (GO) and Postojna (PO) thrust-faults are very active. Very active also is the Idrija (ID) fault, identified as a strike-slip with a subvertical plane. The events between the UD and GO faults can probably be almost all attributed to the GO fault.

SEISMOTECTONIC SETTING AND PLATE KINEMATICS

Assuming the main structural elements of the reconstructed regional tectonic setting and correlating these elements with the carefully obtained hypocentral distribution of the seismicity in the investigated area, it is now possible to understand much more clearly than previously the seismogenesis involved and its kinematics. While in the Southern Alps, the observed active deformation process and the seismic activity were attributed (Amato et al., 1976) to an evident dominant pure compressive effect, consequent to the underthrusting movement of the Adria plate (Fig. 13), and this was successively confirmed, the tectonogenic picture of the northern

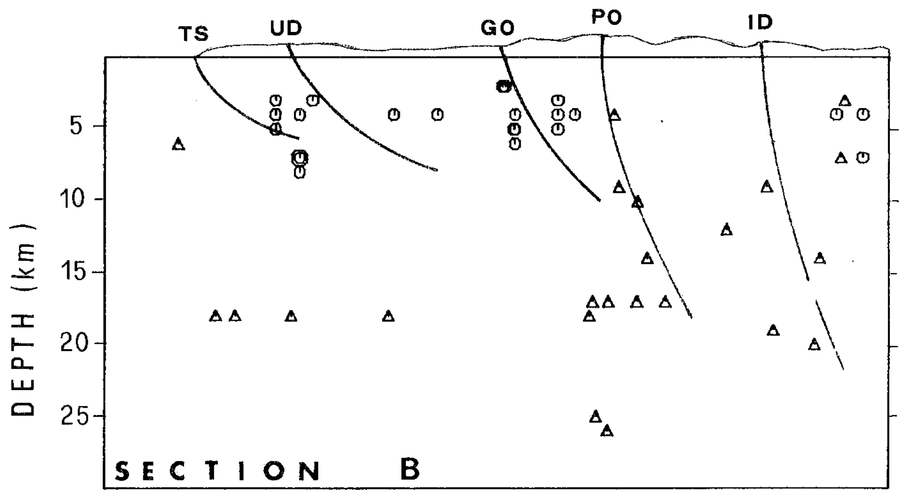


Fig. 16 - Seismotectonic cross-section B in northern External Dinarides (for location and symbol explanation see Fig. 14). Substantially, the same faults as in the previous figure (Fig. 15) are also active here but with a smaller number of events.

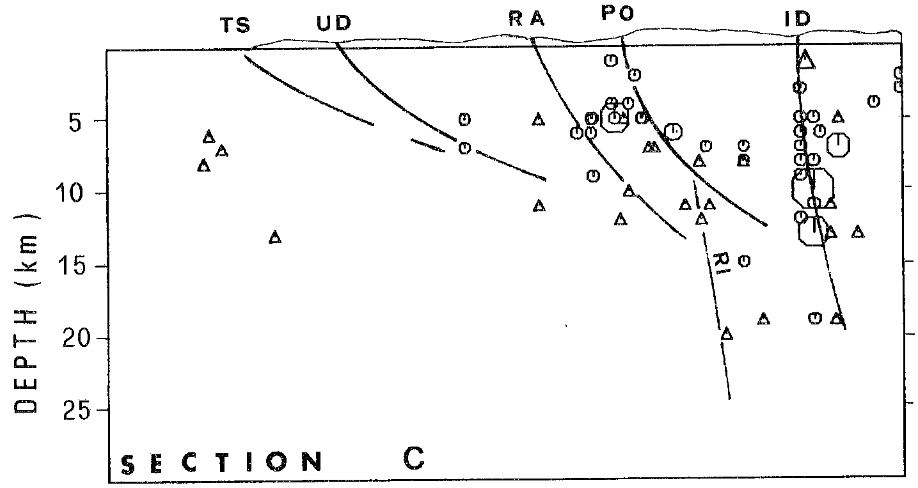


Fig. 17 - Seismotectonic cross-section C in northern External Dinarides (for location and symbol explanation see Fig. 14). The GO thrust fault is substituted by the Rasa (RA) fault which is attributable to a transpressive thrust-fault with dextral strike-slip component. The PO thrust-fault probably covers the buried northward prolongation of the very active Rijeka (RI) strike-slip fault and seems connected to the ID fault. Here the ID fault has a very clear and active subvertical plane associated with a prominent dextral strike-slip movement.

External Dinarides is kinematically not so simple to reconstruct in a controlled manner. For this reason, the fine seismic analysis was concentrated in particular on the External Dinarides sector of the Alps-Dinarides contact (Fig. 14).

Seismotectonic section A (Fig. 15) on the northwestern extremity of the External Dinarides (for location see Fig. 14) shows that the Trieste (TS) thrust-fault is practically inactive, at least in historical times. The Udine (UD) thrust-fault shows sporadic activity in sections A (Fig. 15) and B (Fig. 16). Both the TS and UD thrusts were generated in Middle-Alpine orogenic activity (Paleogene) when a diffuse NW-SE trending thrust faulting took place over the whole External

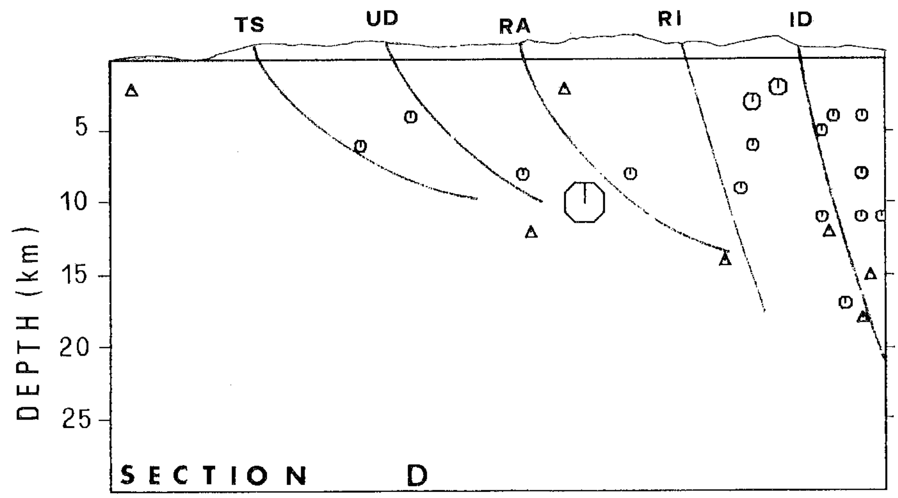


Fig. 18 - Seismotectonic cross-section D in northern External Dinarides (for location and symbol explanation see Fig. 14). TS and UD thrusts are little to non active. RA, RI and ID faults are very active. RA thrust seems connected to RI fault.

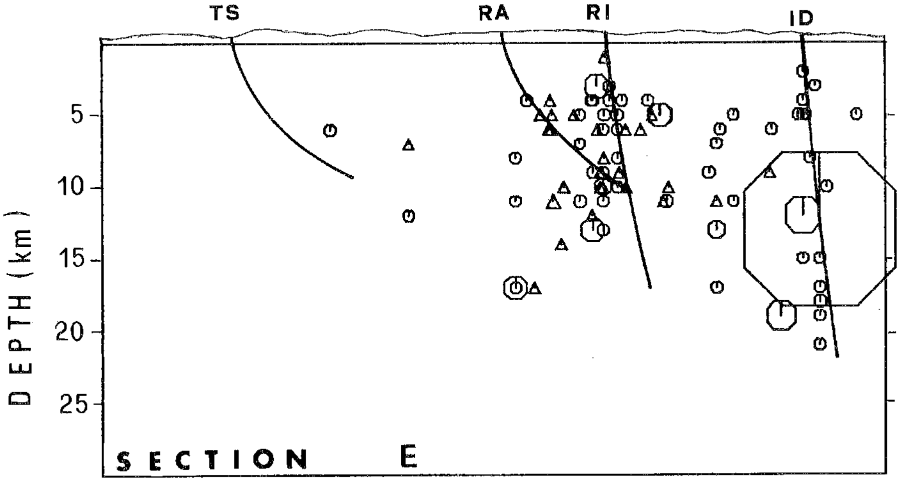


Fig. 19 - Seismotectonic cross-section E in northern External Dinarides (for location and symbol explanation see Fig. 14). TS thrust is practically inactive (at least in the upper part); UD thrust is terminated north of this section. RA thrust and RI strike-slip fault are very active and approach each other. ID strike-slip fault also is very active.

Dinarides and affected also the eastern sector of the South Alpine system. Successively, during the Neo-Alpine phase, TS and more evidently UD thrusts were slightly reactivated. The TS and UD faults are probably the result of a transpressive deformation with a consistent dextral strike-slip component. It is possible that in the recent tectonic activity, the TS and UD thrusts were almost only affected in their deeper part by modest strike-slip movements of the more internal faults of Rijeka and Idrija (RI and ID: Figs. from 14 to 20).

The Gorizia (GO), Rasa (RA) and Postojna (PO) thrust-faults, as all the seismotectonic sections show (Figs. 15 to 20), are very active throughout their planes. Also the GO, RA and PO faults were generated during the same Paleogenic phase of the Alpine orogenesis as the TS and UD thrusts. But, while the TS and UD faults have been inactive or only modestly active

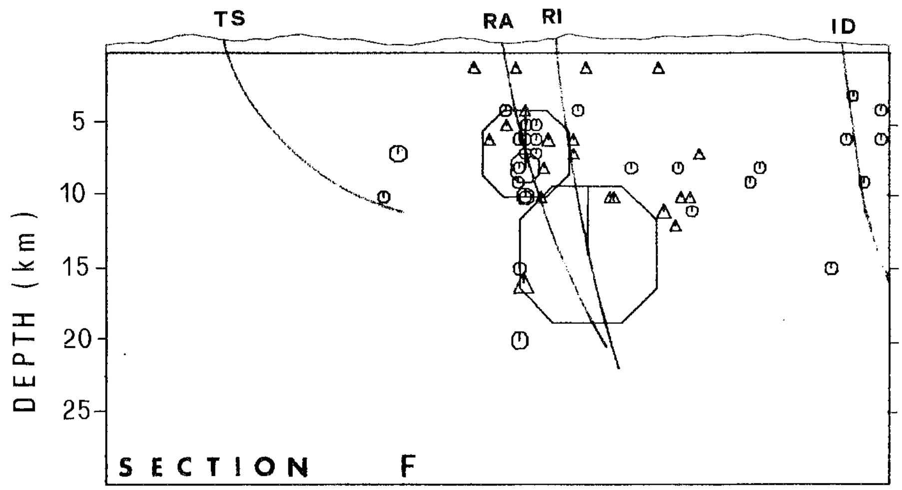


Fig. 20 - Seismotectonic cross-section F in northern External Dinarides (for location and symbol explanation see Fig. 14). RA and RI faults are very close and active; their fault plane seems subvertical. ID fault is active and its plane is evidently subvertical.

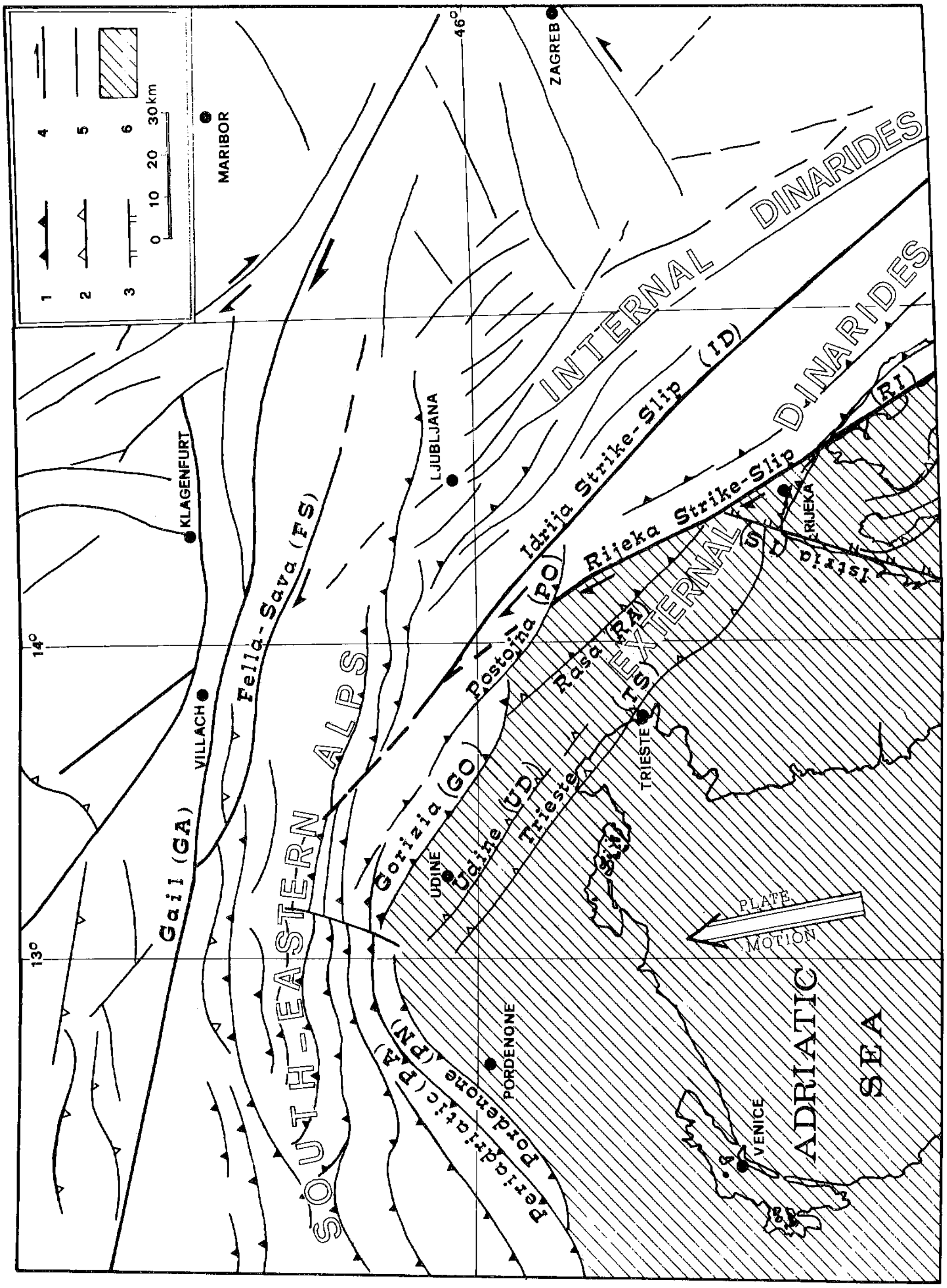


Fig. 21 - Tectonokinematic map of eastern Southern Alps and northern External Dinarides. This tectonic setting and the inferred plate motion give a full explanation of the carefully reconstructed 3-D seismicity distribution. 1 = Active thrust-faults (Pordenone PN, Periadriatic PA and others of the Southern Alps) and active transcurrent thrusts of the External Dinarides (Gorizia GO, Postojna PO, and Rasa RA in part). 2 = Thrust-faults and transcurrent thrusts (i.e. Trieste TS, and Udine UD) insignificantly active in historical times. 3 = Active normal fault (i.e. transtensive Istria IS fault). 4 = Strike-slip faults and very active transpressive strike-slip faults of Rijeka (RI) and Idrija (ID). 5 = Tectonic lineaments. 6 = Adria plate. Moving towards NNW, the Adria plate is disconnected along the RI and ID faults and determines the maximum seismic activity of a compressive type at its apex in Friuli, and of a prevailing strike-slip type on the northern External Dinarides.

in historical times, the GO, RA and PO thrusts have been very active. Thrusting displacements progressively increase from the Istria to Friuli areas (see Fig. 4). All three faults (GO, RA and PO) are not pure thrust-faults, but are affected by strong dextral strike-slip movement components produced by the relative NNW motion of the Adria plate. During the Neo-Alpine orogenic activity, they were intensively reactivated with a definite predominance of the transcurrent deformation which persists also at present (see the focal mechanism on the RA fault in Fig. 4). In conclusion, GO, RA and PO are active faults associated with an evident transpressive deformation.

Two other faults are very important in the context of the seismotectonic picture of the External Dinarides: the Rijeka (RI) and Idrija (ID) faults. They are the most active ones of the northern Dinarides and are clearly formed by dextral strike-slip fractures with modest transpressive components (Figs. from 15 to 20). This interpretation is supported also by the focal mechanisms for the area (see Fig. 4): the Dinaric strike is well clear though a vertical motion on the RI fault occured as well in the general dextral strike-slip context. The RI and ID faults are oblique to each other and increase their distance going southwards. The seismicity in the Sneznik mountain area (Ilirska Bistrica in Fig. 14) can be explained by the interaction of the RA and RI faults.

The RI fault disappears beneath the PO transcurrent thrust-fault (Figs. 14 and 17). Very probably, north of section C (Fig. 17), the RI fault terminates on the ID strike-slip fault around the zone of Idrija village (Fig. 14). This hypothesis may explain the high seismicity of the Idrija zone (see Fig. 14). The ID fault forms the easternmost active tectonic element of the External Dinarides and together with the RI fault disconnects the NNW motion of the Adria plate (Fig. 21).

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