BOLLETTINO DI GEOFISICA TEORICA ED APPLICATA VOL. 41, N. 2, pp. 133-148; JUNE 2000

Seismotectonic and macroseismic characteristics of the earthquake of Bovec (NW Slovenia: April 12, 1998)

G. BERNARDIS(1), M. E. POLI(2), A. SNIDARCIG(1) and A. ZANFERRARI(2)

(1)*Istituto Nazionale di Oceanografia e di Geofisica Sperimentale,*
Dipartimento Centro Ricerche Sismologiche, Udine, Italy
(2)*Dipartimento di Georisorse e Territorio, University of Udine, Italy*

(Received February 17, 2000; accepted May 30, 2000)

Abstract. On the 12th April 1998, a wide area in the middle valley of the Socˇa/Isonzo River near Bovec (NW Slovenia) was affected by an earthquake of $MD = 5.6$. It was followed by a long seismic sequence from which the 40 aftershocks, with $MD \geq 3.0$ recorded until the 30th June 1998, have been analysed. The study area belongs to the External Dinarides: it is characterised by a set of dextral NW-SE strike-slip faults that act as kinematic release for the Eastern Southalpine Chain. The main shock presents a classical focal mechanism of strike-slip fault ($P = 179/02$; $T = 269/02$) with vertical planes of motion, NW-SE (dextral) and NE-SW (sinistral), and a hypocentre depth of about 15 km. The main aftershock of the 6th May 1998 ($MD = 4.6$) shows the same focal mechanism, with the hypocentre at about 10 km and the epicentre shifted 6 km towards SE. Also the aftershocks with $3.5 \leq MD < 4.0$ show a prevailing strike-slip focal mechanism. On the contrary, the focal mechanism of the events with $3.0 \leq MD < 3.5$ are more diversified: the earthquakes with transtensional or extensional focal mechanism with planes ranging from NW-SE to N-S prevail over the earthquakes which present a fault plane solution typical of low-angle NW-SE to NE-SW trending reverse faults. Both the main shock and the aftershocks are kinematically compatible with the actual strike-slip tectonic framework of this region. The Čez Potoče fault, one of the main dextral NW-SE strike-slip faults, along which the main shock and aftershock hypocentres are distributed, is considered to be the seismogenetic fault. The temporal analysis suggests a migration of the events towards SE along this fault. The analysis of the distribution and the type of damages indicated that there is no correspondence between the instrumental epicentre and the macroseismic one. The intensity of the latter has been valued equal to the VIII-IX MCS, with heavy structural settlings and noteworthy phenomena of site amplification. The earthquake

---

Corresponding author: A. Snidarcig; Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Dipartimento Centro Ricerche Sismologiche, V. Treviso 55, 33100 Cussignacco (UD), Italy; phone +39 0432 522422; fax +39 0432 522474; e-mail: asnidarcig@ogs.trieste.it

caused some effects also in the Friuli-Venezia Giulia region (macroseismic intensity surveyed equal to V-VI MCS) where the anomalous distribution of the damage appears to be connected with the partial or ful retrofitting of the buildings after the earthquake of 1976. Such a fact once more shows the fundamental importance of strengthening the buildings, particularly the old ones, in order to mitigate the seismic risk.

1. Introduction

On the 12th April 1998 at 10:55:53 GMT an earthquake with MD = 5.6 occurred in western Slovenia, in a zone located at about 15 km from the Italian-Slovenian border (Fig. 1). Up to now the historical seismicity of this area was considered of low level. The earthquake that affected the Lepena-Kobarid-Bovec area (middle valley of Soča/Isonzo River) caused considerable damage to the buildings and noteworthy phenomena of site amplification in the epicentre area (macroseismic intensity higher than VIII MCS). The Friuli-Venezia Giulia region also had same effects (macroseismic intensity surveyed equal to V-VI MCS).

In this work we analyse the earthquake of Bovec and its seismic sequence, comparing the results with the seismotectonic framework of the region and identifying the probable seismogenetic structure in the Čez Potoče fault. Afterwards we present the results of the survey and of the macroseismic analysis of the damages.

2. Geological setting

The area affected by the earthquake presents a complex geological history in which the inherited Mesozoic structures play a fundamental role. In particular the NW-SE striking crustal discontinuities, that bounded the eastern edge of the Mesozoic Friuli Carbonate Platform towards the Slovenian basin (Buser, 1987; Sartorio et al., 1997), still rule the structural evolution of this area. Two different Cenozoic structural units connect here (Fig. 2): the Paleogene W-vergent External Dinaric Chain (Mlakar, 1969; Aubouin, 1973; Cousin, 1981), the front of which extends as far as the Dolomites (Doglioni and Bosellini, 1987) and the Eastern Southalpine Chain formed by a few deformational phases from the Middle Miocene to Holocene (Massari, 1990; Venturini, 1990; Carulli and Ponton, 1992; Castellarin et al., 1992; Poli and Zanferrari, 1995). The Eastern Southalpine Chain is formed by a system of SSE-vergent, ENE-WSW to E-W trending overthrusts which extend from Lake Garda to the Italian-Slovenian border. Here, both the External Dinarides and the Eastern Southern Alps are cut off by a set of dextral NW-SE strike-slip faults, Neogene to Quaternary in age (in particular: Branik, Postojna, Idrjia, Čez Potoče and Bled-Mojstrana faults). In the present stress field of the region ($\sigma 1 \cong$N-S), this set of strike-slip faults acts as a kinematic release for the Eastern Southalpine Chain (Venturini, 1990; Bressan et al., 1998).

From the seismotectonic point of view, in literature, this region is traditionally set in a strike-

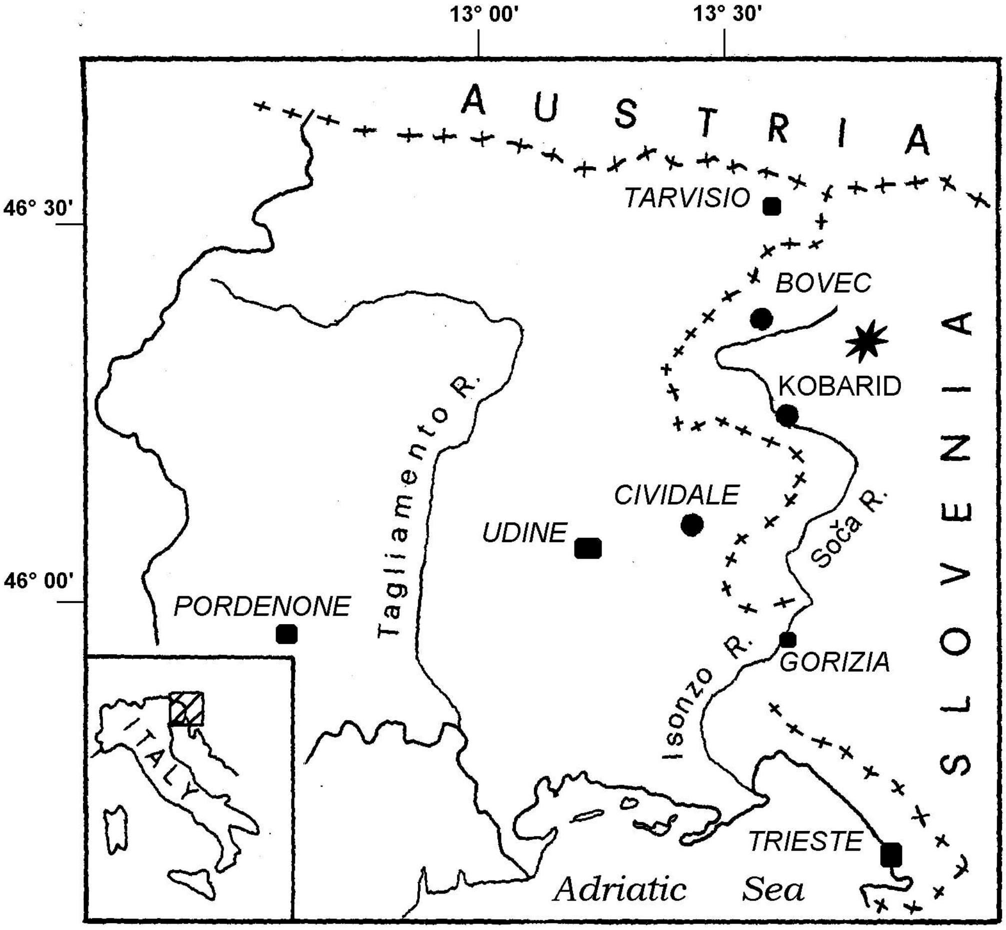

Fig. 1 – Geographical setting of the area affected by the earthquake of Bovec of 12/04/98. An asterisk indicates the instrumental epicentre.

slip deformational regime (Bressan et al., 1998) with a strong transpressive character (Slejko et al., 1989; Carulli et al., 1990; Del Ben et al., 1991; Renner and Slejko, 1994). Scandone (1997) classifies this area inside the "seismogenetic zones characterised by transpressive mechanism".

Recently, on the basis of an analysis of the focal mechanism of the earthquakes, collected from 1974 to 1998 by the Seismometric Network of Friuli-Venezia Giulia (SNFVG) Region, Poli and Renner (1998) noted the presence of a large number of low magnitude events with normal or weak transtensive focal mechanism and the absence of seismicity connected to transpressive deformations in the Cividale-NW Slovenia area.

3. Regional seismicity

According to the catalogue of the Eastern Alps earthquakes (O.G.S., 1987) and the Strong

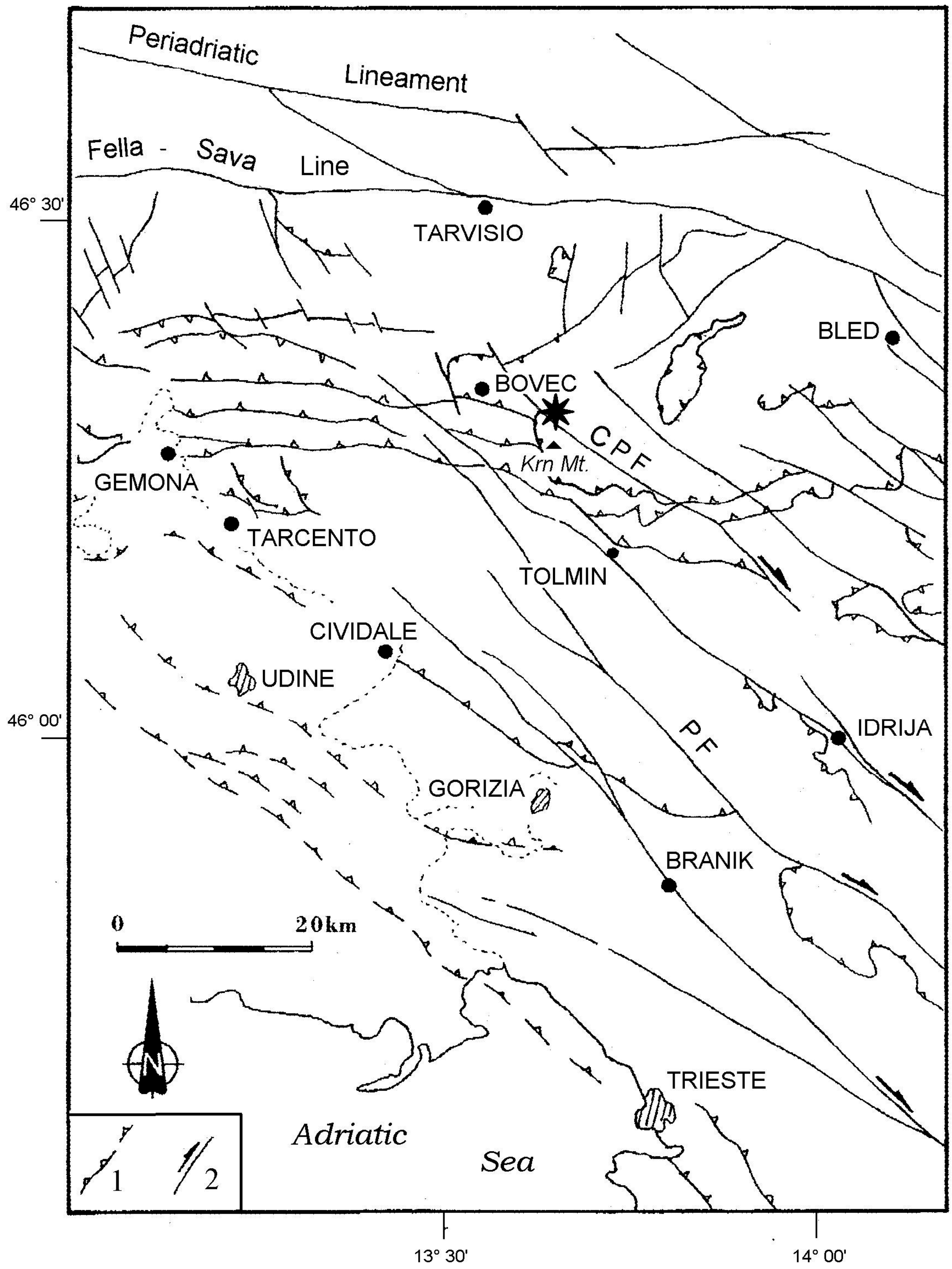

Fig. 2 – Tectonic sketch-map of Western Slovenia and Eastern Friuli. Instrumental epicentre of the earthquake (asterisk) is located just near the Čez Potoče fault (CPF) that belongs to the strike-slip fault system of Branik, Postojna (PF), Idrija and Bled-Mojstrana. Legend: 1) outcropping (continuous line) or presumed and buried (dotted line) overthrusts; 2) high angle, prevalently strike-slip, faults. Dotted line marks the boundary of the Friuli plain.

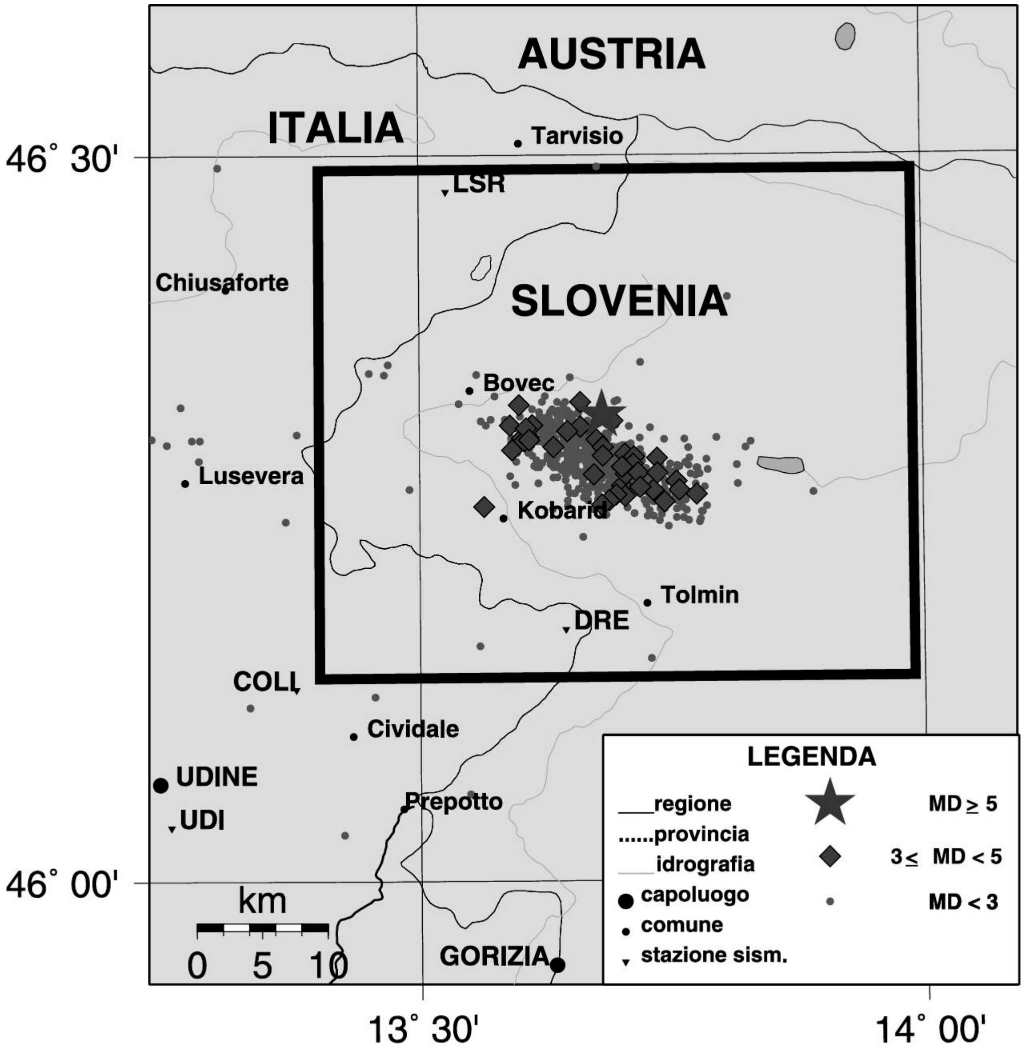

Fig. 3 – Epicentres distribution of the sequence of the earthquakes of Bovec from 12/04/98 until 30/06/98.

Earthquakes Catalogue (Boschi et al., 1997), the historical seismicity of this region shows only one event with intensity greater than or equal to the VIII MCS (Idrija earthquake of 26/03/1511: X MCS). According to the catalogue NT4.1 (Camassi and Stucchi, 1996) on the other hand, the Idrija earthquake should be located in eastern Friuli. Therefore, apart from this event, the historical seismicity can be defined of low level.

Instrumental seismicity started from 1931, when the seismological station of Trieste was installed. Then, with the installation of the Seismometric Network of the Friuli-Venezia Giulia Region (RSFVG) in May 1977, a better monitoring has been obtained, for very low magnitude as well. The monitored instrumental seismicity is also of low level. In fact, only six events, out of the 77 of low magnitude recorded between May 1977 and the 11th April 1998 in the area of Fig. 3, show a magnitude ranging from 3.0 and 3.1.

Table 1. Earthquakes in the Bovec-Kobarid area. Period 12/04/1998 – 30/06/1998.

N	date	time	MD	rms	lat.	lon.	erh	depth	erz.	gap	Q loc.	plane 1	plane 2	axis P	axis T	axis B	score
				s			km	km	km			str./dip	str./dip	str./dip	str./dip	str./dip	stn/er
1	12/04	10:55:32	5,6	0,9	46,323	13,678	1,6	15,2	1,9	89	C D/B	314/87	224/90	179/02	269/02	040/86	52/0
2	12/04	11:13:28	3,1	0,6	46,282	13,695	1,3	11,7	2,1	101	C D/B	082/53	314/52	198/01	288/70	107/30	11/1
3	12/04	11:50:02	3,1	0,4	46,307	13,612	0,9	11,1	1,3	85	C C/B	158/60	277/49	121/54	220/06	314/34	17/1
4	12/04	12:29:27	3,0	0,4	46,298	13,568	1,0	7,3	2,0	86	C C/B	202/60	337/39	273/12	158/64	008/22	14/1
5	12/04	12:41:06	3,0	0,4	46,325	13,625	0,9	8,3	1,9	87	C C/C	083/18	294/74	217/60	017/29	112/08	18/3
6	12/04	12:43:54	3,2	0,4	46,325	13,632	0,7	5,3	1,7	87	C C/C	075/42	240/49	336/04	094/82	246/08	17/3
7	12/04	13:35:27	3,7	0,3	46,260	13,565	0,7	15,1	0,8	77	B C/A	092/73	200/44	152/17	044/46	251/37	27/2
8	12/04	14:24:08	3,2	0,7	46,297	13,636	1,6	15,3	2,1	89	C D/B	204/46	329/59	187/59	084/08	350/30	17/2
9	12/04	16:15:39	3,5	0,4	46,307	13,600	0,8	14,0	1,2	85	C C/B	088/73	197/44	149/17	040/46	254/35	30/6
10	12/04	20:54:00	3,2	0,3	46,305	13,607	0,7	12,8	1,0	85	C C/B	162/59	291/43	123/61	229/09	324/30	22/2
11	12/04	22:13:47	3,8	0,3	46,313	13,600	0,7	13,7	1,0	85	C C/B	079/57	297/40	186/09	298/68	093/18	31/6
12	13/04	03:23:26	3,2	0,4	46,310	13,605	0,8	11,6	1,1	85	C C/B	140/65	263/41	206/13	096/56	304/26	25/4
13	13/04	04:01:40	3,0	0,3	46,302	13,590	0,6	10,4	1,0	86	B B/B	047/34	293/75	359/23	238/50	104/30	9/0
14	13/04	04:58:42	3,1	0,4	46,313	13,655	0,8	13,5	1,1	87	C C/B	044/21	281/78	212/53	357/31	098/17	18/1
15	13/04	23:06:34	3,0	0,6	46,303	13,625	1,3	10,7	2,1	86	C D/B	151/60	317/30	079/74	236/15	327/07	11/1
16	15/04	16:11:17	3,0	0,6	46,305	13,665	1,1	5.2	2,9	87	C D/B	149/82	258/22	081/49	221/34	325/21	18/2
17	15/04	19:40:30	3,9	0,6	46,268	13,733	1,1	7,7	2,2	87	C D/B	160/54	252/87	021/22	122/27	258/51	32/3
18	15/04	22:42:10	3,7	1,0	46,315	13,693	2,1	11,8	3,6	89	C D/B	307/88	217/90	172/01	262/01	037/87	32/8
19	16/04	17:21:44	3,4	0,5	46,280	13,672	1,0	6,0	2,2	86	C C/C	090/73	352/65	219/05	313/31	121/59	19/1
20	16/04	20:50:54	3,1	0,6	46,298	13,665	1,7	10,9	4,0	129	C D/B	142/62	020/45	257/19	002/56	162/32	16/2
21	17/04	21:59:32	3,0	0,9	46,300	13,672	1,9	11,5	3,0	87	C D/B	142/55	321/35	054/80	232/20	321/00	12/0
22	18/04	10:15:40	3,2	0,5	46,298	13,692	1,0	10,8	2,0	88	C D/B	029/07	284/88	201/46	007/43	104/06	25/4
23	18/04	20:19:56	3,0	0,4	46,272	13,705	0,8	8,0	1,4	86	C C/B	148/80	015/15	044/54	247/34	149/11	18/3
24	18/04	23:17:50	3,0	0,5	46,265	13,700	1,1	11,4	1,7	86	C D/A	098/48	245/47	172/01	079/73	262/18	20/4
25	20/04	21:13:25	3,0	0,4	46,288	13,710	0,9	9,2	1,7	104	C C/B	074/58	293/38	180/10	297/68	087/19	14/1
26	21/04	10:50:37	3,3	0,3	46,325	13,597	0,6	15,1	0,9	86	C C/B	168/52	354/38	056/82	261/07	170/03	26/2
27	22/04	06:56:28	3,7	0,5	46,265	13,692	1,1	14,4	1,4	85	C D/A	309/53	216/86	166/29	269/22	030/50	26/4
28	26/04	21:02:39	3,0	0,4	46,315	13,603	0,8	10,7	1,3	86	C C/B	087/48	273/42	180/03	315/86	090/02	21/2
29	04/05	10:40:35	3,2	0,5	46,282	13,701	1,0	11,4	1,6	87	C D/B	050/23	294/79	228/51	007/31	110/20	18/2
30	06/05	02:53:00	4,6	0,6	46,282	13,717	1,2	10,9	2,3	87	C D/B	307/88	217/90	172/01	262/01	037/88	44/7
31	08/05	10:11:12	3,2	0,5	46,275	13,703	1,0	12,2	1,5	86	B C/A	005/39	168/52	033/79	265/07	175/10	24/3
32	11/05	23:30:48	3,7	0,4	46,275	13,727	0,8	10,8	1,7	87	C C/B	306/80	217/84	171/11	262/03	008/78	28/5
33	13/05	01:58:53	3,5	0,4	46,280	13,715	1,3	12,1	1,8	87	C C/B	329/82	239/90	194/06	284/06	59/80	27/4
34	13/05	21:37:39	3,2	0,5	46,263	13,783	1,1	12,2	1,9	87	C D/B	035/27	236/64	164/69	319/19	052/08	23/5
35	15/05	13:37:48	3,5	0,5	46,305	13,642	1,0	10,7	1,4	86	C C/B	355/87	262/39	232/36	116/31	357/35	26/7
36	24/05	17:45:23	3,1	0,5	46,268	13,685	1,2	12,1	1,5	97	C C/B	084/30	319/72	031/23	261/56	131/23	16/2
37	28/05	12:31:53	3,3	0,4	46,273	13,720	0,7	9,5	1,3	87	C C/B	018/11	287/90	208/44	006/44	107/11	19/3
38	10/06	23:32:41	3,2	0,5	46,292	13,613	1,0	13,5	1,4	85	B C/A	021/30	264/75	205/53	333/25	076/24	27/3
39	12/06	15:21:34	3,1	0,5	46.290	13,672	0,8	7,9	1,8	86	C C/B	344/69	230/43	101/15	210/50	001/36	15/2
40	13/06	18:40:17	3,1	0,4	46,263	13,677	0,8	13,8	1,1	85	B C/A	141/53	311/38	076/82	226/08	316/04	18/1
41	17/06	18:10:09	3,1	0,6	46,297	13,647	1,0	6,0	2,3	86	D D/C	115/82	215/41	175/26	062/39	289/35	21/3

4. The seismic sequence

At 10:55:53 GMT on 12 April 1998 a shock of MD = 5.6, with the epicentre located near Lepena valley at about 10 km SE of Bovec and the hypocentre at a depth of about 15 km, started a seismic sequence (Fig. 3). Out of more than 4000 aftershocks, about 770 events were located up to 31/12/1998. Among the events located, the lowest class of magnitude is equal to 1.7 whereas the most representative classes of magnitude range from 1.9 to 2.5 MD, with a maximum of about 2.0. This confirms the completeness of the data surveyed by the RSFVG.

The sequence analysis is limited from April to June 1998, since this period was considered the most representative (Table 1). All the aftershocks of this period with MD≥3.0 were analysed. The one of greatest magnitude (MD = 4.6) occurred on 06/05/1998 at 02:53:00 GMT.

Most of the seismicity, which was not located, was recorded by only one station or only the two RSFVG stations of Drenchia and Lussari. Quoting the month of April, as an example in this area, after the main event, 2500 aftershocks occurred, but only 455 of them have been located.

Hypocentre determinations have been made using Hypo71 (Lee and Lahr, 1975). Due to the lack of parameters on the crustal structure of this part of the External Dinarides, it was necessary to adopt the crustal model used in RSFVG data processing, calibrated on the neighbouring Eastern Southalpine region.

Besides the RSFVG stations, for hypocentre locations, we used the foreign neighbouring network data. To make the use of all the data homogeneous, it was necessary to introduce a system that could take into consideration the epicentre-station distance. More exactly a full weight was given to all the stations falling within a radius of 100 km from the epicentre, half a weight as far as 170 km and no weight to all the others. The phase reading was done using the program Xpitsa by Scherbaum and Johnson (1993). This method, together with the previously mentioned facts about the crustal model, have certainly introduced some inaccuracy in determining the hypocentre. This could be the reason for some high values of *erh* and *erz,* listed in Table 1.

Focal mechanisms concerning the earthquakes of the sequence are shown in Table 1 and Fig. 4. They have been determined applying FOCPLT (Whitcomb et al., 1973), using the direction of the first motion of P-wave arrivals of 52 Italian and foreign stations; the main focal mechanisms of the sequence (MD ≥ 3.7) with polarities of first arrivals are shown in Fig. 5. The main shock of 12/04/1998 (No. 1, MD = 5.6) shows a pure strike-slip fault mechanism (P = 179/02; T = 269/02) with vertical NW-SE (dextral) and NE-SW (sinistral) planes of motion. The main aftershock of 06/05/1998 (No. 30, MD = 4.6) shows the same focal mechanism, but at a lower hypocentral depth.

Also the nine aftershocks with $3.5 \leq M < 4$ generally present a strike-slip focal mechanism. On the contrary the shocks with $3.0 \leq M < 3.5$ show transtensional or extensional focal mechanism with orientations of planes ranging from NW-SE to NS. This type of focal mechanism prevails over the fault plane solutions typical of low-angle NW-SE to NE-SW trending reverse faults. This fact suggests that the deformation recovery in the crustal volume affected by the main shock may be produced through the reactivation of several pre-existing systems of discontinuity.

5. Seismotectonic analysis

The analysis of the earthquake sequence of Bovec points out that both the main shock and the aftershocks with larger magnitudes show fault-plane solutions that are coherent with the present regional stress field ($\sigma 1$ approximately N-S and sub-horizontal) and the strike-slip tectonic regime of the region. The distribution of epicentres is NW-SE striking, except for event No. 7 located near Kobarid (Fig. 4).

From the tectonic sketch-map (Fig. 2) compiled from Selli (1953), Kuščer et al. (1974), Cousin (1981), Bigi et al., (1990) and Geodetski zavod Slovenije (1993), we can notice in correspondence to the epicentre's alignment an important sub-vertical fault with NW-SE direction, called the Čez Potoče fault (from Potoče Pass, located 2 km north of Krn Mt.), (Winkler, 1923; Cousin, 1981: p. 388 in vol. 1) in literature. In the above mentioned works the fault is drawn as about 20 km long. According to Cousin, this fault cuts the pile of the Paleogene Dinaric nappe, putting the dolomitic successions of the Middle Triassic of the SW block against the Upper Triassic ones of the NE block. According to Cousin this fault became active during the Miocene-Pliocene age. We therefore suggest that the Čez Potoče fault is seismogenetically active as a dextral strike-slip fault and that the Bovec earthquake is to be related to it.

To analyse the distribution of the hypocentres, four vertical seismic sections were realised, the former NW-SE orientated and placed on the trace of the Čez Potoče fault, and the three others perpendicular to it. These latter were not considered here because no significant alignment was observed, apart from a similar concentration of the aftershocks at a 10-12 km depth. Such a type of distribution is more evident on the section A-B that affects the hypocentre zone for all its length (Fig. 6). The hypocentre distribution of the events on the section A-B suggests their temporal migration towards SE along the system of the Čez Potoče fault.

Only a few data on the crustal structure of the study area are available. Aljinović et al. (1984) show that the top of the "acoustic basement" dips steeply from Istria eastwords. In particular the DDS profiles indicate that below NW Slovenia this surface is located at about a 12 km depth. Cati et al. (1987) have observed that the magnetic basement deepens from the central Friuli plain eastwards, and assume that just underneath Cividale, located at about 30 km from the epicentre zone, the top of the magnetic basement is at a depth of more than 9 km. The presence of an important discontinuity at about a 15 km depth in the NW-Slovenian crust, is also confirmed by DDS profiles of Pregolović et al. (1995). Nevertheless these authors interpret this surface as the active plane where the Alpine plate underthrusts the Dinaric one.

6. Macroseismic survey and analysis of the damage

The instrumental epicentre of the 12th April 1998 earthquake was located inside the Triglavski Narodni Park, in a mountainous, not densely populated, area with a very irregular distribution of settlements.

A few days after the event, a macro-seismic survey was carried out in the affected area. On the basis of the data collected, the intensity (Fig. 7) and isoseismal maps (Fig. 8) were obtained.

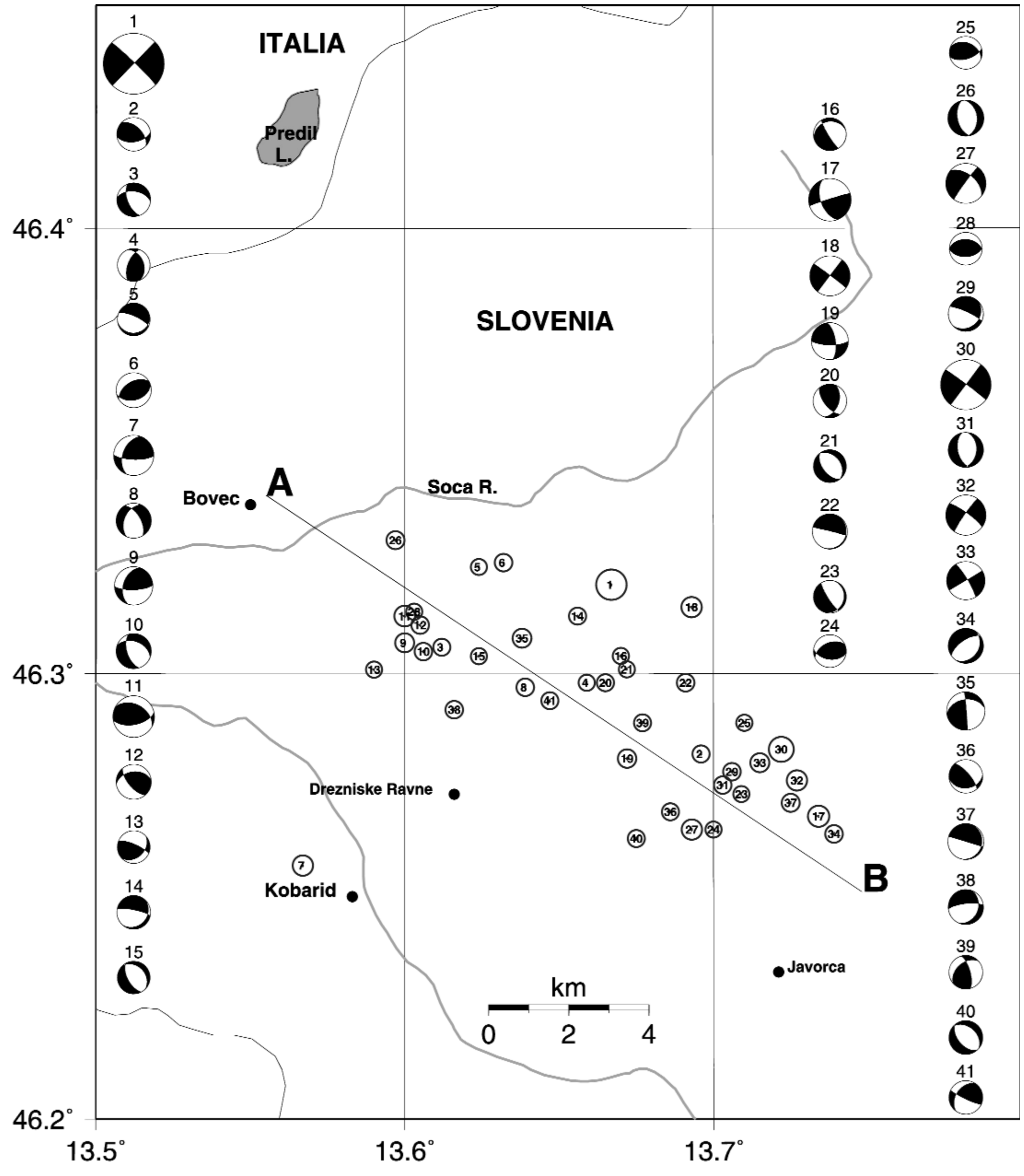

Fig. 4 – Focal mechanisms of events with MD≥3.0. A-B: track of section in Fig. 6.

These maps, clearly show that the macroseismic epicentre is different from the instrumental one: the settlements that suffered damage are located in fact 8-12 km away from the epicentre. The villages most affected were: Drežniske Ravne, Bovec, Javorca and the southern part of the Lepena valley.

Moreover, the widespread phenomena of amplification, due to the geological characteristics of the sites, occurred in this area (Camassi et al., 1998). This phenomenon is very evident at

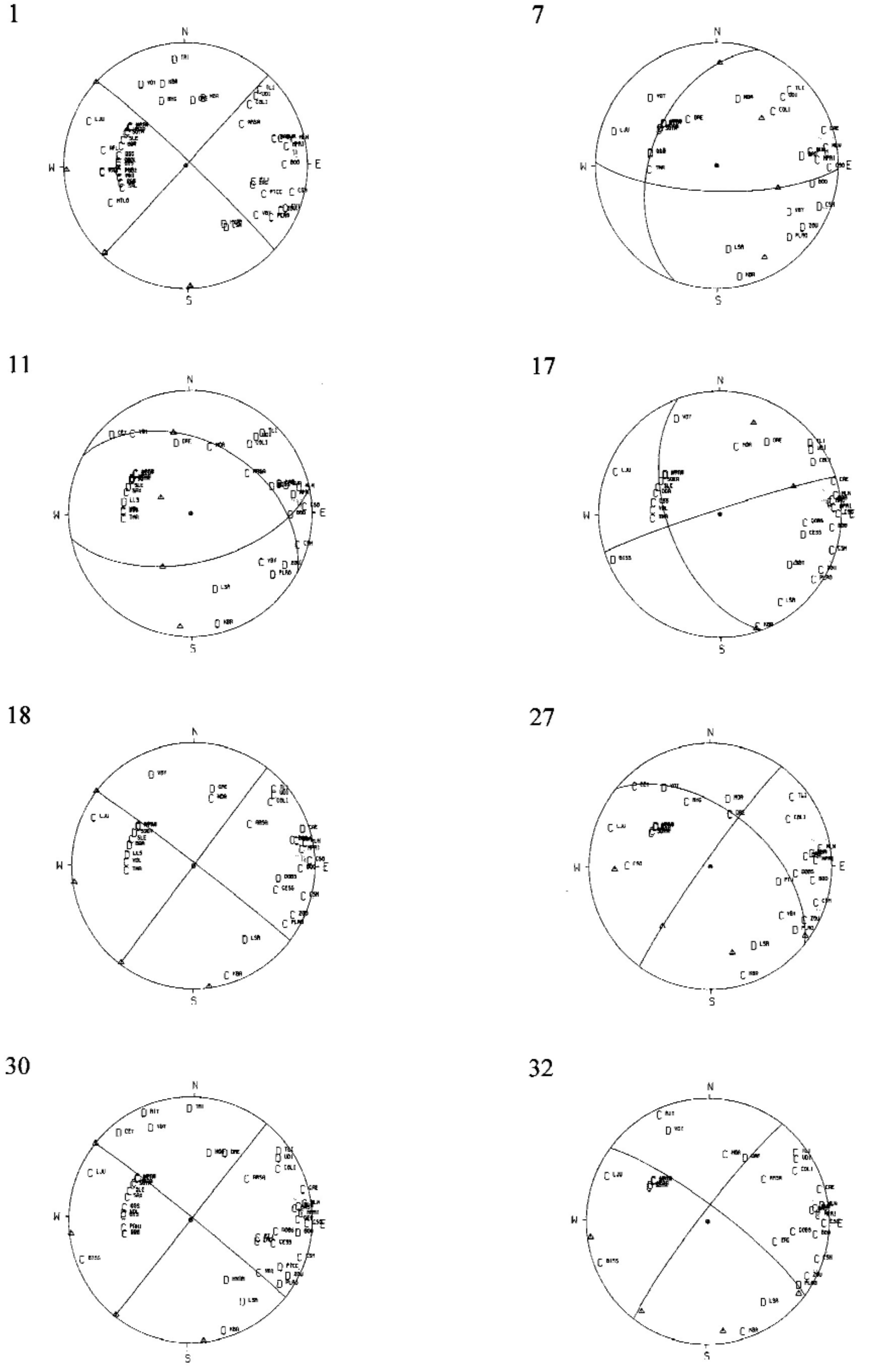

Fig. 5 – Main focal mechanisms (MD≥3.7) of Fig. 4 with polarities of first arrivals; C compression and D dilatation.

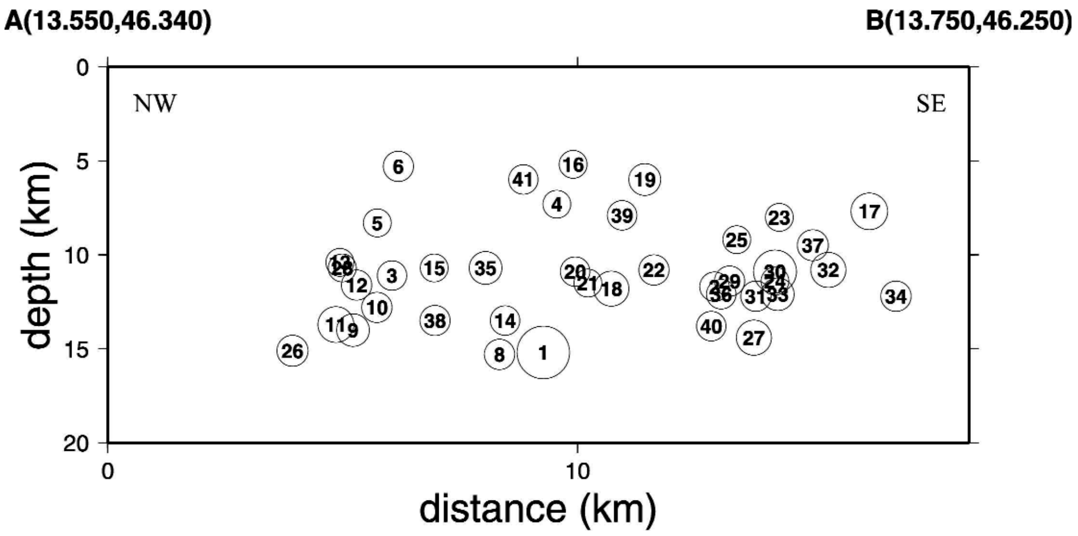

Fig. 6 – Crustal section showing hypocentres of events of MD≥3.0 whose epicentre locations are shown in Fig. 4.

Drežniske Ravne (Fig. 9a) (macroseismic intensity greater than the VIII MCS degree), where 60% of the buildings present serious damage, and 30% suffered large collapses of vertical structures and were therefore demolished.

Evident phenomena of amplification have been observed also in the lower part of Bovec (Mala Vas locality: Fig. 9b), with a macro-seismic intensity estimated at approximately VIII MCS. On the other hand the upper part of Bovec presents extensive but less heavy damage, except for the buildings located on a slope which are characterised by some foundations settlements due to ground instability.

In Javorca (Fig. 9c), where most buildings were conceived in an outdated way or anyway very old and already often in ruins, heavy structural damage occurred, with a partial collapse of roofings and load-bearing walls. Moreover, curbs, rafters and lintels were so damaged that many buildings are irretrievable. The level of damage in this place is estimated at about VIII MCS degree.

The southern side of the Lepena valley (Fig. 9d), a less populated area, presented some damage to buildings which was generally caused by a total collapse of roofs and some load-bearing walls. The estimated macro-seismic intensity here is around VIII MCS degree.

Many rock falls and rock topples occured in the area in general, in particular in the Lepena valley. The large number of landslides is connected both to the diffusion of fractured carbonate lithology and the steepness of the slopes.

It is interesting to note that the isoseismals map (Fig. 8) has a general form which essentially reflects the structural seismogenetic outline one, except for the site effects, particularly evident in the localities of Bovec, Drežniske Ravne and Magozd, where the presence of alluvial sediments with a complex structure, sometimes combined with inadequate care in

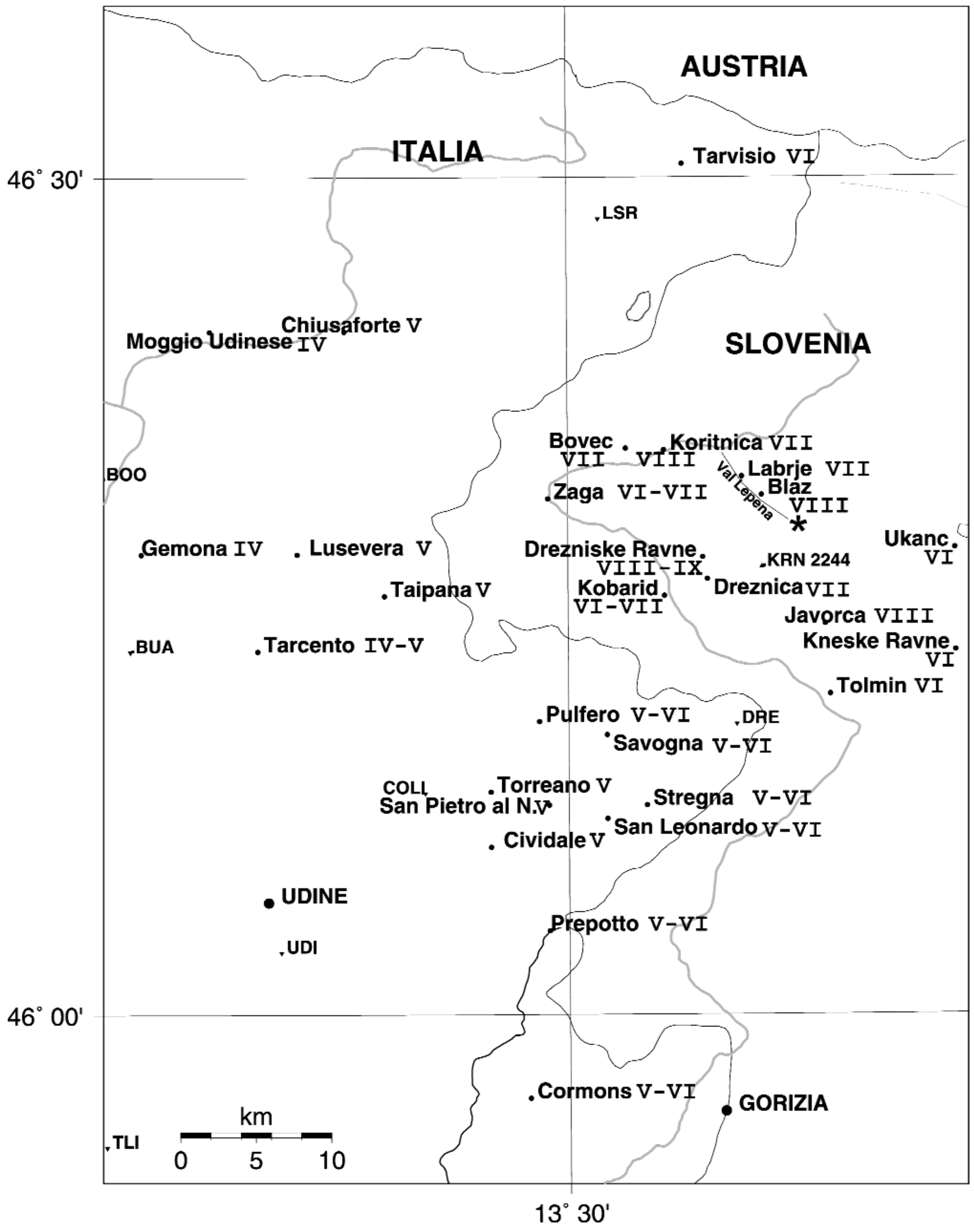

Fig. 7 – Intensity map. An asterisk indicates the instrumental epicentre.

constructionmight have contributed to the irregular distribution of the damage.

Particular care was put into surveying the damage caused within the Italian territory, i.e. in the Friuli-Venezia Giulia region. The most studied zone is the one going from Gorizia to

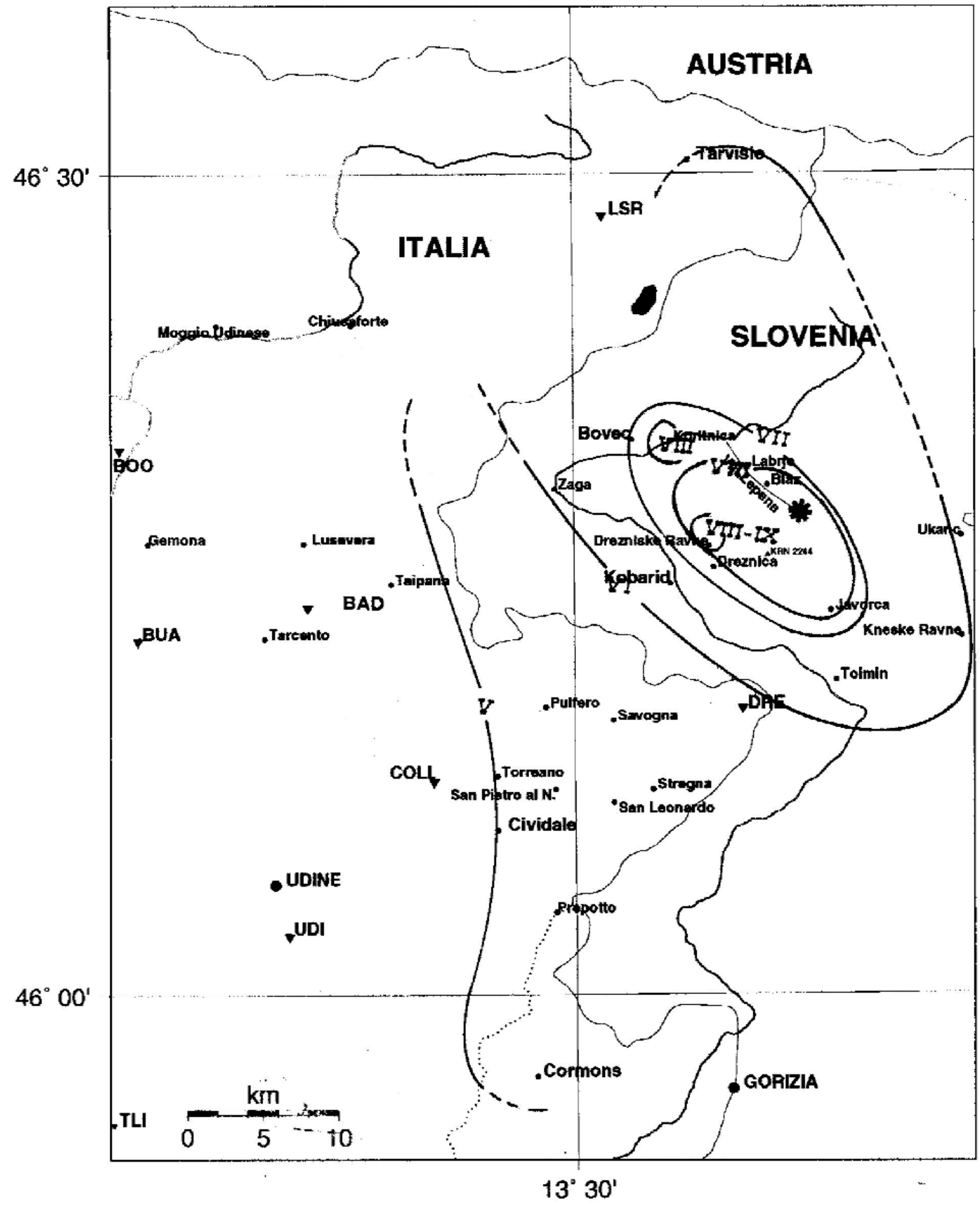

Fig. 8 – Isoseismal map.

Tarvisio. The effects on the populated areas nearest to the epicentral zone were moderate: they don't exceed the V-VI MCS degree.

The eastward concavity of the isoseismals of the V and VI degrees on Italian territory highlights the fact that the mitigation of the damage is related to the better dynamical response of the buildings due to their widespread strengthening after the event of 1976. In fact, the less

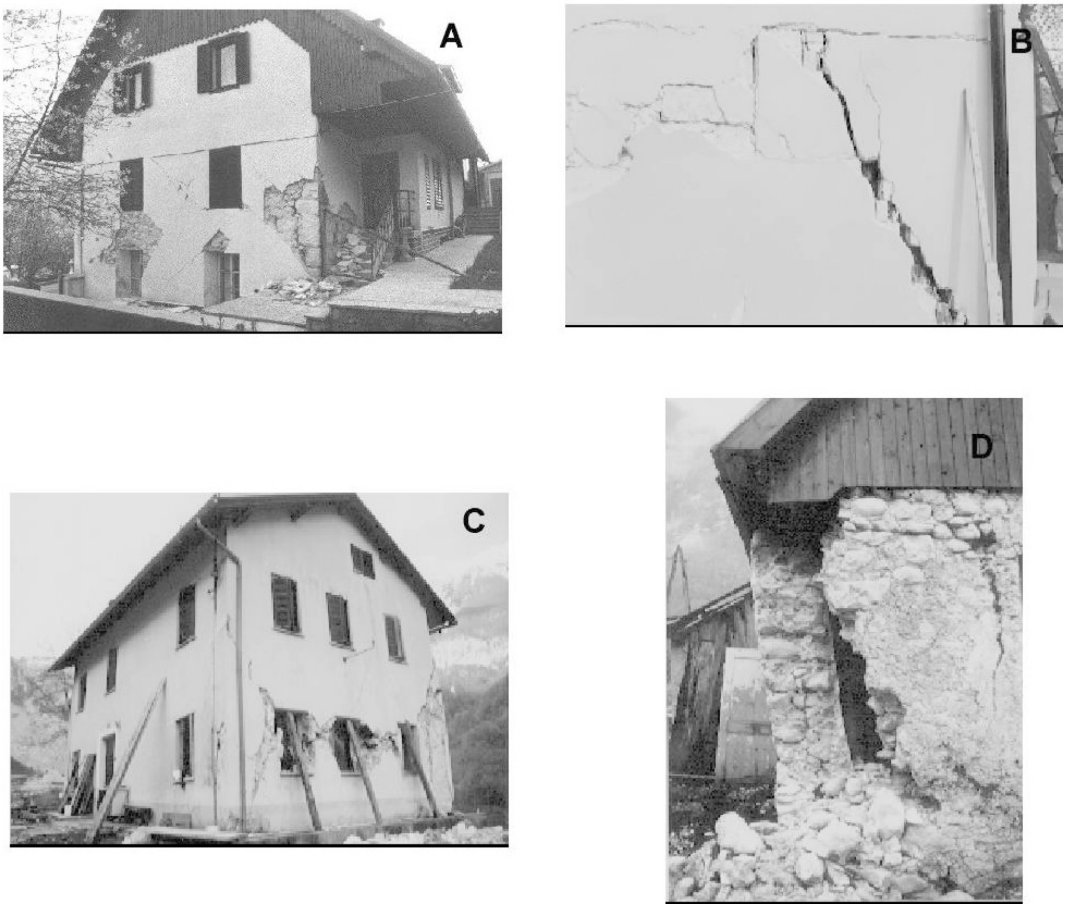

Fig. 9 – Examples of structural damage on buildings in the epicentre zone: Drežniske Ravne (A), Mala Vas (B), Javorca (C) and the Lepena valley (D).

strengthening done in the marginal areas as regards the epicentre of 1976 (near Gemona), justifies the northward extension of the VI degree isoseismal that includes Tarvisio and the V degree ones as far as Cormons. On the contrary, the V degree isoseismal is strongly shifted towards E because in the most affected area of the Friuli quake there was a ful retrofitting of the buildings after the earthquakes that struck the area in 1976.

7. Conclusions

The earthquake that occurred on 12/04/1998 involved a region that was previously considered as having a low seismicity level. Only the earthquake of Idrija, in 1511, which still presents two different epicentre solutions, can represent an important historical record. Therefore, the event of Bovec (MD = 5.6) is important to better classify the seismic hazard of

NW Slovenia.

The dextral strike-slip focal mechanism of the main shock and of the main aftershocks fits into the present kinematic framework of the area. Here a system of dextral NW-SE strike-slip faults acts as tectonic release for the Eastern Southalpine Chain. The Čez Potoče fault, along which the main shock and almost all the aftershocks occurred, belongs to this system and has been identified as the seismogenetic fault.

The macroseismic survey showed that the instrumental epicentre does not coincide with the macroseismic one: the localities with the most damage were Drežniske Ravne, Bovec, Javorca and the southern part of the Lepena valley, which are almost 8 km away from the instrumental epicentre. There were extensive phenomena of site amplification connected to the geological characteristics of the sites.

In the Friuli-Venezia Giulia region the effects of the quake were moderate. The particular pattern of the VI and V MCS degree isoseismals in eastern Friuli, indicates the close connection between the mitigation of the damages and the completeness of the strengthening interventions carried out after the disastrous earthquakes of 1976. This fact once more underlines the importance of retrofitting buildings, particularly the old ones, in order to mitigate the seismic risk.

Acknowledgements. This paper was presented at the GNGTS XVII meeting (Roma, 12-14 November, 1998). The Authors are grateful to C. Cecotti for his useful suggestions. Many thanks to B. Delouis and D. Mayer-Rosa who read the manuscript critically. The work was financed by the CNR/Gruppo Alpi grant (coordinator A. Zanferrari).

References

Aubouin J.; 1973: *Des tectoniques superposées et de leur signification par rapport aux modèles gèeophysiques: l'exemple des Dinarides; paléotectonique, tectonique, tarditectonique, néotectonique*. Boll. Soc. Geol. Fr. (7), XV, 1973, **5-6**, 426-460.

Aljinović B. and Blašković I.; 1984: *Comparison of the basement of sediments and the Mohorovicic discontinuity in the coastal part of Yugoslavia.* In: A. Brambati and D. Slejko (eds): The OGS Silver Anniversary Volume, OGS, Trieste, 1981, 61-67.

Bigi G., Castellarin A., Coli M., Dal Piaz G. V. and Vai G. B.; 1990: *Structural model of Italy, Sh. 2.* Scale 1:500 000. C.N.R. Quaderni Ric. scient., **114**.

Boschi E., Guidoboni E., Ferrari G., Gasperini P. and Valensise G.; 1997: *Catalogo dei forti terremoti italiani dal 461 a. C. al 1990.* Istituto Nazionale di Geofisica, SGA - storia geofisica ambiente, Roma, 644 pp.

Bressan G., Snidarcig A. and Venturini C.; 1998: *Present state of tectonic stress of the Friuli area (eastern Southern Alps).* Tectonophysics, **292 (3-4)**, 211-227.

Buser S.; 1987: *Development of the dinaric and the Juilan carbonate platform and of the intermediate slovenian basin (NW Yugoslavia).* Mem. Soc. Geol. It., **40**, 313-320.

Camassi R. and Stucchi M.; 1996: *NT4.1 un catalogo parametrico di terremoti di area italiana al di sopra della soglia del danno.* (CNR - GNDT, Milano) 1-86.

Camassi R., Monachesi G. and Mucciarelli M.; 1998: *Rapporto preliminare sugli effetti massimi occorsi in occasione del terremoto del 12 aprile 1998 (Alta Valle dell'Isonzo - Slovenia)* http://www.geofisico.wnt.it/latestnews/980412/Slovenja.

Carulli G. B. and Ponton M.; 1992: *Interpretazione strutturale profonda del settore centrale carnico-friulano.* St.

Geol. Camerti, vol. spec. (1992/2), CROP 1-1A, 275-284.

Carulli G. B., Nicolich R., Rebez A. and Slejko D.; 1990: *Seismotectonics of the Northern External Dinarides.* Tectonophysics, **179**, 11-25.

Castellarin A., Cantelli L., Fesce A. M., Mercier J. L., Picotti V., Pini G. A., Prosser G. and Selli L.; 1992: *Alpine compressional tectonics in the Southern Alps. Relationships with the N-Appenines.* Annales Tectonicae, **6**, 62-94.

Cati A., Fichera R. and Cappelli V.; 1987: *Northeastern Italy., Integrated processing of geophysical and gelogical data*. Mem. Soc. Geol. It. **40**, 273-288.

Cousin M.; 1981: *Les rapports Alpes-Dinarides dans les confins de l'Italie et de la Yugoslavie.* Soc. Geol. Nord, 5, vol.I (521 pp) e vol. II (521 pp.).

Del Ben A., Finetti I., Rebez A. and Slejko D.; 1991: *Seismicity and Seismotectonics at the Alps-Dinarides contact.* Boll. Geol. Teor. Appl., **33**, 155-177.

Doglioni C. and Bosellini A.; 1987: *Eoalpine and mesoalpine tectonics in the Southern Alps.* Geol. Rundsch., **76**, 735-754.

Geodetski zavod slovenije; 1993: *Slovenija Geolośka Karta* (1: 500000).

Kušćer D., Grad K., Nosan A. and Ogorolec D.; 1974: *Geology of the Soća valley between Bovec and Kobarid*. Geologija-Razprave in Poroćilia.

Lee W. H. K. and Lahr J. C.: 1975: *HYPO71 Revised: a computer program for determining hypocenter, magnitude and first motion pattern of local earthquakes*. U.S.G.S. open file report 75-311, Menlo Park, 113 pp.

Massari F.; 1990: *The foredeeps of the northern Adriatic margin: evidence of diachroneity in deformation of the Southern Alps.* Riv. It. Paleont. Strat., **96**, 351-380.

Mlakar I.; 1969: *Krovna zgradba idrijsko zirovskega ozemlja. - Nappe structure of the Idrija-Ziri region*. Geologija, **12**, 5-72.

OGS; 1977 - 1998: *Bollettino della Rete Sismometrica del Friuli-Venezia Giulia.*

Poli M. E. and Renner G.; 1998: *Meccanismi focali distensivi e tettonica a strike-slip duplex estensionali nelle Prealpi Giulie (Italia NE- Slovenia NW).* Riassunti 17° Convegno Naz. Gruppo Geof. Terra Solida, Roma 10-12 novembre 1998, 143-145.

Poli M. E. and Zanferrari A.; 1995: *Dinaric thrust tectonics in the Southern Julian Prealps (Eastern Southern Alps, NE Italy).* In: First Croatian Geological Congress, Opatija 18-21 october 1995, Proceedings, **2**, 465-468, Zagreb.

Pregolovič E., Aljinovič B. and Bahun S.; 1995: *New data on structural relationships in the North Dalmatian Dinaride Area.* Geol. Croat., **48/2**, 167-176.

Renner G. and Slejko D.; 1994: *Some comments on the seismicity of the Adriatic region.* Boll. Geof. Teor. Appl., **36**, 141-144.

Sartorio D., Tunis G. and Venturini S.; 1997: *The Iudrio valley section and the evolution of the northeastern margin of the Friuli Platform (Julian Prealps, NE Italy-W Slovenia).* Mem. Soc. Geol., **49**, 163-193.

Scandone P.; 1997: *Linea di Ricerca 2 "Sismotettonica".* In: A. Corsanego, E. Faccioli, C. Gavarini, P. Scandone, D. Slejko and M. Stucchi (eds), L'attività del GNDT nel triennio 1993-95, (CNR - GNDT, Roma), 67-96.

Scherbaum F. and Johnson J.; 1993: *PITSA, Programmable Interactive Toolbox for Seismological Analysis, IASPEI Software Library Vol. 5.*

Selli R.; 1953: *La geologia dell'alto bacino dell'Isonzo.* Giornale di Geol., **2**, 19.

Slejko D., Carulli G. B., Nicolich R., Rebez A., Zanferrari A., Cavallin A., Doglioni C., Carraro F., Castaldini D., Iliceto E., Semenza E. and Zanolla C.; 1989: *Seismotectonics of the Eastern Southern-Alps: a revew.* Boll. Geof. Teor. Appl., **31**, 109-136.

Venturini C.; 1990: *Cinematica neogenico-quaternaria del Sudalpino orientale.* Studi Geol. Camerti vol. Spec. In: M. Boccaletti, G. Deiana and G. Papani (eds), Atti conv. Neogene thrust Tectonics, 109-116.

Whitcomb J. H.; 1973: *Part I. A study of the velocity structure of the Earth by the use of core phases. Part II. The 1971 San Fernando earthquake series, focal mechanisms and tectonics.* Ph. D. thesis, California Institute of Technology.

Winkler A.; 1923: *Ueber den Bau der östlichen Südalpen*. Mitt. Geol. Gesell., **XVI**, 1-272.