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Seismicity of Croatia in the period 1993–1996 and the Ston-Slano earthquake of 1996

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Seismic activity in Croatia and surrounding areas in the 1993–1996 period was mostly confined to the previously identified seismically active areas. Nine events (excluding aftershocks) with the magnitude equal to or exceeding 4.5 occurred during that time. The most important earthquake sequence is the one that started on September 5, 1996 (M_L = 6.0, I_o = VIII °MSK) in the Ston-Slano area (greater Dubrovnik region). Microseismic locations of hypocenters of thousands of aftershocks, as well as the the best double-couple CMT solution for the main-shock indicate that the earthquakes occurred on the NW–SE striking reverse fault system dipping towards NE.

Keywords: Seismicity, Croatia, Ston-Slano earthquake

1. Introduction

As a part of the Mediterranean zone of the Alpine-Himalayan seismic belt, Croatian territory comprises several distinct geotectonic units of which the most important are: the Pannonian Basin, the Eastern Alps, the Dinarides, the transition zone between the Dinarides and the Adriatic Platform, and the Adriatic Platform itself. The seismicity is mostly expressed in the coastal part (the Dinarides), because of tectonic processes related to the collision of the Adriatic Platform and the Dinarides (e.g. Prelogović et al., 1982; Aljinović et al., 1984; Herak, 1986; Anderson and Jackson, 1987). The Pannonian Basin is characterized by rare occurrence of large events which is typical of intraplate seismicity.

The aim of this paper is to summarise the regional seismicity in the period 1993–1996 and to analyse the most important events, thus continuing the work on the compilation of earthquake catalogues with epicenters in Croatia and the surrounding areas, which began under the UNDP/UNESCO project of exploration of seismicity in the Balkan region, for the period 1901–1970 (Part I) and before 1901 (Part II) (Shebalin et al., 1974). The Croatian seismicity for the years 1986 through 1992 was described by Herak and Cabor (1989), Markušić et al. (1990), Herak et al. (1991) and Markušić et al. (1993). Based on those papers and other available data Herak et al. (1996) revised the Croatian Earthquake Catalogue for the period 1908–1992.

The data presented in this paper of the 1993-1996 period have been compiled and processed for all recorded earthquakes in Croatia, regardless of the magnitude. The map of epicenters shows the locations of all epicenters (Fig. 1). Special attention was paid to the earthquakes with magnitudes greather or equal to M_L = 4.5 (see Table 1), especially the Ston-Slano earthquake that occurred in the greater Dubrovnik area in 1996. Individual earthquakes have also been macroseismically analysed.

Table 1. Hypocentral parameters for earthquakes with magnitude $M_L \geq 4.5$ in Croatia and the surrounding areas during the 1993–1996 period.

Date	Origin time (UTC)			Epicenter		Depth (km)	M_L	I_{max} (°MSK)
	h	m	s	φ (N)	λ (E)			
1993, May 29	8	43	11.1	45.552	15.285	13.3	4.6	VI–VII
1993, June 01	19	51	9.9	46.232	16.547	18.8	4.7	VII
1994,February 25	16	3	5.9	43.654	16.679	10.6	4.6	VI
1994, May 22	22	56	47.7	43.075	17.124	6.7	4.6	V–VI
1995, May 22	12	50	30.9	45.640	14.246	18.0	4.6	VI
1995, July 15	6	45	22.2	42.713	17.469	3.2	4.7	VI–VII
1995, August25	9	27	20.9	45.407	17.694	18.8	4.8	VII
1995, September 28	23	44	41.8	42.604	18.134	4.6	5.0	VI
1996, September 5	20	44	9.0	42.755	17.898	10.5	6.0	VIII
1996, September 5	21	43	31.5	42.779	17.769	9.3	4.9	–
1996, September 6	3	31	52.3	42.745	17.818	13.1	4.7	–
1996, September 7	4	17	55.9	42.782	17.765	11.3	4.5	–
1996, September 7	5	45	33.5	42.811	17.826	7.8	4.5	–
1996, September 9	15	57	5.4	42.729	17.782	7.5	5.0	VII
1996, September 10	5	9	26.4	45.420	16.265	16.0	4.5	VI
1996, September 17	13	45	23.1	42.784	17.928	16.4	5.1	–
1996, October 20	15	0	2.9	42.755	17.868	10.1	4.6	VI

2. Data and method

In order to determine the earthquake parameters, the phase arrival time data were collected by analyzing the set of original seismograms from the permanent and temporary seismological stations in Croatia. Those data were supplemented by readings reported in monthly bulletins of seismological stations in the neighbouring countries. For each earthquake five main parameters were determined: hypocentral time, epicentral latitude, epicentral longitude, focal depth and earthquake magnitude (M_L).

Hypocentral time and coordinates of the focus were determined by the HYPOSEARCH method (Herak, 1989) using the three-layered model published by B.C.I.S. (1972) and both P- and S-waves arrival times. The exceptions were the Central Adriatic earthquakes and the earthquakes in the central part of the External Dinarides, where the velocity models published by Herak (1990) and Herak et al. (1988) were used.

Whenever the information about the felt earthquake was received, the macroseismic investigations were carried out. The macroseismic data obtained by fieldwork and/or by the questionnaires received from the shaken areas were compiled. The intensities were estimated according to the MSK scale whenever the data required in its definition were available (e.g. the quantitative description of damages). In all other cases MCS scale was used. When the description of the macroseismic effects of an earthquake was sufficiently detailed, isoseismal maps were drawn. The shapes of macroseismic areas were generally irregular and asymmetrical reflecting the existence of main geological structures of the respective area (faults, mountain belts). The 8 intensity maps and related details are given in the following sections.

A total of 4193 earthquakes (for which at least 6 onset time readings were available) were located in Croatia and the surrounding areas in the period 1993–1996 (Fig. 1). The completeness threshold (M_{LC}) of the obtained earthquake catalogue may be estimated by using the formula (Aki, 1965; Zhang and Song, 1981):

$$b = \frac{\log e}{\mathrm{M_L} - \mathrm{M_{LC}}} \frac{N-1}{N} \tag{1}$$

which gives the maximum likelihood estimate of the value of the coefficient b in the Gutenberg-Richter's (1944) relation. In the above expression M_L denotes the mean magnitude of all earthquakes in catalogue which satisfy $M \geq M_{LC}$ and N is the number of such earthquakes. Fig. 2 presents b-values as computed by (1) for several assumed values of M_{LC}. It is seen that for $M_{LC} \geq 2.9$ coefficient b assumes almost constant value, so we may assume the catalogue to be complete for the magnitudes M_{LC} greater or equal to 2.9.

3. Features of Croatian seismicity in the period 1993–1996

The basic characteristic of the regional seismicity in the period 1993–1996 is the concentration of epicenters in particular areas and localities, as can be seen on the epicentral map (Fig. 1).

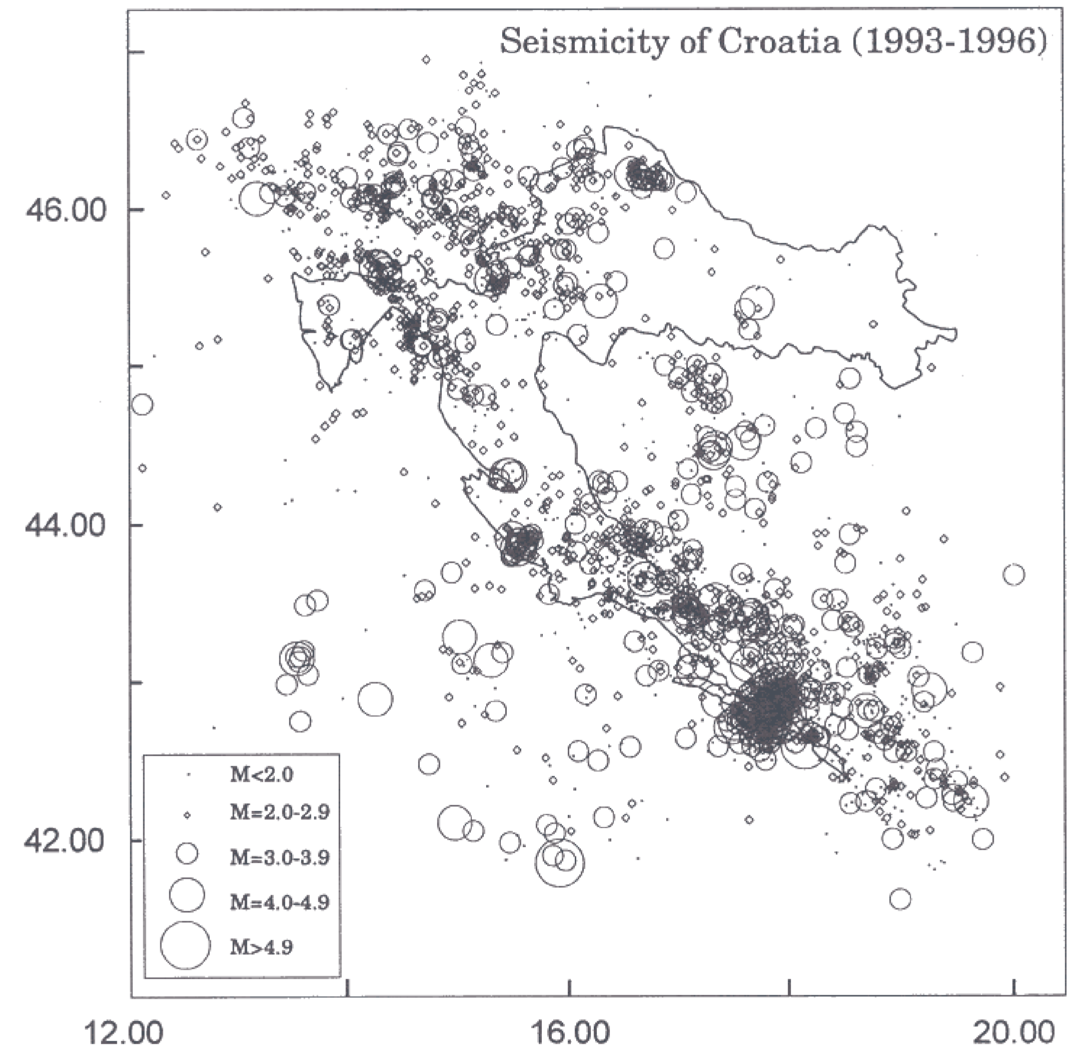

Figure 1. Map of epicenters in Croatia and the surrounding areas in the period 1993–1996.

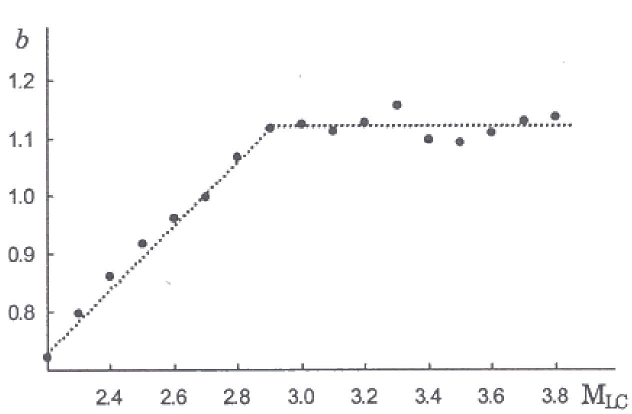

Figure 2. The b-values for the 1993–1996 period for several assumed catalogue completeness thresholds, M_{LC}.

Regarding the concentration of earthquakes, the analysis of seismicity was confined to two areas: (1) the continental part of Croatia, where only $M_L \leq 4.8$ earthquakes occurred, and (2) the coastal part of Croatia, where the magnitudes ranged up to 6.0.

3.1. Continental part of Croatia

This zone covers the western part of the Dinarides, the western margin and the southern part of the Pannononian Basin. The tectonic and structural relationships within this zone are rather complex. The primary faults related to the western margin of the Pannonian Basin strike NE–SW, while those associated with the deep structures of the link between the Eastern and the Western Dinarides strike NNE–SSW. The faults striking NW–SE and W–E occur as a consequence of the Dinarides and Alpine related movements, respectively (Šikić, 1976).

The most significant seismically active areas in the continental part of Croatia were those of Požega, Ludbreg, Ribnik and Petrinja.

In the *epicentral area of Požega* a small earthquake sequence was recorded during June 1993, with magnitudes up to $M_L = 3.3$. The strongest earthquake in the continental part of Croatia during the observed 1993–1996 period occurred on August 25, 1995 at 09:27 ($M_L = 4.8$, I_{max} = VII °MSK) in the vicinity of Požega. Within two days, the strongest shock was followed by a small group of very weak events. The main shock was recorded by many seismological stations all over Europe. 95 P and S onset time data were collected for locating the epicenter (Table 1). The azimuthal gap was 59. The event was felt throughout the continental part of Croatia and the surrounding areas in Bosnia and Herzegovina and in Hungary. The heaviest damage was reported in Novi Mihaljevci, where macroseismic investigations revealed that large and extensive cracks, a few centimeters wide, occurred in the walls of some old low quality brick masonry buildings. On some buildings, with reinforced concrete frame and brick infill walls, 1 mm wide cracks occurred, and mortar fell from the walls. The map of isoseismals is displayed in Fig. 3. As it can be seen, the microseismic epicenter lay within the pleistoseismal, very close to the highest reported intensities. The isoseismals are strongly elongated in the NNW–SSE direction. It seems that, according to the map of the most important seismogenic faults (Fig. 4) this earthquake was generated within a system of reverse faults to the NW of the epicentre.

Seismic activity in the *Ludbreg epicentral area* was a continuation of an intense seismic activity in this area since 1988. It was the most seismically active area in the continental part of Croatia during the observed 1993–1996 period. The strong seismic activity began in March 1993, with a series of 23 earthquakes (the strongest event occurred on March 16, 1993 at 22:43 with the magnitude $M_L = 3.7$) that preceded a greater earthquake sequence in

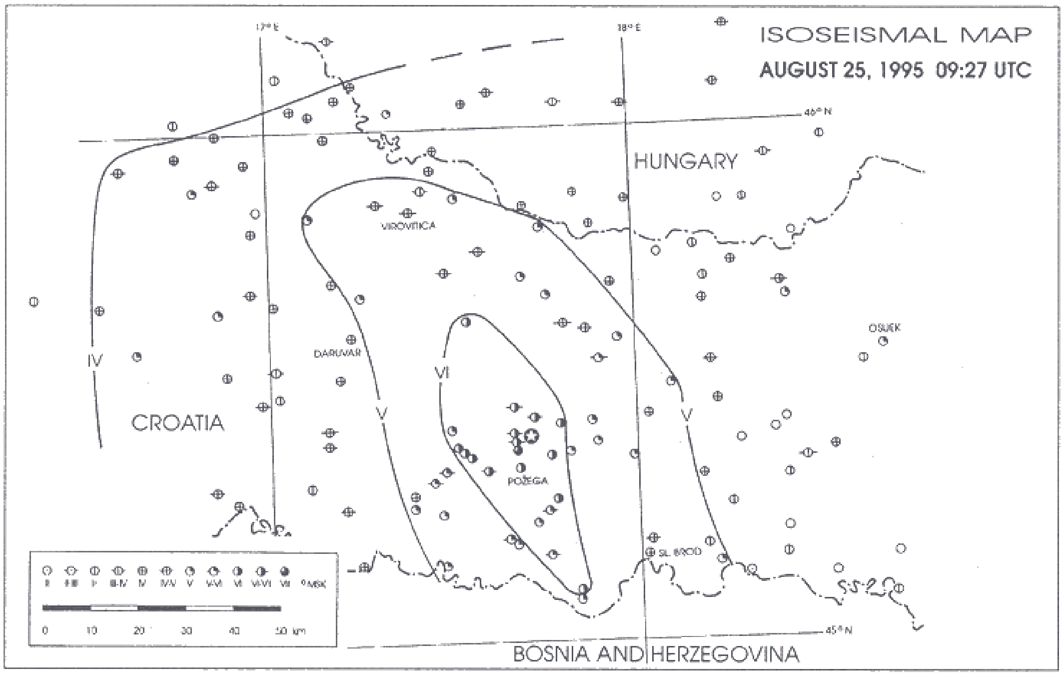

Figure 3. Isoseismal map for the Požega earthquake of August 25, 1995 (09:27). The white star indicates the position of the microseismic epicenter.

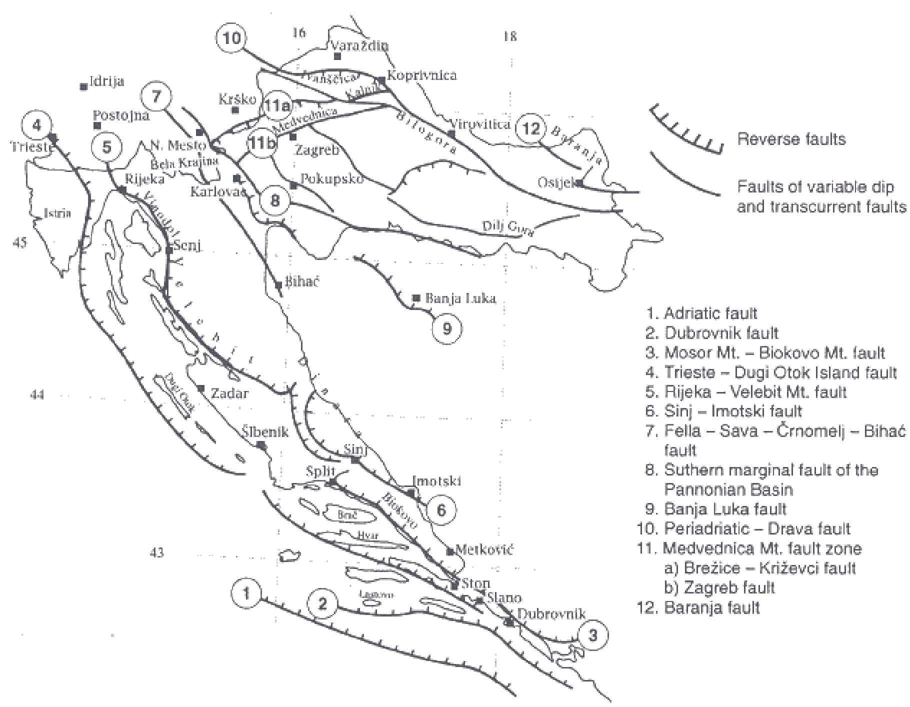

Figure 4. Map of the most important seismogenic faults (after Markušić and Herak, 1998).

June 1993. These foreshocks occurred to the east of the main shock, spreading in the N–S direction. The main shock occurred on June 1, 1993 at 19:51 with the epicenter near Ludbreg (M_L = 4.7, I_{max} = VII °MSK). Hypocenter location (Table 1) was calculated by using 108 P and S onset data. The azimuthal gap was 46. The event was widely felt in the northwestern part of Croatia, in the western part of Slovenia, and in the border areas of Hungary and Austria. The maximum intensity of VII °MSK was reported in Duga Reka, Radljevo Selo and Ribnjak, where parts of chimneys on some old houses fell down and a few centimeter wide cracks occurred in some structural walls. The tiles slipped off the roofs and fairly large pieces of mortar fell from the walls. On an old house in Ribnjak one brick wall was driven out a few centimeters. The distribution of intensities and the isoseismals are displayed in Fig. 5. The microseismic epicenter of the main shock along with the majority of fore- and aftershock epicenters are located in the zone where the Periadriatic Drava fault system and the faults from the Medvednica zone meet (Fig. 4). Isoseismals are elongated in the NW–SE direction along the Periadriatic Drava fault, though the straightening of the VI° and V° isoseismals on its southeastern side is probably caused by the transversal faults that strike SW–NE along Kalnik and Medvednica (Fig. 4). The available FPS (Herak et al., 1995) indicates that reverse faulting with a left-lateral strike slip compo-

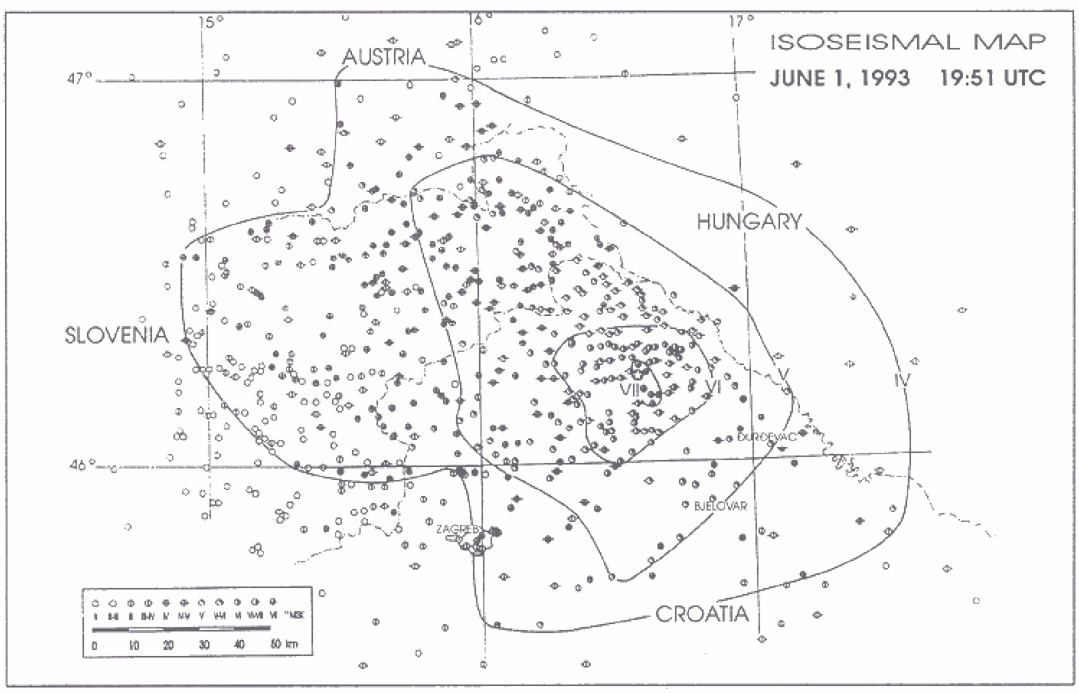

Figure 5. Isoseismal map for the Ludbreg earthquake of June 1, 1993 (19:51). The microseismically located epicenter is shown by the white star.

nent occurred, probably on a part of the SW–NE striking regional fault system. The main shock was followed by an aftershock activity that lasted for about a month. We were able to locate 42 aftershocks with magnitudes up to M_L = 3.8 till the end of the year. After the 1993 earthquake sequences this area was rather quiet, with only nine recorded earthquakes ($M_L \leq 2.9$).

The *epicentral region of Ribnik*, situated at the border area between Croatia and Slovenia, experienced a notable seismicity during May 1993, when the strongest event (M_L = 4.6) during 1993–1996 period occurred on May 29, 1993 at 8:43. (Table 1) The location of focus was calculated on the basis of 119 P and S onset time data, with a small azimuthal gap (Gap = 41°). Macroseismic investigations were carried out, but due to wartime circumstances in Croatia it was impossible to collect data from some Croatian regions. The maximum reported intensity was I_{max} = VI–VII °MSK in Lipnik, where mortar fell from the church ceiling and some walls cracked. In Ribnik some tiles slipped off the roofs. The isoseismal map is presented in Fig. 6. According to the map in Fig. 4, there are two longitudinal faults (Fella-

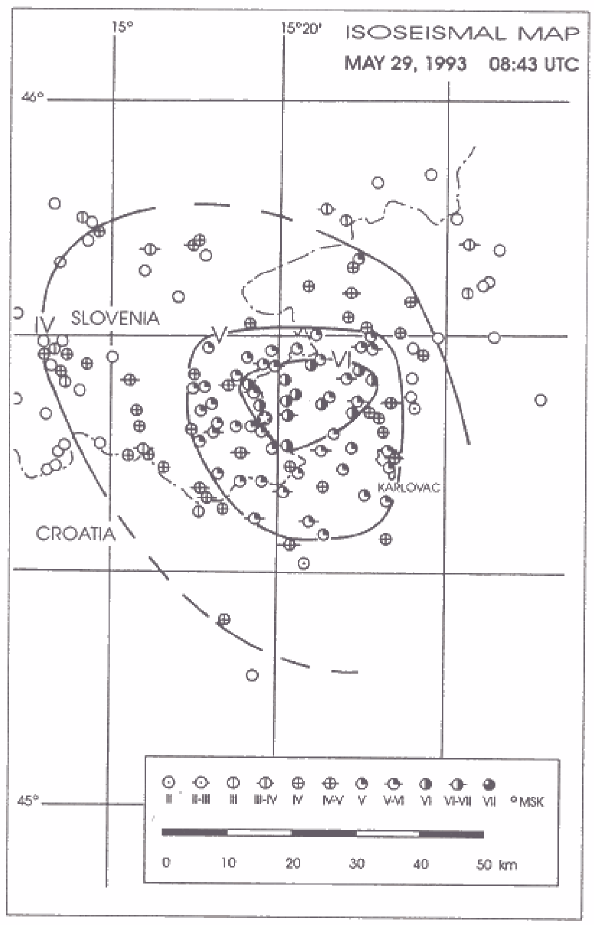

Figure 6. Isoseismal map for the earthquake which occurred in the Ribnik area on May 29, 1993 (08:43). The white star indicates the position of the microseismic epicenter.

Sava-Črnomelj-Bihać fault and the southern marginal fault of the Pannonian Basin) in the area enclosed by the V° isoseismal. It seems that this fault system is responsible for the efficient seismic energy propagation in the NW–SE direction. The microseismic epicenter is located within the pleistoseismal. The pleistoseismal elongation in the NE–SW direction could have been caused by the local soil conditions.

The *Petrinja epicentral area* was mostly quiet during the observed period with the exception of one strong event. It occurred on September 10, 1996 at 5:09 with magnitude $M_L = 4.5$ (Table 1). The results of macroseismic field investigations revealed the maximum intensity of VI °MSK in Sisak, Petrinja, Graberje, Drenova, Glina, Novoselci, Komarevo and Velika Svinjička. Considerable damage was reported from the shaken area, although it was not easy to distinguish the damage caused by an earthquake from that caused by the war. The roof-tiles slipped off some old houses, parts of chimneys fell down, mortar fell from walls and ceilings, cracks in mortar occurred (Sisak, Petrinja, Drenova, Graberje) and some smaller objects in houses overturned (Komarevo, Velika Svinjička). The map of isoseismals is displayed in Fig. 7. The microseismic epicenter is located within pleistoseismal near the longitudinal fault (Fig. 4) which is probably responsible for the occurrence of this earthquake.

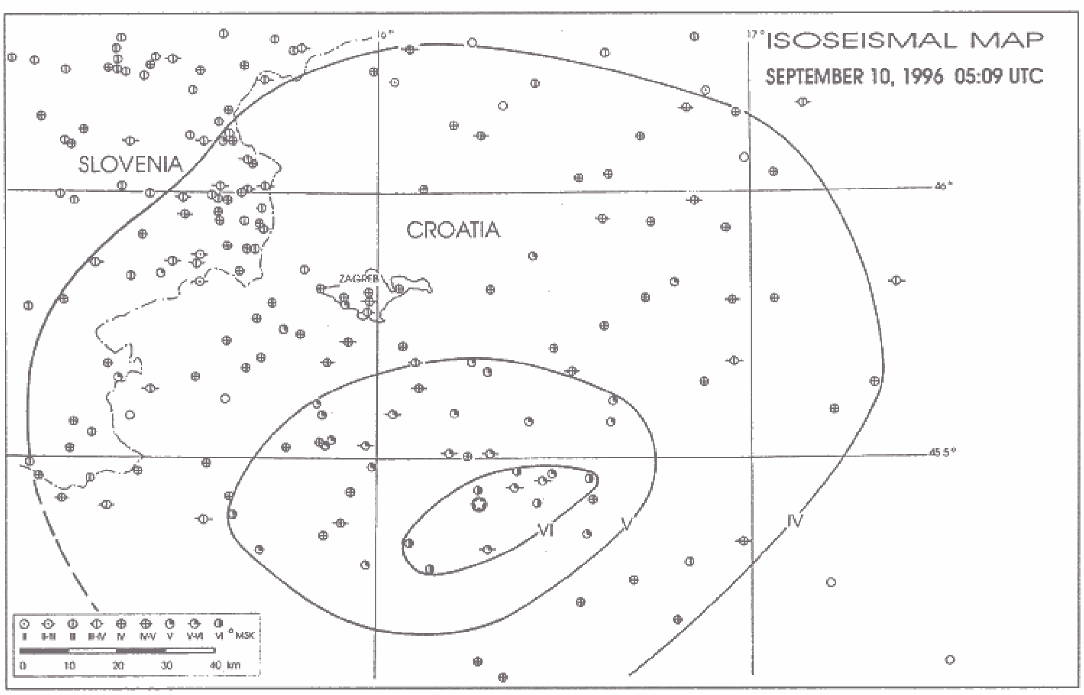

Figure 7. Isoseismal map for the Petrinja earthquake of September 10, 1996 (05:09). The microseismically located epicenter is shown by the white star.

3.2. Coastal part of Croatia

As a result of intense seismicity originated by the subduction of the Adriatic microplate under the Dinaric massif, the most seismically active area in Croatia is its coastal part with the Dinaric mountains. The most significant seismically active areas during 1993–1996 period were Rijeka, Sinj-Dinara Mt., the Neretva Channel, Mljet, Dubrovnik and Ston-Slano.

The *greater Rijeka epicentral area* spreads in the NW–SE direction from Ilirska Bistrica in Slovenia towards Crikvenica and Krk island following the Rijeka-Velebit fault (Fig. 4). The event that occurred on May 22, 1995 at 12:50 with magnitude M_L = 4.6 and maximum intensity I_{max} = VI °MSK (Table 1) near Ilirska Bistrica in Slovenia was the strongest earthquake recorded in this area during the 1993–1996 period. It was strongly felt in Rijeka and its surroundings. The intensity of V–VI °MSK was reported in Mučići near Rijeka. The calculated FPS (Herak et al., 1995) for this earthquake indicates faulting with a right-lateral component, that occurred in the seismotectonically active zone between the Trieste-Dugi otok fault and the Rijeka-Velebit fault (Fig. 4). In the northern part of the island of Krk, weak earthquakes with magnitudes up to M_L = 3.7 were frequently recorded.

The belt of the highest seismic activity in Croatia stretches southeastwards from the Dinara Mt., through the carst fields of Sinj and Imotski towards the Pelješac peninsula and Dubrovnik.

Significant seismic activity of the *Sinj-Dinara Mt. area* during the 1993–1996 began in February 1994 in the vicinity of Sinj. The strongest event occurred on February 25, 1994 at 16:03, with magnitude M_L = 4.6 and maximum intensity of I_{max} = VI °MSK (Table 1). The macroseismic field survey shows that mortar fell from walls, walls cracked and some smaller objects overturned (Sinj). The isoseismal map is displayed in Fig. 8. The microseismic epicenter is located within the pleistoseismal near the Sinj-Imotski fault system (Fig. 4). The published fault-plane solution (Herak et al., 1995) is poorly constrained, and indicates right-lateral faulting on a nearly vertical NW–SE striking fault.

Seismic activity in the *Neretva channel area* during the observed period was expressed mainly in 1994, when on May 22 at 22:56 the strongest event occurred with magnitude M_L = 4.6 and maximum intensity of V–VI °MSK (Table 1). The collection of macroseismic data was restricted by the fact that the microseismic epicenter is located in the sea. The event was strongly felt in Gradac where window-panes and glassware rattled, freely hanging objects swung, furniture trembled and many people ran outdoors. There was no reported damage. The intensity distribution is shown in Fig. 9. The earthquakes in the southern coastal part of Croatia are generally assumed to be generated on the system of reverse faults striking in the NW–SE direction (Adriatic fault, Dubrovnik fault and Mosor Mt.-Biokovo Mt. fault, see Fig. 4).

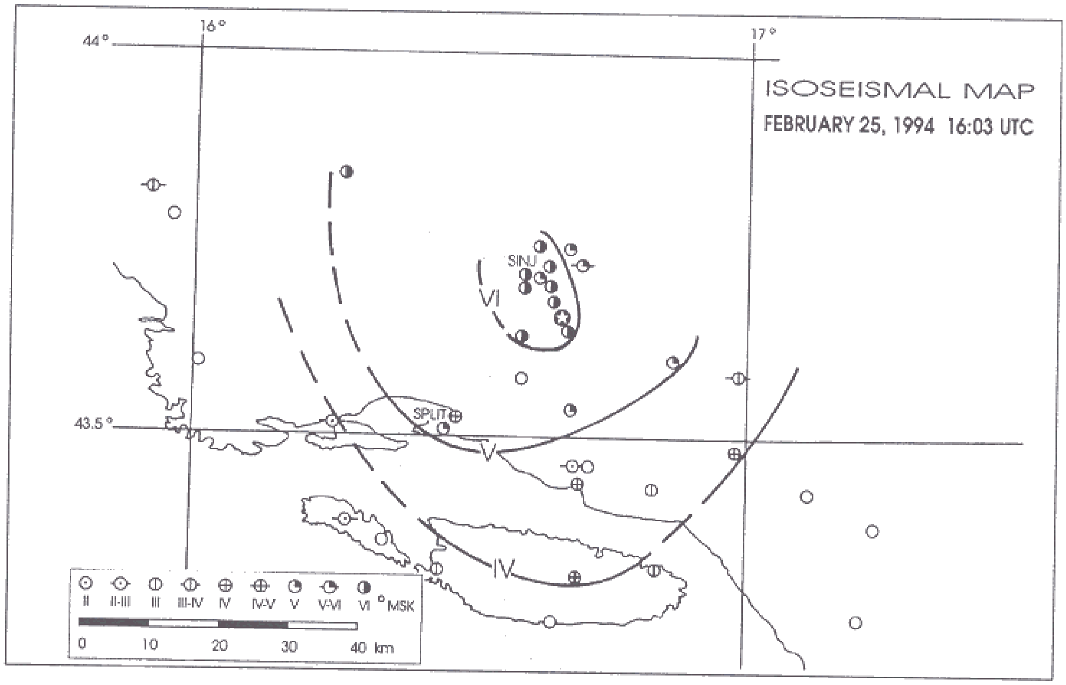

Figure 8. Isoseismal map for the Sinj earthquake of February 25, 1994 (16:03). The white star indicates the position of the microseismic epicenter.

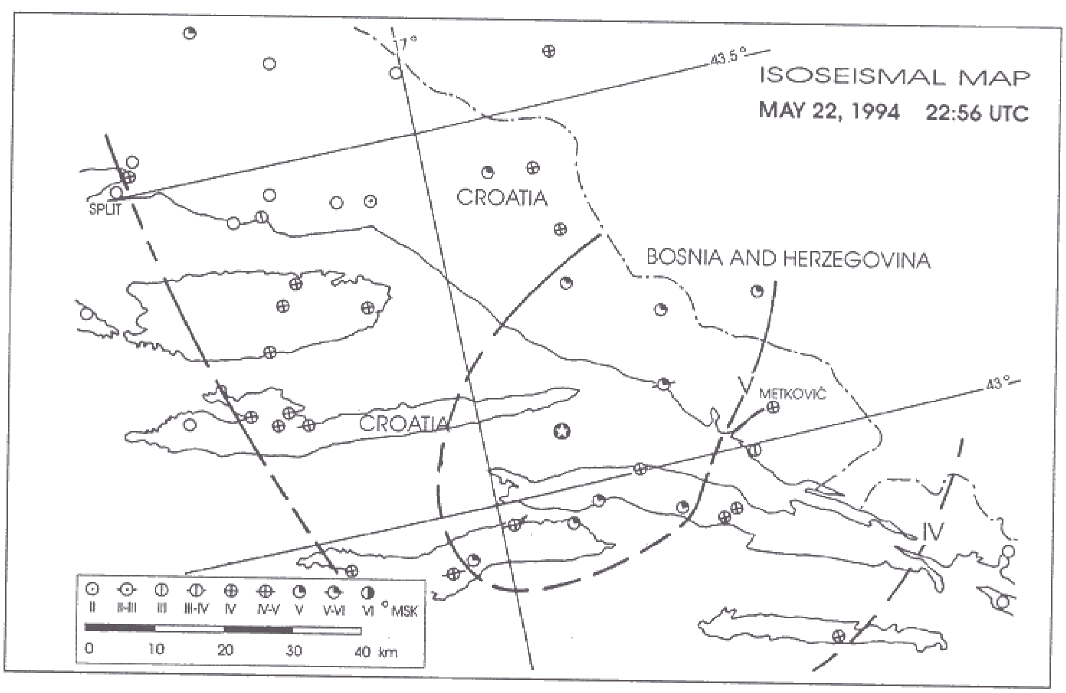

Figure 9. Isoseismal map for the earthquake which occurred in the Neretva channel area on May 22, 1994 (22:56). The microseismically located epicenter is shown by the white star.

The strongest event in the *Mljet epicentral area* occurred on July 15, 1995 at 6:15 in the vicinity of Mljet island with magnitude $M_L = 4.7$ (Table 1). The earthquake could not be macroseismically processed because of the data deficiency caused by the fact that the event occurred under the sea. The highest reported intensity was I_{max} = VI–VII °MSK in Ston where one simple stone masonry building was highly damaged. Aftershock sequence of 23 earthquakes occurred within a few days after the main shock.

The *Dubrovnik epicentral region* exhibited significant seismic activity that began with the strongest earthquake on September 28, 1995 at 23:44 ($M_L = 5.0$, I_{max} = VI °MSK). Hypocenter location (Table 1) was calculated by using 102 P and S onset data. The azimuthal gap was 45°. Macroseismic investigations revealed that the highest intensities were reported in Trsteno, Mokošica and Dubrovnik where tiles slipped from the roofs, mortar fell from the walls, some walls cracked and some smaller objects overturned. The intensity distribution is presented in Fig. 10. The microseismically located epicenter is placed within pleistoseismal close to the Dubrovnik fault (Fig. 4) which seems to be responsible for the occurrence of this earthquake. The shape of isoseismals strongly indicate that seismic energy was propagated along reverse fault zone (Dubrovnik fault and Mosor Mt.-Biokovo Mt. fault)

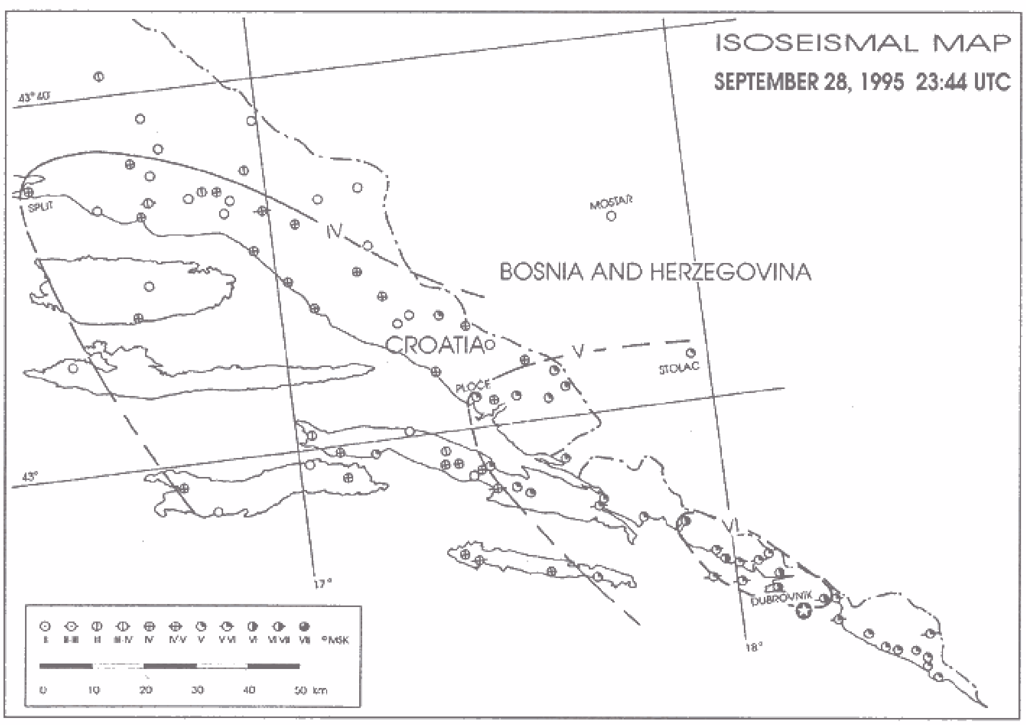

Figure 10. Isoseismal map for the Dubrovnik earthquake of September 28, 1995 (23:44). The white star indicates the position of the microseismic epicenter.

in the SE–NW direction (Fig. 4). Its CMT as well as the first polarity FPS are consistent with nearly pure strike-slip motion with the P-axis pointing SW–NE (Markušić and Herak, 1998). The nearest seismological temporary station at Stravča (STA) recorded 149 earthquakes that followed the main shock. We were able to locate 62 aftershocks with magnitudes ranging from 1.5 to 3.6.

The strongest earthquake during the observed period in Croatia occurred on September 5, 1996 at 20:44, in the vicinity of Slano (M_L = 6.0, I_{max} = VIII °MSK), causing great damage in the *Ston-Slano region* (Table 1). The main shock was followed by a remarkable aftershock sequences that lasted until the end of 1996. In order to understand the tectonic significance of the Ston-Slano earthquakes, more attention is paid to this seismic sequence in a separate section.

4. The Ston-Slano earthquake of September 5, 1996

The Ston-Slano earthquake sequence (main shock 5 September, 1996, M_L = 6.0, I_{max} = VIII °MSK) completely destroyed three villages, and caused heavy damage in a number of southern Dalmatian cities. It is the largest seismic series in the greater Dubrovnik area since the catastrophic earthquake (I_{max} = X °MCS) of 1667. The peak near-field ground acceleration recorded in Ston was as high as 0.65 g (Fig. 11). The *a posteriori* analysis of seismicity pattern in a larger area of Southern External Dinarides (using the CN algorithm) revealed significant seismicity anomalies (TIP) one year prior to this earthquake (Herak et al, 1998). The main shock was followed by thousands of aftershocks, of which 1350 could have been reliably located. The aftershock epicenters fall into a well defined elongated ellipse with the major axis directed NE–SW (Fig. 12).

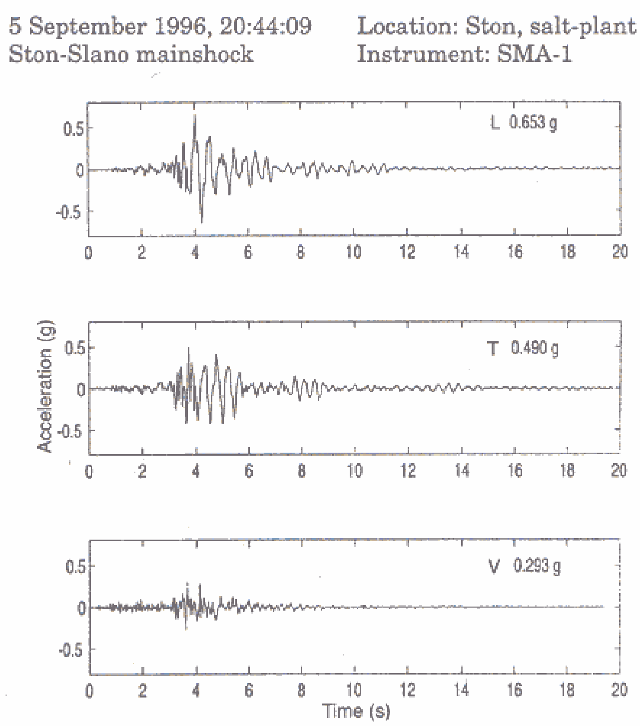

Figure 11. Accelerograms of the September 5, 1996 Ston-Slano earthquake, recorded in the salt-plant in Ston.

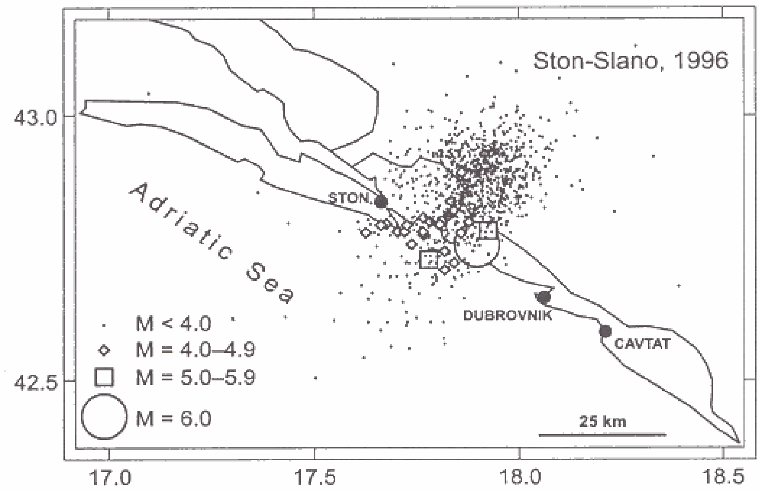

Figure 12. Epicenters of the Ston-Slano seismic sequence.

4.1. Seismotectonic model

The seismotectonic model (Fig. 13) is proposed on the basis of geotectonic data, hypocentral locations and the available fault-plane solutions (*e. g.* Herak et al., 1995). It shows basic movements of the Adriatic platform towards NNW and the related resistance of the Dinaric structures. The consequence is a strong compression within the Dinarides, resulting in reverse and overthrust structures (profile A–A', Figs 12 and 13). Parts of the Di-

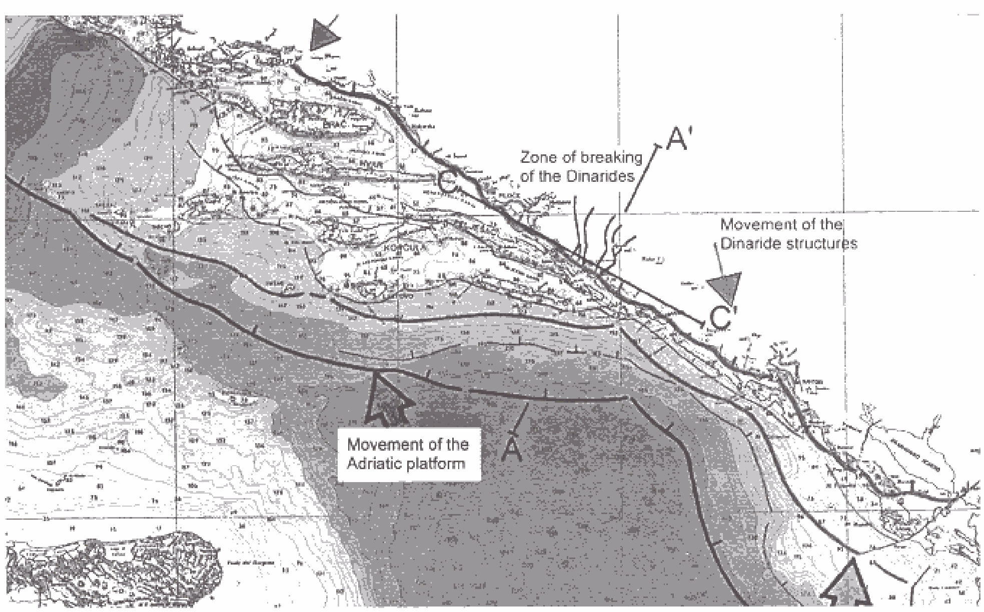

Figure 13. Proposed seismotectonic model of greater Ston-Slano area. For cross-sections A–A' and C–C' see Fig. 14.

narides move to the SW and SE. In the zone of maximal pressure the Earth's crust breaks, and the fault traces striking N–S to NE–SW are observed at the surface. The canyons in the relief occur too. Seismotectonic activity is also related to these faults (profile C–C', Figs 12 and 13). Most of the foci lie within the reverse structures of the Dinarides in the depths of up to 20 km. The CMT best double couple solution indicates reverse faulting on a NW–SE striking fault. One of the nodal planes dips to the NE, which is in agreement with the observed distribution of earthquake foci (Fig. 14) and with the geometry of the system of faults in this area (Adriatic fault, Dubrovnik fault and Mosor–Biokovo fault, see Fig. 4).

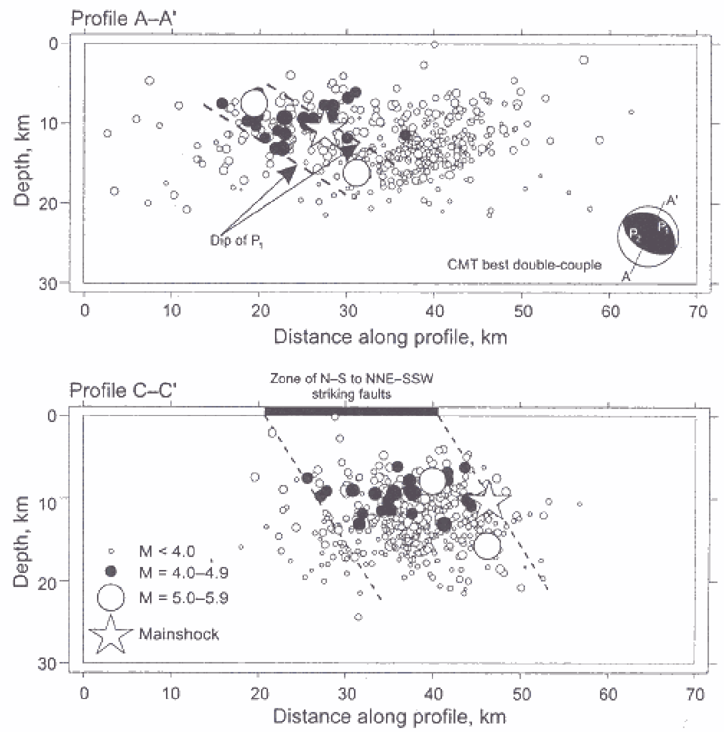

Figure 14. Cross-sections through the aftershock zone along the profiles A–A' and C–C' (see Fig. 14). The dip of the fault P1 (striking WNW–ESE) according to the CMT best double-couple is shown by dashed lines on the profile A–A'.

4.2. Macroseismic investigations

Macroseismic data were collected by the field survey and by questionaries received from the shaken area. Immediately after the main shock, 6 seismologists from the Geophysical Institute in Zagreb studied macroseismic effects in the region from Zadar to Molunat. Seismologists from the Geophysical Survey of Slovenia also visited the epicentral area, and reported about it in Vidrih et al. (1997). Macroseismic map is presented in Fig. 15.

The heaviest damage was found in Slano, Ston and in the villages in the mountaineous hinterlands towards Herzegovina. In Slano, which is close to

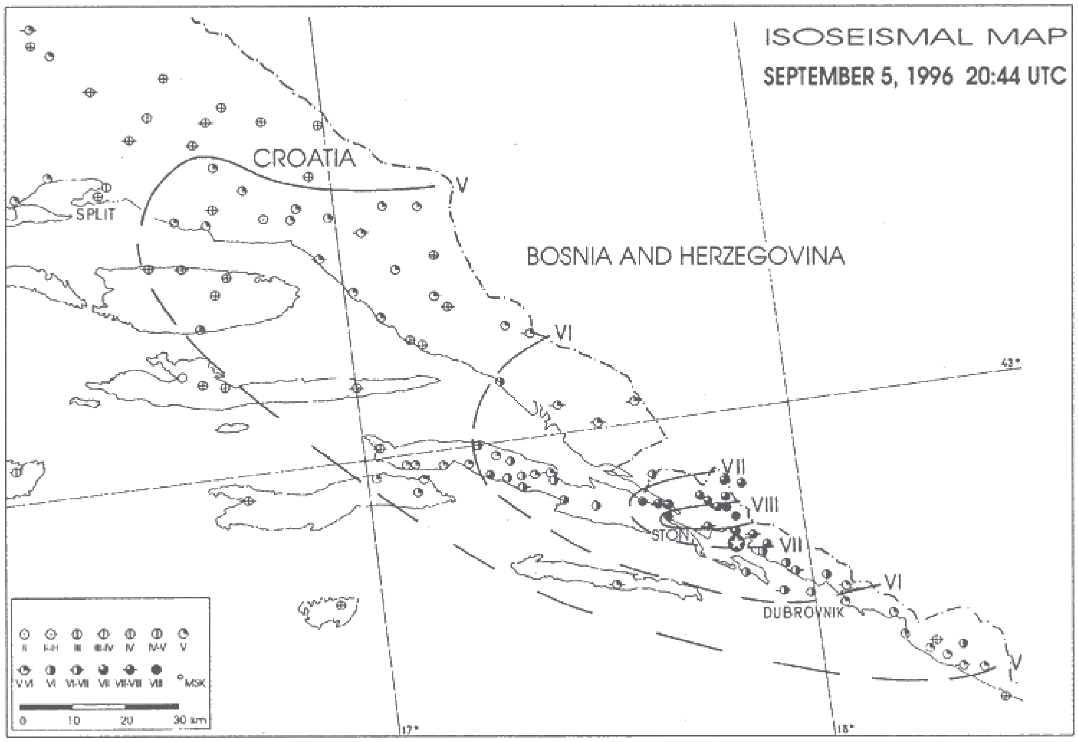

Figure 15. Isoseismal map for the Ston-Slano earthquake of September 5, 1996 (20:44). The microseismically located epicenter is shown by the white star.

the microseismically located epicenter, many chimneys were toppled and tiles fell from the roofs. Main walls cracked, as well as concrete beams over the windows.

In Ston, some 25 km to the NW away from the epicenter, numerous houses were partly demolished, especially those that sustained minor damage due to the earthquake of 15 July, 1995. The old city centre suffered most severe damage. Wide cracks (up to 10 cm) opened up in the main walls, which bulged or skewed in numerous cases. The roofs and gables collapsed. The bell fell from the church. Most of inhabitants were moved to tents and trailers.

In the Doli village the walls cracked to a lesser extent if compared to Ston. Roofs and chimneys were damaged.

The villages Mravinca, Trnova and Podimoć were inaccesible after the earthquake, because of landslides and embankments and dry-stone walls that collapsed and blocked the roads. In Mravinca the church is completely destroyed, and many tombstones overturned. All houses, farming objects, water reservoirs, etc. were severely damaged. Wide cracks opened in the main walls of most of the houses, and parts of some houses, especially the old ones, collapsed. A horse was killed when a stable collapsed. The effects in Trnova and Podimoć were similar. Of 13 houses in Trnovica, 3 are unsuitable for residence. Huge rocks, as large as 20-30 m^3 rolled down from the Tmor Mt. One of such boulders, 1.5–2 m in diameter, collided with the house in Čepikuće. The most distant places where some damage is reported are Zagvozd and Grabovac, where a few tiles moved on the roofs of old houses.

Very often it was reported that the level of well water changed, and the flow of most of springs was reduced or the springs ran dry. The inhabitants of the epicentral area recount of creation of the new submarine spring between Ston and Doli, that caused the turbidity and intense red coloration of the sea due to large quantities of discharged soil and mud. There were numerous reports of the animals being upset a few days before the earthquake (paroqees, canaries, jakals, dogs...).

It is important to note that no buildings renewed or re-erected after the war-time destruction sustained any serious damage.

4.3. Velocity profiles

The microseismic data (arrival times of various local and regional phases) are used to assess the velocities of seismic waves within the seismogenic volume. The method employed is the one used by Herak and Herak (1995), and consists of considering all possible pairs of travel-times observed at some station for earthquakes belonging to this sequence. The original algorithm was slightly modified to allow taking only events within a given depth range into account, thus enabling estimation of the local depth-velocity profiles. The velocities were estimated in a stack of overlapping layers 6 km thick and are presented in Fig. 16. It is seen that the standard errors are the largest for the shallowest depths due to small number of events located

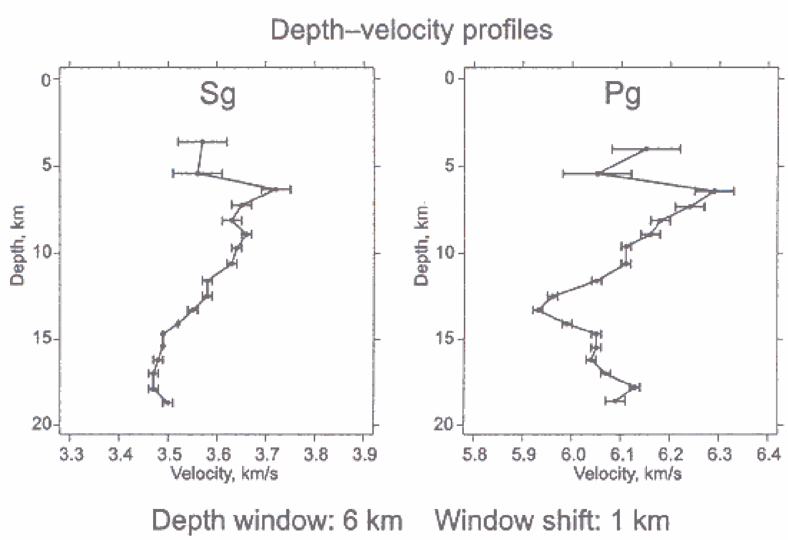

Figure 16. Velocity-depth profiles estimated for the Ston-Slano epicentral region (see text for details).

there. Both P- and S-wave profiles show maximal velocities at the depth of some 7 km. Below this point, velocities decrease until the depth of 13 and 18 km for P- and S-waves, respectively.

5. Conclusion

Seismic activity in Croatia and the surrounding areas in the period 1993-1996 was confined to the previously identified seismically active zones. The majority of earthquakes occurred in the coastal part of Croatia. Altogether 4193 earthquakes were located. All well located earthquakes occurred in the upper part of the Earth's crust with range in depth between surface and 20 km.

The strongest event during the observed period occurred in the Ston-Slano region on September 5, 1996 at 20:44 (M_L = 6.0, I_{max} = VIII °MSK). The main shock was followed by thousands of aftershocks, of which 1350 could have been reliably located. The CMT best double couple solution indicates that the main shock was caused by reverse faulting on a NW–SE striking fault system dipping towards NE, which is in agreement with the system of faults in this area. Using the microseismic data for the greater Ston-Slano area, the velocities of seismic waves were estimated in a stack of overlapping layers. For P- and S-wave profiles, maximal velocities occurred at the depth of aproximately 7 km. Then, velocities decrease till the depth of 13 (P-waves) and 18 km (S-waves).

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SAŽETAK

Seizmičnost Hrvatske u razdoblju 1993–1996. i potres u području Stona i Slanog iz 1996. godine

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Seizmička aktivnost u Hrvatskoj i susjednim područjima uglavnom je u razdoblju 1993–1996. bila ograničena na do sada poznata epicentralna područja. U tom se razdoblju dogodilo devet glavnih potresa s magnitudom 4.5 ili višom. Najvažnija serija potresa počela je 5. rujna 1996. u dubrovačkom primorju (područje Stona i Slanog). Glavni je potres imao magnitudu 6.0 i intenzitet u epicentru VIII °MSK. Mikroseizmičke lokacije hipocentara više od tisuću naknadnih potresa, kao i CMT rješenje za mehanizam pomaka u žarištu, ukazuju na to da se potres dogodio na reversnom rasjedu, nagnutom prema SI i pružanja SZ–JI.

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