Determination of the recent structural fabric in the Alps – Dinarides area by combination of geodetic and geologic methods

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Abstract

In this paper, we investigate the correlation between the results of geodetic measurements within the research geodynamic GPS-network CRODYN and the geological data about recent geological structures in the area of Eastern Adriatic. Comparison of movements of surface geological structures and geodetic measurements yielded strong correlation between the two independent methods. Hence, combined recent structure of the area was obtained. We used the data about the geoid and total vertical deflections in this research, too. These data enabled the in-depth resolution of earth masses with higher density, as well as the movements of the masses which are correlated with geologic structures. The quantitative and independent geodetic data represent immense contribution to the complete assessment of recent geological structural dynamics in the Alps-Dinarides area.

Introduction

The sound knowledge of the geological structure relations and recent tectonic dynamics is essential in the study of the geoid surface and especially in finding the course for its irregularity (Pribičević 2001a, 2001b). It is clear that the vertical and horizontal movements of each point on the surface result from the tectonic displacement of parts of geological structures. That is why it is of utmost importance that the recent tectonic activity in the study area is correctly assessed together with the structure deformations and that this information is acceptably correlated with geodetic data.

The most comprehensive illustration of geological data is found in the Basic Geological Map scale 1:100 000. Knowledge on the regional structure fabric, structural classifications and deep geological structure was summarised in numerous papers (Dewey et al., 1973; Martinis, 1975; Premru, 1976; Mioč, 1982; Herak, 1986; Aljinović et al., 1987; Skoko et al., 1987; Horvath, 1984; Mantovani et al., 1992, 1995; Prelogović et al., 1995, 1997; Moors & Twiss, 1995; Decker & Peresson, 1996). Special care was taken to make use of data on the seismotectonic activity and stress regime (Finetti et al., 1979; Reber et al., 1987; Ribarič, 1983; Anderson & Jackson, 1987; Skoko & Prelogović, 1988; Slejko et al., 1989; Carulli et al., 1990; Grünthal & Stromeyer, 1992; Živčić, 1991; Slejko, 1993; Prelogović & Lapajne, 1994; Lapajne et al., 1994; Prelogović et al., 1998; Mišković, 1999; Bada, 1999). Also, numerous reflection seismic sections from the archive of the INA Oil Industries - Naftaplin from Zagreb were studied to compare the surface structures with depth.

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Geological structure relations and recent tectonic activity

In the study area, the four principal structure units are delineated: Adriatic micro-plate (1 in Fig. 1), Dinarides (2), Pannonian basin (3) and Alps (4). Contacts between these units are marked with faults. Due to the prevailing compression in the Alps and Dinarides area the reverse structural relations are formed. Within the principal units, the regional structure units are discerned. In this way the Dinarides are composed of the Adriaticum (2a), Dinaricum (2b) and Supradinaricum (2c). In the studied parts of the Alps, there are the Southern Alps and Fore-Alps (A-E) and Eastern Alps (F). Influenced by the ongoing tectonic movements, parts of the regional structure units undergo different spatial displacement, which results in the variable activity along the sections of their marginal faults. Those are the most important faults of the structure fabric and that's why some fault sections in Fig. 1 have different names. In the recent structure fabric, some smaller structure units can be defined within the regional units. They are characterised by different structural relations between them, different types of structures and faults, tectonic activity and displacements. In total, 30 structure units were delineated in the area of Dinarides (1-30 in Fig. 1) and 6 in the studied part of Alps (marked A-F).

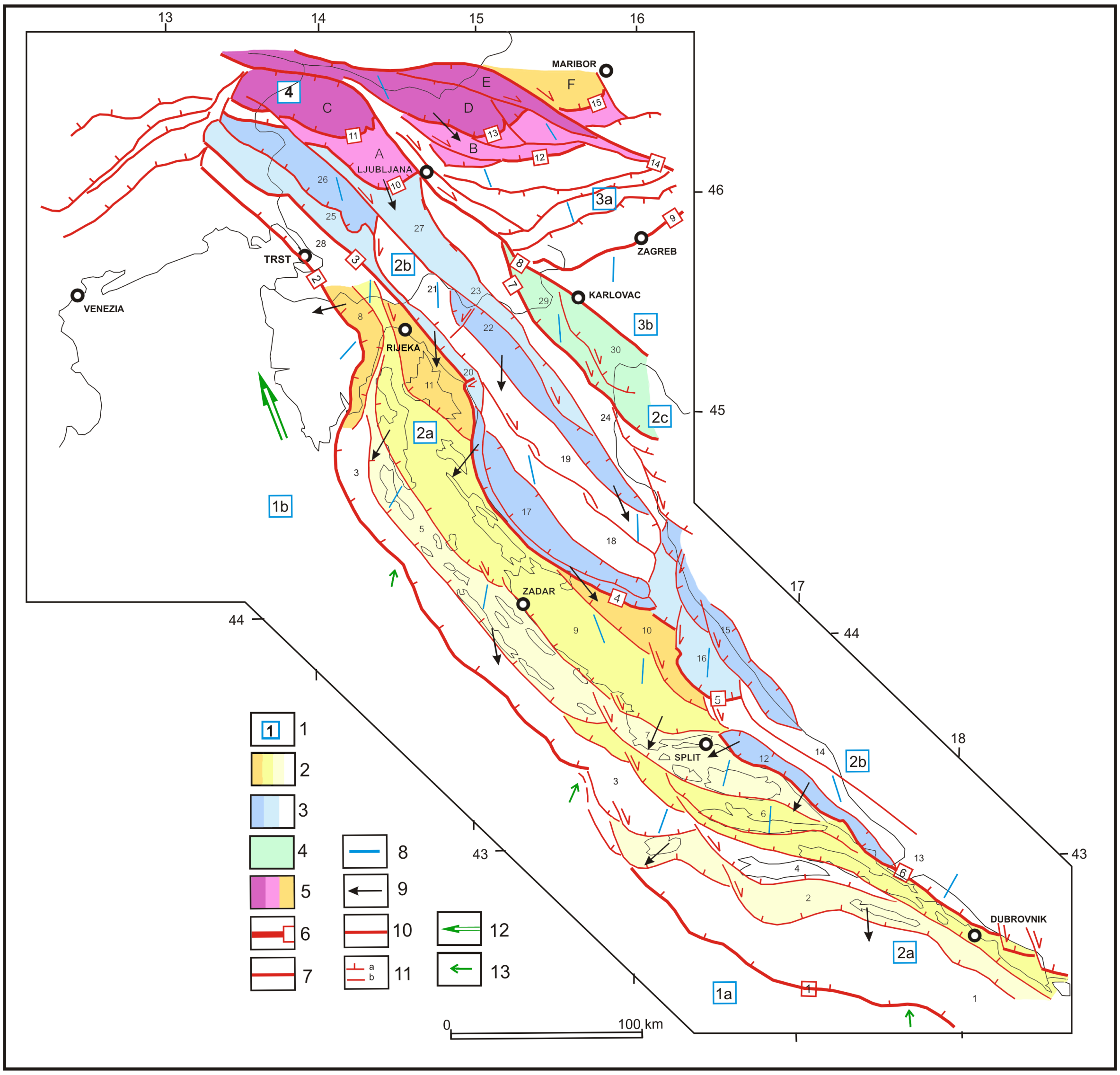

Figure1: Structure map

Legend: 1 – principal structure units: Adriatic micro-plate (1a – Southern part, 1b – Northern part), Dinarides (2a – Adriaticum, 2b – Dinaricum, 2c – Supradinaricum), Pannonian basin (3a – Western marginal part, 3b – Southern marginal part), Alps (4 A,B,C,D – Southern Alps, 4F – Eastern Alps); structure units within: 2 – Adriaticum; 3 – Dinaricum; 4 – Supradinaricum; 5 – Alps; 6 – the most important faults of the structure fabric: Vis-Southern Adriatic fault (1), Trieste-Učka-Vis fault (2), Gorica-Rijeka-Vinodol valley fault (3), Mt. Velebit fault (4), Knin-Muć fault (5), Mt. Mosor-Mt. Biokovo-Dubrovnik fault (6), Črnomelj-Slunj-Cazin fault (7), Fella-Ljubljana-Karlovac fault (8), Žumberak Mts.-Mt. Medvednica fault (9), Kobarid-Gorenja Vas-Ljubljana fault (10), Julian Alps fault (11), Domžale-Zagorje-Laško (12) fault, Savinja Alps fault (13), Periadriatic-Drava fault (14), Pohorje Mts. fault (15); 7 – faults delimiting structure units; 8 – orientation of the maximal horizontal component of regional stress; 9 – directions of displacement of structure units at the surface; 10 – fault sections with prevailing strike-slip; 11 – reverse faults (a) and fault sections lacking positively defined character of displacement (b); 12 – direction of the regional movement of the Adriatic microplate; 13 – inferred direction of displacement of the parts of Adriatic micro-plate.

Movements of the Adriatic micro-plate (1) are crucial in formation of the recent structure fabric. Pushed by the African plate it is being indented into the European continent thus causing deformation of the Earth's crust and gradual shaping of the Alpine-Dinarides orogenic belt. In the youngest active period, area of the Adriatic micro-plate is being significantly reduced so that the micro-plate is fragmented. That's why it is important that the recent tectonic activity can only be assessed having in mind that there are the two larger fragments of the Adriatic micro-plate – the southern part (1a) and the northern part (1b). Their existence is revealed by the different orientation of the maximal horizontal component of stress, by different displacement of structures and by seismic activity as well. Variations in direction of displacement of both parts of the micro-plate are observed and interpreted to be probably influenced by their retrograde rotation and be different rates at which this transport takes place.

The structure units of the Dinarides and Southern Alps are resisting to displacements of the parts of the Adriatic micro-plate. Within the structure fabric, this process is constrained by the size, spatial position and relations between the rock masses of different density, because these masses condition the formation of the stress field which in turn influences the deformations and displacement of structures. This is illustrated in Fig. 1 by the variable orientation within some regional structure units – in the Dinarides between 340-160^0 and 30-210^0, and in the Southern Alps between 320-140^0 and 340-160^0. The parts of the Adriatic micro-plate exhibit variable directions of displacement, i.e. their rotation. The Southern part of the micro-plate (1a) causes the strongest compression of the area between the island of Mljet and Dubrovnik. West of this region, displacements of the parts of structure units in SW direction were measured, while east of the region, the displacements were towards SE. Displacements of the Northern part of the Adriatic micro-plate (1b) condition the compression in the Alpine area and in the northern part of the Dinarides. Eastern region is characterised by the dextral tectonic transport of structure units. Directions of displacement of the parts of the Adriatic micro-plate are marked in Fig. 2, together with the main directions of displacement of the parts of Alps and Dinarides. Especially observed are the parts of the Dinarides whose deformations are conditioned with displacements and activity of the Southern and Northern part of the Adriatic micro-plate (1a,b). Furthermore, the common characteristics of displacement and deformation of the studied part of Alps and the northern part of the Dinarides are stressed out. This means that the influence of activity of the Northern part of the Adriatic micro-plate (1b) is observable till the area of Northern Dalmatia.

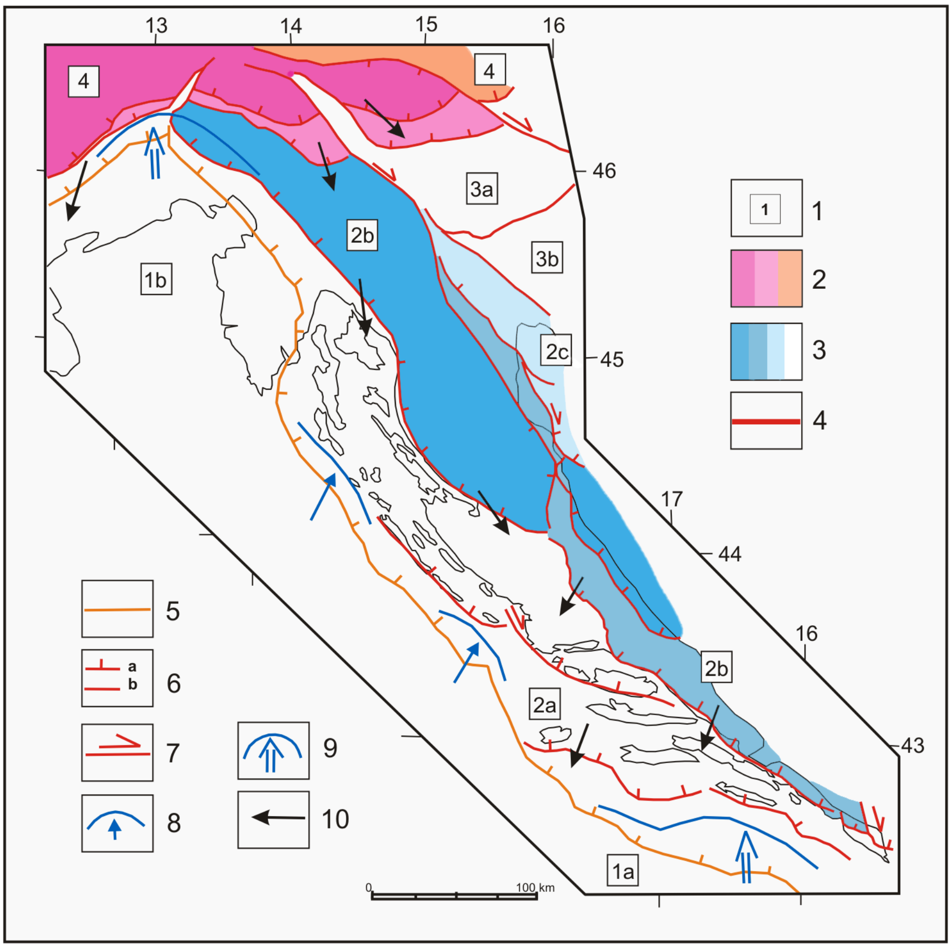

Figure 2: Displacements of the Adriatic micro-plate, Dinarides and Alps.

Legend: 1 – principal structure units: Adriatic micro-plate (1a – Southern part, 1b – Northern part), Dinarides (2a – Adriaticum, 2b – Dinaricum, 2c – Supradinaricum), Pannonian basin (3a – Western marginal part, 3b – Southern marginal part), Alps (4); 2- the most important parts of the Dinarides; 3 – the most important parts of the Alps; 4 – contacts between the seismotectonically active structural units, marked at the surface by the fault zones; 5 – borders of the youngest compressional structures; 6 – reverse faults (a) and fault sections lacking positively defined character of displacement (b); 7 – fault sections with prevailing strike-slip; 8 – inferred direction of displacement of parts of the Adriatic micro-plate; 9 – direction of displacement of the Adriatic micro-plate in regions of the more pronounced subduction, and of reverse-overthrust displacements and compression; 10 – the most important directions of displacement of the structure units close to the surface.

The common character of deformation of the recent structural fabric in the Southern Alps and northern part of the Dinarides can be proved by analysis of the subsurface data. The Bouguer anomaly gravity map (Fig. 3) can be used for direct comparison with the surface structure relations, and the following most important characteristics are observed:

- the minimal and maximal values of gravimetric anomalies depict locations of the rock masses of different density at shallower and deeper positions;
- the masses are most subsided under the Southern Alps and Northern part of the Dinarides; this also marks the area of the largest compression caused by tectonic movements of the Adriatic micro-plate;

- strike of the minimal axes illustrates the 3D position of the reverse relations between the structures;
- regions of maxima between Trieste and Ljubljana, and in the Savinja Alps as well, mark folding of structures and reverse relations; maxima around Zagreb and Maribor are also caused by the folding and compression in these areas, but rather caused by the dextral tectonic transport and transpression;
- zones of increased gravimetric gradients depict the step-like subsidence of rock masses in depth, i.e. the most active fault sections, while their position and strike coincide with the prevailingly reverse displacement of structures;
- changes in strike of structures and faults in the northern part of the Dinarides result from the dextral tectonic transport of structures that are located to the right of the area of the largest compression.

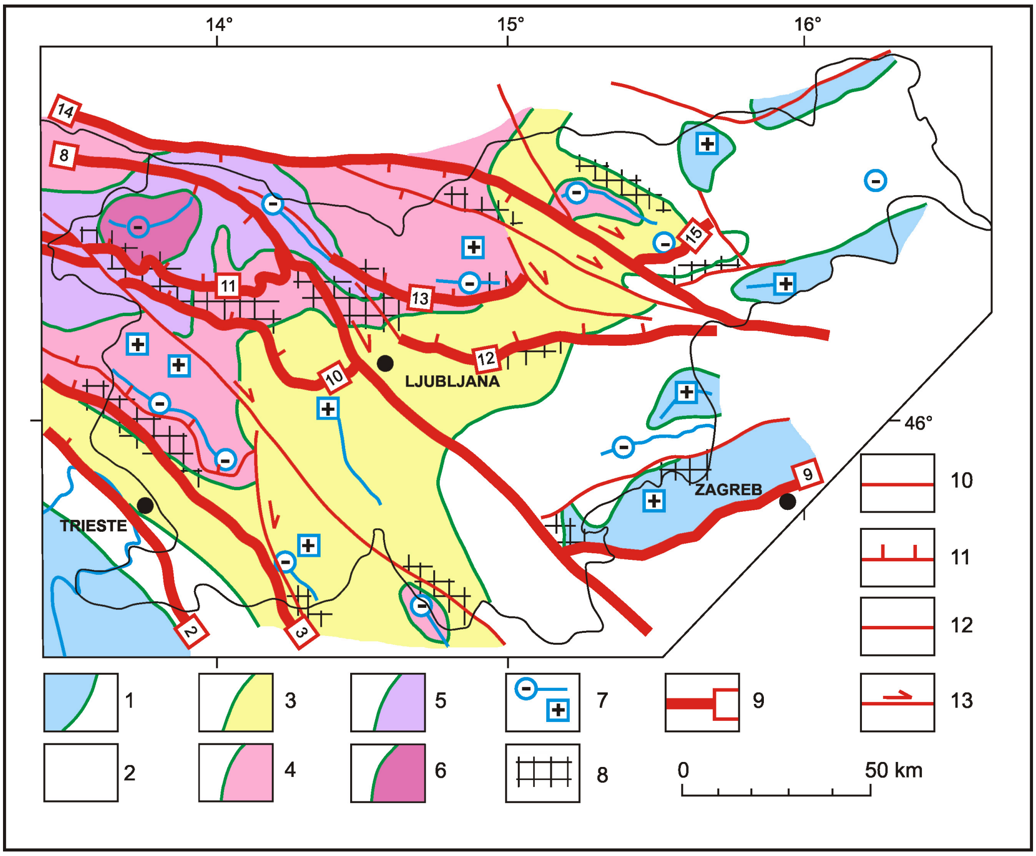

Figure 3: Zones of marked compression in the contact area between the Alps and Dinarides.

Legend: areas with values of the Bouguer gravimetric anomalies (in mgal): 1) –10; 2) –10 to –30; 3) –30 to –50; 4) –50 to –70; 5) –70 to –90; 6) less than –90; 7 – the minimal and maximal value axes of the Bouguer gravimetric anomalies; 8 – zones of the increased gravimetric gradients; 9 – the most important faults of the structure fabric (locations of fault traces at the surface): Trieste-Učka-Vis Isl. fault (2), Gorica-Rijeka-Vinodol valley fault (3), Fella-Ljubljana-Karlovac fault (8), Kobarid-Gorenja Vas-Ljubljana fault (10), Julian Alps fault (11), Domžale-Zagorje-Laško fault (12), Savinja Alps fault (13), Periadriatic-Drava fault (14), Pohorje Mts. fault (15); 10 – other important faults of the structure fabric; 11 – reverse faults; 12 - fault sections lacking positively defined character of displacement; 13 – fault sections with prevailing strike-slip.

There is a good example of the geoid deformation and activity of the recent structure fabric in the contact zone between the Southern Alps and Dinarides. What is observed at a glance, are the biggest uplifts of the geoid surface in the Julian Alps, Savinja Alps, Pohorje Mts. and in the Dinarides south of Ljubljana. These are the marked areas of more pronounced compression that directly resist the movements of the Adriatic micro-plate. The zones of marked tectonic activity are best illustrated by the geoid surface gradients shown in Fig. 4. Bigger gradients are in the zones that are directly compared with the fault zones (Fig. 2). Active faults are also depicted by the abrupt changes in strike of the geoid contour lines, for instance such as between Ljubljana and Novo Mesto. The most important conclusion is the presence of marked recent tectonic activity which causes permanent changes of the structure fabric and of the geoid surface as well.

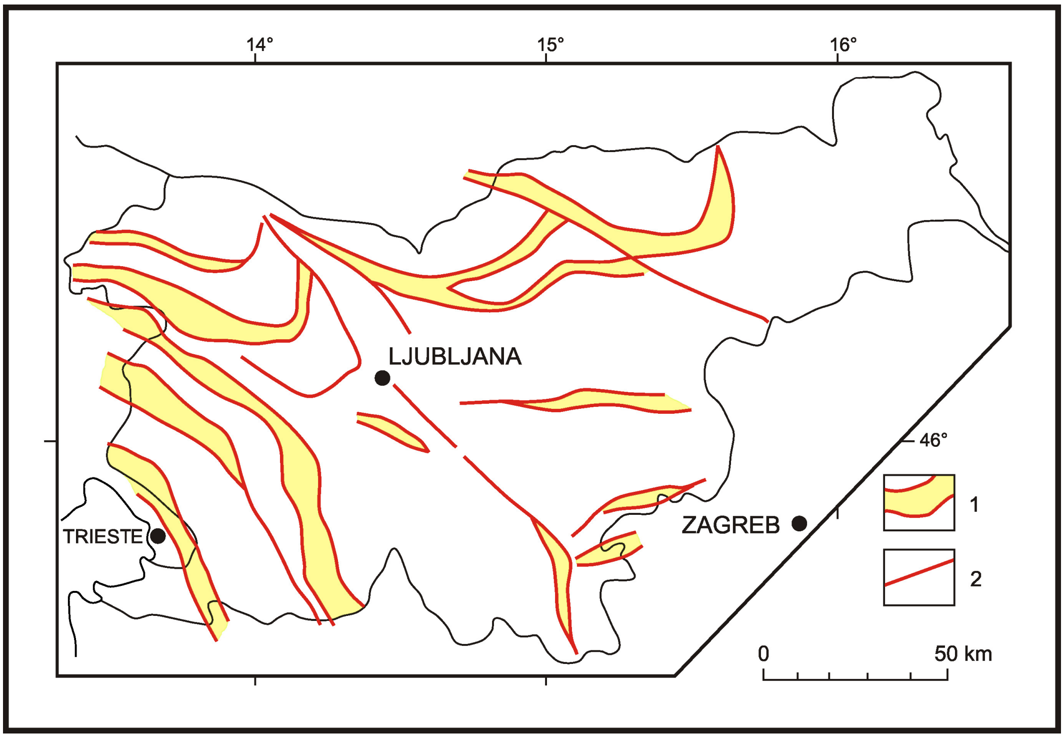

Figure 4: Zones of tectonic activity as inferred from the shape of the geoid surface. Legend: 1 – zones of the increased gradients of the geoid surface; 2 – contacts between the areas of the different strike of the geoid surface.

References

Aljinović, B., Prelogović, E., Skoko, D. (1987): New data on deep geological structure and seismotectonic active zones in region of Yugoslavia. Geod. vjsnik, 40, 255-263, Zagreb.

Anderson, H., Jackson, J. (1987): Active tectonics of the Adriatic region. Geophysics. Y.R.A.S., 91, 937-983.

Bada, G. (1999): Cenozoik stress field evolution in the Panonian basin and surrounding orogens. Vrije Univ., 1-204, Amsterdam.

Carull, G.B., Nicolich, R., Reber, A. Slejko, D. (1990): Seismotectonics of the Northwest External Dinarides. Tectonophysics, 174, 11-25.

Decker, K., Peresson, H. (1996): Tertiary kinematics in the Alpine-Carpathian-Panonian system: Links between thrusting, transform foulting and crustal extension. In Oil and Gas in thrust belts and basins. (Ed. W. Liebl and G. Wessely). Laan van Vollentrove, Netherlands.

Dewey, J.F., Pitman, W.C. Ryan, W.B., Bornin, J. (1973): Plate tectonics and the evolution of the Alpine System. Geod.sve.Am. Bull., 84, 3137-3180, New York.

Finetti, I., Russi, M., Slejko, D. (1979): The Friuli earthquake (1976-1977). Tectonophysics, 53, 261-272.

Herah, M., (1986): A new concept of geotectonics of the Dinarides. Deta geod. JAZV,. 16, 1-42, Zagreb.

Horvath, F. (1984): Neotectonics of the Panonian basin and the surrounding mountain belts: Alps, Carpathians and Dinarides. Am. Geophys., 2(2), 147-154.

Grünthal, G. Stromeyer, D. (1992): The Recent Crustal Stress Field in Central Europe: Trajec - tories and Finite Element Modeling. Jour. of Geophys. Research, Vol. 97, No B8, 11.805-11.520.

Lapajne, J., Prelogović, E., Šket-Motnikar, B., Zupančić, P. (1994): Corelations in the estimation of seismic source parameters for Krško NPP site in Slovenia. 9th Inter. Seminar on Earthquake Prognostics, San Jose, Costarica, 19-23. Sept., 1994., San Jose.

Mantovani, E., Albarello, D., Babbucci, D.R., Tramburelli, C., (1992): Recent Geodynamic Evolution of the Central Mediterranean Region. Tipografia Senese, 1-88, Siena.

Martinis, B. (1975): The Friulian and Julian Alps and Pre-Alps. Struc.moled of Italy. C.N.R. Quaderni de "La Ricerca Scient", 90, 17-49, Roma.

Mišković, D., Pesec, P., Sangl, G. (1999): GPS Re-Measurement in the Bovec-Tolmin Earthquake Region. Proceedings of the Second International Symposium Geodynamics of the Alps-Adria Area by means of terrestrial and satellite methods, Dubrovnik, Sept. 28 - Oct. 2, 1998, 225-240, Graz, Zagreb.

Moores, E., Twiss, R.Y. (1995): Tectonics. Fremman and Co., New York.

Prelogović, E., Kuk, V. (1998): Seizmotektonska aktivnost zapadnog dijela Hrvatske. Zb. radova, Znan. skup "Andrija Mohorovičić", 10.-12.03.1998., 115-124, Zagreb.

Prelogović, E., Janvičić, D., Aljinović, B., Velić, J., Saftić, B., Dragaš, M. (1995): Dinamika nastanka struktura južnog dijela Panonskog bazena. 1. Hrv. geol.kong., Opatija 18.-21.10.1995. Zb. radova, 2, 481-486, Zagreb.

Prelogović, E., Lapajne, J. (1994): Seismotectonic study.- In: Fajfer, P., Lapajne, J. (Eds.): Probabilistic Assesment of Seismic Hazard at Krško NPP. Fak. Arh. Grad. in Geod., Ljubljana.

Prelogović, E., Saftić, B., Kuk, V., Velić, J., Dragaš, M., Lučić, D. (1997): Tectonic activity in the Croatian part of the Panonian basin. Tectonophysics, 297, 283-293.

Premru, U. (1976): Neotektonika uzhodne Slovenije. Geologija 19, 211-249, Ljubljana.

Pribičević, B. (2001a): Uporaba geološko-geofizičnih in geodetskih baz podatkov za računanje ploskve geoida Republike Slovenije. (Doktorska disertacija). Edicija Znanstvenih monografija Ljubljana, Univerza v Ljubljani, Fakulteta za gradbeništvo in geodezijo.

Pribičević, B., Medak, D., Domanđić, D. (2001b): Research on geodynamics of the Adriatic micro-plate. Zbornik predavanj Raziskave s področja geodezije in geofizike 2001, Vodopivec Florijan (ur.). Ljubljana 2001, 29-39.

Reber, A., Slejko, D., Suhadolc, P. (1987): Seismic behaviour at the Alps-Dinarides Contact. Soc. Seal.Ital., 40, 321-326.

Ribarič, V. (1983): Prilozi proučavanju seizmičnosti i seizmičkog zoniranja Slovenije. Disertacija, 1-336, Arh. geofiz.zavoda. PMF, Zagreb.

Skoko, D., Prelogović, E. (1988): Seismic potential of Yugoslavia territory. Proc. of the Ninth World Conf. on Earthquake Engeneering, August 2-9, 1988, Vol. II, 163-168, Tokyo-Kyoto.

Skoko, D., Prelogović, E., Aljinović, B. (1987): Geological structure of the Earth's crust above the Moho discontinuity in Yugoslavia. Geophys. J.R.A.S., 89, 379-382.
Slejko, D. (1993): A review of the Eastern Alps - Northern Dinarides seismotectonics. In: Boschi, E., Mantovani, E., Morelli,A. Eds.: Recent Evolution and Seismicity of the Mediteranian Region. NATO ASI Ser., Kluwer Acad. Publ., 251-260.
Slejko, D., Carnulli, G.B., Nicholich, R., Reber, A., Zanferarri, A., Cavallin, A., Doglioni, C., Carraro, F., Castelani, D., Iliceto, V., Semenza, E., Zanolla, C. (1989): Seismotectonics of the Eastern Southern Alps a review. Boll. di Geofis. Teoretica et Apl., Vol. XXXI, 109-136, Trieste.
Živčić, M. (1991): Mehanizam pomaka u žarištima potresa na području Slovenije. Seizmološki zavod, Ljubljana.