GEODESY, TECTONICS AND GEODYNAMICS OF DINNARIDES

Damir Medak (1), Boško Pribičević (1), Eduard Prelogović (2)

(1) Faculty of Geodesy, University of Zagreb, Kačićeva 26, Zagreb,
(2) Faculty of Mining, Geology and Petroleum Engineering,
University of Zagreb, Pierrotieva 6, Zagreb

ABSTRACT

This paper summarises recent activities on merging the geodetic, geologic and neotectonic evidence of geodynamics in Croatian part of Dinnarides. The area of the City of Zagreb, which is the boundary zone of Eastern Alps, Dinnarides and Pannonian Basin is included as well. It is shown here that the evidence for fractures of Eastern Adriatic differs from the previous hypotheses. This conclusion is derived from the results of various geodetic measurements: satellite positioning (GPS), astro-geodetic measurements of deflections of the vertical. These results are combined with geologic measurements and results of seismic activity studies in order to give more detailed and more accurate picture of the current situation in the tectonically very active region of Dinnarides. Several GPS-campaigns performed in the City of Zagreb area are examined as well. Due to the proximity of Croatian capitol, special attention has been paid to the effects of possible hazard on construction code.

INTRODUCTION

Research on the regional structure fabric, structural classifications and deep geological structure of Dinnarides was summarised in numerous papers (Dewey et al., 1973; Martinis, 1975; Premru, 1976; Herak, 1986; Aljinović et al., 1987; Skoko et al., 1987; Horvath, 1984; Mantovani et al., 1992, 1995; Prelogović et al. 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; Anderson & Jackson, 1987; Skoko & Prelogović, 1988; Slejko et al., 1989; Carulli et al., 1990; Grünthal & Stromeyer, 1992; Slejko, 1993; Prelogović & Lapajne, 1994; Lapajne et al., 1994; Prelogović et al., 1998; Mišković, 1999; Bada, 1999). Several papers from the NATO Workshop confirmed that the geology, tectonics and geodesy should closely cooperate in solving the hypotheses of movements in the area of Adriatic micro-plate and Dinnarides (Pinter et al. 2006).

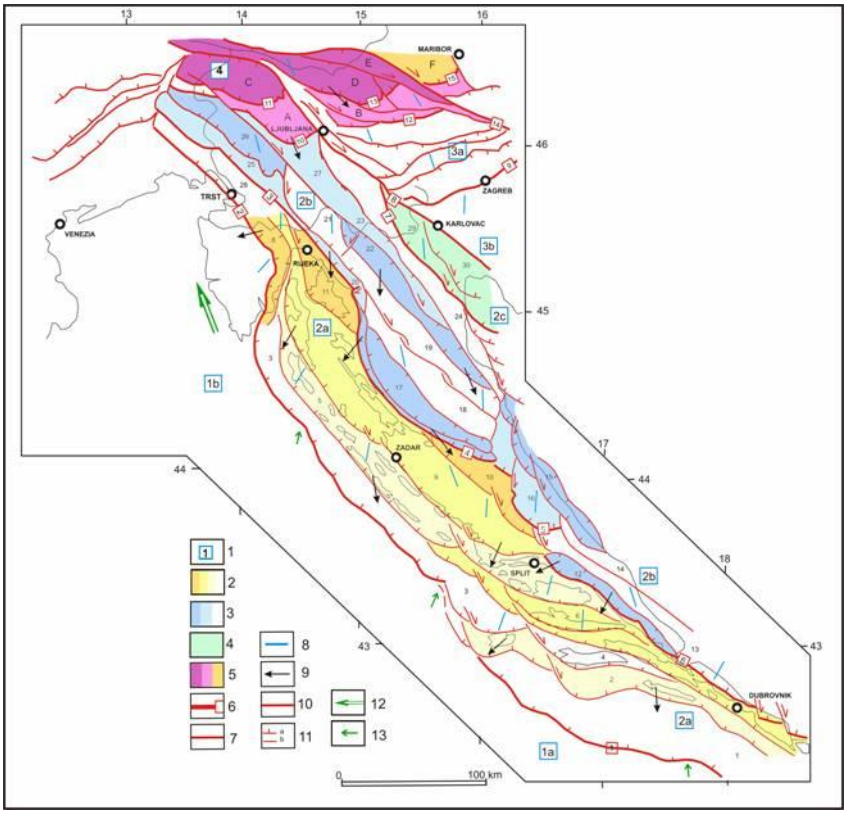

Figure 1: Structural map of the Dinnarides

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.

GEOLOGIC STRUCTURES AND TECTONIC ACTIVITY

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.

GEODETIC-GEODYNAMIC GPS-MEASUREMENTS

Aside from CEGRN GPS-campaigns, researchers from the Faculty of Geodesy, University of Zagreb are performing precise GPS-measurements on the Geodynamic Network of the City of Zagreb since 1997. First results has been presented in (Medak and Pribicevic 2001), and a comprehensive description of achievments can be found in (Medak and Pribicevic 2006).

Figure 2 shows the vector displacement field derived from campaigns in 1997, 2001 and 2004. In 2005 this network has been densified with the new points in the seismically most active area in eastern Medvednica. In 2006 we have planned to make another series of measurements of the whole network.

Figure 3 shows the damaging effects of tectonic activity in the area of Kasina, where the most seismic activity is recorded.

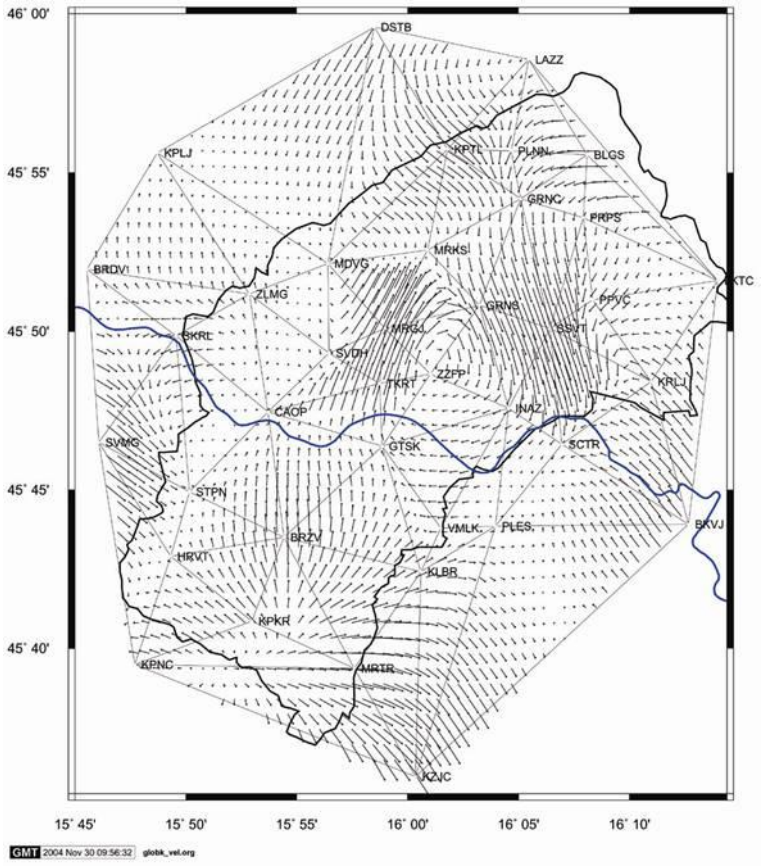

Figure 2. Displacement map in the area of Zagreb geodynamic network.

Figure 3. Examples of damages on houses in the epicentral area near Zagreb.

CONCLUSION

The zone of Dinnarides delineated by the Alps in the north, the Adriatic in the south west, and with the Pannonian basin in the north-east is seismically and tectonically very active area, which deserves further interdisciplinary research. Geodesy is contributing a lot with precise GPS-measurements which yield very accurate displacements even on local or regional level. The CEGRN network observed several times in this region has proven the hypothesis that Dinnarides are an important research area. Several campaigns performed on the Geodynamic GPS-Network of the City of Zagreb confirm the hypothesis that the movement of Eastern Alps toward Dinnarides and Pannonian basin are causing significant tectonic activity in the Mount Medvednica area. Further measurements and interdisciplinary and international cooperation is necessary in order to track these potential hazard movements.

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.

Herak, M., (1986): A new concept of geotectonics of the Dinarides. Deta geod. JAZU, 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.

Medak, D. Pribicevic, B. (2001): Geodynamic GPS-Network of the City of Zagreb - First Results, Quantitative Neotectonics and Seismic Hazard Assessment: New Integrated Approaches for Environmental Management / Gabor, Bada (ed.). p 80.

Medak, D., Pribicevic, B. (2006): Processing of geodynamic GPS-networks in Croatia with GAMIT software, The Adria Microplate, GPS Geodesy, Tectonics and Hazards / Pinter, Nicholas et al. (eds).

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.

Pinter, N., Grenerczy, G., Weber, J., Stein, S., Medak, D. (2006): The Adria Microplate: GPS Geodesy, Tectonics and Hazards. Nato Science Series: IV. Earth and Environmental Sciences - Vol. 61, Springer, Amsterdam.

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.

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.

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. Ball. di Geofis. Teoretica ed April., Vol. XXXI, 109-136, Trieste.