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PRELIMINARY STUDY ON SEISMIC ACTIVITY OF THE CARPATHIAN ARC FOR DIFFERENT HYPOCENTRE DEPTHS

ÚVODNÍ STUDIE SEISMICKÉ AKTIVITY KARPATSKÉHO OBLOUKU PRO HYPOCENTRA V RŮZNÝCH HLOUBKÁCH

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Abstract

The most seismically active area in Central Europe – The Carpathian Mountains Arc is the very interesting region for seismologists because of having non-homogeneous distribution of the earthquakes. Until now, the Central European seismologist community has been focused predominantly on analysing the seismicity of individual regions and countries within the Carpathian Arc. In this research we analysed the entire region in terms of the depth range and seismic activity between years 1976 to 2016. This work is intended to point out significant differences between the seismic activities of the different part of the Carpathians Arc, especially in the Southern part, where the seismic activity is much bigger than in the northern part of the arc. The results suggest that localization of the earthquakes is very important in terms of tectonic, because the earthquakes are located in a restricted area in the bending zone between the Eastern and Southern Carpathians where at least three units are in contact: The East European plate, Intra-Alpine and Moesia sub-plates (Marmureanu et al., 2011). In most cases the seismic events are immediately related to the movements on existing fault surfaces (Kovac et al., 2004). The results suggest that the hypocentres distribution strongly depends on the depth range of the earthquakes.

Abstrakt

Nejvíce seismicky aktivní oblast ve Střední Evropě, Karpatský oblouk, je velice zajímavá pro seismology, z důvodů existence nehomogenního rozdělení zemětřesení. Až dosud komunita středoevropských seismologů se zaměřila převážně na analyzování seismicity jednotlivých regionů a zemí, kterými prochází Karpatský oblouk. Při tomto zkoumání jsme analyzovali celý region z hlediska hloubkových dosahů a seismické aktivity v letech 1976–2016. Tato práce chce poukázat na významné rozdíly mezi seismickou aktivitou různých částí

Karpatského oblouku, zejména v jeho jižní části, kde je seismická aktivita mnohem větší než v severní části oblouku. Výsledky naznačují, že lokalizace zemětřesení je velice důležitá z pohledu tektoniky, neboť zemětřesení se lokalizují ve vymezené oblasti v ohybové zóně mezi Východními a Jižními Karpaty, kde se stýkají minimálně tři geologické jednotky: Východní Evropská deska, dále Intra-alpinská subdeska a Moesinská subdeska, MARMUREANU et al., (2011). Ve většině případů seismické jevy mají bezprostřední vztah k pohybům po plochách existujících zlomů, KOVAC et al., (2004). Výsledky ukazují, že rozdělení hypocenter silně závisí pásu hloubek zemětřesení.

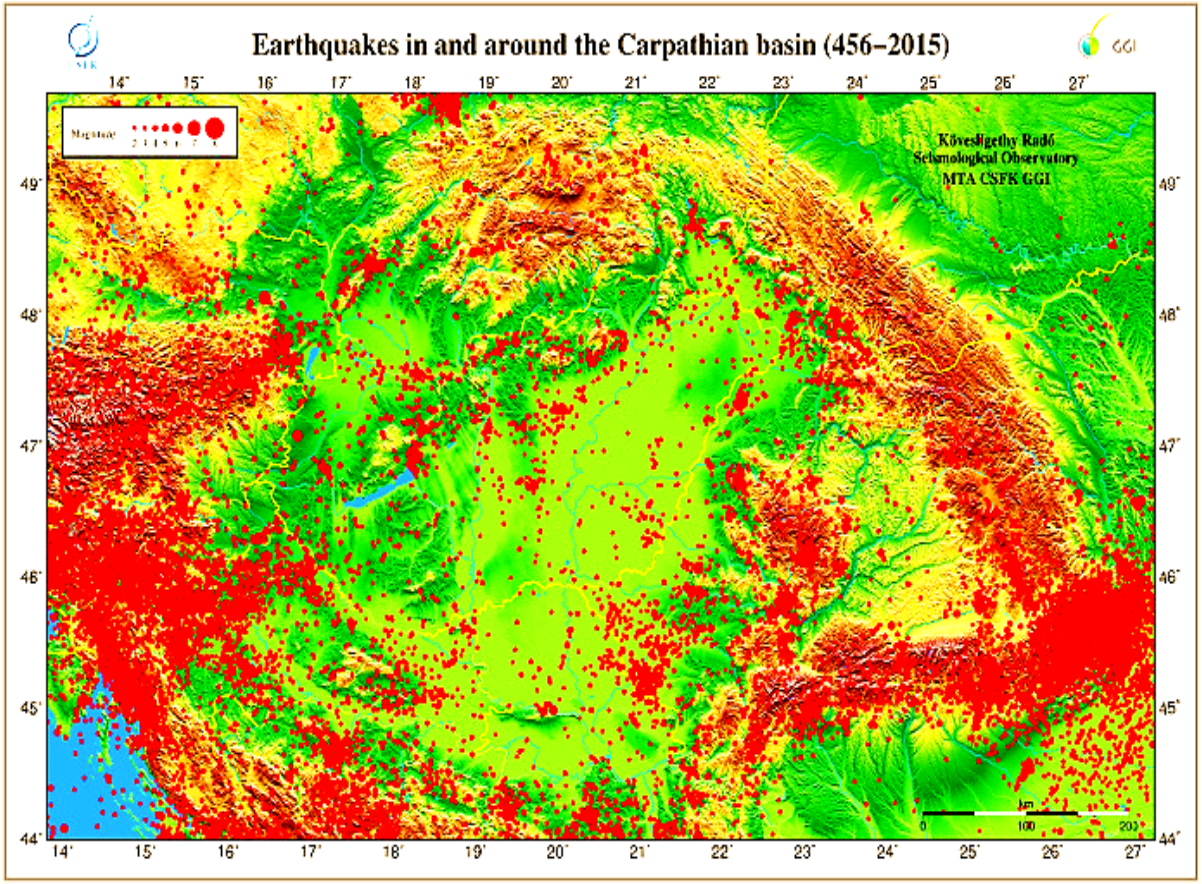

Fig.1 Earthquakes observed inside and out of the Carpathian basin from 456 up to 2015 years. Symbols are proportional to Richter magnitude.
Source:http://www.seismology.hu/index.php/en/seismicity/seismicity-and-seismic-hazard/22-seismicity-of-hungary)

Keywords

Carpathians Arc, earthquakes, seismic activity, depth of the shock's hypocentre

Klíčová slova

Karpatský oblouk, zemětřesení, seismická aktivita, hloubka otřesového hypocentra

1 Introduction

The Carpathians Mountain Arc is part of the Alpine Mediterranean Belt. This region is the seismically most active area in Central Europe. The Carpathians are usually divided into three major sections: Western Carpathians (north-eastern Austria, eastern Czech Republic, southern Poland, western Slovakia, and northern Hungary), Eastern Carpathians (south-eastern Poland, eastern Slovakia, southwestern Ukraine, and northern Romania), Southern Carpathians (Romania, Serbia). The Western Carpathians region characterise a moderate earthquake activity, KOVAC et al., (2004).

Our research area is located between the seismically active Mediterranean area and the nearly aseismic East European platform. For this reason, the spatial distribution of the earthquake epicentres within the studied area is not homogeneous. There are significant differences between the seismic activity of the southern and the northern part of the Carpathians Arc, see fig.1. Tremors are mostly observed in the Vrancea zone (the southern end of Eastern Carpathians) in Romania, see fig.2.There, the earthquake epicentres are restricted to an area of the bending zone between of the Eastern and Southern Carpathians where at least three tectonic units come into contact, MARMUREANU et al., (2011): The East European plate, Intra-Alpine and Moesia sub-plates, fig.3. In most cases the seismic events are immediately related to the movements on existing fault surfaces – KOVAC et al., (2004).

In order to determine the variability of seismic activity in the area of the Carpathian Arc, a unified catalogue of shocks from this area from 1976 to 2016 was created. This catalogue was built on the base of data from regional seismic catalogues supplemented with data from seismic platform IRIS and EMSC.

2 Tectonic frameworks of Carpathians Arc

The Carpathians were formed in the Alpine–Carpathian–Pannonian (ALCAPA) region during the Alpine orogenesis, see fig.4. They record a complex tectonic history, involving extrusion of microplates (ALCAPA, Tisza-Dacia and Adria), ocean closure, subduction, slab rollback, slab detachment and asthenospheric upwelling, see BIELIK et al., (2004).

ALCAPA region consists of the Carpathian Orogen and Pannonian Basin which are a result of the Neogene evolution. The Pannonian Basin system is through to have been formed as a back-arc system due to lithospheric extension and mantle upwelling behind the Carpathian Arc, in HORVATH, (1993). The tectonic evolution and present-day structure of the ALCAPA region is still a matter of discussion; TASAROWA et al., (2009). At least two hypotheses of tectonic evolution are known. The first of them, presented by KNAPP et al., (2005) and too Gemmer and Houseman, (2007) interprets evolution of the Carpathian-Pannonian Basin region in terms of

gravitational collapse of the continental lithosphere. In their works the existence of the subduction underneath the Carpathian Mountains was excluded. In turn, the second interpretation includes the subduction of oceanic lithosphere as a key process during the tectonic evolution of the ALCAPA region. Considering all known geological and geophysical evidences the last interpretation of tectonic evolution is more commonly accepted.

Nowadays, the still active Vrancea seismic zone located in the bend region of the South-eastern Carpathians is seen as the latest stage of the subduction underneath the Carpathian Mountains; SPERNER et al., (2004) and MARTIN et al., (2006). This interpretation is well supported by the volcanic activity in the region.

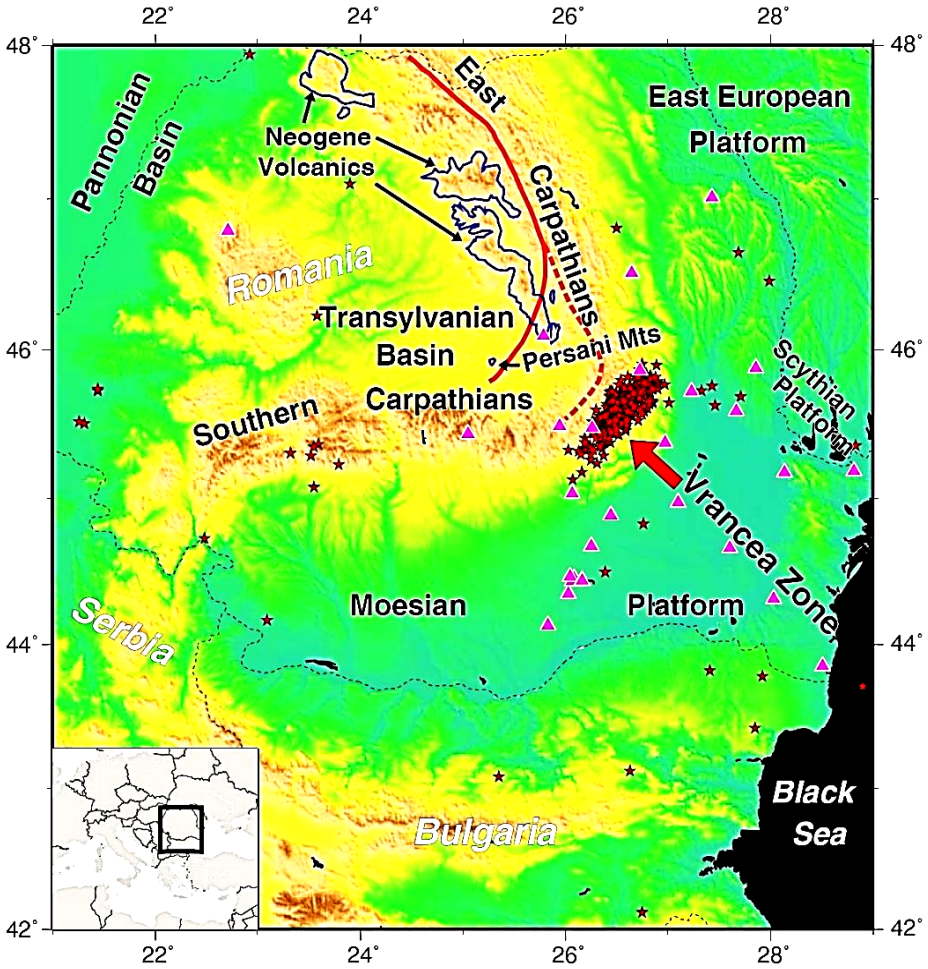

Fig.2 Topographic map of the Eastern and Southern Carpathian Mountains; RUSSO et al. (2005)

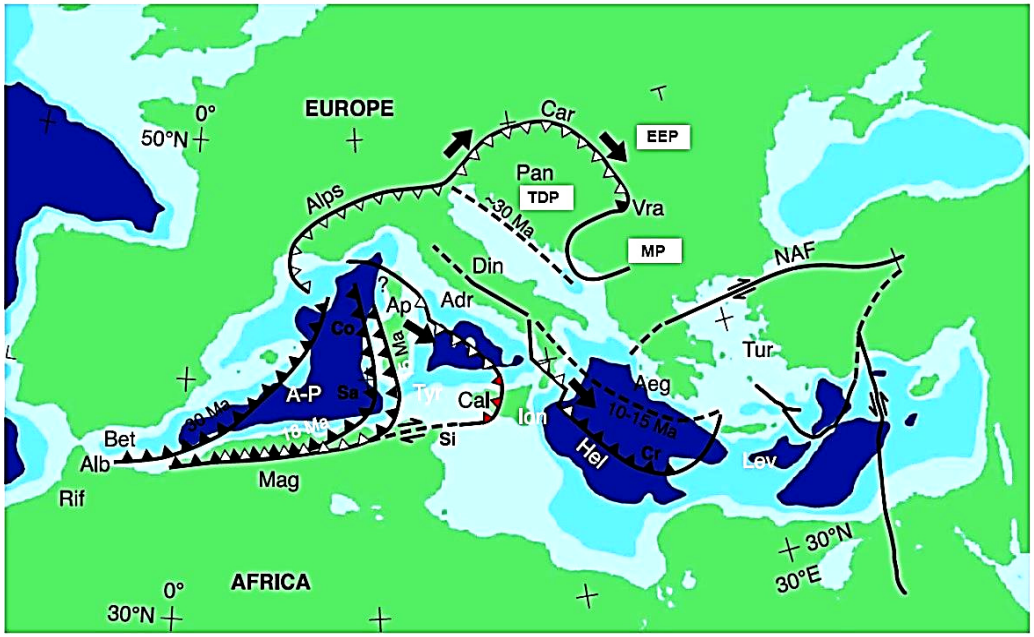

Fig.3 Map of the main thrusts and faults in Europe, after WOTEL and SPAKMAN, (2000). Major tectonic units: East European Plate – EEP, Moesia Plate – MP, Tisza-Dacia Plate – TDP, Car – Carpathians, Din – Dinares, Vra – Vrancea zone.

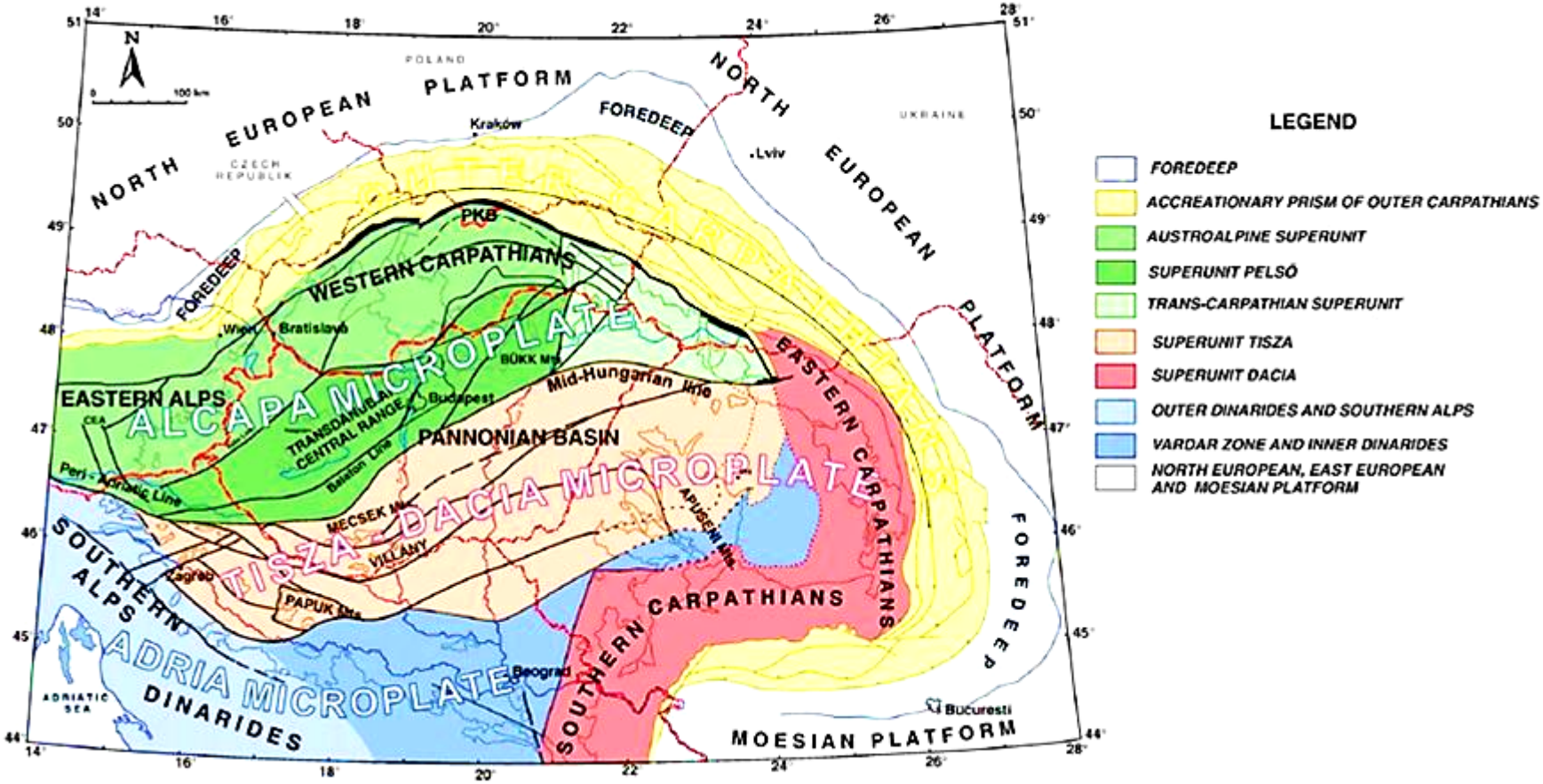

Fig.4 ALCAPA, Tisza–Dacia and Adria microplates and their division into geological superunits after KOVÁČ, (2000); in: TAŠÁROVÁ et al., (2009)

3 Characteristics of the depth of shock hypocentre

Throughout the entire Carpathian Arc, earthquakes occur at relatively shallow depths, up to 33 km below the earth surface. The exception to this is the Vrancea area in Romania (southern Carpathians), where tremors occur at both small and big depths, even up to more than 200 km below the earth surface. Geologically, the Vrancea zone of Romania is characterized by a laterally restricted, steeply NW-dipping seismogenic volume (30 × 70 × 200 km) situated beneath thickened continental crust within the highly arch region of the Carpathian orocline and miscorrelation of hypocentres with the position of known or inferred suture zones in the Carpathian orogenic system; KNAPP et al., (2005).

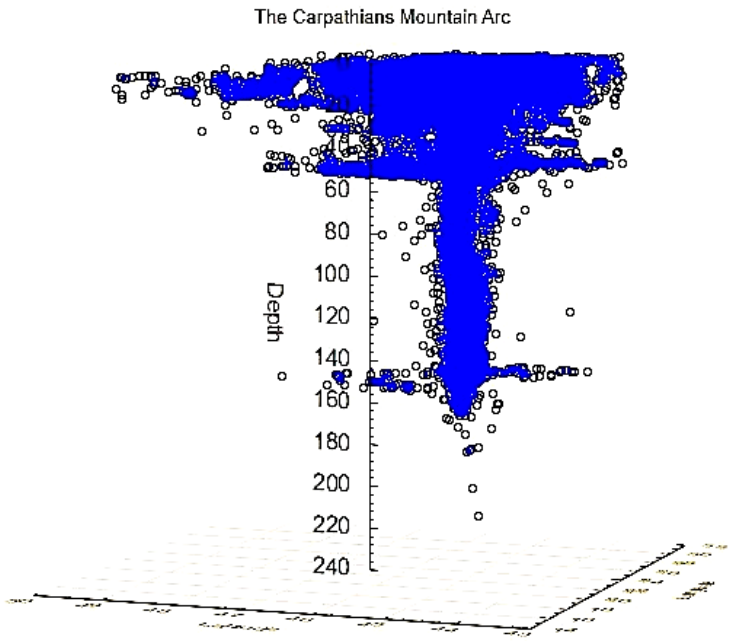

Fig.5 Depth distribution of seismic events from the whole research area – The Carpathians Arc

Analysing the depth distribution of events in the Carpathian Arc, fig.5, we will see that almost all of the shocks have hypocentres in the first 50 km, with the exception of intermediate depth earthquakes in Vrancea zone. Our seismic catalogue included 23 137 events from which 1214 (70 %) are located in the first 50 km of depth: 3 348 (14.47 %) are below 5 km of depth, 6 347 (27.43 %) are in the depth range of 5–15 km, 3 766 (16.3 %) are between 15–30 km depth and 2 753 (11.9 %) between 30–50 km of depth. Shocks whose depth was between 50–100 km were 1971 (8.5 %): in the range 100–150 km was 4 398 (19 %) and above 150 km of depth were 553 (2.4 %). Only two shocks were above 200 km of depth.

We studied the Carpathians Arc in terms of seismic activity and depth distribution in the Western, Eastern and Southern Carpathians. Territory of the Western Carpathians characterizes moderate earthquake activity; see KOVAC et al., (2004). Tremors were located in the shallow depths do not exceed 20 km; fig.6. There were 241shocks from the area of Western Carpathians with local magnitude being in interval 1.6 to 5.3. One can observe a small increase in seismic activity, fig.7, in this region during last years.

The number of tremors from the area of Eastern Carpathians was 3641 about local magnitude being in interval being in interval 1.6 to 5.0. Shocks originated mostly up to 60 km of depth; in fig.8. Besides, in the depth range 60–140 km tremors are group near the Vrancea area. Seismic activity of the Eastern Carpathians was relatively stable up to year 2005; fig.9. In 2005, the number of events significantly increased and since 2006 a clear upward trend is observed. In this sudden increase we can distinguish several increases in seismic activity repeated a few times after which were a small decrease in the number of shocks.

We noted 19 256 shocks about local magnitude range in interval 1.6–7.8 in the Southern Carpathians. The strongest tremors were located in this region. The events were mostly located up to 60 km of depth, see fig.10, similar as in the Eastern Carpathians. Furthermore, in the depth range between 60–149 km shocks epicentres are groups into relatively small limited area named the Vrancea region (45°–46°N, 25.5°–27.5°E). Moreover, in interval 149–150 km of depth tremors extend beyond the area of Vrancea reaching up to the Pannonian Basin. Below 150 km of depth events again grouped only in the Vrancea area.

Seismic activity in the Southern Carpathians is similar to Eastern Carpathians; fig.11. There was also a sudden increase in seismic activity after 2003. However, this increase was much larger than in the eastern part of the Arc.

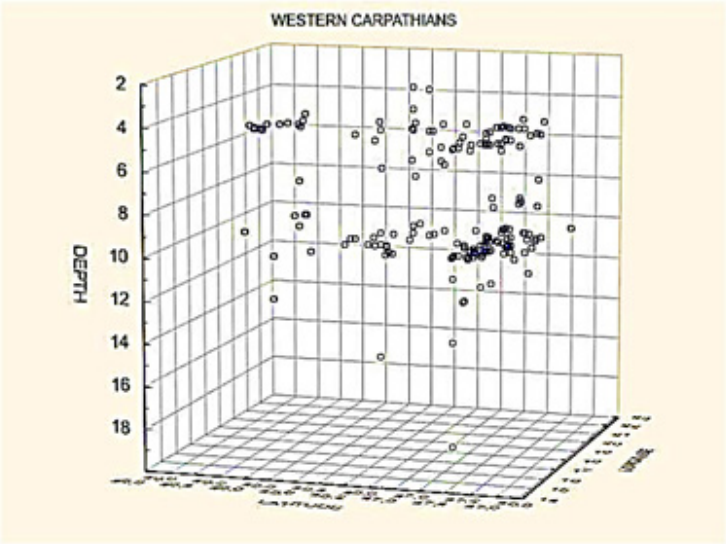

Fig.6 Spatial distribution of seismic events from western part of the Carpathians Arc

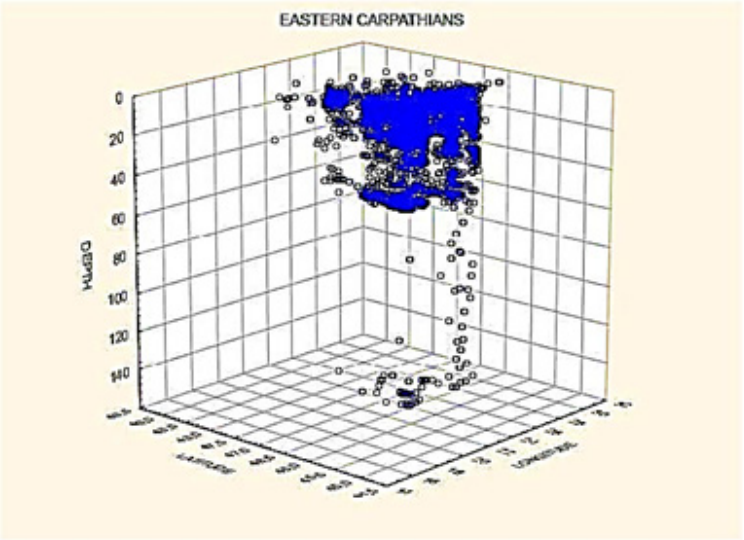

Fig.8 Spatial distribution of seismic events from eastern part of the Carpathians Arc

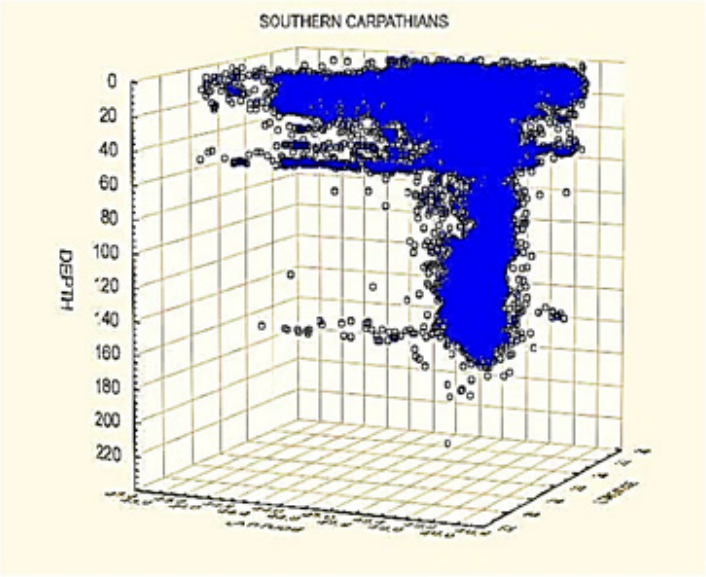

Fig.10 Spatial distribution of seismic events from southern part of the Carpathians Arc

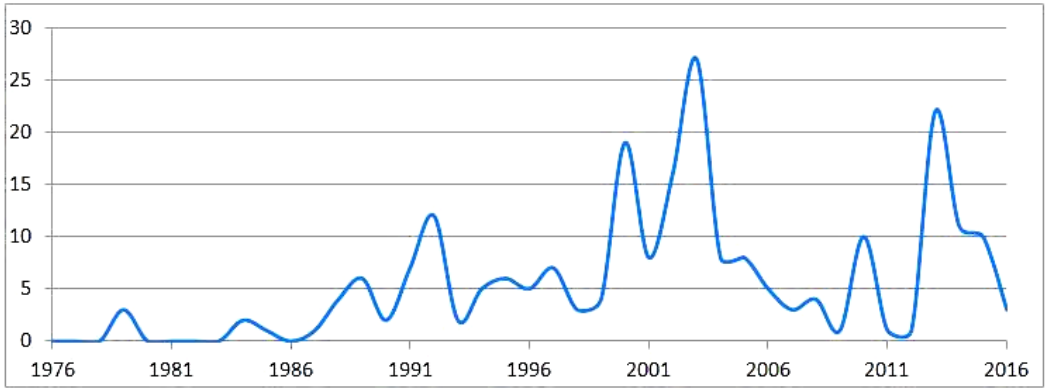

Fig.7 Seismic activity of the western part of the Carpathians Arc

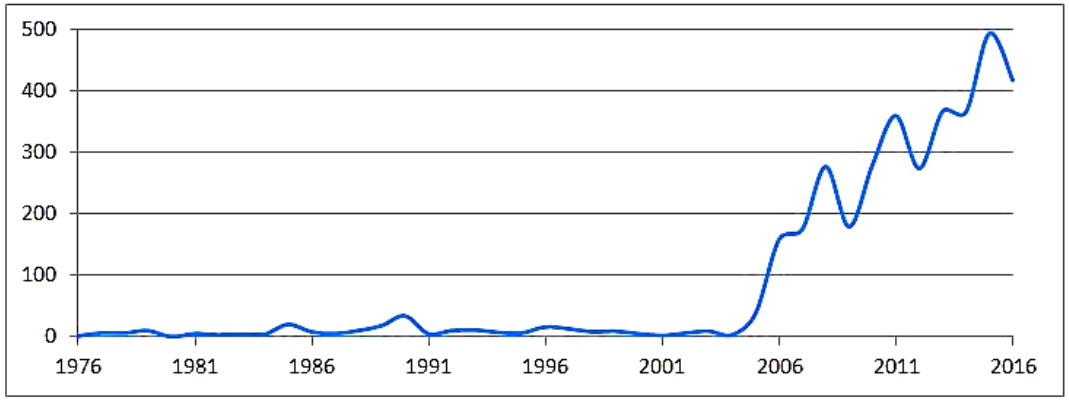

Fig.9 Seismic activity of the eastern part of the Carpathians Arc

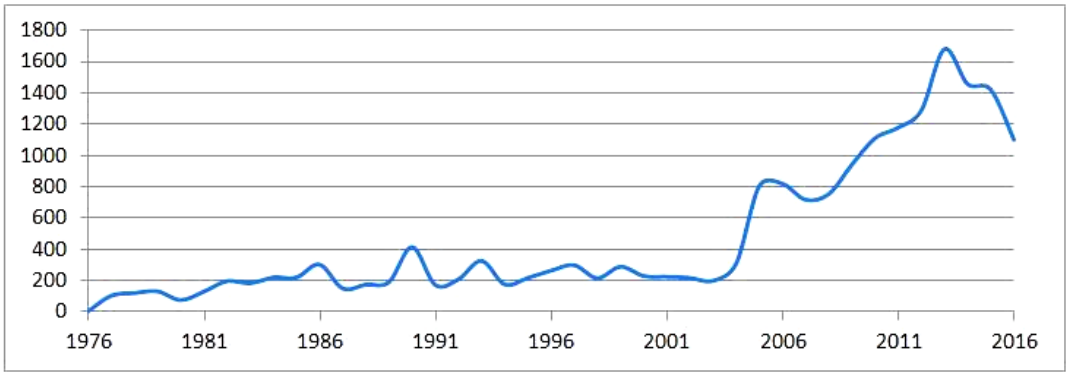

Fig.11 Seismic activity of the southern part of the Carpathians Arc

4 Discussions

If we look at the comparison of seismic activity of the individual regions of the Carpathians Arc, see fig.12, we could see that biggest increase of the number of shocks became in the Southern Carpathians after 2003 y. This could be caused by the fact, that the only active Benioff zone in the Carpathian arc related to the subduction process is situated in the Vrancea area, at a junction of the Eastern and Southern Carpathians in Romania; in KOVAC et al., (2004). In our study we classified Vrancea zone to the Southern Carpathians. A sudden increase in seismic activity also occurs in Eastern Carpathians after 2005.

In the Western Carpathians, despite generally low seismic activity, more or less every 11 years (1990–1992, 1999–2004, 2009–2014) activity increases several times in comparison for its mean value. However, in the Southern Carpathians until 2004 the level of seismic activity was relatively low, around 200–300 events per year. An abrupt increase in seismic activity in 2005 was to about 800 events per year, which then went into a strong upward trend obtaining 1700 events per year in 2013.

A similar character of changes in seismic activity was observed in the Eastern Carpathians; however, here the seismic activity was much about 3 times lower than in the Southern Carpathians. In comparison of changes in seismic activity at different depth intervals in the Southern Carpathians, fig.13, it can be clearly seen that the increase in seismic activity after 2004 is mainly due to shocks occurring shallowly, up to a depth of 40 km. Activity of these shocks increased 13-fold between 2004 and 2013. In the case of events from intermediate depths this increase in seismic activity was only 2-fold. The number of events in the depth range 40–55 km during the years 2007–2011 decreased 3-fold and then it was systematically growing again.

This is a different situation than for other depth ranges in the Southern Carpathians, where after 2013 seismic activity decreases. In turn, in comparison of changes in seismic activity at different depth intervals in the Eastern Carpathians, fig.14, there is seen very clear upward trend in the seismic activity of shallow shocks – up to 40 km in depth, but it concerns mainly shallower shocks, with a depth of up to 20 km. In the Eastern Carpathians, similar to the Southern Carpathians, the number of events in the depth range 40–55 km decreased 5-fold in the period 2008–2014 and then it was systematically growing again. This situation is different from other depth ranges, where after 2014 seismic activity decreases.

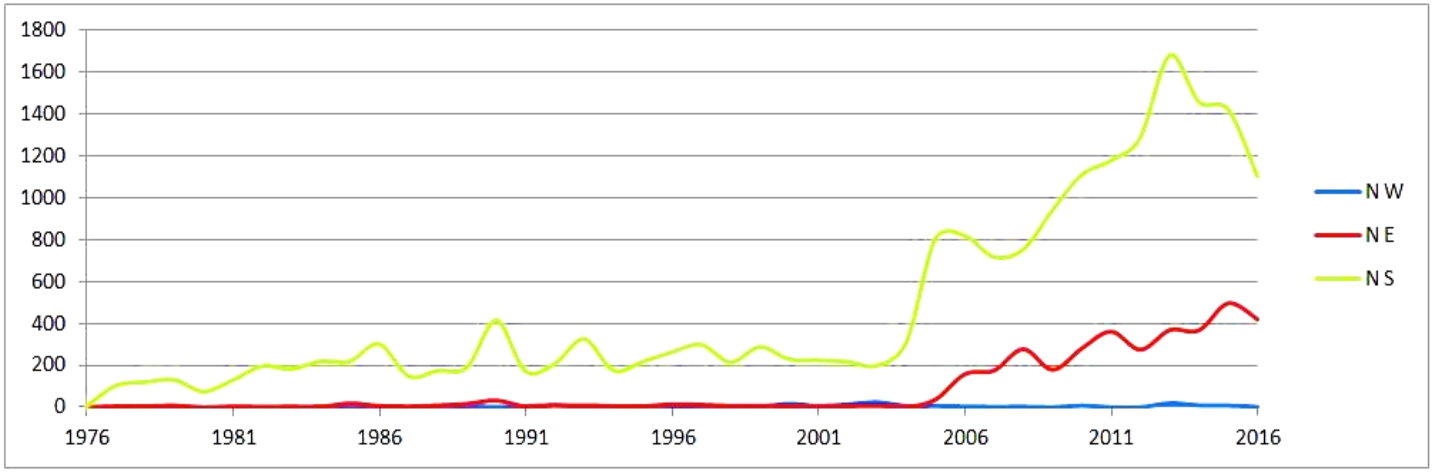

Fig.12 Comparison of seismic activity of the Western, Eastern and Southern part of the Carpathians Arc.
NW – number of tremors from the Western Carpathians,
NE – number of tremors from the Eastern Carpathians,
NS – number of tremors from the Southern Carpathian

5 Conclusions

Throughout the entire Carpathian Arc, earthquakes occur at relatively shallow depths, up to 33 km below the earth surface; 58 % of all shocks. The exception to this is the Vrancea area in Romania, in Southern Carpathians, where tremors occur at both small and big depths, even up to more than 200 km below the earth surface. 70 % of shocks registered in Carpathians Arc are located in the first 50 km of depth.

In the Southern Carpathians a high increase in seismic activity after 2004 was found in all depth ranges. However, it stands out particularly increases trend; it concerns shocks, which have hypocentres relatively shallowly, up to 40 km of depth. The most significant seismicity in the Carpathians Arc is located in a relatively small area – in the Vrancea zone in the Southern Carpathians.

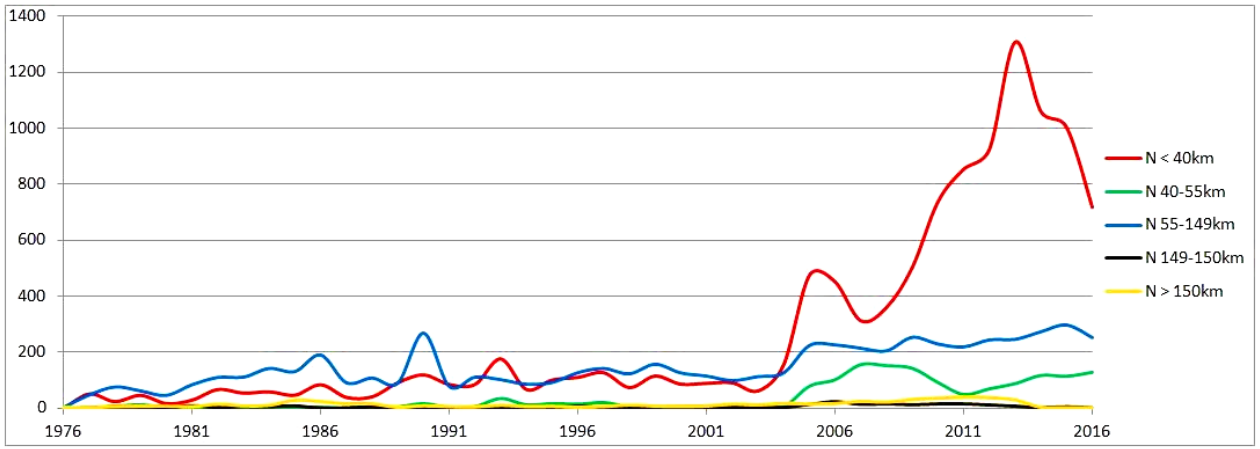

Fig.13. Comparison of seismic activity of the Southern part of the Carpathians Arc in different depth ranges: red - up to 40 km, green – between 40 – 55 km, blue – between 55 – 149 km, black – between 149 – 150 km and yellow – below 150 km

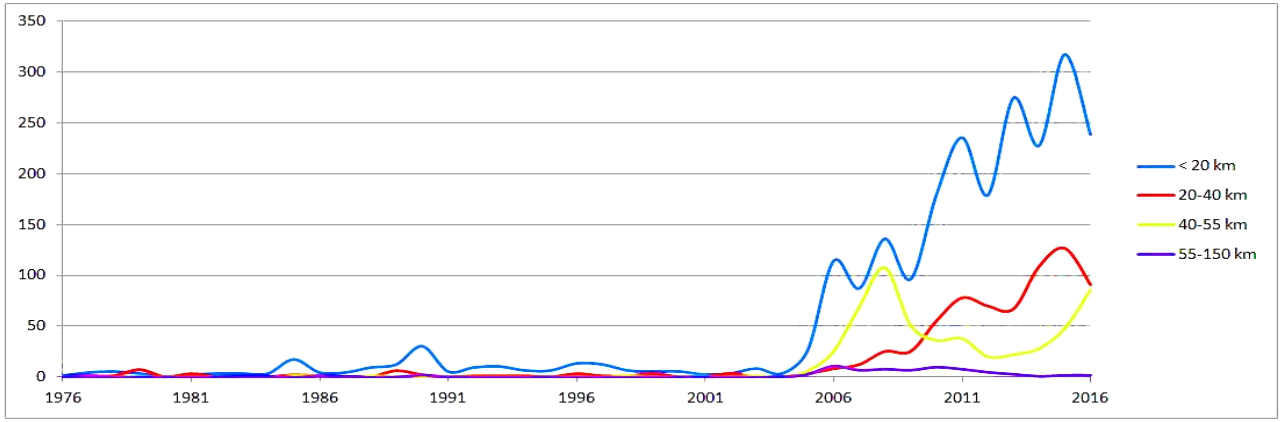

Fig.14 Comparison of seismic activity of the Eastern part of the Carpathians Arc in different depth ranges: blue - up to 20 km, red – between 20 – 40 km, green – between 40 – 55 km and violet – between 55 – 150 km

Both in the Eastern and in the Southern Carpathians a decrease of seismic activity in 2009–2014 and a renewed increase of activity after this period was observed, while the seismic activity of shocks occurred in the shallow depth is decreasing in recent years. In the Western Carpathians a small number of shocks were observed which may result from the relatively low seismic activity of this region. Despite generally low seismic activity, it increases several times more or less every 11 years.

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