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SEISMIC ACTIVITIES AND SEISMOTECTONIC FAULTS IN BOSNIA AND HERZEGOVINA

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SUMMARY

Earthquakes are one of the biggest hazards of humanity. Even today it is not possible to predict the exact magnitude, location and time of an earthquake, but, nevertheless, modern seismology and science are able to point to the potential danger and risk of earthquake-like movements in an area, at one time. Some of the signs that announce the earthquake are the changes in magnetic and electric field of the Earth, changes in groundwater levels, radon, ground deformation, tremors, changes in animal behavior, etc. ... In order to make any measurements in this direction, the location of seismic cracks in a particular area must be known. Here are given the locations of seismic cracks in the area of Bosnia and Herzegovina.

Keywords: *seismology, prediction, earthquakes, earthquake-like area*

INTRODUCTION

Only the ignorant and uninformed can be surprised by earthquakes, one of the greatest threats to humanity. The Earth has been shaking from the beginning, for over 4.5 million years. During that long period of time, it solidified only up to 0,5 %. Under the thin crust that belts the Earth, there is mostly a slithering, glowing matter which is constantly moving.

The Earth's crust today consists of 22 uneven parts, 22 continental plates, touching and rubbing at the junctions. Some parts crack, some become compacted and some move. This process is the result of their movements in all directions. The tectonic plate movement's speed rates from a few milimetres to a few centrimetres a year, because they float on the slithering matter. Earthquakes occur at those junctions, visible from satellites. Up to 90% of the earthquakes in the world occur at these joints and very rarely somewhere on a plate, far from the edges [1].

Every year, there are several thousands of earthquakes. Most of them are weak, i.e. their detection is possible only using sophisticated technical instruments. Only tens of them (per year) are strong enough to be noticed by a man. Certainly, some of them can cause a great material damage and human casualties. Some of them may be disastrous.

The seismic activity for the region of Bosnia and Herzegovina has been documented for a period of 2000 years. That catalogue recorded stronger earthquakes (magnitude M>3.0) on Bosnia and Herzegovina's territory, especially in the last 100 years, since the continuous instrumental monitoring has been done. For studying the connection between seismic activity and variations in the level of radon concentration activity, the most interesting regions on B&H's territory are: Banja Luka, Doboj, Tuzla, Sarajevo (Ilidža), Mostar, Foča, Gacko and Trebinje.

The earthquake, that hit Italy on April 6, 2009, killed more than 200 people and injured 1500. Now, it is being discussed if the earthquake could have been predicted. Namely, an Italian seismologist Gioacchino Giuliani had predicted a big earthquake in the area of an Italian city, L'Aquile,several weeks before it actually happened, but he had been reported to the authorities for spreading panic among the citizens. Giuliani based his prediction on a radon gas concentration around seismically active areas, but the scientific attitude was that an earthquake could not be predicted.

The assessment of an earthquake risk for an area is traditionally done on bases of how frequent stronger earthquakes occur, during a longer period of time. The latest development in geodetic measurement techniques contributed largely to improve predictions of earthquake risk zones, based on reliable mathematical models obtained by real measurements. The prediction method lays on a fact that the Earth's crust consists of the tectonic plates which may cause an earthquake by movement. Precise measurements of stable points' horizontal movements determine forces and tensions between the neighbouring plates. Nowadays, these measurements are done viaGPS. The models obtained, especially those interpreted by geologists and seismologists, may lay a firm foundation of middle-term planning expense for strengthening buildings in architecture, particularly bridges and viaducts, which need to be built right in the fault zones [2].

EARTHQUAKES LIKE A NATURAL DISASTER AND EARTHQUAKE PREDICTIONS

Over the decades, researchers have been trying to give a reliable prediction about the place of an earthquake. One of the signs is the intensified radioactive radon leeking. Even Gioacchino Giuliani reported that the devices recorded higher amounts of radon, 6 to 24 hours before the earthquake.

All the researches done so far, when thepossible signs had been recorded (radon leeking or electrified liquids), did not show one or any complex signs that could predict, with credibility, future soil movements. It is necessary to use as many detectors as possible to knit a spread network for monitoring variations in radon concentration. It seems that this gas, on certain occassions, predicted serious earthquakes.Amongst those who study earthquakes, the orientation that prevails is that it is wiser to have an accurate forecast than a far-reaching prediction. Forecasts of certain geographical areas would be based on historical discoveries and recent measurement at faults, similar to weather forecasts. According to the US Geographical Survey, it is 62% possible that an earthquake of 6,7 on the Richter scale, or stronger, would hit San Francisco area before 2032 [3].

Radolić V., a professor at Natural Sciences, Osijek University, with his associates, studies radon anomalies caused by earthquakes. In his thesis "The study on radon anomalies in soil and water, as a possible earthquake prediction", he writes: " The basic, potential option for predicting an earthquake is based on a claim that an earthquake is not a sudden, isolated event but a long-term one, and the preparation processes are followed by different physical phenomena, i.e. earthquake signs".

To be familiar with the preparation mechanisms and the earthquake occurance, namely, the development and the manner of its sign, makes it possible to answer, in general, three basic questions about the eartquake prediction: when (time), where (locaton) and how many (magnitude). There are several different events i.e. physical parametres, as earthquake signs:

- Some place seismicity anomalies (areas of seismic rupture occurance),
- Variations in straining and deformation fields,
- Changes in the speed of seismic wave spread,
- Chages in soil and groundwater levels,
- Changes in gravity and geomagnetic fields,
- Changes in electrical conductivity i.e. in soil and groundwater resistance,
- Anomalies in geogas concentrations (Rn, Ar, He, N_2, H_2, CO_2, CH_4),

- Anomalies in dissolved ions concetration (HCO_3^-, Cl^-, SO_4^{2-}, Na^+, Ca^{2+}) in hydrothermal vents, etc.

Radon anomalies cannot be observed from the distance further than some edge distance, so it is necessary to assess the effective area of earthquake prediction. The annual indoor radon concetration in Croatia was ranging from 4 to 751 Bqm^{-3}, where the arithmetic mean and standard deviation were of 68 and 85 Bqm^{-3}, meaning the geometric mean and standard deviation were 50 and 2,3 Bqm^{-3}, respectively [4].

Measurements like these haven't been done for Bosnia and Herzegovina and there is no radon map for Bosnia and Herzegovina. Earthquake predictions are very important for the safety of all the people in the world. Geologic disasters, resulting in huge material damage and human casualties, are widely predicted by monitoring seismic activities of a certain area. The method, which includes radon concetration measurements, plays an important role in the predictions of seismic events over the last decade.

WHY AND HOW AN EARTHQUAKE OCCURS

Seismology does not deal only with the surface earthquake manifesto, but also looks into destruction process and disorders that occur from the hearth (the place from where earthquakes originate) to the surface manifesto, and they are the result of converting hearth potential energy to kinetic – destructive energy. According to the causes of their occurance and the manner of their manifesto on the surface, earthquakes can be: tectonic, volcanic, urvinic and atificial. The usual cause of earthquakes in many cases is a tectonic plate mechanism i.e. the lithospheric plate movements and interaction.

Taking the mechanic characteristics of rocks in account, the rocky matter is elastic when under the force, meaning it can 'accumulate' the stress. This process can last several thousands of years in the Earth's crust. When the force releases, in some cases, the matter elastically recovers its original state. However, processes inside the Earth's crust usually lead to the continuous straining of the rocky matter reaching its critical value and bursting. After that, the rocky blocks move with an enormous energy emission which passes through the Earth's crust in a form of seismic waves, causing the movement of the particles around.

Also, an earthquake can occur without having the rocky matter burst. This happens when the rock is no longer under the force and recovers its original state. At the very return to its original shape and volume, the same seismic energy emission may cause an earthquake.

The planet Earth consists of several layers of different physical and chemical characteristics, which, accordingly, act differently. The outer Earth's layer – the Earth's crust (approximately 70m thick) has typical solid matter characteristics. The crust is divided in many entities i.e. the tectonic plates (there are a few bigger and a lot of smaller ones). The asthenosphere, just by moving i.e. by convective drifting, enables the tectonic plates to 'float' on it, making them move relatively in relation to one another [5].

The very zones where one tectonic plate hits the other are the places of the most intense earthquakes. This fact was used by scientists who registered the most intense earthquakes and defined the edges of the lithospheric plates. Only 10% of the registered earthquakes occurs in the inside of the tectonic plates, and most of them happen along their edges. An earthquake represents the movement of the Earth's crust parts as a result of the elastic energy emission. During an earthquake, the Earth's crust moves, trembles or bursts i.e. there is the seismic energy emission which is transmitted from the source via seismic waves.

The first element of an earthquake is a fault. Along the fault,rocky blocks move. The focus represents the place of the maximum seismic energy emission on a fault. The centre of the focus is called a hypocentre or focus (Anglo-Saxon). Another important element of an earthquake is also epicentre, the vertical projection of a hypocetre on the Earth's surface.

In order to interpret earthquakes, their destructive force on buildings and the Earth's relief identically, seismologists accepted the unique international earthquake scale (MCS scale).

The actual amount of the energy emitted in a hypocentre of an earthquake is determined by an earthquake magnitude; it is determined by the Richter scale.The scale was invented by Charles F. Richter who had designed the numerical scale during the 1930s, presenting the relative magnitudes of the earthquakes in the South California. The comparison between MSC andthe Richter scale is shown in Table 1. Acceleration (a) stands for the soil acceleration expressed in*mm/s*

Table 1 Comparative ratio between MCS and RICHTER scale

MSC scale	Acceleration	Gutemberg-Richter scale
I	2,5	1
II	2,5 – 5	2
III	6 – 10	3
IV	11 – 25	3
V	26 – 50	4
VI	51 – 100	4
VII	101 – 250	5
VIII	251 – 500	6
IX	501 – 1000	6,3
X	1001 – 2500	7,6
XI	2501 – 5000	7,6
XII	Over 5000	8,6

The intensity of an earthquake weakens as a wave backs away from an epicentre, leaving an asymmetric shape of an isoseismal, depending on the geological content of the terrain, on a tectonic ratio between rocky matters and the hearth's depth. Greater the depth, weaker the intensity, and vice versa. The ratio between the magnitude in the hearth and its conversion into intensity in the epicentre is used for dividing seismic zones, the important element for the construction and other buildings at the Earth's surface.

An earthquake cannot be predicted at the specific date or time. Richer once said "*only liars, charlatans and fools can predict an earthquake!*"

Surely, science and technology have advanced since his time and the situation is different nowadays. Like we already know, it is impossible to foresee an exact magnitude, place and time of an earthquake, not even today, but still moder seismology and science are able to point to the danger and potential risk of an earthquake occurance in an area, at one specific period of time.

There are long-term and short-term earthquake predictions. The long-term predictions predict earthquakes which are to happen in the years to come or even ten years in advance. This prediction type takes into account tectonic and geologic characteristics of a zone for which the prediction is to be done. This prediction is the most probable for areas along the edges of the tectonic plates, where earthquakes occur at relatively regular time intervals.

The short-term earthquake predictions are much less effective than the long-term predictions. It is known that earthquakes do not carry very obvious precursors (anomalies or signs) unlike volcanic eruption. Therefore, it is hard to predict an erthquake in an area in, for example, seven days [6].

Some of the earthquake signs are changes in magnetic and electric fields of the Earth, changes in groundwater and radon concentraion levels, soil deformations, tremors, changes in animal behaviour, etc. One of the most important signs is a tremor, that can be of different intensity.

EARTHQUAKE-LIKE AREAS IN THE WORLD

Considering the srong earthquake prevalence in the past, it can be concluded that they occur in unstable geosynclinic areas of the Alpine-Himalayan belt (Mediterranean belt) and the Indo-Malay-Japanese (Circum Pacific) belt. Accordingly, earthquakes can be expected in Mediteranean area: in the Atlantic ocean, over Gibraltar and the coasts of the Mediterranean sea, including Apennines and the Balkans, then in the Caucasus mountains, in the Himalayan area, in the Indian archipelago, on Sumatra and Java, on Sunda archipelago across the East.In the Circum Pacific area, earthquakes occur in the edges of the Pacific and along the east coasts of Asia.

EARTHQUAKE-LIKE AREAS OF EX-YUGOSLAVIA

Ex-Yugoslavia belongs to the Alpine-Himalayas mountain range, one of the very mobile areas of the Earth, regarding the earthquake occurance. Earthquakes are usually tectonic and mostly linked to the ratio structure inside the Earth's crust.

Having many greater fault ambivalent parts on the ex-Yugoslavia territory (Macedonia, the Dinarides, Pomoravlje, Posavina, etc.), mobile even today, it is understandable why block movements, and the earthquakes they create, occur in these locations.

According to scientific findings about the neotectonic activity of the Earth's crust in this part of the Mediterranean geosyncale i.e. the Alpine-Himalayan orogen, there are six major earthquake-like areas on ex-Yugoslavia territory:

- The river Sava's basin region,
- The Dinarides region,
- The Alps region,
- The Carpathian-Balkanides region,
- The Rhodope masiff region,
- Šara and Pindo region.

Statistically, seismic activities on ex-Yugoslavia soil are mostly present in the zones where earthquakes may reach VII degree on the international MCS scale [7].

EARTHQUAKE-LIKE AREAS IN BOSNIA AND HERZEGOVINA

Researching the connection between an earthquake occurance and the location of earthquake lines (faults along which earthquakes occur), it can be stated that in Bosnia and Herzegovina there are these earthquake lines, Figure 1.

a) The Posavina's earthquake line, which matches so-called «Zagreb's crack» starts from Petrinja in Croatia by Sisak, then goes along the river Sava valley and enters Serbia at Zvornik
b) Banja Luka's earthquake line is a line from Banja Luka to Novi Grad and futher to Petrova gora
c) Travnik's earthquake line so-called «Big tertiary basin from Travnik to Sarajevo», with several mineral springs (Ilidža, Kiseljak, Busovača)
d) The upper river Vrbas' earthquake line is situated in the south of Ključ, along the river Neretva, in the northwest of Jablanica
e) The river Neretva's earthquake line which matches the seismogenic line form Sarajevo to Nevesinje

Studying the connection between an earthquake occurane and Bosnian and Herzegovinian tectonics, there are several earthquake-like regions: Trebišnjica, Gacko, Foča, Prača, Sarajevo, Travnik, the town of Mrkonjić (Mrkonjić grag), Kupres, Stolac and Mostar.

Figure 1. The map od seismotectonic faults on Bosnia and Herzegovina territory.

The next table 2, shows the list of the stronger earthquakes on Bosnia and Herzegovina territory [8].

Table 2 Stronger earthquakes in the region of Bosnia and Herzegovina in the last 100 years

No.	Date			Earthquake parametres					Ep. zones
	Day	Month	Year	Latitude	Longitude	M	h	Io	
1	22	07	1901	43.033	17.600	5.3	07	7.3	Metković
2	27	03	1903	43.200	17.300	5.2	10	7.1	Vrgorac
3	15	12	1904	43.800	16.600	5.2	10	7.1	Prolog
4	27	04	1905	44.567	16.367	5.0	13	6.8	B. Petrovac
5	06	10	1905	42.700	18.017	5.2	10	7.1	Dubrovnik
6	02	01	1906	45.900	16.100	6.1	10	8.4	Kasina
7	03	10	1906	43.083	17.933	5.1	14	7.0	Stolac
8	25	06	1907	44.417	17.983	5.1	16	7.0	Žepče
9	01	08	1907	43.383	17.600	5.8	23	8.0	Ljubuški
10	01	08	1907	42.967	17.967	6.0	20	8.3	Ljubinje
11	01	08	1907	43.200	17.683	5.1	05	7.0	Ljubuški
12	03	08	1907	43.333	16.967	5.2	20	7.1	Imotski

No.	Day	Month	Year	Latitude	Longitude	M	h	Io	Ep. zones
13	22	02	1917	42.783	17.900	5.0	10	6.8	Slano
14	04	06	1921	43.500	16.800	5.2	10	7.1	Brač
15	06	02	1923	43.500	17.100	5.5	06	7.6	Jajce
16	15	03	1923	43.300	17.367	6.5	15	9.0	Tihaljina
17	30	05	1924	43.133	18.067	5.0	11	6.8	Stolac
18	14	02	1927	43.017	18.000	5.9	20	8.1	Stolac
19	27	03	1938	46.200	16.800	5.6	10	7.7	Knin
20	17	12	1940	44.983	17.917	5.0	15	6.8	Derventa
21	29	12	1942	43.200	17.550	6.0	15	8.3	Imotski
22	04	02	1946	42.800	17.800	5.1	10	7.0	Mljet
23	31	08	1950	44.883	17.433	5.4	06	7.4	Drugovići
24	11	01	1962	43.200	17.200	6.1	10	8.4	Makarska
25	11	06	1962	43.583	18.433	6.0	19	8.3	Treskavica
26	13	04	1964	43.300	18.100	5.7	10	7.8	Nevesinje
27	03	07	1967	44.000	19.200	5.1	06	7.0	Luke
28	26	10	1969	44.800	17.300	5.6	24	7.7	Banja Luka
29	27	10	1969	44.800	17.200	6.4	25	8.8	Banja Luka
30	31	12	1969	44.883	17.217	5.3	18	7.3	Banja Luka
31	25	08	1970	43.200	18.300	5.0	10	6.8	Gacko
32	24	06	1972	43.710	16.860	5.3	33	7.3	Grahovo
33	20	06	1974	44.200	17.900	5.1	04	7.0	Zenica
34	29	10	1974	44.583	18.467	5.1	10	7.0	Dobošnica
35	16	02	1978	43.250	17.083	5.1	16	7.0	Glamoč
36	17	04	1979	42.510	18.600	5.4	10	7.4	Trebinje
37	03	10	1979	43.350	18.100	5.1	14	7.0	Nevesinje
38	22	06	1980	43.433	17.467	5.1	10	7.0	Posušje
39	13	08	1981	44.700	17.300	5.5	14	7.5	Banja Luka
40	08	04	1984	44.550	17.130	5.0	33	6.8	Sanski Most
41	13	05	1984	42.950	17.833	5.4	20	7.4	Hutovo
42	13	05	1984	43.000	17.770	5.6	33	7.7	Hutovo
43	25	11	1986	44.067	16.317	5.9	21	8.1	Grahovo
44	08	11	1987	44.033	16.317	5.0	09	6.8	Grahovo
45	06	12	1989	43.640	16.890	5.0	24	6.8	Livno
46	03	04	1990	43.419	17.387	5.6	10	7.7	Grude
47	03	04	1990	43.380	17.320	5.1	21	7.0	Imotski
48	27	11	1990	43.853	16.633	5.7	24	7.8	Livno
49	27	11	1990	43.850	16.630	5.3	33	7.3	Livno
50	27	11	1990	43.895	16.641	5.3	10	7.3	Livno
51	27	11	1990	43.870	16.640	5.2	33	7.1	Livno
52	28	09	1995	42.625	18.162	5.2	10	7.1	Trebinje
No.	Date			Earthquake parametres					Ep. zones

Where is (in the table):

No.	the ordinal number of an earthquake in this catalogue
Date	the date an earthquake happened
Latitude, longitude	geographical coordinates of an earthquake epicentre
M	an earthquake magnitude at the hypocentre (Richter)
h (km)	he depth of a hypocentre
I (°MCS)	the maximum seismic intensity (Mercalli scale)
Ep. zones	epicentral zones (the nearest populated area/place)

SUMMARY

Based on the information on seismicity and seismotectonics of Bosnia and Herzegovina, it can be concluded:

1. the highest earthquake frequency is in Herzegovina area (the Croatian border) and in the north of Bosnia(Banja Luka),
2. in the regions of Banja Luka, Derventa and Tuzla, in the last 25 years, there was an increase in seismic activity,
3. the depth of a hypocentre ranges from 6 to 30 km. The shallowest earthquakes were recorded in Drina area (Prača, Višegrad, Srebrenica, Zvornik), and the deepest ones in the northwest and the west of Bosnia,
4. all the earthquakes that happened were of tectonic origin,
5. the most active tectonic faults are those in Vrbas, Treskavica and Stolac areas,
6. based on the implemented model of the seismocity of the studied seismogenic areas, the similar seismic activity can be expected in the future.

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REFERENCES

[1] Albini, P., Cecić, I., Morelli, G., Sović, I., Živčić, M. (1994). A preliminary investigation of the January 4th, 1802 earthquake, Materials of the CEC Project "Review of Historical Seismicity in Europe", 2, CNR, Milano. pp.205-214.

[2] Bikit, I., Slivka, J., Čonkić, LJ., Kramar, M. (1994). Specifični problemi merenja prirodnih radionuklida. Beograd. JDZZ, Jonizujuća zračenja iz prirode.

[3] Grabrovec, D., Allegretti, I. (1995). On the digitizing of historical seismograms. Geofizika, Vol. 11, pp. 27-31.

[4] Herak, D., Herak, M. (1995). Body-wave velocities in the circum-Adriatic region, Tectonophysics, 241, pp. 121-141

[5] Herak, M. (1991). Lapse time dependent Qc-spectra observed in the Dinarides region. Physics of the Earth and Planetary Interiors, 67, pp. 303-312

[6] Herak, M., Kuk, V., Herak, D. (1993): Seismological investigations after the Peruća dam explosion of January 28, 1993. International Water Power and Dam Construction.vol. 45, pp. 41-46.

[7] Markušić, S. (1991): Determination of velocities of refracted longitudinal Pn waves in the Dinarides. Zagreb. Geofizika, Vol. 8, pp. 101-113 (in Croatian).

[8] Sović, I. (1992): On the difficulies in determination of the macroseismic intensity in the Dalmatian hinterlands and sothwestern Herzegovina. Ljubljana. Second AB workshop on macroseismic methods. pp 105 – 108 (in Croatian).