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Short communication

ENERGY CHARACTERISTICS OF SOME EPICENTRAL AREAS IN THE VARDAR ZONE

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A b s t r a c t: Seismological phenomena are a natural phenomenon associated with the development of the Earth. They inflict huge damage and cause a large number of human casualties. The territory of the Republic of Macedonia is, seismically, very active part of the Mediterranean area where a large number of earthquakes have occurred. When studying these phenomena, the determination of the energy released during earthquakes is of great importance. This paper deals with the seismic energy of the Vardar zone through the empirical formula for the dependence of the magnitude of the earthquake M and the activated geotectonic surface. Seismicity in Vardar zone is particularly pronounced in the areas of crossing of the reactivated old faults from the Vardar direction with neotectonic faults that predominantly stretch in the transverse direction. Vardar zone is defined as the most labile tectonic unit on the Balkan Peninsula with very expressed seismicity. This paper presents the energetic characteristics of the epicentral areas separated in the Vardar zone: Kumanovo, Skopje, Veles–Sveti Nikole, Štip–Radoviš, Kavadarci and Valandovo.

Key words: energy; characteristics; magnitude; Vardar zone; epicentral areas

INTRODUCTION

Earthquake is a natural occurrence that origin in the deep parts of the Earth with rapid release of energy in the focus area. Such released energy spread through the ground and on the Earth's surface is manifested as earthquake. Related to the depth of the focus, earthquakes are divided in: depth earthquakes – their focus is deeper from the limit of the earth's crust (depth to 800 km) and earthquakes whose focuses are in the earth's crust, so called tectonic earthquakes. Depth earthquakes are formed in the subduction zones of the tectonic plates, mixing the subduction material leads to complex physical-chemical processes that generate large quantity of energy which is reason for this type of earthquakes (Blažev and Arsovski, 2003).

From physical point of view, released seismic energy is directly related to the volume of activated earthquake focus.

At the origin of earthquakes, the potential energy of strain is quickly released and transformed in part of the kinetic energy of seismic (elastic) waves, and some other types of energy. Energy characterizes the essence of occurrence of earthquakes and is one of the main physical characteristics of the focus. The seismic energy, spreading in space, excites particles and they begin to oscillate. The energy released in the focus is greater, and the oscillation of the ground is more intense (Delipetrov, T. et al., 2014).

Vardar zone is defined as the most labile tectonic unit on the Balkan Peninsula where Alpine orogeny processes were so expressed and continued in neotectonics stage.

Seismicity in this zone is particularly pronounced in the areas of crossing of the reactivated old faults from the Vardar direction with neotectonic faults that predominantly stretch in the transverse direction.

Looking at the spatial distribution of the earthquakes so far (Figure 1) in the Vardar zone, the following epicentral areas can be separated: Kumanovo, Skopje, Veles–Sveti Nikole, Štip–Radoviš, Kavadarci and Valandovo.

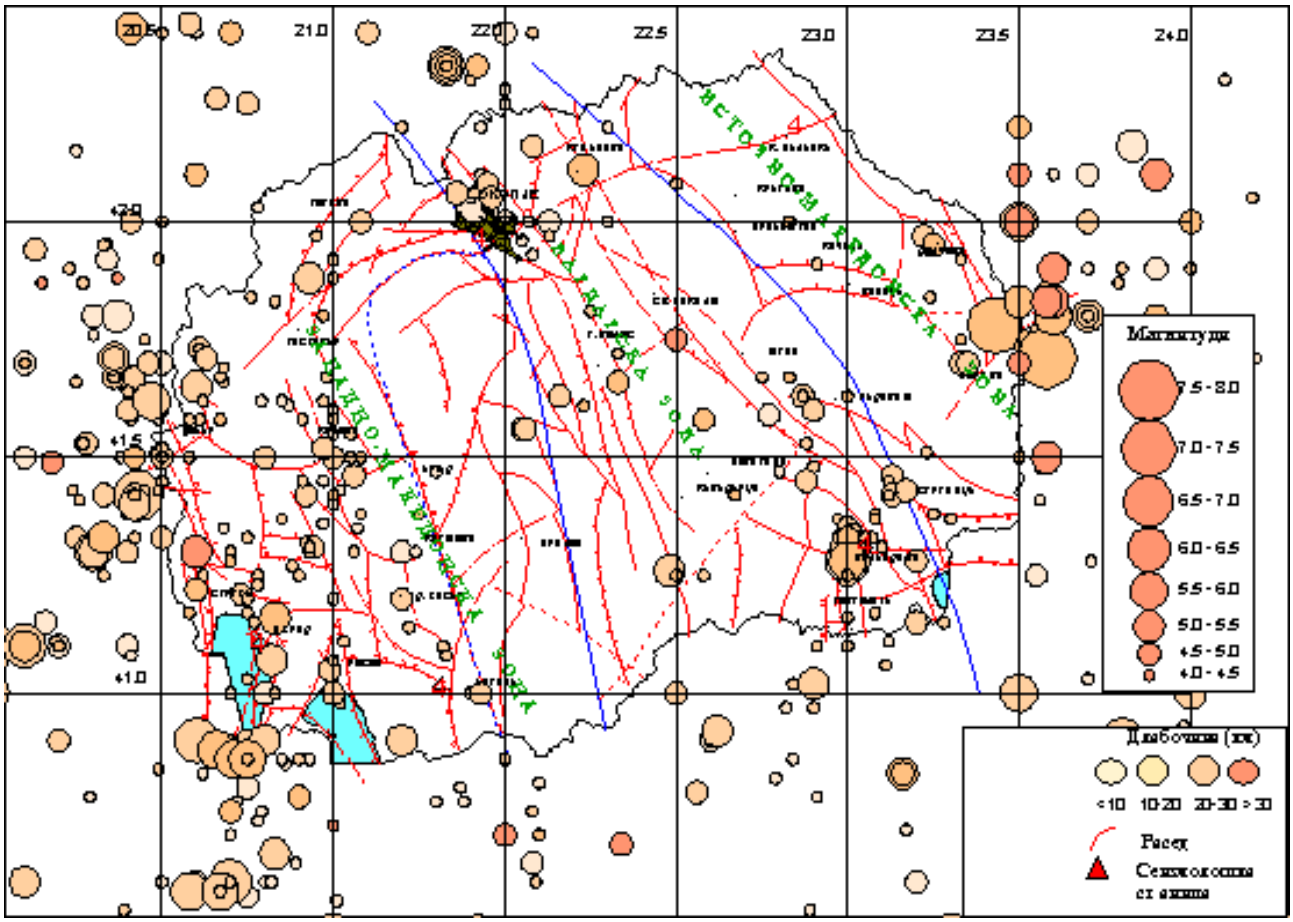

Fig. 1. Map of the earthquake's epicenters in the Repubic of Macedonia and surrounding recorded between 1900–2000 for $4.0 < M < 8.0$ (Donevam 2014)

ENERGY CHARACTERISTICS OF THE EPICENTRAL AREAS IN VARDAR ZONE

One of the most important parameters in seismicity is seismic energy released during earthquakes. Using the empirical formula of Gutenberg-Richter for calculation the relation between the energy and magnitude (Storcheus, 2011):

$$\log E = 1.5M + 4.8$$

calculation is made for released seismic energy of every earthquake occurred in certain epicentral area, and then that energy is summarized for all earthquakes and obtained is the total released seismic energy of the area.

Also, calculated is percentage contribution of every epicentral area in the total released energy in Vardar zone. Calculations are made for a period of 75 years (Delipetrov et al., 2014).

Epicentral area Kumanovo. In this epicentral area are analyzed several earthquakes with magnitudes from 2.7 to 5.3, occurred in a period of 75 years and the calculated total released seismic energy is $E = 87.19 \cdot 10^{-11}$ (J) that corresponds to earthquake with magnitude $M = 5.43$.

Knowing that in this area was occurred earthquake with magnitude $M = 5.3$, it's clear that the largest part of the energy released within 75 years is emitted through the strongest earthquake.

Average annual released seismic energy of the Kumanovo epicentral area is $E = 1.16 \cdot 10^{11}$ J and corresponds to magnitude $M = 4.18$.

In the total released seismic energy in Vardar zone, this epicentral area (focus) contributes with 0.47 %.

Epicentral area Skopje. This epicentral area is connected to the tectonic activity of Skopje depression which represents neotectonics depression.

In Skopje epicentral area is very expressed concentration of earthquake focuses in almost a local terrain on depth of 2–12 km.

Small depth of the focus of the main earthquake in 1963 mainly led to such a large macroseismic manifestation on the surface (the maximum surface effect in the central parts of the city was up to IX degrees on the MCS scale). After this catastrophic earthquake, detailed seismic and seismotectonic investigations were carried out in this area. It can be said that the Skopje seismogene area is the most explored region not only in the Vardar zone, but also in Macedonia.

For determination of the released seismic energy are taken 27 occurred earthquakes which according the Catalogue of occurred earthquakes belong to Skopje epicentral area.

The total released seismic energy, calculated for this area, is $E = 935.40 \cdot 10^{11}$ J for a period of 75 years and corresponds to an earthquake with magnitude $M = 6.2$.

Average annual released energy is $E = 12.47 \cdot 10^{11}$ J, corresponding to earthquake with magnitude $M = 4.10$.

On this active seismogenic focus belongs 5,05% of the total released seismic energy in the Vardar zone.

Epicentral area Veles–Sveti Nikole. For the time being, this region has been characterized by a relatively constant occurrence of only weak earthquakes (magnitude $M = 3.3$ to 4.8).

The total released seismic energy in this area is $E = 69.62 \cdot 10^{11}$ J which corresponds to earthquake with magnitude $M = 5.4$.

Average released annual seismic energy is $E = 0.93 \cdot 10^{11}$ (J), corresponding to earthquake with magnitude $M = 4.1$.

The contribution of this epicentral area in the total released seismic energy in Vardar zone, in period of 75 years, is 0.38 %.

Epicentral area Štip – Radoviš. This focal zone, tectonically is closely related with the neotectonics movements, or formation of the Lakavica ridge. In this area, as in the previously described, so far only weak earthquakes have appeared. From the recent seismic activity in this area or analyzed 22 earthquakes with magnitude from 2.7 to 4.6, in a period of 75 years, the total released seismic energy is $E = 16.28 \cdot 10^{11}$ J which corresponds to an earthquake with magnitude $M = 4.9$.

Average annual released seismic energy amounts to $E = 0.22 \cdot 10^{11}$ J, or earthquake with magnitude $M = 3.7$.

This epicentral area contributes with 0.09 % in the total released seismic energy in Vardar zone.

Epicentral area Kavadarci. This area is located in the south-western part of Varadr zone where in Pliocene–Quaternary was manifested volcanism (Alšar – Kožuf) and the Mrežicko fault was reactivated.

This area, similarly to the previous, is characterized with relatively weak earthquakes.

In a period of 75 years, from the analyzed 10 earthquakes with magnitude $M = 2.8 – 5.1$, the total released seismic energy is $E = 151.44 \cdot 10^{11}$ J that corresponds to an earthquake with magnitude $M = 5.6$.

Average annual released seismic energy in epicentral area Kavadarci is $E = 2.02 \cdot 10^{11}$ J and corresponds to earthquake with magnitude $M = 4.3$.

Only 0.82% of the total released seismic energy in Vardar zone belongs to this focus.

Epicentral area Valandovo. Seismicity in this area is conditioned with the neotectonics activity of the Valandovo fault that pass along the southern edge of the Valandovo depression. It is crossed with north-northwest oriented fault system that created complex tectonic node.

In this epicentral area occurred the strongest earthquake in Vardar zone till now with magnitude $M = 6.7$. This major earthquake was preceded by a foreshock activity in a wider area, approaching gradually to the epicenter of the main earthquake occurred on 8. III. 1931.

From the impact of this earthquake the most affected was the village of Pirava, near Valandovo. Beside Pirava and Valandovo, another 40 settlements from Gevgelija to Strumica were destroyed.

After this strong earthquake, similarly to the foreshock activity, occurred aftershock activity and the region covered with this action was very large. This showed the size of the Valandovo focus and complex tectonic structure of this area.

For a period of 75 years were analyzed 28 earthquakes occurred in this epicentral area. The total released seismic energy amounts to $E = 7816.92 \cdot 10^{11}$ J and corresponds to an earthquake with magnitude $M = 6.73$.

Average annual released seismic energy in this focus is $E = 104.23 \cdot 10^{11}$ J, corresponding to earthquake with magnitude $M = 5.5$.

In the total released seismic energy in the Vardar zone, Valandovo epicentral area contributes with 42.2 %.

Table 1 presents the energy characteristics of the epicentral areas in Vardar zone (period of 75 years).

T a b l e 1

Energy characteristics of epicentral areas in Vardar zone

Epicentral area	Total energy E (J)	Corresponds to magnitude M of	Average annual energy E_y (J)	Corresponds to magnitude M of	Energetic contribution (%)
Kumanovo	$87.19 \cdot 10^{11}$	5.43	$1.16 \cdot 10^{11}$	4.18	0.47
Skopje	$935.4 \cdot 10^{11}$	6.2	$12.47 \cdot 10^{11}$	4.4	5.05
Veles – Sveti Nikole	$69.62 \cdot 10^{11}$	5.4	$0.93 \cdot 10^{11}$	4.1	0.38
Štip - Radoviš	$16.28 \cdot 10^{11}$	4.9	$0.22 \cdot 10^{11}$	3.7	0.09
Kavadarci	$151.44 \cdot 10^{11}$	5.6	$2.02 \cdot 10^{11}$	4.3	0.82
Valandovo	$7816.92 \cdot 10^{11}$	6.73	$104.23 \cdot 10^{11}$	5.5	42.2

Calculating the energy of all analyzed earthquakes in the period of 75 years and summarizing obtained results is determined the total released seismic energy in Vardar zone which amounts to $E = 1.86 \cdot 10^{15}$ J, or this amount of energy corresponds to an earthquake with magnitude $M = 7$.

From this is clear that the largest part of the released seismic energy belongs to the strongest earthquakes ($7 > M > 6$).

Average annual released seismic energy in Vardar zone is $E = 246.94 \cdot 10^{11}$ J. This energy corresponds to earthquake with magnitude $M = 5.73$.

CONCLUSION

From the presented data is clear distinguishing of several epicentral areas in Vardar zone: Kumanovo, Skopje, Veles–Sveti Nikole, Štip–Radoviš, Kavadarci and Valandovo. In two of them, Skopje and Valandovo are generated earthquakes with magnitudes $M > 6$. The other focuses, the analyzed period of 75 years, is characterized with appearance of relatively smaller number of weak earthquakes.

Seismogenic zones in Vardar zone are on depth of 10 to 35 km, except Skopje epicentral area with depth of 2 to 10 km. from this can be conclude that all focuses are in the Earth's crust and appearance of earthquakes is consequence of the tectonic movements.

Considering the seismological parameters as function of tectonic parameters, can be concluded the following characteristics:

1. The amount of the released seismic energy depends on tectonic activity in the Vardar zone. In this area, as regions with high seismicity are considered Skopje and Valandovo. The terrains are with highly expressed up to date (neotectonics) activity and are regions of crossing of regional faults, or places with active tectonic movements. These tectonic conditions accumulate large quantity of potential energy which, during earthquake, is released as kinetic, seismic energy.

2. Examining the epicentral map of Vardar zone, can be seen that spatial distribution of epicenters in this zone is a function of tectonic conditions. According this condition are distinguished regions of Skopje and Valandovo.

3. Time distribution (the frequency of occurrence of earthquakes) showed that in the regions with expressed neotectonics activity, the frequency of earthquakes is the largest.

Generally, for Vardar zone can be concluded that in the seismogenic areas Skopje and Valandovo, despite the occurrence of strong earthquakes, most of the weaker earthquakes also occur here.

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Р е з и м е

ЕНЕРГЕТСКИ КАРАКТЕРИСТИКИ НА НЕКОИ ЕПИЦЕНТРАЛНИ ПОДРАЧЈА ВО ВАРДАРСКАТА ЗОНА

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Клучни зборови: енергија; карактеристики; магнитуда; Вардарска зона; епицентрални подрачја

Сеизмолошките појави претставуваат природен феномен поврзан со развојот на Земјата. Тие нанесуваат големи материјални штети и причинуваат голем број човечки жртви. Територијата на Република Македонија претставува сеизмички многу активен дел од медитеранската област каде се случиле голем број земјотреси.

При проучувањето на овие појави од големо значење е определувањето на енергијата која се ослободува за време на земјотресите.

Во овој труд е даден осврт на сеизмичката енергија на Вардарската зона преку емпириската формула за зависноста на магнитудата на земјотресот *M* и активираната геотектонска површина.

Сеизмичноста во Вардарската зона е особено изразена во областите каде се сечат старите реактивирани раседи од вардарски правец со неотектонските раседи кои доминантно се протегаат во напречен правец.

Вардарската зона е дефинирана како најлабилна тектонска единица на Балканскиот Полуостров со многу изразена сеизмичност.

Во овој труд се прикажани енергетските карактеристики на епицентралните подрачја кои се издвоени во Вардарската зона: Куманово, Скопје, Велес–Свети Николе, Штип–Радовиш, Кавадарци и Валандово.