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STRUCTURAL-TECTONIC AND SEISMIC CHARACTERISTICS RELATIONSHIPS IN THE CENTRAL PART OF THE TRANSCARPATHIAN INTERNAL DEPRESSION

Purpose. To investigate structure-tectonic and faults features of the central part of the Transcarpathian internal depression and their relations with earthquake epicenters localization and peculiarities of seismic waves spreading on the base of instrumental observations in regime geophysical observatories of the Carpathian geodynamic polygon. **Methods and results.** The study developed methodology for specification of local earthquake focus depths by means of neuron-network modeling, computer processing and systematization of observation data at the Carpathian geodynamic network and adjusting areas on the basis of recent mapping and graphical information. On the examples of earthquakes registered by the regime geophysical station "Mukachevo", focal mechanisms of earthquakes were determined using first arrival polarities. **Scientific novelty.** The research determined the relationships between structural and tectonic features in the central part of the Carpathian backdeep, the recent geodynamics of the region's basement, peculiarities of seismic waves spreading, and formation of local earthquake focuses. It was stated that the influence of the igneous rocks of the Vyhorlat-Hutyn volcanic ridge significantly reduced the time of seismic waves passing in the sedimentary layer and partly in the basement. To determine a focal mechanism of the earthquake, the velocity of seismic waves in the layers should be taken into account on a case-by-case basis, taking into account the location of seismic stations with respect to deep and surface faults and the impact of volcanic rocks, and not using standard velocity models for seismic stations resulting from the stations that give significant results in calculations of output seismic wave angle and facilitate the selection of nodal surfaces. **Practical value.** Detailed investigations allow determining characteristics of earthquake epicenters, velocities and direction of seismic waves spreading in accordance with the structure of the basement and sedimentary layer. This will, in turn, provide an opportunity to supplement the data of long-term monitoring of natural and technological hazards in the region.

Key words: Transcarpathian internal depression, tectonic displacements, Vyhorlat-Hutyn volcanic ridge, earthquake epicenters, nature of earthquake source.

Introduction

The Transcarpathian internal depression in the north-east contacts the area of the Pienin ridge and the Marmarosh crystalline massif. It borders on Maramuresh basin in the south-east, the Panonian depression in the south-west, and it turns into the East-Slovak depression in the north-west [Krupsky, 2001].

The recent tectonic structure of the Transcarpathian internal depression is characterized by the intense dislocation, the presence of faults and displacements in longitudinal and cross directions. The Transcarpathian (Pieninic) and Panonian deep faults have the most amplitude among them. [Hnylko, 2011; Hnylko, 2012]. The similarly-named Transcarpathian (Pieninic) fault separates the internal depression from the Pienin zone, and the Panonian fault from the Panonian depression, respectively. Some researchers [Krupsky, 2001] single out up to 12 regional longitudinal and 9 crossing faults which divide the depression into a series of rectangular blocks.

However, the extension of tectonic displacements is not only straightforward, longitudinal or transverse, it is also characterized by a more complex configuration. Three structural and tectonic levels can be defined in the structure of the backdeep. They include the Paleozoic, Mesozoic-Paleogene and Neogene levels. The first two are the basement of the Transcarpathian internal depression, and the thickness of the latter exceeds 3 km. The Transcarpathian internal depression is divided into several zones with peculiarities of a seismic regime which are identified with the tectonic structure. These zones consist of the Chop-Mukachevo and Solotvin depressions The Oashi fault is the border between them [Pronyshyn, & Pustovitenko, 1982].

The zones, distinguished in the study, differ in a sequence type, according to earthquakes repetition patterns, the amount of energy, the speed of released conditional deformations, and their activation over time. [Pronyshyn, & Pustovitenko, 1982; Pronyshyn, & Kuznetsova, 2011; Maksymchuk, et al., 2014].

It was possible to define the presence of three ranges of epicenter concentrations along the Carpathians associated with the Transcarpathian (Pieninic) and Panonian deep faults, as well as with the axial fault zone of the Neogene Transcarpathian internal depression [Melnychuk, 1982]. The connection of the Transcarpathian earthquakes with crossing faults is investigated in a number of works [Pronyshyn, & Pustovitenko, 1982; Pronyshyn, & Kuznetsova, 2011; Seghedi, 2004].

Purpose

Investigations of tectonic structure and fault tectonics with the localization of epicenters of earthquakes interrelations in the central part of the Transcarpathian internal depression and peculiarities of seismic waves spreading on the basis of instrumental observations at regime geophysical stations (RGS) in the Carpathian geodynamic network.

Methods and results

The structure of the Ukrainian part of the Carpathian region depends on the geodynamics in the Alpine period, when there were rapid geological development variations. Passive rifting (spreading) in the middle and late Triassic, Jurassic and early Cretaceous has changed into a collision. At the first stage, crushing zones, deep-ocean troughs with inten se magmatic activity were formed, and as a result of the collision through magma conducting channels, magmatic rocks, which were in the bottom of the deep trenches during the stretching, appeared on the surface.

Magmatic Alpian formations can be divided into two types: the one which appeared at the stage of stretching, and the other which corresponds to a stage of collision. Magmatic formations of the first type are represented by complexes that are common in the Marmarosh, Pienin zones and in the Rakhiv-Burkut tectonic group of zones. In the basement of the Transcarpathian internal depression, the ophiolite complexes were determined by the results of drilling (hyperbasites, basalts, diabases, andesite basalts, trachites, basalt tufts and deep-water sedimentary rocks with the undergone metamorphism after an influence during contact with volcanic rocks). The magmatism of the collision stage is connected directly with the formation of the molas of the Transcarpathian internal depression and its products have an autochthonous nature. Volcanic rocks of the final stage – lava formations of the Vyhrolat-Hutin ridge – are the youngest formations of the Ukrainian Carpathians formed after the accumulation of the Neogenic molasses in the Transcarpathians (Fig. 1).

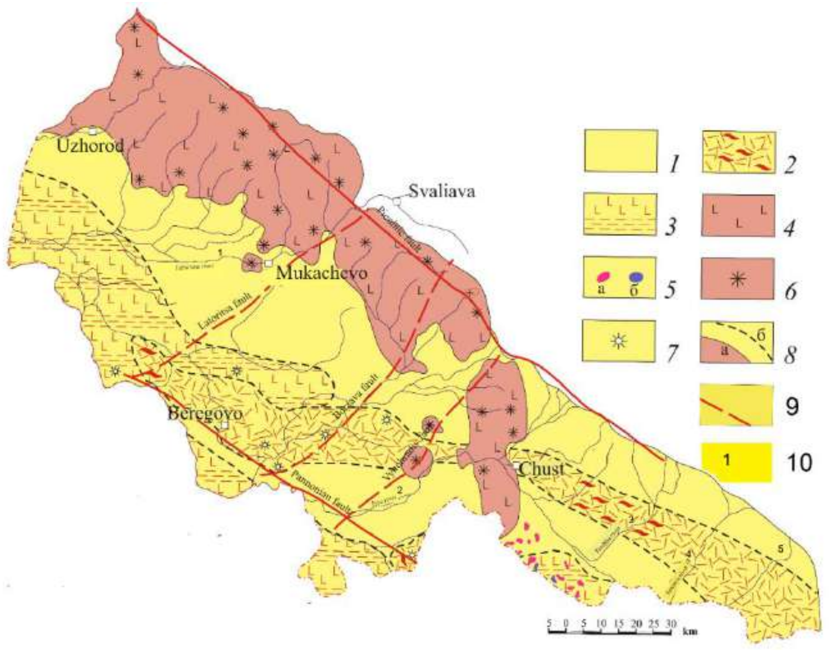

Fig. 1. Scheme of magmatic rocks distribution in the Transcarpathian internal depression [Medvedev, 2015]:

1 – Transcarpathian internal depression; 2 – 8 – Miocene magmatic complexes: 2 – Novoselytsya acidic tuffs (a) and Baden ignimbrites (b) complexes; 3 – Dobrobrat volcanic-sedimentary complex (Sarmat); 4 – Vyhorlat-Hutyn complex (Pannonian-Pliocene); 5 – intrusions (a – acidic; b – basic); 6 – volcanic centers; 7 – hidden volcanic centers; 8 – boundaries of magmatic complexes distribution (a – on the surface; b – hidden);9 – schematic representation of tectonic faults; 10 – rivers: 1-Latoritsa; 2-Tysa; 3-Tereblia; 4-Teresva; 5-Black Tysa

According to researchers [Kruglov, et al., 1985; Starostenko, 2013], early Alpine magmatism of the Transcarpathians is enclosed in the interval of the Jurassic-Early Cretaceous. Other lower boundary time is fixed in the Triassic.

All the studies indicate that the Mesozoic volcanism of the Ukrainian Carpathians did not appear once, but in several phases during the late Triassic-early Cretaceous, that is, high magmatic activity remained in the region for about 100 million years.

The significant number of crossing tectonic displacements with the northeastern orientation divides the Transcarpathian internal depression into several rectangular blocks and crosses the NW part of the Carpathian fold structures almost at right angles. Such faults are associated with submeridial segments of the river valleys of Lauterica, Borzhava, Tereblya, Black Tisa (Fig. 1), etc. In connection with the Transcarpathian fault, they are also associated with the sources of the Neogene volcanic Vygorlat-Hutin ridge.

In 1965, a complex research at the newly created Carpathian geodynamic network was started. Located in the NW part of the Ukrainian Carpathians on the border with Slovakia, Hungary, Romania, it covered the territory where the recent tectonic movements appeared contrastingly and sharply differentiated, and recent tectonic activity was caused by seismicity, abnormal thermal field, and the presence of a regional zone of abnormal electrical conductivity [Kuznetsova, 1978].

The Carpathian geodynamic network includes the main tectonic units of the south-western slope of the Carpathians and the Carpathian inner deep. In the southern part, there is an extremely unique structure of the rocky zone, which coincides with the Transcarpathian (Pienin) deep fault (Fig. 2). It is considered to be the most important seismotectonic line: here are the epicenters of the most frequent and strong earthquakes.

In the territory of the network, in its western part is the Pleistocene Chop basin, which is the zone of maximum newest downloading of the crust. In the south, there is the Bregove zone of Miocene faults and volcanism which has a horst structure. This zone is still known as the Panonian deep fault (Fig. 2) and stands out as a tectonic element separating the Transcarpathian internal depression and the Hungarian depression.

The first works on the creation of points network and regime geophysical stations were started in 1965 by the foundation of 16 secular gravity rappers on the Batevo profile, 5 of which were located directly on the territory of the network . Three geodynamic profiles for long-term geodetic and geophysical observations were based in 1977–1980 (Irzhava – Kuznitsa, Khust – Lower Bistry, Teresva – Ust Chorny). They aimed to study geodynamic processes directly in the zone of the Transcarpathian (Pieninic) deep fault in the middle of its passage. [Maksymchuk, et al., 2001].

In the mid-80's, observations at the geodynamic network were expanded because seismotectonic processes needed a detailed study. Their purpose was to develop a methodology for studying earthquake precursors. The relevance of those studies at the network was due to the significant seismic activity of the Transcarpathians, high population density, concentration of industrial enterprises, and main oil and gas pipelines of international importance.

Therefore, it was necessary to organize permanent observations in regime geophysical stations (RGS) in order to define time-series variations in the geophysical parameters of local anomalies which are directly related to the preparation of local earthquakes [Maksymchuk, et al., 2001]. During a short period of time, from 1985 to 1995, the territory of the network was constructed, equipped, and the RGS stations Brid, N. Selishche, Trosnyk, Beregove, Mukachevo started working. They are currently functioning alongside the existing seismic stations of Uzhhorod, Mezhgiriya, Kosiv, and Rakhiv. Digital seismic stations were installed at all RGS. In addition, semi-automatic meteorological stations, as well as micro-barometers were deployed at Trosnyk, N. Selishche, Mukachevo stations. Geomagnetic regime observations are carried out at the RGS Trosnyk, N.Selishche, Brid, and Berehove (Fig. 2).

The increasing number of seismic stations in the Transcarpathians has significantly improved the situation with the defining earthquake parameters, including the accuracy of determining the depth of the hypocenters. This situation contributed to the study of the Transcarpathian internal depression seismicity features, the spatial patterns of distribution and the development of the seismotectonic process in the region.

The central part of the Transcarpathian internal depression is characterized by high mobility and contrast of oscillatory movements. It is bounded by the Transcarpathian deep fault in the NE, the Latoritsky fault in the NW, and the Vynohradiv fault in the SE (Fig. 2). In this part there is a large number of earthquake sources and various intrusions (from acid to ultrabasic). Together with a large number of series of less significant transverse faults (genetically associated with the Transcarpathian (Pieninic) deep fault) they play an important role in the nature of the spreading seismic waves from the epicenter of earthquakes.

The central part of the Transcarpathian internal depression consists of three (Latoritsky, Borzavsky, Vynohradivsky) faults of the first order and a significant number of magmatic formations, related with zones of transverse and longitudinal displacements crossing with the Transcarpathian deep fault. This territory can present the most interesting data to study the links between structural-tectonic seismic processes, and the distribution and passing seismic waves from the epicenters of earthquakes throughout the Transcarpathian internal depression. In particular, in this part during 2001–2012 [Maksymchuk, 2014] there were 33 earthquakes with the energy class more than 7 (Fig. 2).

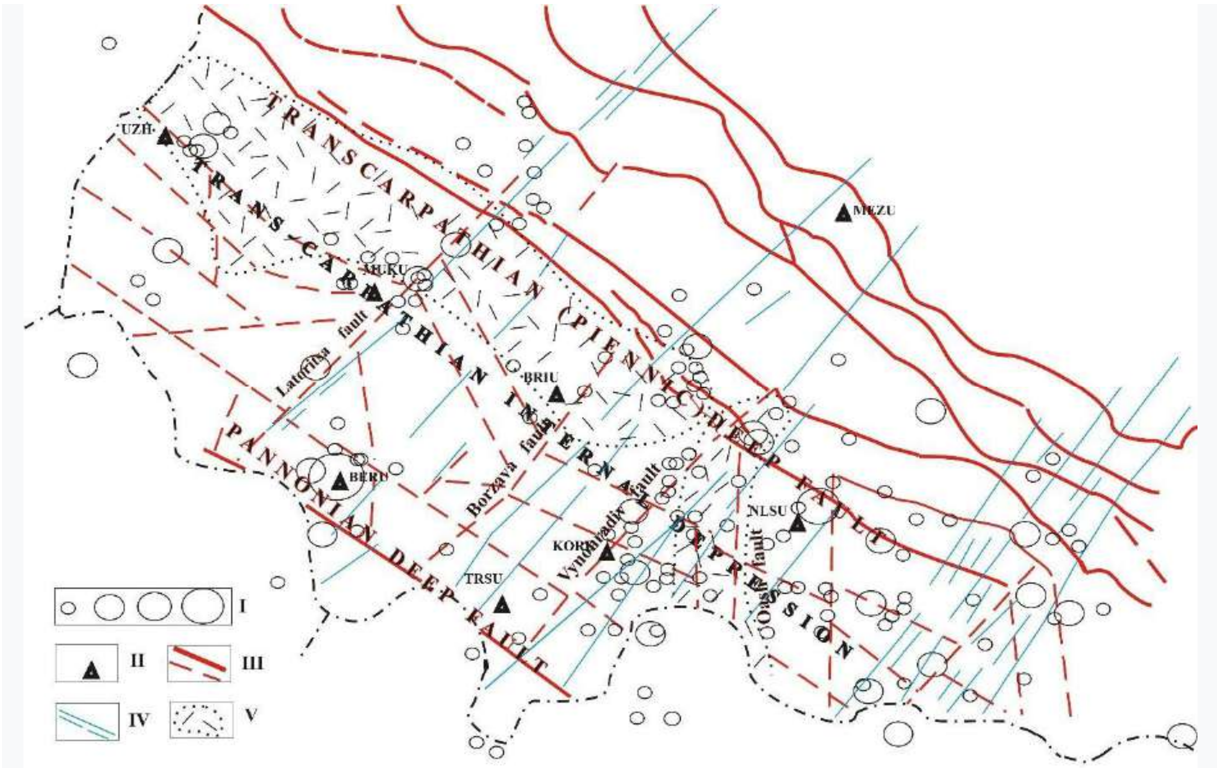

Fig. 2. The tectonic faults scheme of the Transcarpathian internal depression, based on materials [Krylov, 1988]:

I – energy class of earthquakes (Kp); II – seismic station (RGS); III–IV – boundary tectonic zones and faults of the crust; V – Vyhorlat-Hutyn volcanic ridge

The Transcarpathian (Pieninic) and Panonian deep faults are characterized by stable seismic activity, as well as the central fault zone, where annually 2 to 5 earthquakes are fixed [Seismological…, 2001–2013 years]. Vynohradiv fault is distinguished among the crossing faults and has practically identical indices (from 3 to 5 events annually). The zone of intersection of the Latoritsa fault with the central fault zone is the most seismically active area in the Transcarpathian internal depression crossing. It showed its high activity in 2005–2006 near the city of Mukachevo (Fig. 3), where a series of more than 8 earthquakes with an energy class (K) occurred. Taking into account the peculiarities of the geological structure of the territory, as well as the location of the station "Mukachevo" there was a need to clarify parameters of seismic events for further establishment of structural heterogeneities under the action of tectonic deformation patterns.

In the light of the above, it is possible to state the extreme importance of the influence of all the factors described on the nature of the seismic waves spreading from the earthquake epicenters. That is, during calculating the times of seismic waves spreading in the central zone of fault, it is necessary to take into account the influence of both deep and surface faults, the appearance of volcanic formations with centers of volcanism and magmatic rocks on the surface, as well as shallow magmatic rocks.

The complex block structure of the Transcarpathians seismic region does not make it possible to use some common high-speed model of the region for calculating seismic waves` transition. Moreover, during the construction of the focal mechanisms of local earthquake centers more accurate results are obtained when using the seismic wave velocity calculated for the respective seismic event, rather than using standard velocity models for seismic stations, since seismic wave velocities from different azimuths are substantially different.

A significant part of the earthquakes` foci are located in layers with volcanic rocks or a seismic wave passes through them, reducing the wave running time. Other seismic waves pass through a series of shallow faults which increase the wave running time, respectively. Therefore, the use of an averaged velocity model for the determining focal mechanisms of earthquakes gives incorrect results.

In addition, the Mukachevo seismic station is only ≈1 km to the northwest of the Latoritsa fault and near the Transcarpathian (Pieninic) deep fault and is located between two volcanic centers (Fig. 3). According to this arrangement, the P-wave velocities for seismic sources located in the first layer from the earthquakes registered by Mukachevo RGS from different azimuths differ by ≈1500 m/s., and for the sources located in the second layer by ≈1000 m/s.

Let us take a closer look at the results obtained for seismic events that occurred in the central fault zone and were recorded by the Mukachevo seismic station.

Thus, we can observe the velocity of direct P-wave registered by Mukachevo, from V_{p1}≈4500 m/s to V_{p1} ≈ 6000 m/s in the first layer for the seismic sources located in the area of Vyhorlat-Hutyn volcanic ridge and seismic waves passing through it. The velocities in the sedimentary layers exceed significantly. In addition, seismic events that took place on 4 July 2011 and 5 January 2007 showed V_{p1} = 6287 m/s and V_{p1} = 5698 m/s, respectively. Since the sources of these two earthquakes are outside the observed area of the outlet of the magmatic rocks to the surface and the P-wave does not pass through this zone, it can be concluded that the magmatic rocks may be in the first layer at some depth (hidden). [Kozlovskyy, et al., 2017]

For seismic events originating in the second layer, we observe a change in P-wave velocity of V_{p2} from 5200 m/s to ≈5600 m/s, which is the normal velocity of direct P-wave propagation in the basement. However, the wave velocity for the earthquake that occurred on October 17.2006 was V_{p2} ≈ 6524 m/s, which may indicate the presence of volcanic rocks in the basement.

Let us look at some examples of earthquakes recorded by the Mukachevo seismic station and determine the focal mechanisms of these earthquake sources using first arrival polarity data recorded at local seismic networks [Malytskyy, et al., 2014; Malytskyy, et al., 2015].

Two seismic events are selected for visualization. These events are most characteristic of the central part of the region.

1) Earthquake registered by the Mukachevo seismic station on October 17, 2006 (φ=48.61˚N, λ = 22.46˚E, ε = 24140 m, h = 3300 m). The parameters of the focal mechanisms were calculated: 1) for the standard velocity model near the "Mukachevo" RGS (V_{p1} = 4700 m/s, V_{p2} = 5500 m/s).

2) Calculated velocities for this particular seismic event (V_{p1} = 5307 m/s, V_{p2} = 6524 m/s).

In both cases, the breakout option was obtained (Fig. 4), and we observed the difference between the mechanisms at the angle φ –15˚ (Table 1).

When determining the focal mechanism of the earthquake, the choices of nodal surfaces for the standard velocity model (Fig. 5a) and for the velocity model calculated for this particular event (Fig. 5b) differ significantly. In the first case, when breaking nodal surfaces, we observe a variation of 20º; in the second case we observe a variation of only 4º. It can significantly facilitate the selection of nodal surfaces and reduce the error in the determining the earthquake mechanism.

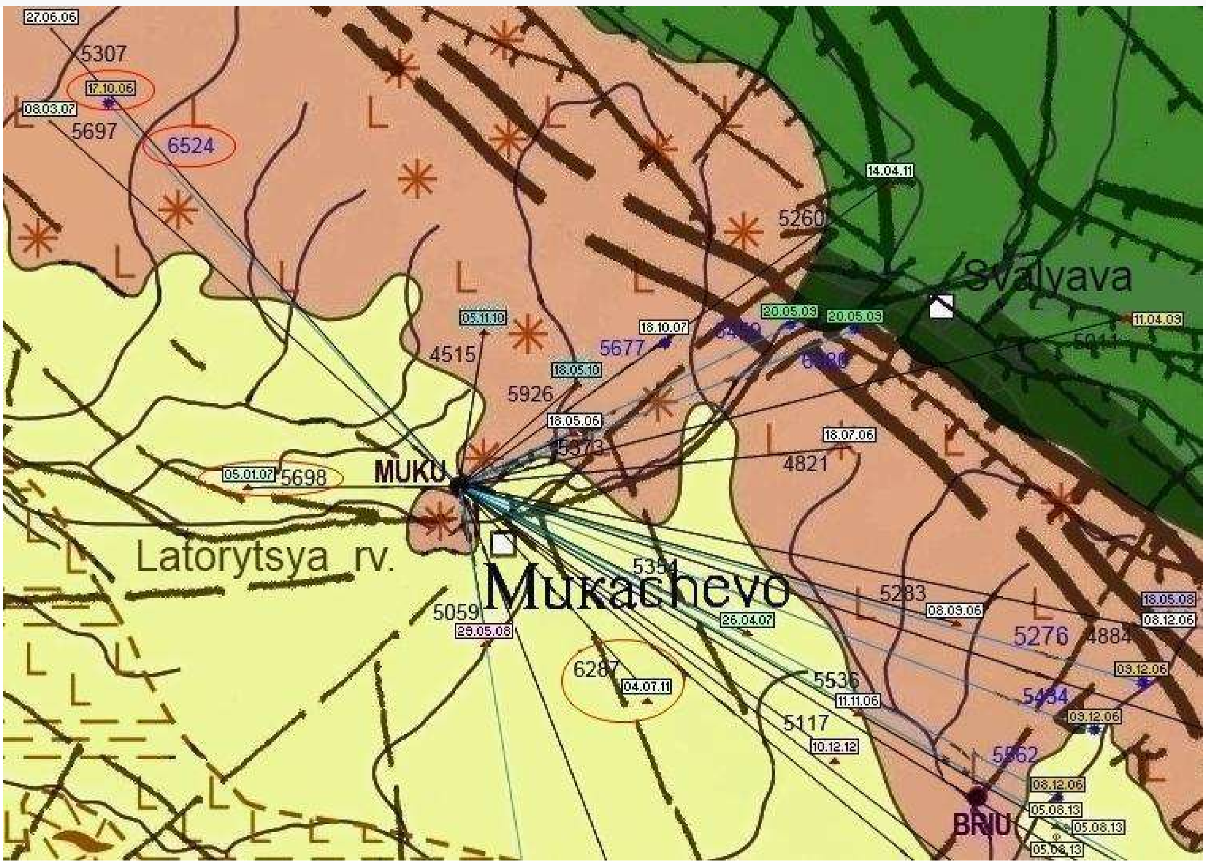

Fig. 3. Distribution of direct P-wave velocities for "Mukachevo" seismic station

Table 1

Focal mechanisms parameters for the event on October 10, 2006

	1 nodal surface			2 nodal surface			P axes		T axes	
	φ	δ	λ	φ	δ	λ	φ	δ	φ	δ
1	292	45	-100	126	46	-80	296	-83	29	-1
2	307	51	-68	94	44	-115	100	-73	22	4

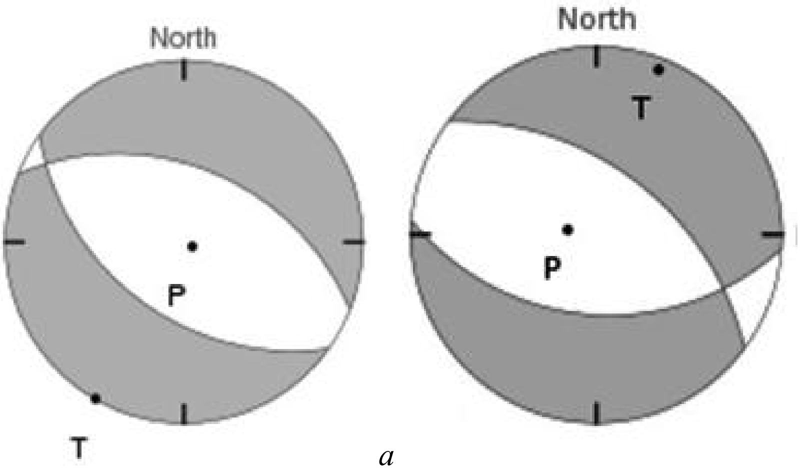

Fig. 4. Focal mechanism of the earthquake on October 10, 2006:
a – with standard velocity model; b – with velocity model calculated for this particular seismic event

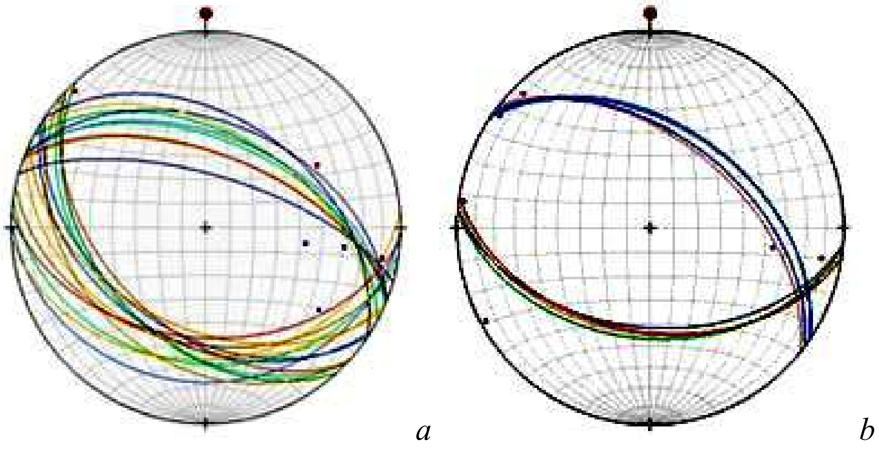

Fig. 5. Options for choosing nodal surface for determining the mechanism of the earthquake on October 17, 2006: a – with the standard velocity model; b – with the velocity model calculated for this particular event

As we can see, the influence of magmatic rocks of Vyhorlat-Hutyn volcanic ridge significantly reduces the time of seismic waves in the sedimentary layer and partly in the basis of these earthquakes location in the area of volcanic rocks, or if the waves pass through such an area [Aki, & Richards, 2002; Dreger, & Helmberger, 1993; Hardebeck, & Shearer 2003].

An earthquake was registered by the Mukachevo seismic station on 09.06.2012. (φ = 48.26˚N, λ = =22.69˚E, ε = 22000 m, *h* = 1000 m). The depth of 1000m is indicated in the bulletin when it is impossible to determine the exact depth of the earthquake. So, it only establishes the layer in which it is located. Therefore, neural network (NN) modeling was used for the depth definition. Optimal neural network architecture (nm) is determined by weighting and number of layers. The most accurate result was obtained by NN with MLP 5:5-6-1:1 architecture with one hidden backward error layer. Such architecture of NN showed the best results when modeling the depth of the earthquake [Kozlovskyy, et al., 2014]. The average relative error in the modeling is ≈3.5 %.

The parameters of the focal mechanisms were determined: 1) for the standard velocity model near the “Mukachevo” RGS (V_{p1} = 4700 m/s), 2) calculated velocities for this event (V_{p1} = 5150 m/s). In both cases, the breakout option (Fig. 6) shows that there is a difference between the mechanisms at the angle φ 12˚.

To determine the parameters of the focal mechanisms using first arrival polarity, it is necessary to know the exact take-off angles of the seismic wave passage. Table 3 shows the calculated seismic wave take-off angles for all seismic stations registering a given seismic event in the variants of the standard velocity model and the velocity model calculated for a single event that occurred on June 9[th], 2012. In the second case, the take-off angle is calculated by considering the change in velocity relative to the azimuth per station. As can be seen from Table 3, the take-off angles of the seismic wave for different models differ.

Thus, in the above examples, when applying the standard velocity model and the velocity model calculated for each case, we observe the difference in angles φ – 12–15º and the take-off angles of seismic wave from 3º to 11º at different seismic stations. It is important in determining the parameters of the focal mechanisms.

Table 2

Parameters of focal mechanisms for seismic event 09.06.2012

	1 nodal surface			2 nodal surface			P axes		T axes	
	φ	δ	λ	φ	δ	λ	φ	δ	φ	δ
1	307	44	-107	150	48	-74	128	78	228	2
2	319	38	-101	153	53	-82	99	80	237	7

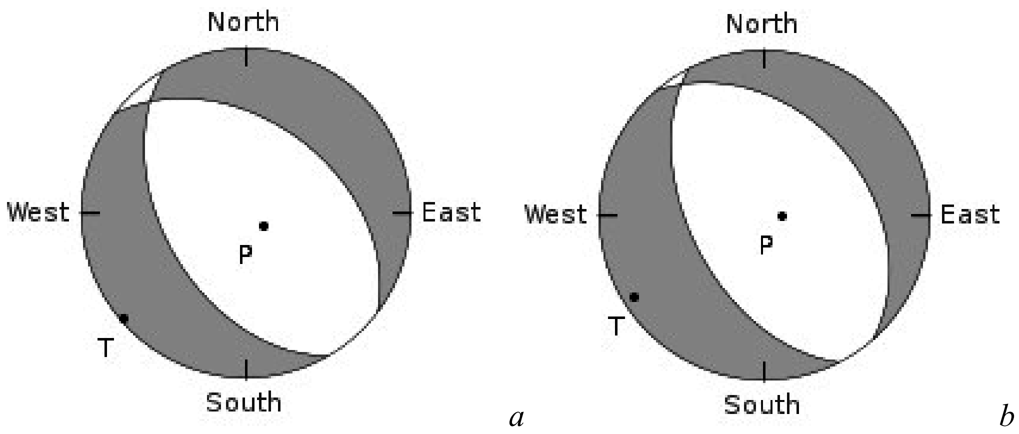

Fig. 6. Mechanism of the earthquake on June 9[th] 2012: a – with the standard speed model, b – with the speed model calculated for this particular event

Table 3

Take-off angles of seismic waves

	Azimuth	Take-off angles (standard model)	Take-off angles (particular event)
BERU	228	107	115
MUKU	359	69	73
BRIU	70	69	66
TRSU	133	69	66
STZU	357	42	53

Conclusions

The data obtained confirm the direct connection of the geodynamic history of the Transcarpathian internal depression formation and the deep structure of the crust with complex block structure due to longitudinal and transverse tectonic displacements in its central part. This determined the nature of earthquake sources distribution and the peculiarity of seismic waves spreading in accordance with the structural and tectonic structure of the region. The localization of earthquake epicenters is associated with crossing nodes of longitudinal and transverse faults.

It has also been stated that the influence of the igneous rocks of the Vyhorlat-Hutyn volcanic ridge significantly reduces the time of seismic waves passing in the sedimentary layer and partly in the basement. To determine the focal mechanism of the earthquake, the velocity of seismic waves in the layers should be taken into account on a case-by-case basis. It is important to consider the location of seismic stations with respect to deep and surface faults and the impact of volcanic rocks, and not to use standard velocity models for seismic stations. It will result in presenting more accurate calculations of take-off angles of seismic waves and facilitate the selection of nodal surfaces significantly.

Research data can be used to enhance the database and in combination with other techniques for monitoring natural and man-made eco-hazard events in the Transcarpathians.

References

Aki, K., Richards, P. G. (2002). Quantitative seismology. Theory and methods. Sausalito, California: University Science Books, 520 p

Dreger, D. S. & Helmberger, D. V. (1993). Determination of source parameters at regional distances with single station or sparse network data. *J. Geophys Res.*, 98, 1162–1179.

Hardebeckm, J. L., Shearer, P. M., (2003). Using S/P amplitude ratios to constrain the focal mechanisms of small earthquakes. *Bull.seism. Soc.Am.*, 93, 2432–2444.

Hnylko, O. M. (2011). Tectonic zoning of the Carpathians in terms of the terrane tectonics. Section 1: Main units of the Carpathian building. *Geodynamics*, no. 1 (10), 47–57. (in Ukrainian).

Hnylko, O. M. (2012). Tectonic zoning of the Carpathians in terms of the terrane tectonics. Article 2. The flyssch Carpathian – ancient accretionary prism. *Geodynamics*, 1 (12), 67–78. (in Ukrainian).

Kozlovskyy, E., Malytskyy, D., & Pavlova A. (2014). Neural-network modeling for the problem softemporal specifying of direct P-wave entering and calculating the depth of anearthquake source. *Geoinformatics*, 3. (in Ukrainian).

Kozlovskyy, E., Malytskyy, D., Parfenuk, A., Grytsay O., Tymoshchyk, V., Yarema, I., Astashkina, O., & Mahnitskyy M. (2017). Influence of magmatic rocks in the Vigorlat-Gutin volcanic ridge during the seismic waves transition., *Geoinformatics*, 3(63). (in Ukrainian).

Kruglov, S. S., Smirno,v S. E., & Spitkovskaya, S. M. (1985). Geodynamics of the Carpathians. *Kyiv: Nauk. opinion.* (In Russian).

Krupskyy, Yu. (2001). Geodynamic forming conditions and oil-and-gas bearing of the Carpathian and Volyn-Podillya areas of the Ukraine, *Kyiv: UkrDHRI.* (in Ukrainian).

Krylov, N. A. (1988). Map faults and main zones liniamentov southwest of the USSR (the calibration using materials space shooting). (In Russian).

Kuznetsova, V. (1978). The study of secular variations of the geomagnetic field. Book: Carpathian geodynamic polygon (In Russian).

Maksymchuk, V., Gorodisky, Yu., & Kuznetsova, V. (2001). Dynamics of anomalous magnetic field of the Earth, Lviv: Eurosvit (in Ukrainian).

Maksymchuk, V. Yu, Pyrizhok, N. B., Pronyshyn, R. S., & Tymoschuk, V. R. (2014). Peculiarities of Transcarpathians seismisity, *Geodynamics*, 2 (17). (in Ukrainian).

Malytskyy, D., Hrytsai, O., Muyla, O., Kutniv, O., Obidina, O., Astashkina, O., Pavlova, A., & Kozlovskyy, E. (2015) On determining focal mechanismsof earthquakes in the Mediterranean region using graphic method. *Geoinformatika* 4 (56), 43–51. (in Ukrainian).

Malytskyy, D., Pavlova, A., & Hrytsai, O. (2014). Determining the focal mechanisms of the events in the Carpathian region of Ukraine. *Geoscientific Instrumentation Methods and Data Systems.* ,3, 229–239.

Medvedev, A. P. (2015). Geodynamic and geochemical aspects of oil and gas accumulation in oil and gas regions of Ukraine. *Institute of Geology and Geochemistry of Combustible Minerals.*

Melnychuk, M. (1982). About the genetic relationship of seismic processes and tectonics of the Carpathian region. *Geophysical journal*, 4(2), 34–41. (In Russian).

Pronyshyn, R. S., & Kuznecova, V. G. (2011). Relationship of the spatial distribution of seismicity with the tectonic structure of the Transcarpathian depression. *Geodynamics. No. 2*. 254–256. (in Ukrainian).

Pronishin, R. S., & Pustovitenko, B. G. (1982). Some aspects of seismic climate and weather in Transcarpathia. *Izv. USSR Academy of Sciences. Earth Physics,* (10), 74–81.

Seghedi, I., Downes, H., Vaselli, O., Szakacs, A., Balogh, K., Pecskay, Z. (2004). Post-collisional Tertiary–Quaternary mafic alkalic magmatism in the Carpathian–Pannonian region: a review. *Tectonophysics*, 393, 43–62.

Seismological bulletin of Ukraine for 2001, 2002, 2003, 2004. red. B. G. Pustovitenko. S. I. Subbotin Institut of Geophisics NAN Ukrain, Simferopol', 2005, 2006, 2007, 2008.

Seismological bulletin of Ukraine for 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012. Sevastopol: NPC Jekosi-Gidrofizika, 2007, 2008, 2009, 2010, 2011, 2012, 2013.

Starostenko, V., Janik, T., Kolomiyets, K., Czuba, W., Środa, P., Grad, M., ... & Artemieva, I. M. (2013). Seismic velocity model of the crust and upper mantle along profile PANCAKE across the Carpathians between the Pannonian Basin and the East European Craton. *Tectonophysics*, *608*, 1049–1072.

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ВЗАЄМОЗВ'ЯЗОК СТРУКТУРНО-ТЕКТОНІЧНИХ ТА СЕЙСМІЧНИХ ХАРАКТЕРИСТИК ЦЕНТРАЛЬНОЇ ЧАСТИНИ ЗАКАРПАТСЬКОГО ПРОГИНУ

Мета. Дослідження взаємозв'язків структурно-тектонічної будови та розломної тектоніки центральної частини Закарпатського прогину із локалізацією епіцентрів землетрусів та особливістю поширення сейсмічних хвиль на основі інструментальних спостережень режимних геофізичних станцій (РГС) Карпатського геодинамічного полігона. **Методика та результати.** Розроблено методику уточнення глибин вогнищ локальних землетрусів із використанням нейронно-мережевого моделювання, комп'ютерного оброблення та систематизації даних спостережень на Карпатському геодинамічному полігоні та прилеглих територій із використанням картографічних та графічних сучасних матеріалів. На прикладі землетрусів, зареєстрованих режимною геофізичною станцією "Мукачево", побудовано механізми вогнищ землетрусів графічним методом. **Наукова новизна.** Визначено взаємозв'язки між структурно-тектонічними особливостями будови центральної частини Закарпатського прогину, сучасним геодинамічним розвитком фундаменту регіону та особливостями поширення сейсмічних хвиль і формування вогнищ локальних землетрусів. Встановлено, що вплив магматичних порід Вигорлат-Гутинського вулканічного пасма значно зменшує час пробігу сейсмічних хвиль у осадовому шарі та частково у фундаменті. Для побудови механізму вогнища землетрусу необхідно враховувати швидкості пробігу сейсмічних хвиль у шарах для кожного окремого випадку, зважаючи на розташування сейсмічних станцій відносно глибинних і приповерхневих тектонічних порушень та вплив вулканічних порід, а не використовувати стандартні швидкісні моделі для сейсмічних станцій, що дає точніші результати розрахунку кута виходу сейсмічної хвилі та суттєво полегшує вибір нодальних площин. **Практична значущість.** Проведені дослідження дадуть змогу предметніше визначати повні характеристики вогнищ землетрусів, швидкості та напрямки поширення сейсмічних хвиль згідно з будовою фундаменту та осадової товщі, що своєю чергою надасть можливість доповнювати дані тривалого моніторингу еконебезпечних природних та техногенних подій у цьому регіоні.

Ключові слова: центральна частина Закарпатського прогину; тектонічні порушення; Вигорлат-Гутинська вулканічна гряда; епіцентри землетрусів; механізм вогнища.

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