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SECTION: GEOLOGY AND GEODESY

NEOTECTONICS AND ITS REFLECTION IN THE RELIEF OF THE WESTERN-PODILLIA HILLS (UKRAINE)

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The Western-Podillia Hills (Opillia) occupy the extreme western most elevated part of the Podillia Upland. In plan, it has a triangular shape and well-defined orographic boundaries. The relief is hilly, and separate ridges or ridges stretching from the northwest to the southeast clearly stand out against its general background. The slopes of the ridges are asymmetrical: the western ones are steeper, the eastern ones are gentler [6]. V. Tesseir [15] called the largest of the ridges the Peremyshlian-Chernelitsky and Bibrka-Mykolaivsky "ridges", considering them to be tectonic formations.

Structurally, the Western-Podillya Hills are located within the western slope of the Ukrainian Crystalline Shield and the Galicia-Volyn Depression (with a basement dip of 2,500 to 5,000 m or more). In the southwest, the highlands border the Precarpathian Mountains, at the base of which lies the Precarpathian Depression, separated from the platform by a deep fault. In relation to the Paleozoic and Mesozoic structure, the Western-Podillia Hills is an inverted form. Its modern appearance was formed as a result of neotectonic uplifts that covered the territory of the southwestern edge of the East European Platform at the end of the Miocene and in the Pleistocene.

In the history of the neotectonic development of the Western-Podillia Hills, two main stages can be distinguished: the Miocene and the Pliocene – Quaternary (more precisely, the Middle Sarmatian – Quaternary). The first of them is characterized by the development of oscillating movements of the earth's crust with a predominance of deflections and related marine transgressions; the second is the universal predominance of the uprisings and the establishment of a continental regime.

The main source of information about the nature of tectonic movements in the Miocene is the deposits of this time, their thickness, conditions of occurrence and facies composition. In particular, the analysis of capacities gives a general idea of the nature of tectonic movements and the distribution of areas of deflections and uplifts,

because the strength of deposits (if minor errors are neglected) is mainly determined by the intensity of deflection of the accumulation area. Deviations from this general regularity due to undercompensation, compaction of sediments and other factors are insignificant and can be considered an exception to the general rule.

As our studies have shown [9], the thickness of Miocene sediments in the territory of the studied region is generally small and very variable. Their maximum values (80-100 m) are observed only in the area of Mount Kamula, in most of the territory of the region, the thickness of the Miocene does not exceed 40-60 m. The accumulation of Miocene sediments occurred in several cycles or stages [8], separated by breaks. Each of the cycles of sedimentation corresponds to a separate phase of deflection, and breaks correspond to phases of tectonic uplift. The thickness and facies composition of deposits of each cycle of sedimentation in the same areas are often very different. Therefore, we carried out the reproduction of the history of tectonic movements both on a regional scale and for individual areas, applying the analysis of the thicknesses and facies of deposits of each cycle separately.

Judging by the absence of Lower Miocene deposits in the section, the beginning of the Neogene period was characterized by a significant uplift of the territory of the entire southwestern edge of the East European Platform and the long-term existence of a continental regime here. Only at the beginning of the middle Miocene epoch, in the Helvetian, did the first phase of neotectonic deflection begin, which was accompanied by the development of a small marine transgression in the southwestern part of the studied region, approximately to the latitude of Berezhan. Helvetian deposits are represented below by marine (sands, sandstones, limestones), and above by continental (lacustrine) formations of insignificant (0-14 m) thickness, which indicates a small range of deflections. At the end of the Helvetian, the area of the sea basin decreased, marking the beginning of a new phase of tectonic uplift of Podillia.

In the early Baden period, the depressions resumed with new force and, starting from the southwest, from the Pre-Carpathian depression, gradually advanced to the southeast, capturing more and more of the platform. At the end of the era, the sea basin covered the entire western part of Podillia, approximately to the line Kremenets – Zbarazh – east of Ternopil. The maximum thickness of the deposits of the Lower Badenian, preserved from erosion, is 80-90 m (in the area of Kamula), of course, it does not exceed 20-30 m. These values can be taken as approximate amplitudes of tectonic deflections in the early Badenian.

A certain regularity is observed in the distribution of the thicknesses of the Lower Baden deposits: the areas with the highest values are located in a chain-like manner in the form of northwesterly trending zones, stretched parallel to the edge of the platform. There are two such zones. The first of them runs along the line Romaniv (70-80 m) – Svirzh (47.0 m) – Tuchne (43.7 m) – Korelichy (22.8 m) and further to the southeast. The second is located further east and follows the line of the north-east. Voronyaki (33.1 m) – Krasnosiltsi (29.8 m) – Yosypivtsi (34.8 m) – Sinozhaty (44.8 m). As can be seen from the given data, within the first zone, located closer to the edge of the platform, it is powerful hundreds of deposits are somewhat larger than in the second, which indicates a greater range of deflections within its boundaries. In

the area located between the specified zones, the thickness of deposits decreases to 5-10 m and less (Przemyslany – 1.3 m; Lone – 3.0 m, etc.). An increase in the thickness of the Lower Baden sediments was also noted in some local areas (Rekshyn village – 46.4 m, Vilkhovets, west of Bibrka – 40.0 m, Strygantsi – 39.7 m, Hlibovychi – 30.3 m, Stilske – 35.0 m, Chizhichi – 30.1 m, etc.). Along with the change in capacities, there is a change in the facies composition of sediments. In the depressions, they are represented mainly by sandy and sandy loamy rocks, in the direction of the uplands, the thickness of the sandy deposits decreases, being replaced by Lithotamnium limestones along the uplifts. The latter form small gentle ridges and separate hills, often elongated in the northwest direction. One of these ridges was described by L. Kudrin [8] in the area of the settlements of Pidhaytsi – Berezhany – Pidvyske – Borshchiv (near the city of Peremyshlyan).

The unevenness of the tectonic movements of certain areas of the bottom of the Early Baden Sea Basin is also indicated by the presence among its sediments of fine folds and inclined layers associated with the gravitational (sliding) processes of the diagenesis stage on the slopes of the sedimentation uplifts, which developed most actively. Thin folds among sandstones, marls, organogenic-detrital and argillaceous limestones of the Lower Badenian are observed near the Nadrichne, Narayiv (northwest of Berezhan), Ushkovichi (near Peremyshlya) and in other places. Inclined bedding of layers on a larger scale with a dip angle of up to 16º is observed in the quarry of calcareous sandstones of the Lower Badenian in the village of Ushkovitsy near the road Przemyslany – Svirzh.

At the end of the early Badenian, after the accumulation of sediments of the Ervillian (Sholomiysk according to L. Kudrin [8]) horizon, there was a short-term uplift of the southwestern edge of the East European Platform, recorded by a break in sediment accumulation.

The late Badenian begins with a new wave of downward movements, which covered an even larger area than the previous, early Badenian. The line of the eastern bank of the Late Baden basin advanced east of Kremenets, Zbarazh, and Volochysk. Areas with the greatest thicknesses of Upper Baden deposits are located, like those of Lower Baden, along the northwest trending lines, but the location of these lines has changed somewhat. In the area of the Romaniv-Korelych zone of depressions, for example, in the late Badenian, depressions are replaced by uplifts. This led to a significant decrease in capacity, and in some places to a complete absence of Upper Baden deposits in this area. The chain of depressions continues to develop in the area of the villages of Voronyak – Krasnosiltsi – Yosypivka – Sinozhaty. The thicknesses of Upper Baden deposits here remain relatively high (Voronyaki – 47.7 m, Krasnosiltsi – 28.1 m – Yosypivka – 31.4 m – Sinozhaty – 25.2 m).

In the eastern part of the Late Baden Basin, roughly parallel to its shore along the line of settlements: Pidkamin – Zbarazh – Skalat – Hrymailiv and further southeast to Kamianets-Podilskyi, a large reef structure is developing – the basis of the modern Tovtrova ridge. The thickness of the Upper Baden deposits within its borders reaches its maximum (near the village of Galushchyntsi – 80.5 m, the village of Bohdanivka – 54.0 m, the town of Zbarazh – 40.5 m).

The clear linear elongation of the reef zone from the northwest to the southeast, parallel to the edge of the platform, attracts attention. This location, as well as the fact that most of the known reef structures are confined to lines or zones of tectonic disturbances, is one of the important arguments confirming its tectonic conditioning.

The facies composition of Upper Baden deposits is heterogeneous. It is dominated by Lithotamnium limestones, quartz and quartz-glauconite sands, and in places chemogenic limestones and dolomites. As in the early Badenian, Lithotamniun limestones accumulated on the most elevated areas of the seabed.

In the early Sarmatian, after a brief uplift, a new wave of subsidence begins and the related development of an extensive transgression, the largest in terms of area in the Neogene period, which gradually, starting from the southwest, advanced to the east. But it did not last long. Already at the end of the Early Sarmatian, a new phase of uplift began in the northwestern part of Podillia, which caused the regression of the sea to the southeast. For the longest time, up to and including the Middle Sarmatian period, the maritime regime was preserved only in the western part of Eastern Podillia, in the area of settlements Shumske, Ostrig, Shepetivka, Starokostyantyniv, etc.

At the end of the Middle Sarmatian, the continuation of the uplift led to a complete regression of the sea and the establishment of a continental regime that exists until the modern era.

The strength of the Sarmatian sediments preserved from erosion is very variable. Its maximum values were noted in the area of the Kremenetsky Mountains (Zholobi village – 87.7 m, Stizhok – 86.3 m), in the Horyn and Vilia watersheds (Veliki Zagaytsi village – 50.2 m, Syvky – 38, 5 m, Viknyny – 71.1 m), as well as in the area of the Avratynsky Highlands (Shyly village - more than 60 m, Moskalivka – 33.3 m, Dmytrivka – 33.9 m), in the rest of the territory the thickness of Sarmatian sediments does not exceed 20-30 m, and in the Western-Podillia Hills they are completely absent.

During the early Sarmatian, further development of the Tovtrova rifogenic zone continues. A thick layer of strong Oncoid limestones accumulated within its boundaries, which now protrude to the surface in many places.

Thus, starting from the middle Miocene, the studied southwestern edge of the East European platform underwent significant deflections, which were accompanied by marine transgressions, into which gradually, starting from the southwest, an ever larger area was drawn in. The deflections took place in several phases, separated by phases of tectonic uplift.

The analysis of sediment capacities and facies of each of the cycles of sedimentation separately, as well as the wide development of underwater gravity processes, indicates that in the Miocene tectonic movements had a distinctly differentiated character both in space and time. The areas of the most intense depressions and their zones, characterized by the greatest deposits, mostly have a clearly defined linearly elongated shape and extend in certain directions, moreover, in the area of development of the Baden deposits, the depressions of the north-western

direction are more clearly expressed, and in the area of the development of the Sarmatian deposits – north-eastern.

Movements of the earth's crust in the studied area had a markedly pronounced wave-like character: zones of deflections were alternately replaced by zones of uplift or, possibly, zones of lag in the general deflection or uplift of the region. This can be traced both within individual cycles of sedimentation and within the entire Miocene history of development as a whole. The wave of depressions of each cycle began in the southwest of the region, on the border with the Precarpathian depression, and moved to the northeast, followed by a wave of uplifts. The waves of each cycle seemed to superimpose each other, as a result of which the wave of the last phase of deflections (Sarmatian) reached the southwestern edge of the Ukrainian crystalline shield. Following it from the southwest, from the edge of the platform, a powerful wave of steady uplift began, which gradually covered the entire territory of Podillia. The general uplift of the territory, which began at the end of the early Sarmatian, ended the first stage of neotectonic development of the studied part of the Volyn-Podilskyi edge of the East European platform.

The general uplift of the southwestern edge of the East European platform, which began at the end of the early Sarmatian, continued throughout the Pliocene, Pleistocene, and Holocene up to the modern era. Maps of the total amplitudes of tectonic movements since the beginning of the Miocene, compiled along the sole of the Miocene sediments, provide a visual representation of the scope of these movements. On such maps, with the help of isolines, the altitudinal location of the sole of the moraine Neogene deposits in relation to the modern sea level is shown, or, in other words, the total amplitudes of neotectonic movements are shown. The construction of such maps is based on drilling materials. Maps of neotectonics, which to one degree or another occupied the studied territory, were compiled at different times by V. Bondarchuk, P. Zamoriy, I. Sokolovskyi [1], I. Sokolovskyi, M. Volkov [11], Y. Svynko [10], I. Hofshtein, A. Zubko [5]. The last two maps compiled on a scale of 1:200,000 are the most detailed, but the first of them covers only the northern part of the Podillia Upland, approximately to the latitude of the city of Ternopil, and the second covers almost all of Western Podillia. All the maps of the named authors show that the western part of the Podillia Upland is characterized by high values of the total amplitudes of neotectonic movements, which reach 300 m or more. The largest (380-400 m) total amplitudes of tectonic uplifts are confined to the western part of the Hologoro-Kremenetska ridge (Kamula, Vapnyarka), from where they gradually decrease in the direction to the southeast, east, and northeast. The 300, 320 m isobases are stretched from north to south and clearly coincide with the eastern border of the Western-Podillia Hills. In the southwestern part of the region, approaching the Transcarpathian depression, the high values of the isobases abruptly break off on the lines of discontinuous faults of the northwest trend. In the eastern direction, the isolines of the total amplitudes of neotectonic movements gradually decrease to 260-250 m and less. At the same time, their gradual decrease is observed from the most elevated central part of the highlands to the east to its edge, to the border with the Ternopil Plateau. But the indicated general regularity of the decrease

in the values of the total amplitudes in a number of points is violated by their local changes in the direction of increase or decrease, which indicates the generally differentiated nature of upward tectonic movements.

The uneven scope of the post-Miocene tectonic movements in different parts of the studied region and the significant deformation of the Baden surface is confirmed by large fluctuations in the level of the sole of the layers of the same age Miocene sediments and the marking horizons located among them, in particular, bentonite x clay

Neotectonic structural forms show signs of a close connection with discontinuous tectonic disturbances hidden at depth, mainly in layers of Precambrian and Paleozoic rocks. In particular, the boundary of the meridional and latitudinal extension of the isobases of the sole of the Neogene sediments corresponds to the tectonic line Radekhiv – Berezhany and further to the Dniester in the sedimentary cover. Researchers [3, 4] described a number of flexures in the Miocene and Upper Cretaceous deposits of the southwestern edge of the East European Platform. All of them are grouped into two rows – external and internal. The outer row is located within the boundaries of the Precarpathian marginal depression, six of them were discovered; the inner one is located on the edge of the platform, there are eleven of them. These flexures reflect the stepped dipping of Miocene and Upper Cretaceous rocks under the molasses of the marginal depression. The length of the flexures is tens of kilometers, the inclination of the wings is 10-20º, the amplitude of the flexures of the inner row is tens, the outer one is hundreds of kilometers. At depth, some flexures turn into large drops. S. Subotin [14] showed that flexures coincide with discontinuous faults in the crystalline foundation. Some flexures are reflected in the relief in the form of ledges over 50 m high, in the structure of river valleys, etc.

In addition to flexures, a number of small folds were found in the sedimentary shell of the studied region (for example, near the village of Zavadivka on the Zolotia Lypa River), which extend in the same direction as flexures and dips in the Neogene deposits in the area of Rohatyn [4].

A map of the highest denudation levels of its modern relief is a visual confirmation of significant tectonic uplifts of the Western-Podillia Hills (Fig. 1). On it, the Western-Podillia Hills, together with the Hologorys and Voronyaks, form one high level with absolute heights of 400 m and more. A similar level is formed by the Tovtrova ridge, clearly stretched from the northwest to the southeast in the form of a chain of high hills. The territories adjacent to them form a level of 350-400 m. The latter occupies almost the entire area of the Ternopil Plateau, part of Transnistria and a narrow strip on the northern escarpment of Podillia.

The contours of the Western-Podillia Hills are quite distinct on the map of the depth of dismemberment of the surface of the Western Podillia (Fig. 2). In general terms, the contours of the areas with the greatest depths of surface dismemberment coincide with the contours of the areas of the highest denudation levels both in the Western-Podillia Hills and in the Tovtrova Ridge.

Therefore, the comparison of the map of the total amplitudes of neotectonic movements [5] with the maps of the highest denudation levels (Fig. 1) and the depth

of the vertical dismemberment of the surface (Fig. 2) shows that the areas characterized by the largest values of the total amplitudes of neotectonic movements clearly coincide in plan with sections of the highest denudation levels and relative heights. This is observed both on a regional scale and in individual small areas of the studied territory. On both maps (Figs. 1, 2), the boundaries and general contours of the Western-Podillia Hills almost completely coincide. The available data convincingly show that this coincidence is not accidental, but is the result of a direct reflection in the modern relief of the intensity of the manifestation of neotectonic movements, although in general the West Podillia neotectonic uplift is inverted in relation to the Paleozoic and Mesozoic structures, because the most elevated part of it coincides in plan with the Lviv Paleozoic depression and the Upper Cretaceous depression superimposed on it.

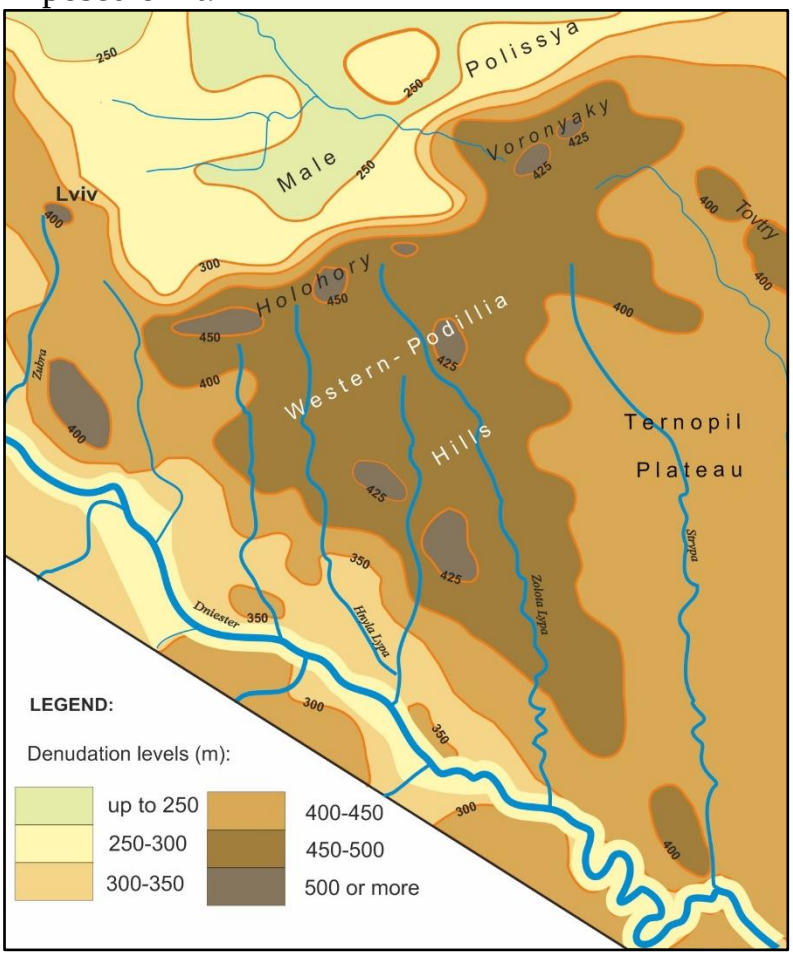

Fig. 1. Maps of the highest denudation levels Western-Podillia Hills

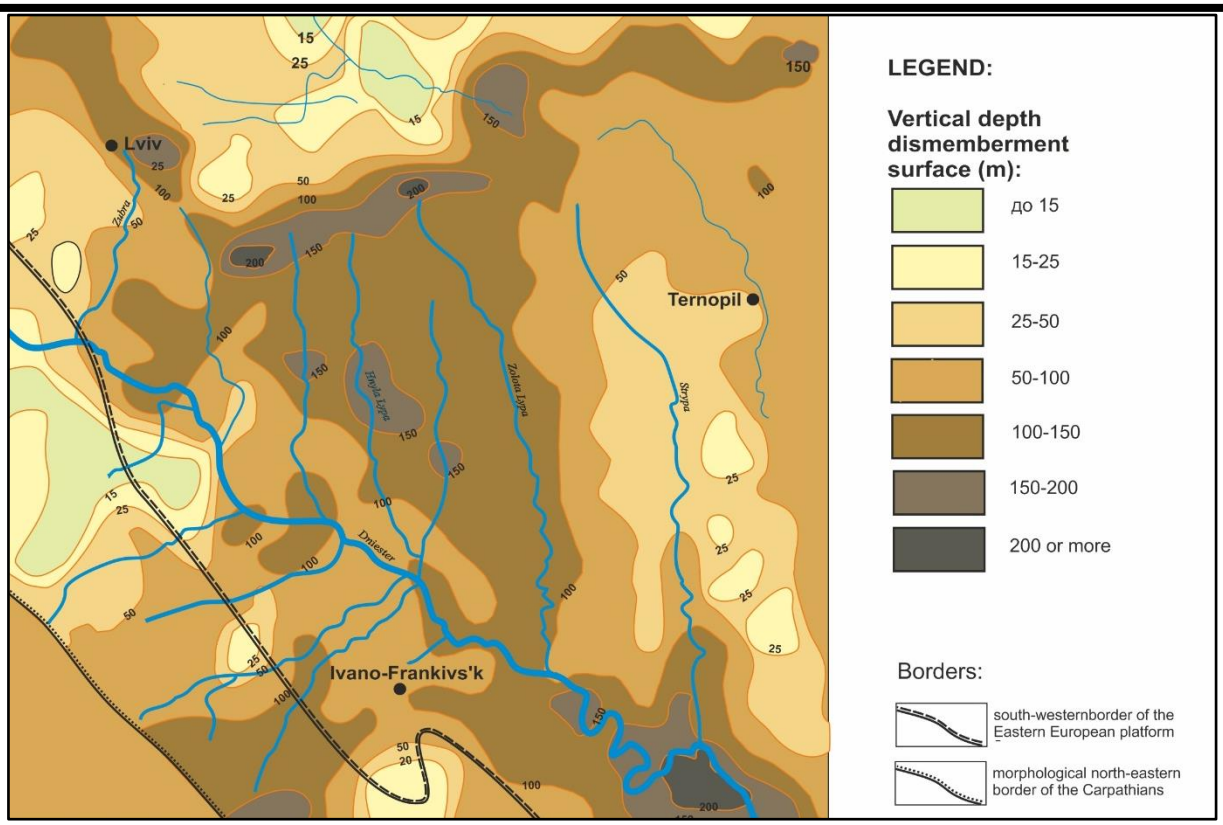

Fig. 2. Map of the depth vertical dismemberment of the surface Western-Podillia Hills

At the same time, the Western-Podillia Hills is a clear example of the fact that the processes of mountain formation in space do not stop suddenly or within narrow bands of foothill depressions, but spread further, deep into the platform, forming wide (hundreds of kilometers) transition zones, which include in addition to foothill depressions, mobile sections of the platform.

There are all the features noted by researchers [6, 12, 13] characteristic of transition zones:

1) neotectonic movements and exogenous processes of relief formation are more intense compared to platforms and less intense compared to orogens, while a tendency to increase their intensity in the direction from platforms to the orogen;

2) the latest structural plan of the transition zone is subordinate to the neostructural plan of the Carpathians, which is manifested in the unidirectional extension of the main structural elements (Podilsky Shaft and Tovtrova Ridge);

3) the presence of a system of recent breaks, flexures and folds parallel to the orogen.

All this indicates that the active tectonic processes taking place in the Carpathians had a significant impact on the adjacent southwestern part of the East European platform. They extended deep into the platform, forming a wide (up to 200-250 km) transitional zone, which includes the Precarpathian depression, the Western-Podillia Hills, the Ternopil Plateau, and the Tovtrova Ridge, extending all the way to the Ukrainian Crystalline Shield.

The opinion of V. Bondarchuk [2] is confirmed that the fault at the base of the Tovtrova Ridge played the role of a kind of hinge, to the southwest of which the

latest tectonic movements caused by mountain formation processes in the Carpathians, were more intense, and much weaker east of it. The inner border of the transition zone between the Carpathians and the East European platform is quite distinct, because it coincides with the line of articulation of the Pre-Carpathian depression with the Carpathians. The outer ("platform") boundary is less clear, it is relatively well defined only within the boundaries of the Tovtrova Ridge, the extension of which clearly coincides with the extension line of the Eastern Carpathians. To the east of the Tovtrova Ridge, and especially within the Ukrainian Crystalline Shield, the linearity of the northwest-trending structures is lost, but the relatively high neotectonic activity of the territory is still preserved up to the Dnipro. This large neotectonic structure, which extends from the Precarpathian depression to the Dnipro, with a high vault in the territory of Volyn-Podillya, I. Hofshtein [5] proposed to call it the Volyn-Podilsky Uplift. In our opinion, it can be considered a transition zone between the Carpathians and the East European platform. The Western Podilsk Highlands is only its most pronounced part, which is characterized by all the typical features of the transition zones mentioned above.

The Carpathian-Podilskyi transition zone can be traced not only in the geological structure, history of geological development and relief of the region, but also in the flora and fauna and the landscape structure as a whole, which gradually change from the Carpathians to the depths of the platform, that is, it can be considered as a typical geographical ecotone (geoecoton) [6].

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