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Features of the composition and deformation of rock within the Marmarosh massif (in Ukraine)

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SUMMARY

The Marmarosh massif (MM) is located in the Transcarpathian Ukraine next to Romanian border being northwest prolongation of the Bucovinian–Getic nappe system. MM is built by metamorphosed Riphean–Vendian, Cambrian and Upper Paleozoic, as well as Meso-Cenozoic rocks. The Bilyi Potik and Dilove nappes were distinguished within MM. In front of MM the narrow Kaminnyi Potik unit composed of Mesosoic roks is present. The Monastyrets unit composed by Paleogen flisch thrusted eastward over MM. We performed geological-structural and tectonophysical work and microscopic study of Riphean – Lower Cretaceous rocks of faults aiming to clarify MM tectonics and evolution. We reconstructed paleostress pattern using sets of slicken-sides. Majority of compression axes is near W-E trending being orthogonal to thrust front of the Monastyrets unit and may be relates to late Alpine stage. Normal-type stress field and south-western extension are also revealed. The extension may be corresponds to tectonic windows formation in the Dilove nappe during neotectonics stage. In thin sections, signs of dynamometamorphism are observed everywhere: microbudding, mylonitization, deformation bands, dynamic recrystallization, subparallel zones of intragranular microcracks, wavy extinction in quartz grains. Structural patterns at thin sections (microbudding, mylonitization, deformation bands, crack systems) are similar to those revealed at outcropes.

Introduction. The Marmarosh crystalline massif is located in the Transcarpathian Ukraine next to Romanian border (Figure1a). It is the northwest prolongation of units known from the Romanian Carpathians as the Bucovinian–Getic nappe. The Marmarosh Massif (MM) is built by dislocated, mesozonally metamorphosed Riphean–Vendian rocks and by sedimentary, volcanic, and epizonally metamorphosed Devonian-Carboniferous, Triassic, and Jurassic formations (Ślączka et al., 2006). The MM is overprinted by Caledonian, Variscan and Alpine deformation. Alpine-age deformation within the Inner Eastern Carpathians (in the Bucovinian nappes) started in mid-Cretaceous times ("Austrian" phase) and continued until Late Cretaceous times (Csontos & Vörös, 2004). During final closure of the remnant Carpathian basin the Bucovinian nappes were emplaced onto Cretaceous to Miocene flysch deposits now forming the Miocene fold-and-thrust-belt of the East Carpathians (Matenco & Bertotti, 2000).

The massif displays a nappe structure, and two subnappes were distinguished (Kruglov, 1989): the Bilyi Potik (the lower) nappe and the Dilove (the upper) nappe. In the frontal part of the Marmarosh Massif, the Kaminnyi Potik nappe, composed of Tithonian–Valanginian sediments and containing the Upper Jurassic basic effusives, is located. The MM thrusted over on the Rakhiv (Black Flysch) nappe, represented mainly by the Valanginian–Hauterivian deposits. The MM and the Marmarosh Klippen zone, situated southwest and west of it, together compose the Marmarosh Unit (Kruglov, 1989) or the Marmarosh nappe (Shlapinskyi, 2007). The Marmarosh Klippen zone is divided into the Vezhany subzone, containing Soimul olistostrome, and the Monastyrets subzone, composed by monocline dipping Paleogene flysch thrusted over on the MM eastward (Figure 1b), (Kruglov, 1989, Gnilko et al., 2015).

Geological map (Matskov et al., 2009) shows within the MM a large number of faults of different types and ambiguous structural relationships between complexes of different ages. Thus to determine the contribution of each tectonic stage in the formation of the tectonic structure of the MM is quite complicate, because of both: multi-stage evolution of the massif and its insufficient study. The aim of the work is to study the deformations of rocks in natural outcrops and thin sections, as well as the relationship of deformations with the material composition of rocks, restoration of paleostress fields, their comparison with results of previous tectonophysical studies and interpretation in context of Carpathian region evolution.

The study results. In 2020, we performed tectonophysical and geological-and-structural studies within the Dilove, Bilyi Potik, Kaminnyi Potik and Rakhiv nappes in the valleys of the Tisa River and its tributaries: Kaminnyi Potik, Lykhyi, Saulyak, Bilyi and others. In outcrops we performed both: measurement of rock structure elements and sampling. Thin sections were made from the rock samples, in which the composition, structural and textural features of the following rock complexes (suits) were studied: the Dilove Complex of the Upper Riphean, the Dolgoruna Complex of the Upper Jurassic, the Chivchiny Complex of the Upper Jurassic, the Kaminnyi Potik Complex of the Lower Cretaceous (Matskov et al., 2009).

Schists of the Dilove Formation (R3.dl) are described in four thin sections and are represented by the following varieties: quartz, quartz-muscovite, muscovite-quartz cataclastic ones. As an example, Figure 1e shows outcrop 26 (coordinates 47.94089, 24.16326) and the composition of the sample from the deformation zone, which is represented by quartz-muscovite mylonitized and carbonated schist (Fig 1h). In the outcrop, the rock is characterized by a thin-layered texture, which is due to the alternation of quartz bands with a slight inclusion of muscovite and extensive zones with its predominance. We can see in thin section muscovite concentrated in zones of deformation and mylonitization. Muscovite aggregates develop along cracks between quartzite breccia fragments. Calcite, which forms individual cracks and isolated inclusions, stands out for its milky white color. Microscopic examination of the thin section from the quartz-muscovite mylonitized schist (Figure1h) shows the main rock-forming minerals of the schist are muscovite (64 ± 2.3%), quartz (21 ± 2.5%), secondary calcite (13 ± 1.2 %). Among the minor minerals, there is a highly dispersed clay material (3 ± 1.2%) and the accessory minerals are leucoxene (single grains). Muscovite is predominantly developed in vast zones of mylonitization and between boudin space (Figure 1d). Quartz is concentrated in microquartzite boudins, while areas of its microgranulation are often observed near the surface of boudins. Finely dispersed clay material forms zones of mylonitization.

The sample shows distinct signs of dynamometamorphism and cataclasis (Pavlov, 2014) at different scale levels. Boudinage, cataclase and mylonitization are clearly visible in the outcrop as well. Under the microscope, the following manifestations of dynamometamorphism were revealed: directive structural elements – subparallel zones of microboudinage and mylonitization, zones of intragranular microcracks, wavy extinction in quartz grains and twinning of calcite grains. Twinning is most clearly manifested in relatively large calcite crystals of the last generation. Almost all quartz grains have jagged boundaries, on which micrograins of recrystallization develop.

Dynamometamorphic changes in the Mesozoic rocks were also revealed in the quartz-carbonate shales of the Dolgoruna Formation, as well as in the quartz-carbonate and clay-carbonate shales of the Kaminnyi Potik Complex (J3-K1 km). As an example, we present outcrop 18 (coordinates 48.04201, 24.17018) (Figure 1c), where the gray quartz-carbonate shale with the white veins is exposed in the NW–trending deformation zone. The rock has a laminated, banded texture, limestone boudins of lenticular shapes are flown around with a light quartz edging, some slicken-sides are found along shear planes. Systems of subparallel cracks filled with the white secondary calcite are developed in boudins at an angle of 60-80° to their orientation.

Microscopic examination of the thin section of mylonitized quartz-carbonate shale (Figure 1d) showed that the rock is composed of the highly dispersed calcite (80%), which predominates in microboudins in zones of mylonitization. The later generation of calcite is observed in thin veinlets along microcracks and on insignificant linear areas of mylonitized zones. The quartz content is about 17%. Its main part is represented in the mylonite mass in the form of relict finely dispersed acute-angled grains. In the zones of mylonitization, there is also a highly dispersed clay material (2±0,6%). In all the studied samples taken from fault zones, various manifestations and structures of dynamometamorphism are observed at the macro- and microlevels.

Tectonic slicken-sides, indicating the direction of movement, were measured at thirteen outcrops. By sets of slicken-sides and as well as paragenesis of the fractures (Gintov, 2005), we restored the stress fields and corresponding deformation regimes using Win Tensor program (Devlaux, Sperner, 2003).The majority of the restored stress fields (8 of 13 definitions) indicate deformation regimes of compression and transpression (combination of compression and strike-slip) with W-E(260-280°)-trending compression axis. The W-E-trending compression was restored within different structural units: Rakhiv, Kaminnyi Potik, Dilove and Bilyi Potik nappes. This may be evidence that the measured slicken-sides were activated at the resent spatial position of the tectonic units. The revealed W-E-direction of compression is suborthogonal to overthrust front of the Monastyrets nappe (the youngest sediments of which belong to the Shopurka beds of Lower-Middle Eocene) on the MM and may be related to the late Alpine stage of tectogenesis, which formed the modern structure of the Carpathian region. Stress fields of normal type, which are characterized by southwestern extension, were restored in three outcrops. It two observation points, the N-S (170-190 °) - oriented compression was restored.

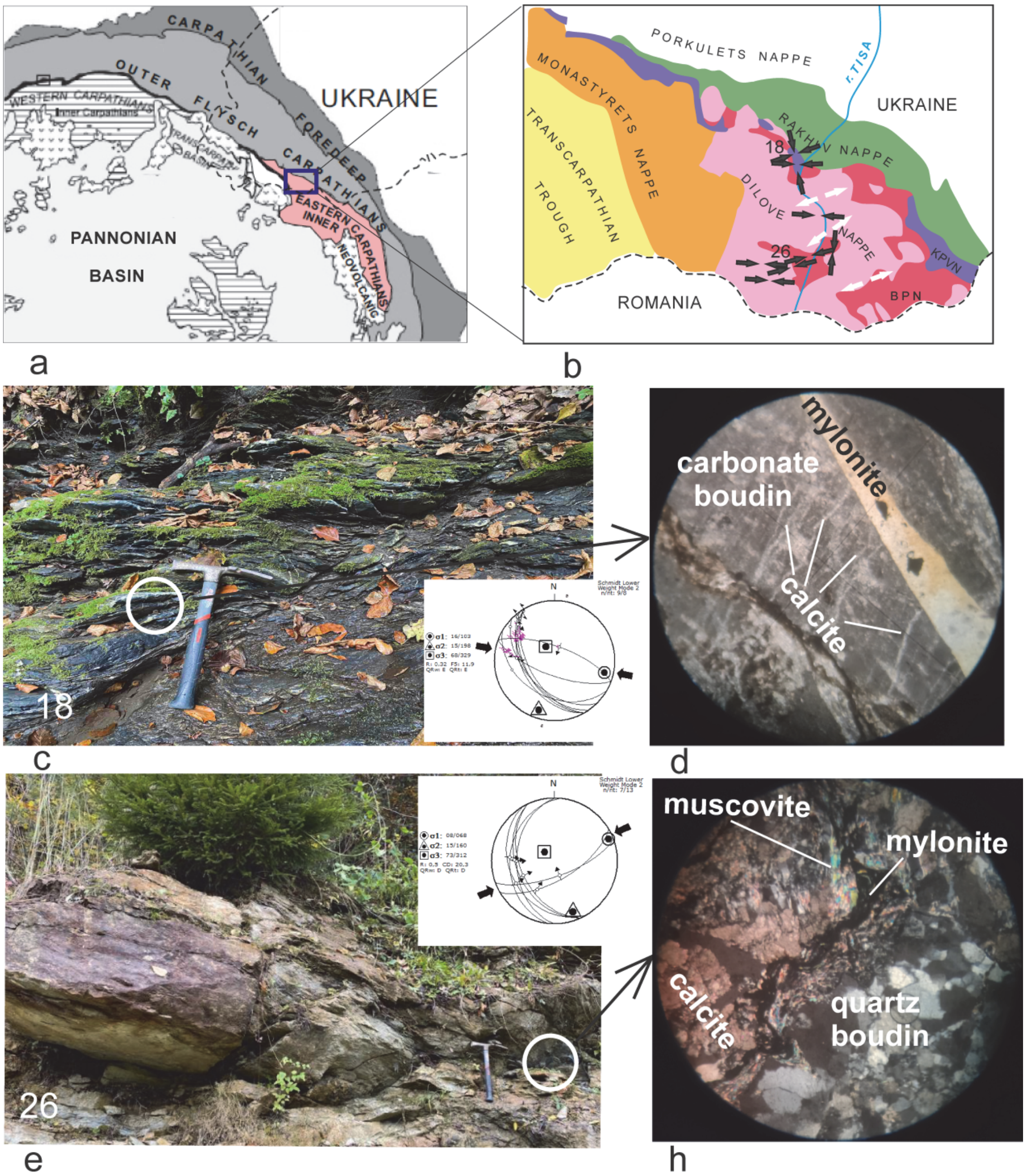

Figure 1 *The stress field of the study area and examples of macro- and microdeformations; a – position of the study area in the Eastern Carpathians, b – the tectonic sceame of the study area after (Kruglov, 1989) with the compression (black arrows) and extetsion (white arrows) axes, reconstructed by sets of slicken-sides. (BPN – Bilyi Potik nappe; KPVN – Kaminnyi Potik and Vezhany nappe); c – the sinistral strike-slip in the fine-laminated dark gray pelitomorphic limestones of the Kaminnyi Potik Complex (J3-K1 kp) and the paleostress reconstruction by the set of slicken-sides; the white circle shows the sampling site; d – the mylonite quartz-carbonate shale (x50 magnification); the two carbonate boudins are separated by the zone of mylonitization; the intraboudin system of subparallel microcracks filled with the late generation calcite is visible; e – the fractures in quartz schist of the Dilove Complex (R3.dl) and the paleostress reconstruction using the set of slicken-sides; h – the quartz-muscovite mylonitized and carbonated schist (polarized light, magnification x65); the contact of the quartzite boudin and the mylonitization zone is visible, along which the muscovite aggregate and the late generation of the secondary calcite develop.*

We compared the reconstructed stress fields to results of previous tectonophysical studies in both the Ukrainian Carpathians and the Eastern Carpathians in Romania. The results of tectonophysical study in the Ukrainian Carpathians show decisive role in the formation and development of the Ukrainian Carpathians SW-NE direction (azimuth 40-60°) of compression forces (Gintov, 2005, Murovska et al., 2019). However, within the MM, the orientation of the compression axes changes to sublatitudinal, forming curved trajectories from south-west – north-east to west – east (Murovska et al., 2019). The current compression of the Transcarpathian Depression according to the mechanisms of earthquakes is characterized by the SW-NE azimut. But in the direction to the MM, the compression trend changes to W-E. The W-E compression calculated by our research may also correspond to modern tectonic processes manifested in seismicity. According to the results of previous tectonophysical studies [Gintov, 2005], the N-S direction of compression was also revealed, which is most pronounced in the SE part of the Ukrainian Carpathians and is interpreted as related to the formation of the Southern Carpathians in the Middle Miocene. This interpretation is consistent with the research (Matenco & Bertotti, 2000), which presents tectonophysical study results of the Eastern and Southern Carpathians. The study (Murovska et al., 2019) recorded presens of the normal type faulting and the corresponding extension paleostress within the Transcarpathian Depression and interpreted them as related to the formation of the Transcarpathian Depression in the Middle Miocene. Stress fields of normal type and southwestern extension revealed by this study may also be connected with the Transcarpathian Depression formation or/and formation of tectonic windows in the Dilove nappe in neotectonics time (Kruglov, 1989).

Conclusions. Based on the sets of slicken-sides, we reconstructed paleostress fields of three main types: (1) the W-E-trended compression perpendicular to the Monastyrets nappe overthrust front onto the Marmarosh Massif (8 of 13 determinations); the compression may refer to the post-Middle Eocene or/and modern stage of tectogenesis; (2) the stress field of normalt type and corresponding south-western extension, which may correspond to the period of formation in the Middle Miocene of the Transcarpathian trough or/and the formation of tectonic windows in the Dilove nappe (Kruglov, 1989); (3) the field of the N-S-trended compaction which can be related to the formations of the W-E oriented Southern Carpathian in the Middle Miocene.

Microscopic study of rocks from fault zones reveals different types of dynamometamorphic microstructures, which were formed under compression and shear conditions: micro boudinage, mylonitization, deformation bands, subparallel zones of intragranular microcracks, etc. Changes in the optical properties of minerals (wavy extinction of quartz), processes of recrystallization of minerals (quartz, calcite), deformational twinning (calcite), new formations of stress minerals (muscovite along the mylonitization zone) are described. All these phenomena are clearly linked with the deformation regimes of compaction and transpression reconstructed in the study area.

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