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Editorial

Editorial for Special Issue "Petrology and Evolution of the Outer Carpathian Mountains"

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This Special Issue, published 15 years after the monumental volume "The Carpathians and their foreland: Geology and hydrocarbon resources" [1], is focused on the Outer Carpathians, forming the externides of the Carpathians, a great, 1300 km-long mountain arc in Central Europe. Significant progress has been made over the last decade, and this collection of papers aims to present certain aspects of the geochemistry, geochronology, petrology, and resources of the Outer Carpathians.

The Outer Carpathians belong to the classical region of the world, where some concepts of geology and petroleum geology were born [1]. Papers by Botor [2] and Zielinska [3] provide information about recent developments in hydrocarbon resources studies. Paper [2] discusses the petroleum system of the northern margin of the Outer Carpathians in Southern Poland. The Outer Carpathian nappes are thrust over the Precambrian rocks of the Małopolska Block (North European Platform) and their Paleozoic, Mesozoic, and Neogene cover. The Pilzno-40 well drilled through the Upper Cretaceous flysch of the Outer Carpathian Skole Nappe and the autochthonous Miocene deposits of Carpathian Foredeep, Cretaceous, Jurassic, Triassic, Silurian, and Ordovician rocks.

The Silurian and Ordovician source rocks were subjects of the modeling of burial and thermal maturity. Comprehensive mineralogical and geochemical studies were an indispensable prerequisite of this modeling. The results indicate that the Paleozoic source rocks likely reached maximum heating in the Late Triassic to Early Jurassic period, which caused a major phase of hydrocarbon generation. The hydrocarbon potential of Paleozoic source rocks was exhausted before Upper Jurassic as well as Cretaceous reservoir rocks and traps were formed. Consequently, the majority of the hydrocarbons generated were lost. The hydrocarbons in Mesozoic reservoirs were possibly charged by the lateral migration of source rocks occurring within the Outer Carpathians, i.e., Oligocene Menilite shales. Thermochronological modeling, leading to the establishment of effective source rocks, helps in the reconstruction of petroleum systems and hydrocarbon exploration in the northern margin of the Western Outer Carpathians and adjacent part of the Carpathian Foredeep.

Paper [3] describes studies on burial temperatures and burial depths at the southern margin of the Western Outer Carpathians. In this area, the Grajcarek Unit of the Pieniny Klippen Belt (PKB) was formed as a result of the convergence of the ALCAPA (the Alps–Carpathians–Pannonia) block and the European plate at the boundary between the Central (Inner) and Outer Carpathians. The Grajcarek Unit consists of Jurassic–Cretaceous siliciclastic and carbonate deposits as well as Upper Cretaceous–Paleocene synorogenic wild flysch, in addition to sedimentary breccias with olistoliths. This Unit is strongly deformed, reflecting the tectonic history of the PKB.

The maximum burial temperatures and burial depths in the Grajcarek Unit were estimated based on studies on vitrinite reflectance data from the samples collected in Jurassic–Palaeocene siliciclastic rocks, especially flysch formations. The vitrinite reflectance

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values were widely scattered due to the depositional effects that affected the vitrinite evolution. These values help to determine the maximum burial temperatures related to the regional compression. This compression was controlled by tectonic burial caused by thrusting and strike-slip faulting.

The European Plate beneath the PKB is cut by the dextral deep fracture zones, which had a crucial role in the style of the deformation of the Grajcarek Unit. The regional vitrinite reflectance variations might estimate cumulative displacement around the NNW–SSE-oriented strike-slip Dunajec fault, which is a continuation of the deep fracture Kraków–Myszków fault zone. The tectonics caused profound changes in organic matter production and preservation.

The paper by Barmuta et al. [4] presents studies on the tectonics of the Western Outer Carpathian nappes. It is focused on the role of large normal faults in the Carpathian fold-and-thrust belt structure. The investigated area is located in the southwestern Polish Outer Carpathians, close to the Polish–Czech border. The Western Outer Carpathians are composed of large nappes (thrust sheets) that originated during the Miocene closing of several sedimentary basins related to the Alpine Tethys and the thinned crust of the European Platform. The sedimentary rocks deposited in these basins were detached and thrust over the North European Platform forming from south to north: the Magura Nappe Unit, the Dukla Nappe, the Fore-Magura group of nappes, and the Silesian, Subsilesian, and Skole Nappes.

The authors use field observations, geological mapping, a high-resolution digital elevation model (DEM), and seismic data interpretation in their analysis of a seismic-scale, thrust-perpendicular fault known as the Rycerka Fault. This fault, displaying a predominantly normal dip-slip component, cuts the Outer Carpathian thrust units—the Magura Nappe and the underlying Dukla Nappe. Its detachment surface is located at the base of the Carpathian nappes.

The authors propose a mechanism responsible for the formation of this fault. The fault development is related to the anticlinal stack formed within the Dukla Nappe below the Magura Nappe. The formation of a relatively narrow duplex caused the growth of a dome-like culmination in the lower Dukla Nappe as well as the differential uplift and stretching of the Magura Nappe above and outside the duplex. Normal faulting along the lateral culmination wall was invoked, accelerated by the regional, syn-thrusting arc–parallel extension. Horizontal movement along the fault plane is a result of tear faulting accommodating a varied rate of the advancement of Carpathian units. The authors emphasize the importance of the orogen-parallel extension in shaping the structure of the Western Outer Carpathians and suggest that numerous thrust-perpendicular or oblique normal faults observed in the Carpathians and other thrust-and-fold belts might have originated by this process.

The paper by Golonka et al. [5] reports on studies on exotic crystalline blocks within the Western Outer Carpathian flysch. Exotic blocks are present in several Alpine orogens within the sedimentary successions, representing remnants of crystalline basements, underlying the flysch basins during Mesozoic and Cenozoic times. Sedimentary Upper Cretaceous successions in the Subsilesian Nappe of the Outer Western Carpathians contain a variety of crystalline rocks, including granitoids and andesites. The authors performed petrological investigations as well as zircon and apatite U-Pb dating on crystalline (subvolcanic) exotic blocks from the Żegocina tectonic zone within the Subsilesian Nappe south of Kraków.

The U-Pb zircon dating of microgranitoid yields a magmatic crystallization age of ca. 293 Ma, while that of andesite yields a ca. 310 Ma age of crystallization. The inherited zircon cores yield Archean, Paleoproterozoic, Mesoproterozoic, and Cadomian ages. The source of both the microgranite and andesite includes significant Neoproterozoic crustal components indicated by whole-rock trace elements and Nd isotope data. The crystallization ages indicate Late Carboniferous–Permian magmatic activity. This activity is also present outside the Western Outer Carpathian Belt, within the Lubliniec–Kraków Late Paleozoic transtensional zone, which is a continuation of the Lubliniec–Kraków zone. This

zone extends below the Carpathians to Moesia. This Late Paleozoic transtensional zone was probably reactivated during Late Cretaceous times under a transpressional regime within the Żegocina tectonic zone, which caused the uplift of the Subsilesian Ridge and intensive erosion.

The paper by Górniak et al. [6] focuses on the Carpathian Foredeep, a large geological structure, extending along the Carpathian arc, that originated via the thrusting of the Carpathian nappes over the North European Platform. This thrusting caused the flexural bending of the foreland crust and the formation of the foreland basin. The research area is located in Southern Poland, at the northern margin of the Foredeep, on southern slopes of the Holy Cross (Świętokrzyskie) Mountains. The studied 0.6 m-thick clay bed belongs to the Badenian (Serravalin Langhian) Pińczów Formation composed mainly of lithothamnium limestones. The authors discuss the hypothesis of the volcanic origin of this clay. They use a combined X-ray powder diffraction, optical and electron microscopy imaging methods, and chemical analysis to unravel the clay composition and bentonite origin. This bentonite is composed almost entirely of secondary montmorillonite formed at the expense of platy and cuspate volcanic glass shards. It represents a classic example of completely altered pyroclastic rock, retaining the original texture developed in rhyolitic volcanic glass fragments. The preserved original features of this rock indicate that it commenced as fallout pyroclastic deposits and therefore represents a record of a large-scale explosive eruption of silicic magma chambers. The average size of the pyroclasts is approximately 20 μm, and their maximum dimension is 100 μm. This very small size indicates a distal location of the source volcanoes, hundreds of kilometers from the studied outcrop, perhaps in the inner arc of the Carpathians. These volcanoes were probably related to the Central Slovakia Volcanic Field or the Hungarian volcanic fields, i.e., the Bükk, Tokaj, and Zempléni Mountains. The violent, explosive volcanic event was associated with a collision leading to the closure of the Western Outer Carpathian basins and the origin of the Carpathian Foredeep.

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