Peperites and other volcano-sedimentary deposits (lowermost Cretaceous, Berriasian) of the Ukrainian Carpathians

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Abstract: In two analyzed regions: Kamyanyi Potik Unit of the Fore-Marmarosh Unit (Chyvchyn Mt) and the Pieniny Klippen Belt (Velykyi Kamianets quarry) of the Ukrainian Carpathians classical peperites are developed. It is a very unique consortium of volcanogenic rocks and limestones which occur together as sedimentary episode of submarine eruption of basaltic lavas on the unconsolidated wet carbonate mud. Peperites co-occur with another volcano-sedimentary rocks (basaltic pillow lavas, pyroclastic debris flows and pyroclastic turbidite system) which are perfect proof for age of volcanic activity by dating of limestones both by macro- and micro-fossils and indicate their Berriasian age.

Introduction

In the frontal part of the Marmarosh Massif in the Ukrainian Carpathians the Outer Dacides–Severinides are represented by the Kamyanyi Potik and Rachiv units (nappes) and are most probably the prolongation of the Black Flysch unit of the Romanian Carpathians (Fig. 1). The Rachiv nappe is represented by folded Lower Cretaceous flysch dipping generally toward the southwest under the Kamyanyi Potik unit and is overthrust on the Porkulets Nappe (Ślączka et al. 2006 with references). The Kamyanyi Potik Unit (Nappe) is the most internal and structurally highest unit of the Fore-Marmarosh units and in many places is directly covered by the Marmarosh nappes of the Central East Carpathians (Marmarosh Massif). But its connection with surrounding units is still matter of discussion by several authors (Boyko 1970; Vialov et al. 1981; Kruglov 1986; Ślączka et al. 2006). By the first author this unit is interpreted as part of the Radomyr zone of the Marmarosh Massif. According to Vialov et al. (1981) it belongs to the Rahiv Nappe, Kruglov (1986) consider this thrust sheet as a part of the Marmarosh Massif, and for Ślączka et al. (2006) this unit is a part of the Marmarosh nappes. The most probably Kamyanyi Potik Unit forms the separate nappe, which extends at the front of the Marmarosh nappes and consists of the uppermost Jurassic Chyvchyn Formation (up to 1000 m thickness) composed mainly by basic effusives, and the earliest Cretaceous (Berriasian–Valanginian(?)) Kamyanyi Potik Formation (thickness 200 m) represented by dark, thin-bedded limestones, black shales, sandstones and conglomerates with volcanic material, which pass upward into thick-bedded psammites (thickness about 400 m).

Volcano-sedimentary units of the Ukrainian Carpathians

The Kamyanyi Potik Unit

Chyvchyn Mount (1766.1 m a.s.l.)

The best places for study of this unit occur both on the Chyvchyn Mount (1766.1 m a.s.l.) — the highest peak of the Chyvchyn Mountains, and in the Rahiv city vicinity (Kamyanyi stream — stratotype of the Kamyanyi Potik Unit) (Fig. 2). First geological structure of this mountains was shown on the geological map published by Zapałowicz (1886) and Pazdro (1934), where volcano-sedimentary deposits were attributed to the Triassic. Recently, geological mapping work showed that this complex forms the tectonic klippe which consists four small tectonic slices (Krobicki et al. 2014; Hnylko et al. 2015) and biostratigraphical investigations (calpionellids — Iwańczuk et al. 2015) indicate Berriasian age at least of lower part of the Kamyanyi Potik Formation. Volcanic–sedimentary complex of the Chyvchyn Mt, does not form a single stratigraphic sequence, as it was considered in previous studies (Hnylko et al. 2007; Matskiv et al. 2009). On the other hand, the basic volcanites of the Chyvchyn Mt have been studied by many geologists (Lomize 1968; Medvedev & Varitchev 2000 with literature cited therein). Recently, geological

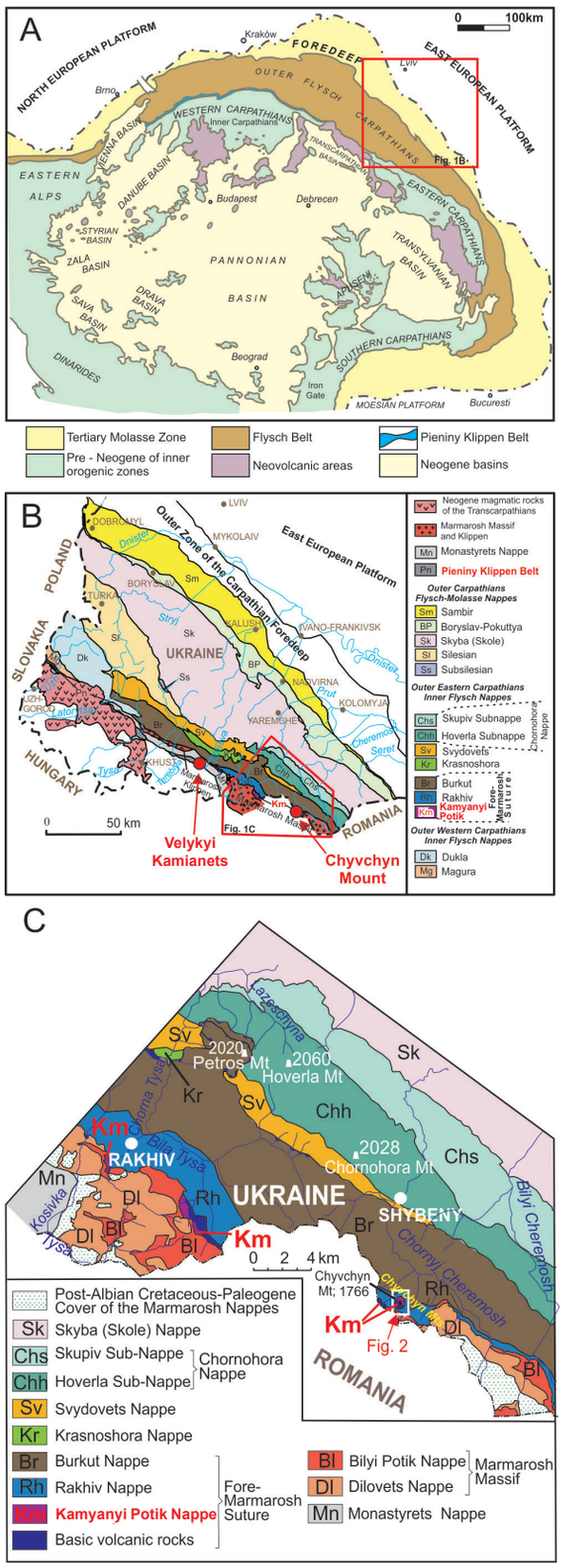

Fig. 1. Tectonic sketch map of the Alpine–Carpathian–Pannonian–Dinaride basin system (**A** — modified after Plašienka et al. 2000) and main tectonic units of the Ukrainian Carpathians (**B** — Hnylko 2012, modified) with location of study area (**C** — after Hnylko et al. 2015 with references)

mapping work showed that this complex forms the tectonic klippe which consists four small tectonic slices (Hnylko et al. 2015).

Structurally the lowermost, **first slice** (I) (100–200 m in thickness) (Fig. 2) is developed as thin-bedded light and dark-gray micritic *Maiolica*-type limestones with lenses of dark cherts and is interbedded by corse/fine-grained calcareous pyroclastic turbidites (flysch) (Kamyanyi Potik Fm.) and is similar to stratotype of this formation in the Kamyanyi Potik stream near Rakhiv (Krobicki 2012; Hnylko et al. 2015). They are thin-bedded layers full of pyroclastic materials with classical features of turbiditic beds manifested by graded fractionation, sharp erosive base of beds, subtle cross-bedding structures, intercalations of shaly–pyroclastic materials between beds — typical Bouma sequence development.

The **second slice** (II) (250–300 m) is filled mostly by calcareous–pyroclastic breccia/conglomerates ("gravelstones") with volcano-tuffitic matrix and different size of blocks, pebbles and olistoliths of micritic and organodetritic limestones (often with corals and other benthic fauna; even huge blocks over 5 m), which genetically represent submarine debris flows. From sedimentological point of view this type of sediment represents classical proximal-type of mass movements very close to source area, and records apron-type submarine debris flows with cohesive mechanism of sedimentation.

The **third slice** (III) (up to 30–40 m) is filled by classical peperites — limestones with irregular clasts of basaltic rocks, sometimes as pillow lava fragments (Krobicki 2018). Peperites are special kind of volcano-sedimentary rocks where sharp-boundaries volcanic pieces (usually basaltic) occur within sedimentary deposits (Figs. 2, 3) and were formed on the sea-floor as effect of submarine eruption and disintegration of magma/lavas intruding and mingling with unconsolidated, or at least poorly consolidated, wet sediment and have to be automatically simultaneous with surrounding sediments (e.g., Busby-Spera & White 1987; Skilling et al. 2002; Chen et al. 2016).

The **fourth slice** (IV) (200–250 m) crop out on the Chyvchyn peak and is represented by massive basalts of typical pillow lava structures. The primary volcano-sedimentary sequence was presumably beginning from basaltic pillow lava flows, then peperites, great debris flows with olistoliths and distal pyroclastic turbidities finally, intercalated by micritic, pelagic limestones (*Maiolica*-type). In this case peperites were transitional event between main submarine basaltic flooding and mingling with carbonate mud on the sea-floor (Krobicki 2018).

The Pieniny Klippen Belt

In the Velykyi Kamianets active quarry (Pieniny Klippen Belt) (Fig. 3) a unique section with continuous Lower Jurassic to lowermost Cretaceous (Berriasian) sedimentary succession occur with precise biostratigraphical data (ammonites, calpionellids and dinoflagellates) (Reháková et al. 2011; Grabowski et al. 2019). In the uppermost part of this section basaltic rocks overlie white *Calpionella*-bearing limestones (Krobicki et al. 2008; Oszczypko et al. 2012), which are dating by this microfossils as Middle Berriasian in age. On the other hand, above basaltic bed occur synsedimentary breccia (so-called Walentowa Breccia Member of the Łysa Limestone Formation — lithostratigraphy after Birkenmajer 1977; see also — Plašienka 2018) with clasts of this, underlying *Calpionella* limestones and with clasts of basaltic rocks. By this reason we have perfect stratigraphical control of the Middle Berriasian age of this basaltic rocks. Additionally, on the contact between *Calpionella*

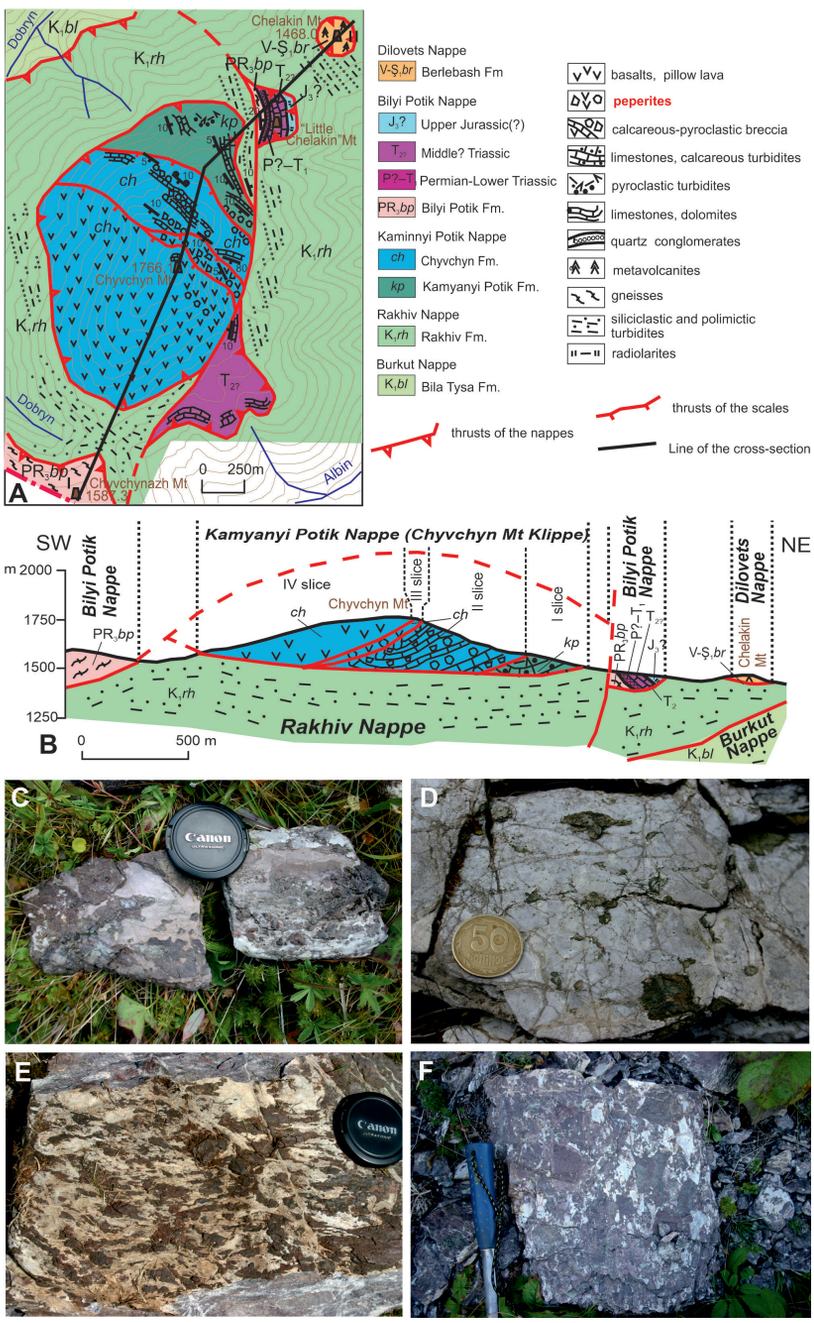

Fig. 2. Geological map of the Chyvchyn Mt. area (**A**) with geological cross-section along the black line (**B**) (after Hnylko et al. 2015) with examples of peperites: basaltic fragments in limestones (**C**); small basaltic "bombs" in coral-bearing limestones (**D**); desintegrated lava flow in limestones (**E**); pyroclastic flow mixed with limestones (**F**).

limestones and basalts (sometimes developed as pillow lavas) peperites have been discovered recently.

Conclusions

In conclusion, in two analyzed cases (Chyvchyn Mt. and Velykyi Kamianets quarry) we have very unique consortium of volcanogenic rocks and limestones which occur together as sedimentary episode of submarine eruption of basaltic lavas on the unconsolidated wet carbonate mud. Such volcano-sedimentary structure is additional perfect proof for age of volcanic activity by dating of limestones, which are sometimes full both in macro-fossils (e.g., corals of the Štramberk-type limestones — shallow-water carbonates known as olistoliths and exotic pebbles in flysch deposits of the Outer Carpathians; e.g., Eliášová 2008; Kołodziej 2015 with literature cited therein) and micro-fossils (calpionellids) which are Berriasian in age (Iwańczuk et al. 2015).

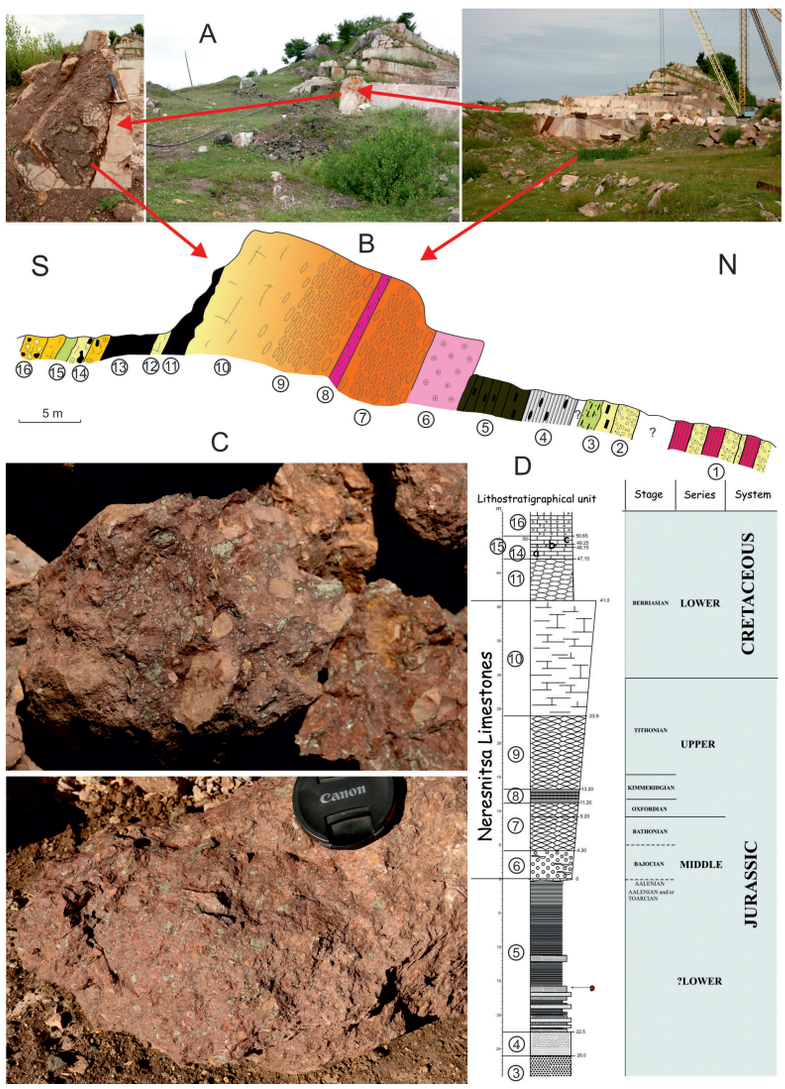

Fig. 3. General view of Velykyi Kamianets quarry (**A**) and studied section (**B**) with Jurassic and lowermost Cretaceous rocks [after Krobicki 2012; modified; lithostratigraphical names adopted from Birkenmajer 1977); explanations: 1–5 — Hettangian(?)–lowermost Bajocian: 1 — white-yellowish conglomerates and cherry shales; 2 — yellow sandstones; 3 — fine-grained sandstones and mudstones with coal; 4 — black shales with spherosiderites; 5 — mudstones with bivalve coquina; Bajocian: 6 — pink crinoidal limestones (Smolegowa and/or Krupianka Limestone Formation); uppermost Bajocian–Oxfordian: 7 — red nodular limestones of the Ammonitico Rosso-type facies (Niedzica Limestone Formation); Kimmeridgian: 8 — red thin-bedded radiolarites (Czajakowa Radiolarite Formation); Upper Kimmeridgian–Upper Tithonian: 9 — red nodular limestones of the Ammonitico Rosso-type facies (Czorsztyn Limestone Formation); 10–16 — Upper Tithonian-Berriasian: 10 — creamy and white Calpionella limestones (Dursztyn Limestone Formation); 11 & 13 — black basalts (including **peperites**); 12 — creamy biodetritic limestones (Harbatowa Limestone Member of the Łysa Limestone Formation); 14 & 16 — yellowish carbonate breccia (Walentowa Breccia Member of the Łysa Limestone Formation)] with examples of **peperites** (**C** — green pieces of volcanogenic material in limestones); 15 — green and purple tuffites; and their stratigraphical position (**D** — after Reháková et al. 2011).

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