Jurassic and Cretaceous phosphatic events and their palaeoceanographic significance during geotectonic evolution of the Pieniny Klippen Basin (Carpathians)

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The Pieniny Klippen Belt (PKB) represents a boundary zone between the Outer and Central Western Carpathians and is interpreted as a separate branch of the north-westernmost Tethyan Ocean (Pieniny Klippen Basin – PKBs). Several facies zones can be distinguished, from shallowest zone (so-called Czorsztyn Succession – corresponds to submarine ridge) trough transitional zone (Niedzica and Czertezik successions) up to deepest one (Branisko and Pieniny successions) in the axial part of this basin. The Czorsztyn, Niedzica and Czertezik successions accumulated in subtidal/neritic shelf environments of the submarine Czorsztyn Ridge and its southeastern slope, while palaeogeographical orientation of the Czorsztyn Ridge was from NE to SW. In whole PKBs history at least three phosphatic events took place in: (i) Early Bajocian, (ii) Berriasian and (iii) Albian times. In the late Early Bajocian (i), just after Czorsztyn Ridge originated by tectonic uplift, sedimentary features recorded condensation episode during start of crinoidal limestones sedimentation (even up to 150 m in thickness). The base of the crinoidal limestones is very sharp and directly overlying, with a stratigraphical hiatus (ca. 2 Ma), the oxygen-depleted dark/black Fleckenkalk/Fleckenmergel-type deposits of Toarcian lowermost Bajocian in age. This part of crinoidal limestones consists of phosphatic concretions pavements, large phosphatic macrooncoids (up to 8–10 cm), light-greenish clasts of micritic limestones, pyrite concretions, and fossils as ammonites, brachiopods and bivalves. Phosphatic concretions (up to 6 cm) occur in almost all PKB successions exclusively within lowermost part (first 1.0 m above base) of crinoidal beds, which is isochronous event. On the other hand, very rapid change of sedimentation from oxygen-depleted environments (during Toarcian–earliest Bajocian) to carbonate sedimentation is record of rapid vertical tectonic movements of the Czorsztyn Ridge and adjacent areas and may be also reflect palaeoceanographical changes after this tectonic uplift and origin of upwelling currents, for which such condensation and phosphatic structures are typical. The second (ii), Berriasian episode of phosphatisation within PKBs was connected with post-Tithonian (Neo-Cimmerian) tectonic uplifting of the Czorsztyn Ridge and surroundings, including Niedzica Succession. The presence of phosphate-rich deposits (phosphorites and microbial phosphate macrooncoids) in this succession, which should be localized in a palinspastic reconstruction near shelf-edge slope boundary, support the idea of upwelling currents as well. In the PKBs this idea is additionally supported by Berriasian brachiopods/crinoids-rich beds of the Czorsztyn Succession and their distribution probably have also been controlled by the upwelling currents, where nutrient-rich oceanic water formed such conditions which caused the proliferation of benthos. The third (iii), Albian episode of phosphatisation of marly deposits on sea-floor occupied by the Czorsztyn Succession zone are represented by phosphatic stromatolites, lithoclasts and microbialite-coated bioclasts within beds of different thickness (a few cm up to dozen ones). Usually, they occur at the base of Albian marls/marly limestones which cover erosional surfaces of older limestones with several fossil-karst phenomena originated as effect of at least two episodes of tectonic uplift and emersions of the Czorsztyn Ridge/Czorsztyn Succession zone.