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Ambient inclusion trails in Palaeozoic crustaceans (Phosphatocopina and Ostracoda)

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ABSTRACT

Hollow microtubular structures with pyrite grains at their termini have been found in phosphatocopines (*Hesslandona toreborgensis* and *Hesslandona* cf. *angustata*) from the late Cambrian of northern Poland, and in the metacopine ostracod *Cytherellina submagna* from the Early Devonian of Podolia, Ukraine.

The Cambrian phosphatocopines are secondarily phosphatised and microtubes (5–20 μm in diameter) are preserved inside the phosphatized bivalved shield, visible on the shield surface as half-open microstructures with pyrite grains at their terminal end. They are visible only where an external coating layer has peeled off. In the Devonian ostracod *C. submagna*, microtubes (*c.* 1–8 μm in diameter) occur within the phosphatized internal mould/steinkern and are visible on the surface of the mould due to the dissolution of the calcite carapace during extraction of the limestone samples.

These microtubular structures are here interpreted as ambient inclusion trails (AITs) due to the presence of terminal pyrite crystals of equivalent diameter to the microtube, polygonal microtube cross-sections, plus longitudinal striations on the microtube walls that record the movement of the migrating angular pyrite crystal. AITs are thought to form when mineral crystals, typically pyrite, are impelled to migrate through a fine-grained mineral matrix under increased fluid/gas pressure.

Our new materials provide the first record of exceptionally preserved AITs occurring in crustaceans and only the third reported occurrence of AITs in the Palaeozoic. The intimate occurrence of AITs with phosphatized crustacean body fossils supports the hypothesis that AITs are likely driven by increases in gas pressure due the decomposition of soft tissue. In the case of *Cytherellina submagna*, our calculations suggest that as little as 20 μg of organic matter decaying within a volume of 0.06 mm^3, encased by an impermeable outer carapace, may have been sufficient to produce a large number (>100) of AITs.

1. Introduction

Ambient inclusion trails (AITs) are microtubular structures that form during the migration of mineral crystals, often pyrite, through a lithified fine-grained substrate such as chert or apatite. AITs have a geological record extending back to the ~3500 Ma Warrawoona Group of Western Australia (Awramik et al., 1983). Most AITs have been reported from the Archean and Proterozoic from various localities in Australia and North America (Tyler and Barghoorn, 1963; Knoll and Barghoorn, 1974; Awramik et al., 1983; Grey, 1986; Buick, 1990; Xiao and Knoll, 1999; Brasier et al., 2006; Wacey et al., 2006, 2008a,b; McLoughlin et al., 2007). Their frequent association with organic matter has led to AITs being investigated as possible indicators of early life on Earth (see Wacey et al., 2008b for an overview).

AIT structures have been studied up to now mostly in petrographic thin sections. Observations from thin sections show that most AITs are infilled by fine-grained minerals such as silica (e.g., 1900 Ma old Precambrian Gunflint Chert of Ontario) or iron carbonates (e.g., ~2000 Ma old Biwabik Formation of Minnesota; Tyler and Barghoorn, 1963). Alternatively AITs may remain empty preserving longitudinal striations on their walls, left behind by the migrating angular pyrite crystal, which itself is frequently preserved at the termination of the trail (Xiao and Knoll, 1999).

As currently documented, the fossil record of AITs is more or less continuous throughout the Archean and Proterozoic. The record of Palaeozoic AITs is very sparse, up to now they have been reported only from the Early Cambrian Soltanieh Formation of Iran and from the Middle Devonian of Northern Scotland, where they are preserved within phosphatic fish scales (McLoughlin et al., 2007; Wacey et al., 2008b). AITs remain unknown from rocks of Mesozoic and Cenozoic age.

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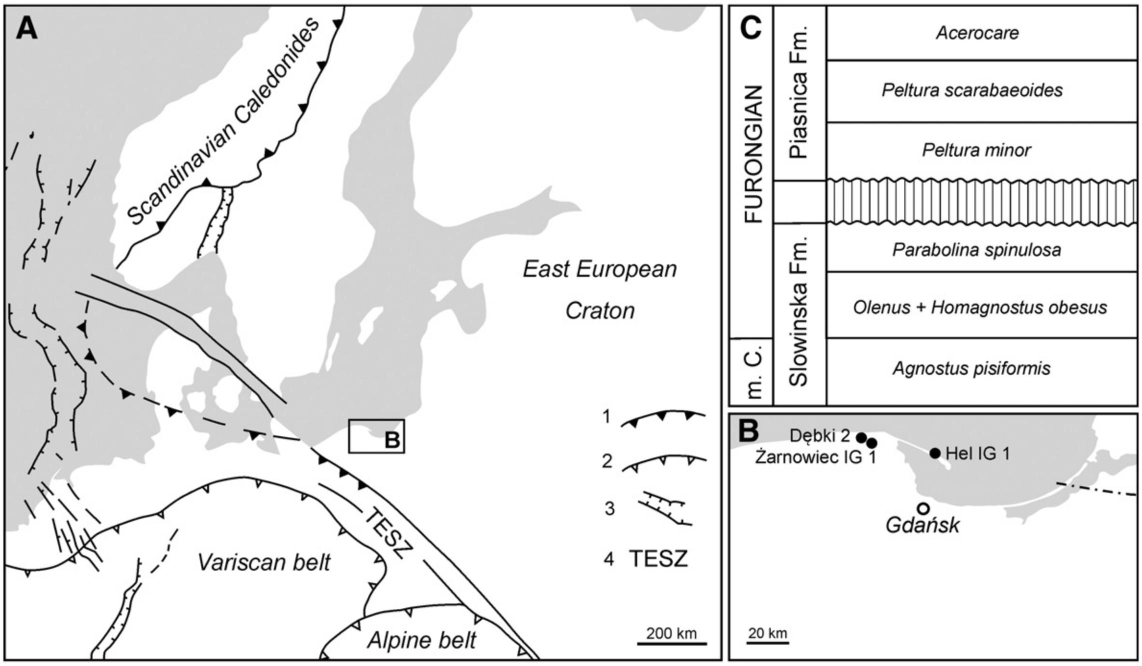

Fig. 1. Geographic position of the studied Cambrian sections in Poland. (A), Map of the Polish part of the Baltic region: 1 — Caledonian deformation front; 2 — Post-Caledonian deformation front; 3 — Rift zones; 4 — Trans-European Suture Zone. (B), Map of northern Poland showing location of the sections described in this paper from Hel IG 1, Żarnowiec IG 1, and Dębki 2 boreholes. (C), General stratigraphy of the middle Cambrian and Furongian strata in northern Poland. Marked area indicates stratigraphic gap (erosion and/or no deposition).

Below, we describe AITs preserved in specimens of phosphatocopine *Hesslandona toreborgensis* Maas et al., 2003 and *Hesslandona* cf. *angustata* Maas et al., 2003 from limestone nodules of the uppermost mid-Cambrian to early Furongian (*c.* 502–495 Ma) of the western part of the Baltic Depression, located at the western slope of the East European Craton. The specimens described come from deposits sampled from drill cores of deep wells Hel IG-1, Żarnowiec IG-1 and Dębki 2 located in northern Poland (Fig. 1).

We also describe the phosphatized internal mould of the ostracod *Cytherellina submagna* (Krandijevsky, 1963) containing a high density of unusual exceptionally preserved AITs from ~416 Ma Lochkovian–earliest Pragian of the Ivanye Zolote outcrop in the Early Devonian of Podolia, Ukraine (Fig. 2). Such AITs preserved in crustacean carapaces from Cambrian of Poland and Devonian of Ukraine, are only the third reported finding of these structures in Palaeozoic rocks.

2. Material and methods

More than 2000 phosphatocopine specimens have been recovered from the relatively small Cambrian drill core samples. However, from 300 specimens investigated in SEM, only three of them show AIT structures. More than 40 specimens are preserved with soft-parts. The material of phosphatocopines is preserved as isolated valves and closed or half-open shields (‘carapaces’).

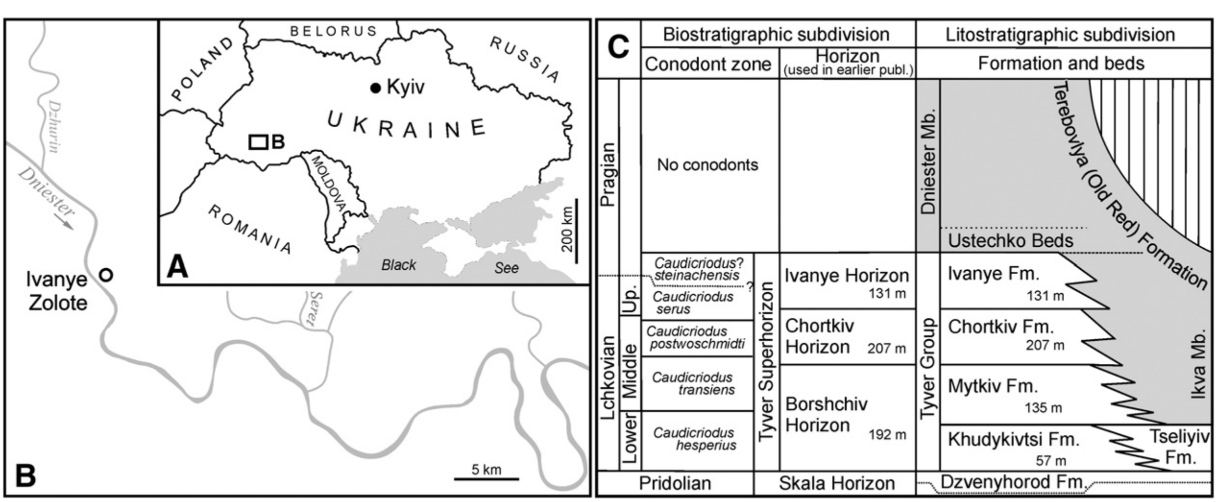

Fig. 2. (A), Geographic position of the studied Devonian section in Podolia, Ukraine. (B), Location of Ivanye Zolote outcrop in the vicinity of Dniester valley. (C), General Lower Devonian stratigraphy of the Podolia region (modified from Drygant and Szaniawski, 2012).