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SPHENOTHALLUS HALL, 1847 FROM CAMBRIAN OF SKRYJE–TÝŘOVICE BASIN (BARRANDIAN AREA, CZECH REPUBLIC)

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Abstract: Two conical tubules from shales of the Skryje Member (Buchava Formation) at the Skryje–Luh and Týřovice–"Pod hruškou" localities, two of the key outcrops of this stratigraphic unit in the Skryje–Týřovice Basin (Barrandian area, Czech Republic), are described. One specimen consists of a small, compressed tubule with a very low expansion angle and wide and flat thickenings. The second, larger specimen exhibits indications of very narrow thickenings of a more abruptly expanding shell. Both specimens are assigned to the genus *Sphenothallus* Hall, but the latter only provisionally. *Sphenothallus* shows a worldwide distribution with numerous species, ranging from Cambrian to Permian in age. However, reported occurrences in the Cambrian are relatively sparse, in the form of rare specimens from the lower to middle Cambrian strata of Laurentia, Eastern Gondwana and European peri-Gondwana. According to accepted palaeogeographical reconstructions, Cambrian *Sphenothallus* occurred in low as well as in higher palaeolatitudes.

Key words: *Sphenothallus*, middle Cambrian, Buchava Formation, Barrandian area Czech Republic.

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INTRODUCTION

The genus *Sphenothallus* Hall, 1847 is a widespread Palaeozoic (Cambrian to Permian) marine taxon of problematical, systematic position. It originally was described as a marine plant by Hall (1847, p. 261), but since the twentieth century it has been recognized as an invertebrate, with previous authors variously classifying it as *incertae sedis* (e.g. Neal and Hannibal, 2000), as a "worm" (Fauchald *et al.*, 1986), or as a hydrozoan or scyphozoan cnidarian (e.g. Van Iten *et al.*, 1992, 2013). In the Barrandian area, a small number of occurrences of *Sphenothallus* have been reported from Ordovician to Devonian fossil associations of the Prague Basin (Brabcová and Kraft, 2003, p. 265), but until now there has been only one study, dealing with these fossils systematically. In that report (Fatka *et al.*, 2012), rare specimens of the smaller *Sphenothallus kozaki* Fatka *et al.*, 2012 and the giant ?*S. kordulei* Fatka *et al.*, 2012 are described from the Jince Formation of the Cambrian Příbram–Jince Basin.

The purpose of the present paper is to describe the first occurrence of presumed conical phosphatic fossils in the middle Cambrian Buchava Formation of the Skryje–Týřovice Basin (Barrandian area; Fig. 1B), which is located north of the previously mentioned Příbram–Jince Basin (Fig. 1A); both basins strikingly differ not only in their geological history, but also in contained fossil associations (see Geyer *et al.*, 2008).

GEOLOGICAL SETTING AND ASSOCIATED FOSSILS

Both specimens were collected from the Skryje Member of the middle Cambrian Buchava Formation in the Skryje–Týřovice Basin (Fig. 1C), which is well known for its diverse fossils (e.g., Barrande, 1852; Šnajdr, 1958; Fatka, 2004). A rich fauna of trilobites, agnostids, hyoliths and brachiopods associated with rare echinoderms and molluscs has been studied for nearly two hundred years (e.g., Šnajdr, 1958; Chlupáč, 1999; Geyer *et al.*, 2008). Acritarchs and ichnofossils have been described since the second half of the twentieth century (for summary, see Fatka, 1999; Mikuláš, 2000). Recently, rare specimens of a poorly biomineralized and soft-bodied Burgess Shale-type fauna were studied by Chlupáč and Kordule (2002), Maletz *et al.* (2005) and Fatka *et al.* (2011); some of these specimens are preserved together with diminutive ichnofossils (Mikuláš *et al.*, 2012). Recently, the fodinichnial association representing a specific type, termed "mortichnia", was established by Fatka and Szabad (2011) in the Skryje Member.

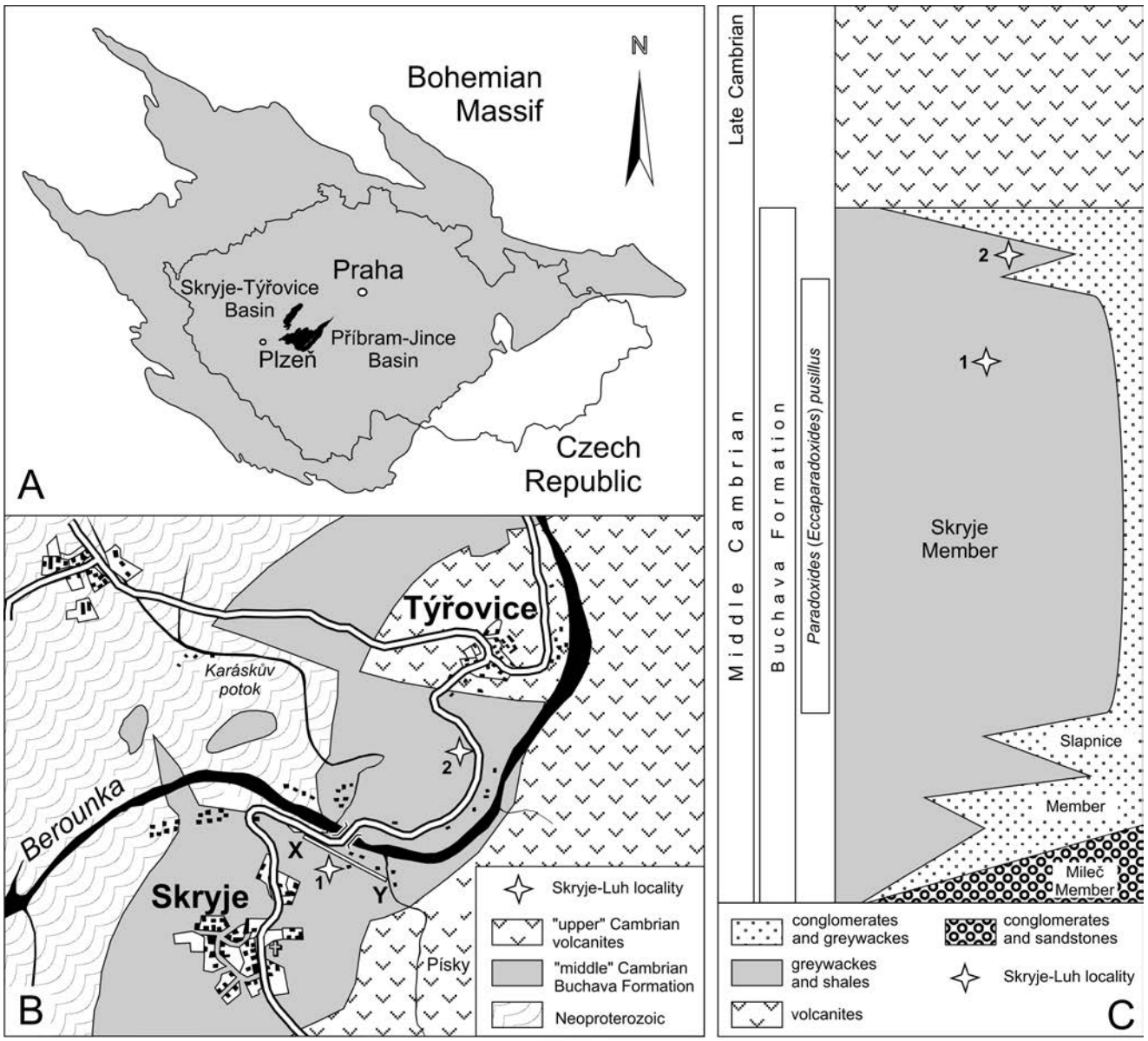

Fig. 1. Map showing location of discovery site of new specimen of *Sphenothallus*. **A.** Czech Republic and Bohemian Massif with Cambrian rocks of Skryje–Týřovice and Příbram–Jince basins. **B.** Detail of discovery area showing distribution of middle Cambrian Buchava Formation with Skryje–Luh locality (1) and Týřovice–"Pod hruškou" locality (2). Geology modified from Mašek *et al.* (1997). **C.** Stratigraphy of Buchava Formation with position of Skryje–Luh locality (1) and Týřovice–"Pod hruškou" locality (2). Stratigraphy after Fatka *et al.* (2011)

General overviews of the depositional setting and stratigraphy of the Skryje–Týřovice Basin, including the Buchava Formation, are available in Kukal (1971), Havlíček (1971), Geyer *et al.* (2008) and Fatka and Mergl (2009). Fatka *et al.* (2011) summarized all earlier data, concerning the lithostratigraphic subdivisions of the sedimentary sequence; three units, the Skryje, Slapnice and Mileč members, are now distinguished within the Buchava Formation (Fig. 1C).

Despite more than 150 years of intensive investigation by both professional palaeontologists and amateur collectors, only two specimens of *Sphenothallus* are known from the Buchava Formation. Both were recently rediscovered in the collection of the late V. Kordule, who carefully gathered Cambrian fossils and brought together diverse non-trilobite fossils, collected by him and several others during the last forty years. *Sphenothallus* sp. originates from the Skryje – Luh locality, while ?*Sphenothallus* sp. was collected at the Týřovice – "Pod hruškou" locality.

Skryje–Luh locality

The large natural outcrop (Fig. 2), known as the "Skryje – Luh locality", belongs to the classical sections in the upper half of the Buchava Formation. In old collections, this outcrop did not get a separate name, and specimens from the slope above the bridge were designated as Skrey in the collection of Joachim Barrande in the National Museum Pra-

gue (Chlupáč, 1999, p. 11), as well as in other institutional collections, including the Schary collection in the Museum of Comparative Zoology, Harvard University, Boston, U.S.A. (O.F. personal observation). Chlupáč *et al.* (1998, p. 169) thought that the "Skryje–Luh locality" was probably discovered by Krolmus as early as 1832. This assumption is based on an observation by Sklenář (1966), who reported on a letter, in which Václav Krolmus, a priest at Zvíkovec, describes a trilobite-bearing site on the right bank of the Berounka River at Skryje. Taking into account all of the characteristics of exposures of Cambrian rocks, including their accessibility, distance from roads and the abundance of fossils, it can be inferred that the first fossils collected in the Skryje–Týřovice Basin region probably originated from this outcrop (XY in Fig. 1B and the polygon in Fig. 2).

Jahn (1896, figure on page 668) first used the designation "Die Schlucht oberhalb der Luher Fähre" (the gorge above the Luh ferry in the original German description) for the outcrop, named by all subsequent authors as the "Skryje – Luh locality". Jahn (1896, p. 727–734, fig. 7) published a detailed description of the section on the right bank of the Berounka River; the section starts at Vosník Hill and extends from there to Šlovice village.

Chlupáč *et al.* (1998) described a section exposed in an extensive trench, excavated through the central part of this outcrop in 1997. Within the sequence studied, six intervals, each defined on the basis of fossil content and lithology, were recognized.

However, the lack of field documentation prevents the exact determination of the interval, from which the specimen of *Sphenothallus* sp. originates.

Týřovice–"Pod hruškou" locality

The history of research and a list of fossils recently were summarized by Fatka (2004).

Associated fossils

At the Skryje–Luh and Týřovice–"Pod hruškou" localities, diverse and usually well-preserved fossils have been collected since the first half of the nineteenth century (see Barrande, 1852; Šnajdr, 1958; Fatka, 1990; Chlupáč *et al.*, 1998; Chlupáč, 1999; Fatka, 2004). The fossil association collected at these outcrops includes common paradoxidid, conocoryphid and solenopleurid trilobites, associated with rarer agnostids (see Šnajdr, 1958; Fatka, 1990). Articulated cinctan, eocrinoid and stylophoran echinoderms (Lefebvre and Fatka, 2003), the usually small and relatively rare brachiopods (Mergl and Šlehoferová, 1991), simple ichnofossils (Mikuláš, 2000), and diverse problematical fossils have been established at several stratigraphical levels.

Conical fossils

Conical fossils of variable morphology, dimensions and chemical composition occur at numerous levels within the Buchava Formation, including the Skryje–Luh and the Týřovice–"Pod hruškou" localities. At least ten species of heavily mineralized conical fossils have been assigned to the class Hyolitha Marek, 1963 (Barrande, 1867; Marek, 1983; Valent, 2006; Valent *et al.*, 2011, 2012, 2013; Valent and Fatka, 2013, unpublished observations). Rarely occurring tiny conical specimens have been classified as *Volborthella tenuis bohemica* Prantl, 1948.

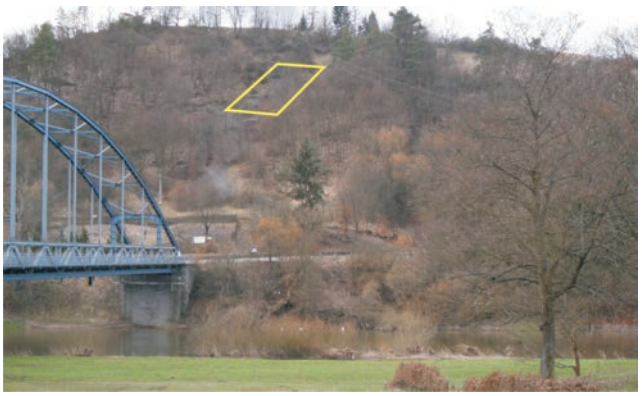

Fig. 2. Classic natural outcrop of shales on the slope designated as Skryje–Luh locality, type section of Skryje Member (see Fatka *et al.*, 2011, p. 854). Portion of outcrop, from which *Sphenothallus* sp. was collected is indicated by polygon

SYSTEMATIC PALAEONTOLOGY

Phylum Cnidaria Hatschek, 1888
Class, Order, Family Uncertain
Genus *Sphenothallus* Hall, 1847
Type species: *Sphenothallus angustifolius* Hall, 1847

Discussion: The genus is characterized by a flexible phosphatic or organophosphatic, slenderly conical (Wang *et al.*, 2003) exoskeleton with a smooth surface and a rounded to sub-elliptical transverse cross-section. The shape of the tubule is strongly influenced by the two marginal thickenings, running from the apex to the aperture. The course of the thickenings directly controls the expansion angle, because they are positioned at the ends of the long axis of the oval cross-section. The tubules are usually compressed, being oriented by the longer axis of the cross-section parallel to bedding. In this orientation, the thickenings are positioned laterally and form the outline of the tubule. Additionally, the thickenings vary in robustness and width, and it is sometimes very easy, in other cases very difficult, to identify the thickenings, depending for example on their mode of preservation, the lithology of the host sediment and the degree of flattening of specimens. It is no less difficult to demonstrate the phosphatic nature of the tubule in specimens, the exoskeleton of which has been dissolved. Characteristic deformation of the smooth and less rigid walls between the longitudinal thickenings confirm the originally flexible phosphatic nature of the tubules. Conversely, preservation of an undeformed smooth surface, lacking the aforementioned secondary features, can make it difficult to determine whether the specimen originally was organophosphatic. Thus, it is sometimes difficult to identify the genus *Sphenothallus* unequivocally. That is why the authors classify the specimen showing the diagnostic features as *Sphenothallus*, while the second specimen is assigned to the genus *Sphenothallus* only tentatively.

Sphenothallus sp.
Fig. 3A, B

Material: Single, almost completely flattened to low-relief tubule,

Table 1

Biometric data and features on measured specimens of *Sphenothallus* sp. and ?*Sphenothallus* sp. All dimensions in mm

	Inv. number	Preservation	Length of shell	Apertural width	Thickening max. width	Expansion angle – apical	Expansion angle – distal
Sphenothallus sp.	L42355	flattened to low relief	14.9	1.35	0.35–0.45	4.7°	3.0°
?*Sphenothallus* sp.	L42356	relief to low relief	20.8	4.1	~ 0.1	8.5°	10.2°

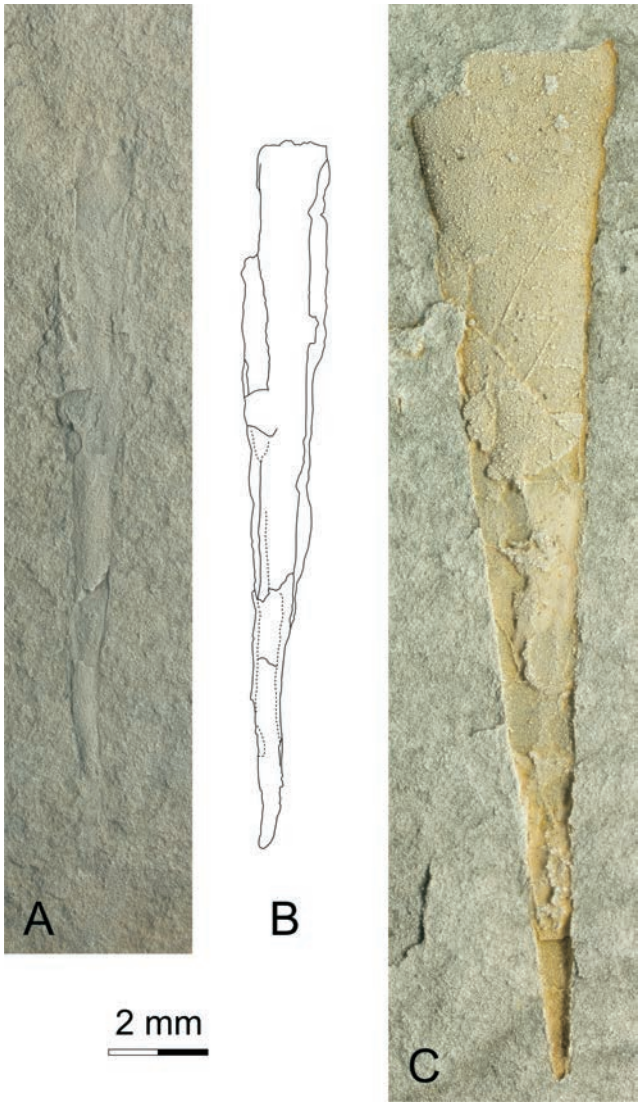

Fig. 3. *Sphenothallus* from Buchava Formation, Skryje–Týřovice Basin, Teplá–Barrandian region, Czech Republic. **A.** *Sphenothallus* sp., flattened to low relief tubule with clearly discernible longitudinal thickenings, L42355; Skryje – Luh locality. **B.** drawing of A. **C.** ?*Sphenothallus* sp., partly flattened specimen, coated with limonite, L42356; Týřovice – "Pod hruškou" locality.Deposited in National Museum in Prague under above given numbers

preserved as an internal mould in shale, stored in the National Museum in Prague under the inventory number L42355.

Description: The nearly complete specimen is preserved in blue-green shale and is oriented parallel to the bedding. It is partly flattened near both the apex and the aperture and preserved in low convex relief in the middle part. The shell was flexible and organ-phosphatic as inferred from the typical deformation of the flattened periderm, comparable to the specimens with preserved walls (with striae or wrinkles of different authors; e.g., Neal and Hannibal, 2000; Zhu *et al.*, 2000). The phosphatic matter had been removed, while the organic component is preserved in the form of a thin film, broken into an irregular tile pattern, concentrated mainly along the longitudinal thickenings, which exhibited the highest concentration of organic matter. The preserved part of the conch is 14.9 mm long and 1.35 mm wide at the aperture. The conch is slightly curved in the proximal portion and straight distally. Its apex is broken and no attachment apparatus can be observed. The expansion angle is very low and ranges from 3° and 4° along the middle and adapertural parts of the fragment. The aperture, incompletely preserved and poorly discernible, is straight and smooth without any distinct structures. The transverse cross-section of the shell was apparently rounded in its outer outline. Longitudinal thickenings are indistinct, being visible in the form of flat folds at several places along both margins. The thickenings appear to expand toward the aperture and reach their maximum width of 0.35–0.45 mm in the flattened apertural region (see Tab. 1).

Remarks: The strongly flattened and wide thickenings indicate that the original skeleton was very thin (i.e. almost flat) and wide. This combination of features differentiates it from other species of *Sphenothallus*. This is also the case for *S. kozaki*, the only species described from the middle Cambrian of Bohemia. That species is characterized by a circular outline of the tubule and poorly defined internal thickenings. However, the thickenings of *Sphenothallus* sp., described herein, are obviously wider by comparison with the tubule width and even thinner. This is indicated by their intensive flattening. In the case of the robust thickenings, they would be more distinct, similar to the deformed specimens of *Sphenothallus ruedemanni* (Kobayashi), figured in cross-sections by Choi (1990, figs 3.3, 3.4). The typical external and internal cross-sections and the structure of thickenings seem to be important diagnostic features. However, it is usually difficult to observe or to reconstruct this characteristic. In the case of observations that are insufficient for a reliable classification, an open nomenclature is an appropriate taxonomy.

Distribution: Barrandian area, Skryje–Týřovice Basin, Buchava Formation, higher stratigraphical levels of the Skryje Shale, Skryje–Luh locality, *Paradoxides* (*Eccaparadoxides*) *pusillus* Biozone (Cambrian Stage 5, Drumian Stage, corresponding to the Caesaraugustian Regional Stage of West Gondwana, see Álvaro *et al.*, 2004; Fatka *et al.*, 2011; Fatka and Szabad, in press).

?*Sphenothallus* sp.
Fig. 3C

Material: A single nearly complete, partly flattened tubule preserved as an internal mould in green shale and deposited in the National Museum in Prague under the inventory number L42356.

Description: The preserved part of the shell measures 20.8 mm in length and 4.1 mm in width at the apertural end. It is partly preserved as an internal mould and partly as an external mould of the opposite wall. The internal mould in the apertural portion is

slightly convex, with a nearly flat central region and vaulted margins. The central part of the shell is represented by an irregularly deformed, partly cracked and nearly flat to slightly concave internal mould. The apical region is preserved as a concave external mould. All surfaces are thinly coated with a yellowish material, probably limonite. This yellowish material forms compact pieces of fine-grained matter, which partly fill cavities in the fossil. Such matter occurs in the deformed central portion, especially at its apical and apertural ends. The adapertural piece, located approximately in the middle of the shell, is sculptured by shallow, but sharp longitudinal wrinkles (in its apertural part and along the margin) and by fine transverse wrinkles (in its apical part). Near the adapical piece, there is a short, very narrow and shallow groove, resembling the impression of a thickening. It extends adaperturally on the right margin of the fossil, but only along a length of 1.5 mm, because it is covered by rock matrix closer to the aperture. The internal mould in the apertural portion of the shell is covered by diagonal structures that are actually very thin, sharp ridges. Because these ridges project into the cavity of the dissolved periderm, they represent infillings of cracks in the shell walls. It appears that some fragments were slightly dislocated along these fractures. The internal mould in the apertural portion is also covered by much less distinct, low, narrow, transverse ridges. These features are irregularly distributed with respect to their distinctness, and range from conspicuous to indistinct. The aperture is not preserved because it has been severed transversally. This fracture is almost straight, bent near the right margin and interrupted by a small cut-out along a short longitudinal fracture, on the left margin. The expansion angle of the tube increases slightly from 8.5° at the apical end to 10.2° in the central(?) part of the tubule, but then increases markedly to 20.8° near the aperture (see Tab. 1).

Remarks: The specimen is here provisionally assigned to *Spenothallus*, because the presence of a pair of longitudinal thickenings is not certain. Similarly, the phosphatic (or chitinophosphatic) nature of the dissolved periderm is uncertain, because of the absence of any typical deformation. On the contrary, it seems that the shell walls were brittle. Thus, alliance of this fossil with known sphenothallids is open to question.

Distribution: Barrandian area, Skryje–Týřovice Basin, Buchava Formation, higher stratigraphical levels of the Skryje Shale, Týřovice–"Pod hruškou" locality, *Paradoxides* (*Eccaparadoxides*) *pusillus* Biozone (Cambrian Stage 5, Drumian Stage, corresponding to the Caesaraugustian Regional Stage of West Gondwana).

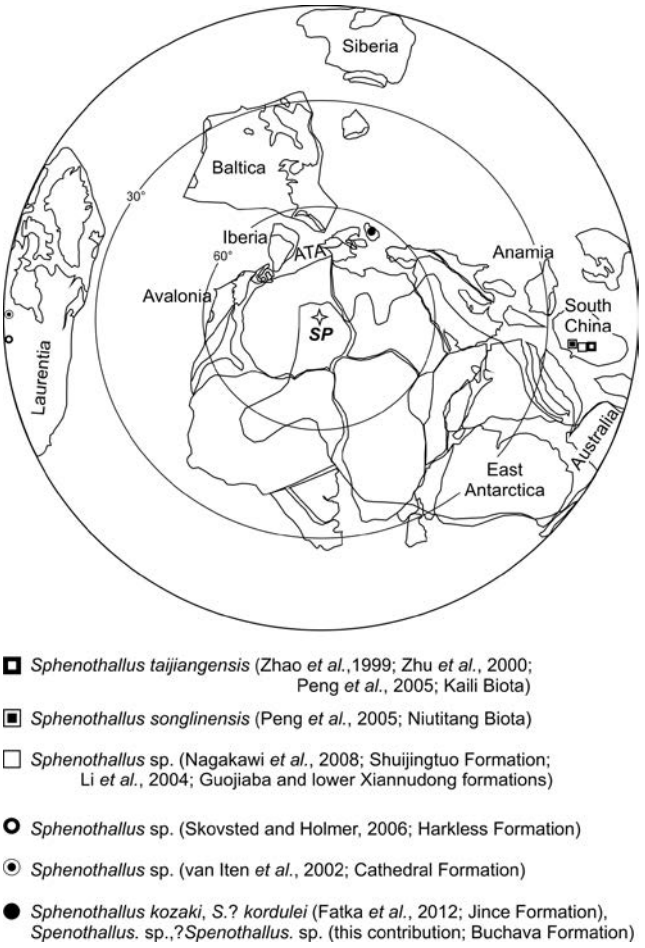

Fig. 4. Palaeogeographical distribution of genus *Spenothallus* Hall, 1847 in lower and middle Cambrian lagerstätten. Cambrian palaeogeography modified after Cocks and Torsvik (2002), Fatka and Mergl (2009) and Torsvik and Cocks (2013)

DISCUSSION

Plotted on the palaeogeographic maps of Cocks and Torsvik (2002), Fatka and Mergl (2009) and Torsvik and Cocks (2013), *Sphenothallus* may be seen to have been present at low as well as higher palaeolatitudes during the Cambrian (Fig. 4). This is similar to the pattern of distribution, established for the Lower Ordovician (Van Iten *et al.*, 2013, fig. 5). The evidently flexible material of the skeleton of *Sphenothallus* sp. supports an epifaunal mode of life, rather than a semi-infaunal or infaunal strategy. Despite the absence of any sphenothallid-like attachment discs, either isolated or attached to invertebrate shells, the ability of this animal to colonize a muddy bottom, as hypothesized by Wang *et al.* (2003), is plausible.

As in the case of the classical Cambrian of the Příbram–Jince Basin (Fatka *et al.*, 2012), the discovery of *Sphenothallus* in the Buchava Formation of the Skryje–Týřovice Basin is surprising, for only two specimens are known after a long and intense field investigation, which yielded several thousand specimens of other fossils. Although extremely rare, this discovery expands our knowledge of organisms with organophosphatic skeletons in the Buchava Formation.

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