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A new vent-related foraminifer from the lower Toarcian black claystone of the Tatra Mountains, Poland

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Recurvoides infernus sp. nov., one of the oldest representatives of the superfamily Recurvoidacea (Foraminifera), is described from a thin black claystone overlying the manganese deposits of the Krížna Unit in the Western Tatra Mountains (Poland). These manganese carbonates/silicates were laid down around a shallow-water exhalative submarine hydrothermal vent that was active in the early Toarcian. The microfossils are possibly the first described Jurassic foraminifera associated with hydrothermal vents. The assemblage is characterized by a high abundance and dominance of this new species. The primary lamination of the black claystone, the lack of any macrofauna, and an elevated TOC content point to oxygen-deficient conditions during sedimentation of these deposits. Furthermore, the nearly exclusive occurrence of agglutinated foraminifers suggests a low pH level. It is likely that the foraminifers colonized vent-related bacterial mats which acted as a rich and stable food source. Modern shallow- and deep-water hydrothermal vents may represent similar habitats.

Key words: Foraminifera, Ammosphaeroidinidae, agglutinated foraminifera, hydrothermal vent, black claystone, suboxia, the Carpathians, Tethys, Jurassic.

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Introduction

The Jurassic fossil record plays an important role in understanding Mesozoic evolution of foraminifera. Many important higher and lower foraminiferal taxa originated in the Early or Middle Jurassic (see Kaminski et al. 2008, in press). The early planktonic foraminifers "almost certainly evolved from benthonic ancestors in the Early Jurassic" (Hart et al. 2002: 115). The bolivinids, common in the Cretaceous and abundant in the Cenozoic, appeared in the late Pliensbachian. The first rzehakinids represented by *Miliammina gerochi* Tyszka, 1997, are known from the Bajocian of the Pieniny Klippen Belt Basin (Tyszka 1997).

Recently, we have discovered early representatives of *Recurvoides* associated with a thin horizon of black claystone found just above the manganese deposits in the Krížna Unit of the Tatra Mountains, Poland (Figs. 1, 2). Jach and Dudek (2005) interpret these Toarcian manganese carbonate/silicate deposits as the product of the shallow-water exhalative submarine vent. We know of very few fossil foraminiferal assemblages associated with hydrothermal vents. The aim of this paper is to document one of the earliest records of Recurvoidacea and vent-related foraminifera.

Institutional abbreviation.—UJ, Collections of the Geological Museum of the Institute of Geological Sciences, Jagiellonian University, Kraków, Poland.

Other abbreviation.—TOC, Total Organic Carbon.

Geological setting

The *Recurvoides*-bearing claystone occurs locally at the Huciański Klin crest above the Huciska Alp in the Western Tatra Mountains (Fig. 1). This claystone and the underlaying Mn deposits constitute a Mn-bearing sequence that crops out exclusively between the Chochołowska and Lejowa valleys (Jach and Dudek 2005). The sequence belongs to the Krížna Unit, which in the Western Tatra Mountains forms a large slab called the Bobrowiec Unit, comprising Lower Triassic through Lower Cretaceous rocks (Bac-Moszaszwili et al. 1979). The only accessible outcrops of the Mn-bearing sequence occur in small mining adits, up to 20 m in length, where manganese ores were exploited in the 19th century (Krajewski et al. 2001; Jach 2002).

The Mn-bearing sequence forms a lens-shaped body, a few hundred meters long and up to 2 m thick. It consists

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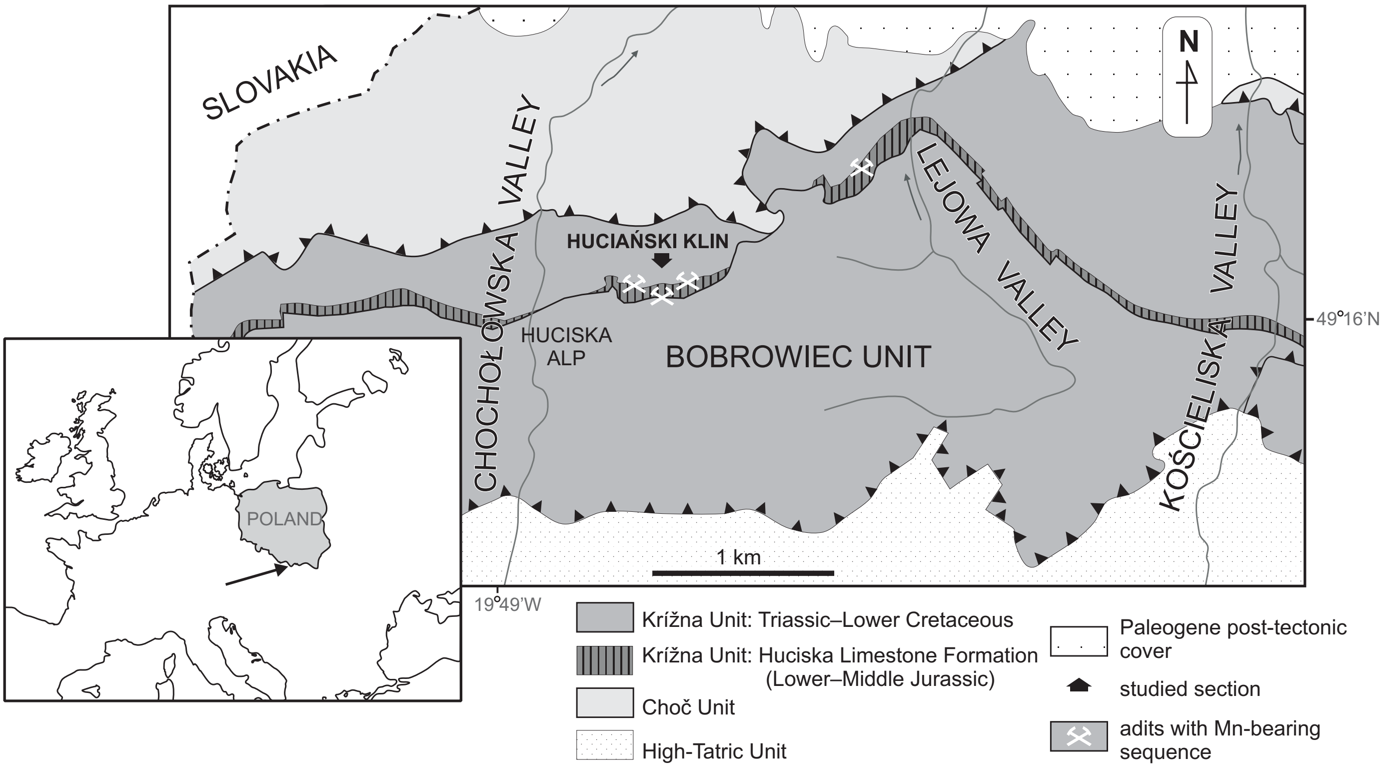

Fig. 1. Geological sketch map of the Polish part of the Western Tatra Mountains (after Bac-Moszaszwili et al. 1979, simplified) showing the location of Huciański Klin sections.

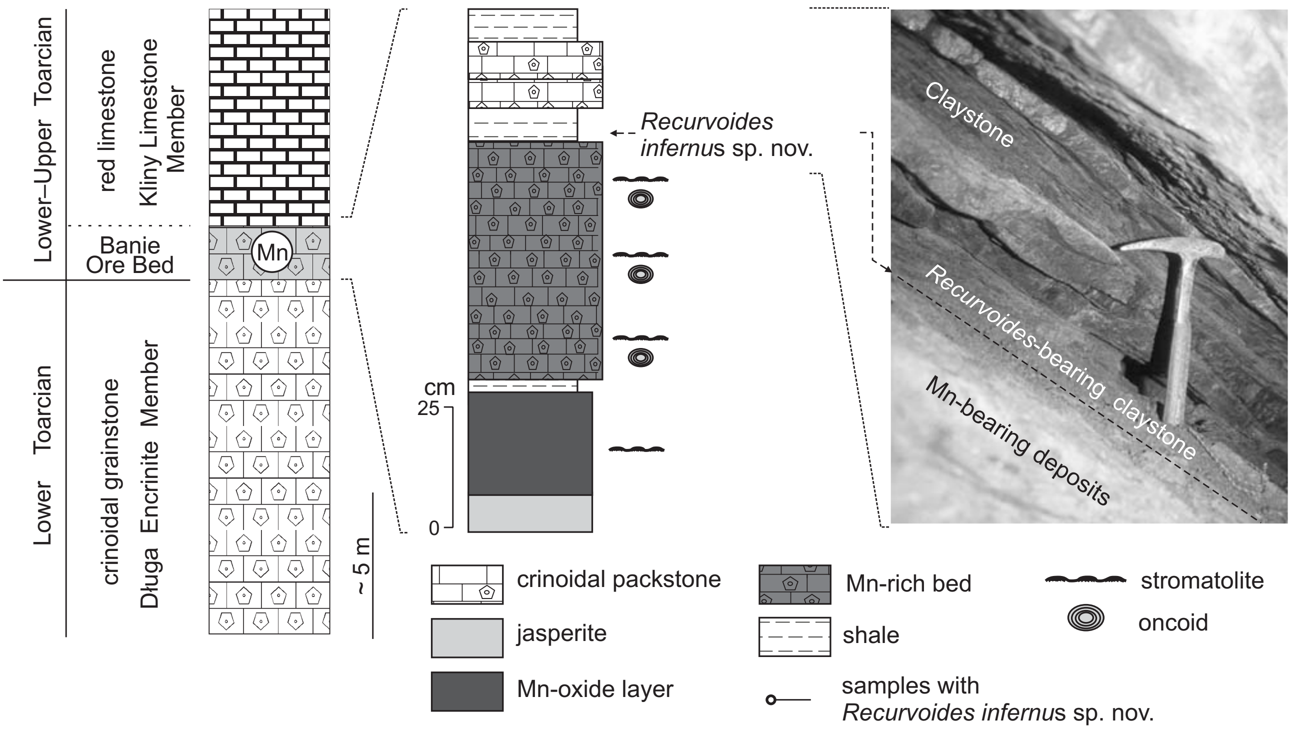

Fig. 2. **A**. Lithostratigraphic log of the Lower–Middle Jurassic rocks of the Krížna unit in the Western Tatra Mountains (after Lefeld et al. 1985). **B**. Lithological sections of the Mn-bearing sequence at the Huciański Klin crest and a photograph from the adit no. 4 described in detail in Jach (2002).

mainly of a Mn-carbonate and silicate bed within a claystone, as much as a few centimetres in thickness (Fig. 2; Jach and Dudek 2005). Due to the lack of direct biostratigraphic data, it is difficult to precisely estimate the age of the Mn-bearing sequence. Its position in the section points to an early Toarcian age (Lefeld et al. 1985; Krajewski et al. 2001). It overlays crinoidal tempestites of early Toarcian age (up to 12 m thick; Jach 2005) and is covered by pelagic, red, partly nodular limestones (Ammonitico Rosso type; Early Toarcian *Harpoceras serpentinum* Zone to Late Toarcian *Dumortieria pseudoradiosa* Zone; Myczyński and Jach 2009). The vent activity might have coincided with the Toarcian Oceanic Anoxic Event (see Jones and Jenkyns 2001).

Recurvoides occurs exclusively in the lowermost part of the claystone which directly overlays the Mn deposits (Fig. 2). It was found in a single adit, where the underlying Mn deposits display their minimal thickness—only 40 cm. The *Recurvoides*-bearing claystone is dark in colour, varies in thickness between 5 and 14 cm, exhibits subtle lamination, and contains up to 1.49 wt% of TOC. The claystone is characterized by abundant clay minerals, quartz, feldspars and goethite, while calcite content is very low (less than 1 wt%). The clay fraction is dominated by illite and illite-rich illite-smectite mixed-layer clays (Jach and Dudek 2005). Morphology of the clay particles suggests in situ crystallization. Although *Recurvoides*-bearing claystones bear a strong resemblance to marine anoxic shales, they seem to be directly related to hydrothermal vent activity (Jach and Dudek 2005). The vent was probably situated at neritic or sub-neritic depths and expelled Mn-, Si-, and Fe-rich water whose temperature was slightly elevated. Its location and activity were probably controlled by an active synsedimentary faulting of the Western Tethyan shelf, which created pathways for ascending hydrothermal fluids (Jach and Dudek 2005).

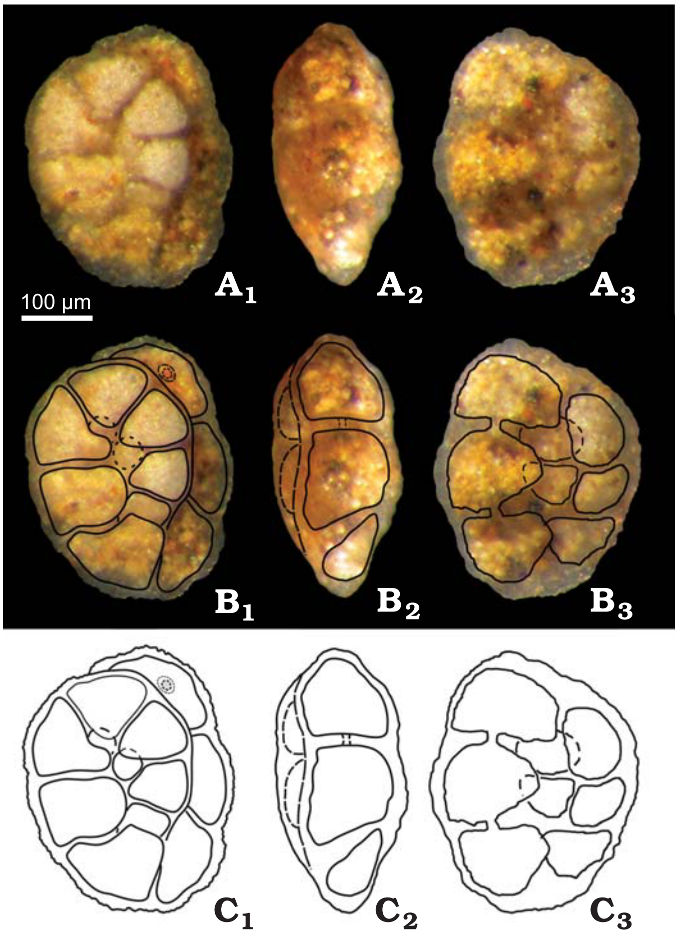

Fig. 3. Ammosphaeroidinid foraminifer *Recurvoides infernus* sp. nov., holotype, UJ 213 P1, Huciański Klin, Tatra Mountains, sample 3236 (4.8b/1m), Toarcian, wet specimen in reflected light. Original microphotographs with highlighted chambers (**A**, **B**) and outline drawings (**C**), in pseudospiral (A_1–C_1), peripheral (A_2–C_2), and side (A_3–C_3) views.

Material and methods

The material used in this study comes from sections located at the Huciański Klin in the Chochołowska Valley (Fig. 1). A total of 25 samples were collected from five mining adits, but foraminifers were retrieved exclusively from 14 samples taken from the adit no. 4. Detailed description of quantitative data, including foraminiferal, palynological, and geochemical records, will be presented elsewhere. Adits at the Huciański Klin locality are labelled after Jach (2002). The claystone was disintegrated using a solution of Glauber's salt and washed over a 68 μm sieve using standard procedures. Foraminifers and all other microfaunal remains were picked. Foraminiferal tests were observed under light stereomicroscopes, using distilled water and/or glycerine as immersion fluids. Images (Figs. 3, 4) were taken with a Canon PowerShot G3 digital camera mounted on a Zeiss Stemi-2000C stereomicroscope, as well as with a standard SEM at the Institute of Geological Sciences of the Jagiellonian University (Kraków, Poland). The coiling mode of the tests was displayed as "rollograms" (Fig. 5), following the method of Bubík (2000).

Systematic paleontology

Class Foraminifera Orbigny, 1826

Superfamily Recurvoidacea Alekseychik-Mitskevich, 1973

Family Ammosphaeroidinidae Cushman, 1927

Subfamily Recurvoidinae Alekseychik-Mitskevich, 1973

Genus *Recurvoides* Earland, 1934

Type species: *Recurvoides contortus* Earland, 1934

Type locality and age: Antarctic, Holocene.

Recurvoides infernus Tyszka, Bubík, and Jach sp. nov.

Figs. 3, 4, 5; Table 1.

Etymology: From Latin *inferno*, hell, pointing to a hydrothermal vent related habitat of this new species.

Type material: Holotype: UJ 213 P1, Figs. 3, 5F; paratypes: UJ 213 P2, Figs. 4A, 5J; UJ 213 P3, Figs. 4B, 5B; and UJ 213 P4, Figs. 4C, 5U.

Type locality: Huciański Klin (adit no. 4, see Jach 2002), Chochołowska Valley, Western Tatra Mountains, Poland.

Type horizon: Lower Toarcian, uppermost part of the Banie Ore Bed,

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Table 1. Biometric data of *Recurvoides infernus* sp. nov., Huciański Klin, Tatra Mts., Toarcian. Abbreviations: NLC, maximum number of chambers in the "straight series" without any change of coiling direction; NPC, number of chambers on the test periphery; NSC, number of chambers visible on the test surface; NT, number of changes of the coiling direction visible on the test surface.

#	Sample	Maximum diameter	NSC	NPC	NT	NLC	Figures	Remarks
1	3213 (4.8b/16m)	0.360	11.5	8	1	8	5A	
2	3213 (4.8b/16m)	0.335	12.5	8.5	1	9	4B; 5B	paratype
3	3213 (4.8b/16m)	0.355	14.5	9.5	1	12	5C	
4	3213 (4.8b/16m)	0.290	9.5	7	1	9	5E	
5	3236 (4.8b/1m)	0.317	9.5	6	2	4	3; 5F	holotype
6	3236 (4.8b/1m)	0.335	13	8	2	8	5H	
7	3236 (4.8b/1m)	0.340	14	8	1	8	5I	
8	3236 (4.8b/1m)	0.445	14	9	1	10	4A, 5J	paratype
9	3236 (4.8b/1m)	0.282	10	8	1	8	5K	
10	3236 (4.8b/1m)	0.265	11	7	1	9	5M	
11	3236 (4.8b/1m)	0.270	12	8.5	1	11	5N	
12	3236 (4.8b/1m)	0.335	11	7	2	5	5O	
13	3236 (4.8b/1m)	0.290	8	7	0	8	5P	
14	3236 (4.8b/1m)	0.285	11	8	1	9	5Q	
15	3237 (4.8a/7.5m)	0.265	7	7	1	7	5V	
16	3237 (4.8a/7.5m)	0.335	10	7	1	8	5S	
17	3237 (4.8a/7.5m)	0.300	11	8	3	5	5T	
18	3237 (4.8a/7.5m)	0.317	12	7	2	7	4C, 5U	paratype
19	3237 (4.8a/7.5m)	0.165	9	6	2	4	5X	
20	3237 (4.8a/7.5m)	0.335	7	7	1	6	5R	
21	3237 (4.8a/7.5m)	0.180	8	6.5	0	6	5Z	

a thin horizon of black claystone overlying manganese carbonate/silicate deposits.

Diagnosis.—Test recurvoidiform–pseudoplanispiral; surface coiling composed of 8 to 12 chambers shows one to three abrupt changes of coiling direction; oval aperture rimmed by lip, situated in lower to middle part of apertural face; wall relatively thin, composed of fine quartz grains.

Material.—Over 350 specimens.

Description.—Test is medium in size, and oval and more or less irregularly discoidal in shape. Oval to crescentic, wider-than-long chambers are numerous, 8 to 14 visible on the surface of the test (average 10.5). The chambers are arranged in semi-evolute irregular recurvoidiform coiling with usually one to three abrupt changes of the coiling direction. The usual angle of change is around 45° but it may also be about 90°. "Straight segments" of coiling are composed of 3 to 12 chambers. Longer regular series of chambers in the distal part of coiling cause pseudoplanispiral appearance of the test with 6 to 9 chambers observed around the periphery. The periphery is originally rounded, but angular in compressed specimens. Intercameral sutures are somewhat depressed to indistinct. Relatively thin agglutinated wall, a few grains thick, is composed of medium to fine quartz grains. Aperture is an oval opening rimmed by a lip, areal in position and situated in the lower to middle part of the apertural face.

Dimensions.—Maximum diameter: 0.18–0.445 mm (average 0.313 mm); maximum diameter of the holotype: 0.317 mm.

Variability.—Specimens assigned to the new species display wide variability of the coiling, which is generally a feature of the subfamily Recurvoidinae. When comparing the rollograms of specimens (Fig. 5), the later part of the coiling visible on the surface of the test can be very roughly characterized by two straight series of chambers separated by a change in coiling direction. The final "straight series" of chambers, when it is long enough, gives a pseudoplanispiral appearance to the test. The relatively high variability of the test size can be explained by the presence of juvenile specimens (Fig. 4B, D) and gerontic specimens (Fig. 4A, E) within the taphocenose.

Remarks.—Thin, organic-cemented walls predisposed squashing of most specimens by compaction during early diagenesis. This squashing resulted in the angulated periphery of compressed specimens. *Recurvoides infernus* seems to be closely related to *Recurvoides baksanicus* Makareva, 1969 described from the Aalenian strata of Northern Caucasus in the Kabardino-Balkarian Republic of Russia (Makareva 1969). The new species differs from *R. baksanicus* by having more chambers around the periphery (most frequently 7 or 8 comparing with 5 to 7) and larger size (0.18–0.445 mm compared with 0.12–0.30). Other differences cannot be confirmed without direct comparison of the fossil material. *R. infernus* distinctly differs from *R. taimyrensis* Nikitenko, 2003 known from the upper Pliensbachian to lower Toarcian of the Barents Sea, Franz Josef Land, and Siberia (Nikitenko and Mickey

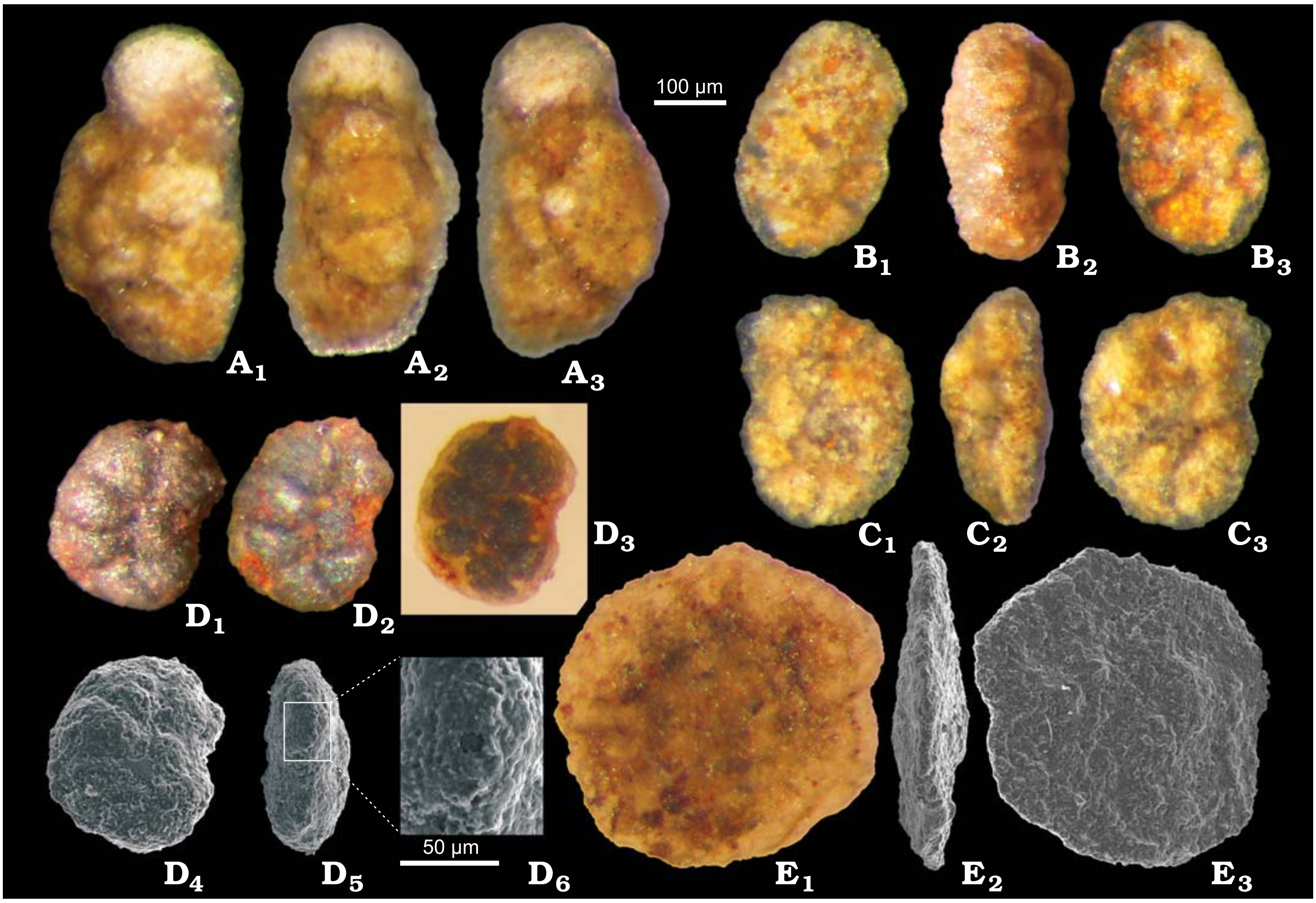

Fig. 4. Variability of ammosphaeroidinid foraminifer *Recurvoides infernus* sp. nov., Huciański Klin, Tatra Mts., Toarcian. **A**. Paratype, UJ 213 P2 (see Fig. 5J for rollogram), sample 3236 (4.8b/1m), in pseudospiral (A_1), peripheral (A_2), and side (A_3) views. **B**. Paratype, UJ 213 P3 (see Fig. 5B for rollogram), sample 3213 (4.8b/16m), in pseudospiral (B_1), peripheral (B_2), and side (B_3) views. **C**. Paratype, UJ 213 P4 (see Fig. 5U for rollogram), sample 3237 (4.8a/7.5m), in pseudospiral (C_1), peripheral (C_2), and side (C_3) views. **D**. Test infilled with pyrite, sample 3236 (4.8b/1m), in pseudospiral (D_1–D_4), peripheral (D_5), and apertural (D_6) views; D_1, dry specimen in reflected light; D_2, wet in reflected light; D_3, wet in transmitted light; D_4–D_6 SEM photographs. **E**. Strongly compressed specimen, sample 3236 (4.8b/1m), in side (E_1, E_3) and peripheral (E_2) views; E_1, specimen in reflected light; E_2, E_3 SEM photographs.

2004) in having a more discoidal shape, pseudoplanispiral appearance, thinner wall, and finer agglutinated grains. *Recurvoides taimyrensis* is more robust and globular (see Nikitenko and Mickey 2004: fig. 8a–e).

There is no objective method to sort biological species from the fossil foraminifer assemblage (Benton and Pearson 2001). Our taxonomic decision to isolate this single species is therefore somewhat arbitrary. The observed variability of this *Recurvoides* assemblage might allow splitting this species into three, four or five taxa. On the other hand, we should be aware that foraminiferal assemblages from stress conditions, such as suboxia, low pH, and hydrogen sulphate or metal pollution may cause development of a high proportion of abnormal tests (Alve 1991; Yanko et al. 1998, 1999; Geslin et al. 2000; Le Cadre et al. 2003; Polovodova and Schönfeld 2008). This was probably the case with our microfauna, under heavy Mn and Fe pollution and suboxic conditions (see Paleoecology section below). On the other hand, abrupt changes in the direction of coiling are not stable in this genus. The presented rollograms show at least one or two, rarely three, changes of coiling direction roughly of 90° or 45°. Some specimens possess a final evolute pseudoplanispiral portion composed of 7 to 12 chambers that represents the ultimate ontogenetic part of the test. We therefore conclude that most specimens in the studied samples belong to the same species. The thin wall, the texture and composition of agglutinated grains, and overall taphonomic features also support this conclusion.

Geographic and stratigraphic range.—Lower Toarcian, Krížna Unit of the Western Tatra Mountains, the Carpathians, Poland.

Discussion

Recurvoides **assemblage and its taphonomic features**.—The foraminiferal assemblage is characterized by a high over-

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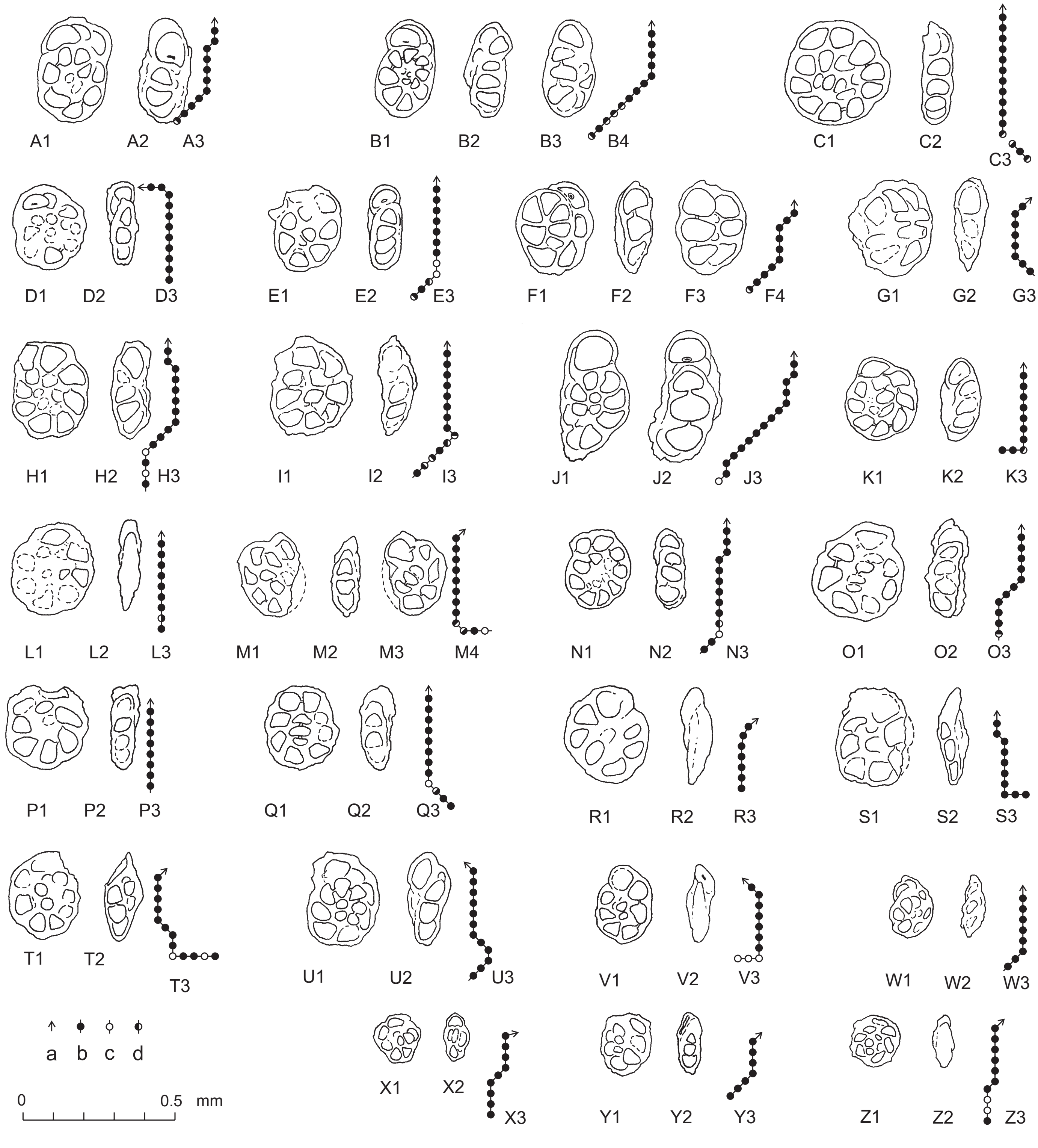

Fig. 5. Variability of ammosphaeroidinid foraminifer *Recurvoides infernus* sp. nov., Huciański Klin, Tatra Mts., Toarcian. **A**–**E**, **W**. Sample 3213 (4.8b/16m). **B**. Paratype, UJ 213 P3. **F**–**Q**. Sample 3236 (4.8b/1m). **F**. Holotype , UJ 213 P1 (see Fig. 3). **J**. Paratype, UJ 213 P2. **R**–**V**, **X**–**Z**. Sample 3237 (4.8a/7.5m). **U**. Paratype, UJ 213 P4 (see Fig. 4B, A, C, respectively). Explanation for rollograms (coiling diagrams): a, position of aperture; b, chamber visible on the test surface; c, chamber covered by the younger coiling; d, chamber partly visible.

all abundance and dominance of the genus *Recurvoides*, comprising 99–100% of the foraminiferal assemblage in 14 samples collected. Besides the highly variable *Recurvoides infernus* sp. nov., another *Recurvoides* species, whose pseudoplanispiral appearance resembles that of some variants of *R. infernus*, may be present, but this distinction needs further study. Calcareous foraminifers are represented by very rare phosphatized casts of *Lenticulina* sp.

Most of the specimens are strongly squashed; nonetheless, the original shape of *Recurvoides infernus* is documented for specimens infilled with goethite, pyrite, apatite, and possibly Mn minerals. All other tests, which do not show any infillings, are strongly compressed. This suggests that their thin wall was very flexible due to the original organic matrix. We infer that synsedimentary and/or early diagenetic mineralization gave the tests the only chance to be preserved in their original shape.

Origin of *Recurvoides*.—The early history of *Recurvoides* and the subfamily Recurvoidinae is poorly known. The oldest foraminifer assigned to the genus by original designation is *Recurvoides wilsoni* Ludbrook, 1967 from the Lower Permian of Australia (Ludbrook 1967). Although the generic characters of *Recurvoides*, including areal aperture, are present in *R. wilsoni*, its relation to the Mesozoic species is unclear due to the large time gap in the known fossil record. A detailed study of *R. wilsoni* and a search for related forms in the Permian and Triassic are needed to decide whether it belongs to a lineage leading to Mesozoic Recurvoidinae or to an independent/unrelated group.

Hess et al. (2007) reported undetermined representatives of this genus from the Rhaetian of the Barents Sea. Further, Nagy et al. (2007) reported *Recurvoides* sp. 1 from the Upper Triassic of Spitsbergen found as rare specimens in the Tverrbekken Member of the Knorringfjellet Formation.

There is a consistent record of the genus in the Jurassic with its highest diversity detected in the Upper Jurassic. However, only about 23 species have been formally described from the Jurassic, including 15 from the Late Jurassic. Possibly, many other species remain undescribed.

One of the oldest Jurassic species is *Recurvoides taimyrensis* Nikitenko, 2003 is probably the oldest formally described species of *Recurvoides* known from the upper Pliensbachian to lower Toarcian of the eastern Barents Sea, Franz Josef Land, NW Siberia (Nikitenko 1992; Nikitenko and Mickey 2004; Basov et al. 2008). All other Liassic records refer just to unnamed *Recurvoides*: Ainsworth and Boomer (2001) from the upper Pliensbachian of the Hebrides Basin, Zakharov et al. (2006) from the Pliensbachian–Toarcian transition of the northern Siberia and Arctic, Nagy and Johansen (1991) from the upper Toarcian of the North Sea.

The Middle Jurassic representatives of *Recurvoides* are known from the Tethyan realm: *Recurvoides baksanicus* Makareva, 1969 from the Aalenian of Northern Caucasus, *Recurvoides caucasicus* Makareva, 1971 from the Bajocian of the same region, and ?*Recurvoides kumurlensis* (Kurbatov, 1971) from the Bajocian of Kugitang, Uzbekistan (Makareva 1969, 1971; Kurbatov 1971). Tyszka and Kaminski (1995) figured rare *Recurvoides* sp. 1 and *Recurvoides* sp. 2 from the Aalenian to Bajocian of the Western Carpathians. ?*Recurvoides ventosus* (Khabarova, 1959) is known from Saratovsk Perivolgian area (Khabarova 1959). From the Callovian strata of Siberia, there are described *Recurvoides scherkalyensis* Levina, 1962 and *Recurvoides singularis* Lutova, 1981 (Levina 1962; Lutova 1981). Unnamed *Recurvoides* representatives were also reported from the Callovian of Spitsbergen by Nagy et al. (1988).

As mentioned above, during the Late Jurassic the subfamily Recurvoidinae reached its first "evolutionary peak" and the representatives of the subfamily are recorded in various parts of the Tethys (Western Alps, Carpathians, Himalayas), and especially in Siberia. Besides the genus *Recurvoides*, the closely related genera *Thalmannammina* and *Cribrostomoides* appeared during the Early and Middle Jurassic, respectively (see Kaminski et al. 2008, in press). The newly described *Recurvoides infernus* is therefore one of the oldest formally defined species of the subfamily so far.

Paleoecology.—The primary lamination of the black claystone, the lack of any macrofauna, and an elevated TOC content indicate oxygen deficient conditions during sedimentation of these deposits. These sedimentary features are related to suboxic or nearly anoxic conditions (sensu Tyson and Pearson 1991). Species of *Recurvoides* are generally considered to live in a broad range of benthic microhabitats from epifaunal (Murray 2006) through surficial epifaunal (Nagy 1992; Nagy et al. 1995; Kaminski and Gradstein 2005), shallow infaunal, i.e., inhabiting the uppermost part of the sediment (Tyszka 1994; Lemańska 2005), and even deep infaunal (Kuhnt et al. 2000). Nevertheless, its surficial epifaunal-shallow infaunal range seems to be most favorable. *R. infernus* was very probably tolerant to suboxia. It possibly benefited from short episodes of better oxygenation caused by pauses in fluid emanation or lateral migration of the vent orifice.

The high dominance of agglutinated foraminifers (99–100%) may indicate a low pH level within the uppermost part of the sediment. We are aware of the possibility of diagenetic dissolution of calcareous tests suggested by very rare phosphatic (apatite) casts of *Lenticulina*, leaving open the possibility that the diversity of the original assemblage was underestimated. On the other hand, we cannot rule out that the original foraminifer assemblage was of very low diversity. The presence of *Lenticulina* sp. would then reflect just short episodes of more favourable conditions.

The dominance of agglutinated foraminifera has been observed near modern, deep- and shallow-water hydrothermal vents (Jonasson et al. 1995; Panieri et al. 2005). Emanated acidic fluids produce low pH conditions, which is in agreement with the chemistry of the studied deposits. The *Recurvoides*-bearing claystone represents the final stage of the vent activity. It is marked by partitioning of Mn and Fe within the vertical section of the Mn-bearing sequence (Jach and Dudek 2005). The uppermost part of this sequence, namely the *Recurvoides*-bearing claystone, is characterized by an elevated Fe/Mn ratio. This indicates that emanating fluids were acidic and dysoxic, in contrast to the alkaline and oxidizing waters of the underlying Mn-rich deposits.

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"One of the many surprises about vent sites is that these seemingly toxic hydrothermal fluids directly support exceptionally productive biological communities in the deep sea" (Little 2004: 542). Undoubtedly, a continuous source of food attracted opportunistic foraminifers that were well adapted to stress conditions. It is likely that these foraminifers colonized bacterial mats thriving on exhalations rich in hydrogen sulphide compounds (see Tarasov et al. 2005). Such bacterial mats, associated with shallow-water exhalations, have been discovered in several active hydrothermal vents (e.g., Tarasov 2006). The hydrothermal fluids issuing onto the sea floor are hot, anoxic, often acidic, and enriched with hydrogen sulfide and various metals, especially Fe, Zn, Cu, and Mn (Canet et al. 2005). Such an environment is partly comparable to the one interpreted from the investigated deposits. Possibly, an active hydrothermal vent or its periphery was successfully colonized by this species that adapted itself to harsh but nutrition-rich conditions.

There are very few reports on the paleoecology of *Recurvoides* from the Jurassic. Hess et al. (2007) described the agglutinated foraminiferal assemblages from the Agardhfjellet Formation (Callovian–Oxfordian) in Spitsbergen as characterized by low diversity with a high dominance of *Trochammina* and locally common occurrences of *Recurvoides* and *Evolutinella*. This (lower) part of the Agardhfjellet Formation consists mainly of finely laminated black shales with a high organic carbon content. These shales were deposited in hypoxic marine distal shelf waters (Hess et al. 2007). Similar suboxic to dysoxic conditions were interpreted for two *Recurvoides* species recorded by Tyszka and Kaminski (1995) in the Aalenian "spherosideritic shales" of the Pieniny Klippen Belt (Poland). According to Zakharov et al. (2006: 406), *Recurvoides* was the only foraminiferal genus in the north Siberia to have crossed the boundary between Pliensbachian and Toarcian stages. All these reports indicate that Jurassic species of *Recurvoides* were stress-resistant taxa, and survived the harsh conditions of oxygen-limited habitats.

Conclusions

Recurvoides infernus sp. nov. represents one of the oldest formally described species of the superfamily Recurvoidacea (Figs. 3–5). The assemblage is characterized by extremely low diversity, with just *Recurvoides* and very rare phosphatized casts of *Lenticulina*. This foraminiferal assemblage is present in a thin horizon of black claystone overlying manganese carbonate/silicate deposits of the Krížna Unit in the Tatra Mountains (Figs. 1, 2). The primary lamination of the black claystone, the lack of any macrofauna, and the enhanced TOC content indicate anoxic-suboxic conditions during sedimentation of these deposits. The nearly exclusive occurrence of agglutinated foraminifers (*Recurvoides*) suggests a low pH level. It is likely that foraminifers colonized suboxic vent-related bacterial mats that provided a rich and stable food source.

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