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# Problematic Mesoproterozoic fossil *Horodyskia* from Glacier National Park, Montana, USA

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ABSTRACT

String-of-beads fossils (*Horodyskia moniliformis* and *Horodyskia williamsii*) from the 1.48 Ga lower Appekunny Argillite of Glacier National Park have been re-examined, and collected from both scree, which yielded most prior specimens, as well as outcrops. The fossils come from laminated silty shales and carbonaceous-swirl shales, with local sandstone paleochannels, interpreted as a very shallow lake margin. Very weakly developed paleosols also are present, but do not contain *Horodyskia*, which lived in very shallow water, seldom exposed and rilled. Chemical index of alteration at horizons with *Horodyskia* are evidence of a warm temperate to subtropical humid paleoclimate, unlike arid and cool paleoclimates at other stratigraphic levels in the Belt Supergroup. Thin section examination reveals that the beads are associated with a system of tubes, including connecting strings, and other tubes radiating outward from each bead. Partial burial and branching of these tubes may be evidence of a benthic sessile life style. A variety of explanations for *Horodyskia* are falsified by our new observations: including pseudofossil, dubiofossil, prokaryotic colony, foraminifera, slime mold, puffball fungus, brown alga, sponge, hydrozoan or bryozoan colony, or metazoan fecal string. Our remaining working hypothesis is that *Horodyskia* beads were endolichen bladders, comparable with living *Geosiphon pyriformis* (Archaeosporales, Glomeromycota, Fungi), which has heterocystic cyanobacterial photosymbionts (*Nostoc punctiforme*). This hypothesis is not without problems, because bladders of *Geosiphon* are mostly erect and clavate, but beadlike only in early growth stages, form clusters or close strings rather than elongate strings, and are terrestrial rather than aquatic. Nevertheless this new hypothesis for *Horodyskia* is compatible with what little is known about fungal evolution, and testable by additional studies of its paleoenvironments and associated fossils.



## 1. Introduction

The Mesoproterozoic string-of-beads fossil *Horodyskia* remains an enigma, as can be appreciated by the diversity of affinities proposed: pseudofossil (Hofmann, 1992), dubiofossil (Horodyski, 1982, 1993), prokaryotic colony (Knoll et al., 2006), foraminifer (Dong et al., 2008), brown alga (Grey and Williams, 1990), sponge (Hofmann, 2001), hydrozoan or bryozoan colony (Fedonkin and Yochelson, 2002), or metazoan fecal string (Yang and Zheng, 1985). This enigma is compounded by its wide distribution in space and time: 1.48 Ga in Montana (Evans et al., 2000; Fedonkin and Yochelson, 2002; age model herein), 1.47–1.07 Ga in Western Australia (Grey et al., 2010), 1.3–0.8 Ga in Tasmania (Calver et al., 2010), 0.65–0.51 Ga in three separate terranes of China (Shen et al., 2007; Dong et al., 2008), and 0.51–0.42 Ga in northern India (Mathur and Srivastava, 2004; Kaufman et al., 2006), A part of the problem is a deceptively simple inferred morphology of spherical or ovoid structures (beads) on a slender tubular structure (string: Fedonkin and Yochelson, 2002; Fedonkin, 2003). Another problem has been lack of detailed information about their sedimentary environment (Martin, 2004). This field and petrographic study has been designed to gather additional details of their micromorphology and sedimentary context relevant to understanding the biological affinities and ecological role of *Horodyskia*.

## 2. Materials and methods

This investigation includes observations from three separate localities in Glacier National Park (Fig. 1), and new collections (curated by Dierdre Shaw in the national park headquarters at West Glacier).

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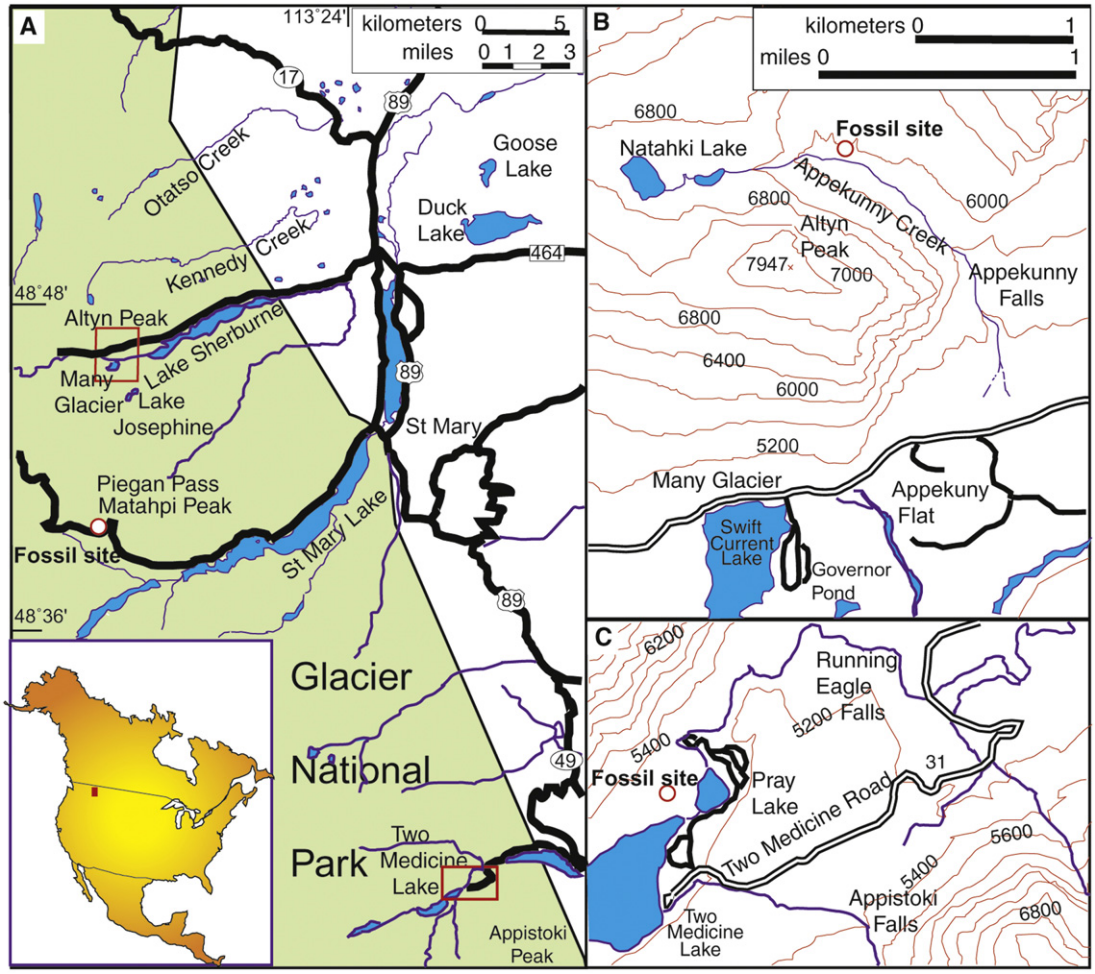


**Fig. 1.** Localities in Glacier National Park, Montana, USA, examined for this study (red open circles): (A) Rising Sun; (B) Appekunny Falls; (C) Two Medicine. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

### 2.1. Appekunny Falls

This locality of Horodyski (1982) is in scree and a low bench of rock immediately above the scree 800 m N13°W from that point on the hiking track when it reaches a level near the top of Appekunny Falls (N48.81884° W113.64379°). Numerous fossils of *Horodyskia* were found in place within a measured section only 2 m thick (Figs. 2 and 3A,B). Many specimens were found in scree below this stratigraphic level, but none above it. The 2 m section shown in Fig. 2 is the only known source of *Horodyskia* in this area, and includes the thin white sandstone marker of Whipple et al. (1984), 53 m stratigraphically above the top of the Altyn Limestone. All specimens illustrated in this paper are from this locality, including *Horodyskia moniliformis* (Figs. 4D,E, 5A–E, 6 and 7E–H), *Horodyskia williamsii* (Figs. 4A–C and 7A–D), large concentric structures (sand stromatolite: Fig. 4F), carbonaceous fragments (*Lanceoforma striata*: Figs. 4F and 5A,C), and "old elephant-skin" crust (*Rivularites repertus*: Fig. 5F). The two species of *Horodyskia* are distinguished largely on the basis of bead size: 1–3 mm for *H. williamsii* and 2–10 mm for *H. moniliformis* following Grey et al. (2010) and Calver et al. (2010).

### 2.2. Rising Sun

Fedonkin and Yochelson (2002) collected specimens from road cuts 1 km west of Rising Sun Campground on Going-to-the-Sun Highway (N48.81463° W113.64104°). These small overgrown outcrops of greenish gray to brown Appekunny Argillite are not more than 5 m stratigraphically above the Altyn Limestone. Very poorly preserved fragments comparable with *H. williamsii* were seen here, but not collected for this study.

### 2.3. Two Medicine

Small rock benches of argillite on a low ridge 200 m on the south flanks of Rising Wolf Mountain southwest of the bridge across Two Medicine Creek at Two Medicine campground (N48.94040° W113.66849°) also yielded specimens of *Horodyskia* (Fedonkin and Yochelson, 2002). Here the fossils are in black argillite very different from the Rising Sun and Appekunny Falls locality. Stratigraphic position is difficult to estimate on this forested spur, but judging from comparable laterally impersistent black argillites seen in surrounding cliffs this locality is some 20 m above the top of the Altyn Limestone. The holotype of *H. moniliformis* (Fedonkin and Yochelson, 2002, Fig. 1) was collected here, as well as another specimen regarded here as *H. williamsii* (Fedonkin and Yochelson, 2002, Fig. 13a). Reference specimens of each species were collected from this locality as part of this work (GLAC24701 and GLAC24702, respectively).

### 2.4. Laboratory methods

Specimens of *Horodyskia* were measured with digital calipers, and also studied in petrographic thin sections. These specimens