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Unusual examples of the silicoflagellate *Lyramula simplex* from the Campanian of northwestern Canadian Arctic

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Abstract Three varieties of the silicoflagellate *Lyramula simplex* based on distinct morphological expressions are documented herein from the Campanian Smoking Hills and Mason River Formations of the Mackenzie District in the Northwest Territories, Canadian Arctic. The presence of two new morphological structures broaden the species concept for this taxon to now include specimens with a spine and an inflation or 'bulb' at the juncture of the two limbs. Variability of this species is inferred to result from local environmental variation associated with a nearshore setting and variable proximity to terrestrial influence. Two new forms of *L. simplex* are proposed herein, *L. simplex* var. *inflata* and *L. simplex* var. *spinosa*, to accompany the original morphology of *L. simplex* var. *simplex*.

Keywords Silicoflagellate, Upper Cretaceous, Canadian Arctic

1. Introduction

Lyramula simplex is one of five silicoflagellate species reported from the Upper Cretaceous of California by Hanna (1928). This species has a simple robust, tubular siliceous skeleton forming a "U" shape. It is distinguished from the usually more common and better known *Lyramula furcula*, which bears a spine at the junction of the two limbs. Hanna (1928) did not explicitly state that *L. simplex* lacks a spine, but this has been a commonly held distinction between these two taxa. This Cretaceous species is also known from the Ural Mountains (Jousé, 1949, 1951; Gleser 1966) and from Seymour Island in the Antarctic Peninsula (Harwood, 1988), but it is uncommon to rare at Alpha Ridge in the Arctic Ocean (Bukry, 1981), at DSDP Site 216 in the E. Indian Ocean (Bukry, 1974), and Site 275 in the S.W. Pacific Ocean (Bukry, 1975; Perch-Nielsen, 1975; Hajós and Stradner, 1975). It is absent from shallow-water, neritic sequences exposed at Devon Island in the Canadian High Arctic (McCartney et al., 2011a).

2. Results

A new occurrence of *L. simplex* is reported here from the Smoking Hills and Mason River Formations near the Horton River, District of Mackenzie in the Northwestern Territories of Canada (Yorath et al., 1975). This taxon was identified in the course of studies on diatoms (Tapia and Harwood, 2002) and silicoflagellates (McCartney et al., 2011b). Silicoflagellate preservation is excellent in many samples of the nearly 200 m-thick interval, where *L. simplex* is present throughout the interval, often as the most common silicoflagellate.

Two interesting varieties of *L. simplex* are noted in this section. The first variety possesses a small spine at the point where the two limbs meet. A second unusual morphology of *Lyramula simplex* bears an inflated region or 'bulb' at the junction of the two limbs. Although the presence of a spine would suggest identification as *Lyramula furcula* (Plate 1, Fig. 10), other aspects of these skeletons suggest a closer connection with co-occurring *L. simplex*, and they are consistently larger than *L. furcula*. In addition, the spines are not as long or pointed as with *L. furcula*. The bulbs are also associated with a skeleton that in shape and size is similar to co-occurring *L. simplex*. For these reasons, we conclude that the spine-bearing and bulbous forms are unusual and previously unreported variants of *L. simplex*.

3. Systematic palaeontology

Lyramula simplex var. *simplex* Hanna, 1928 n. var.
Pl. 1, Figs 1-5
1928 *Lyramula simplex* Hanna: pl. 41, figs. 4, 5

Original description: "A simple U-shaped bar of hollow silica, the terminations being incurved and blunter than in the preceding species [*Lyramula furcula*]; the surface of the bar is more or less scalariform and pitted on the outside. Distance from base of U to extreme tips, 0.0932 mm" (Hanna, 1928).

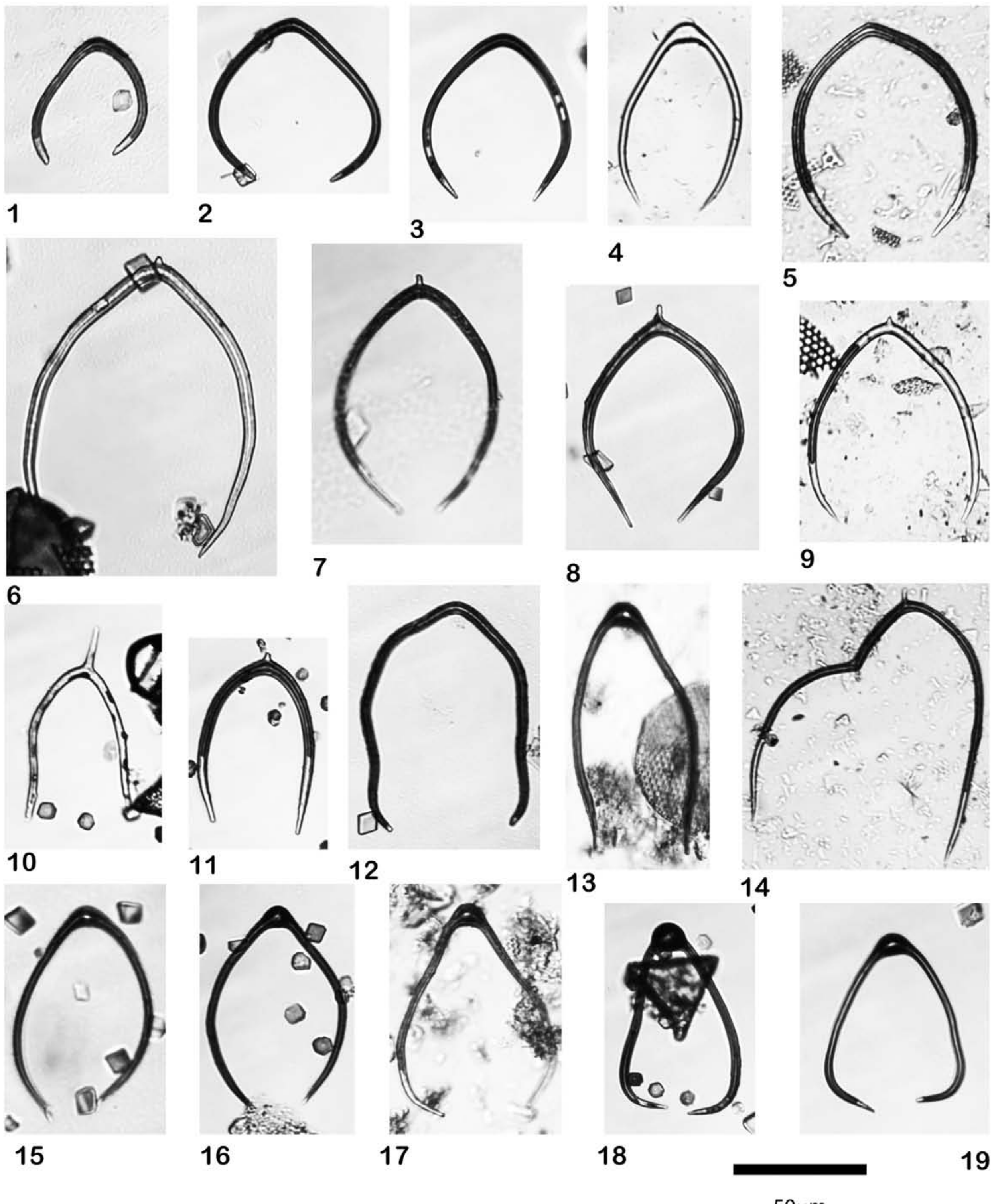
Discussion: We distinguish three varieties of *L. simplex* as an expansion of the morphology of *L. simplex* Hanna. Those specimens that most closely match Hanna's description (without a spine or inflation) are referred here as *L. simplex* var. *simplex*.

Lyramula simplex var. *spinosa* McCartney, Harwood & Witkowski (this study)
Pl. 1, Figs 6-9, 11

Description: A simple U-shaped bar of hollow silica, with two incurved limbs the terminations of which usually point towards each other. The two limbs of this va-

Plate 1

Lyramula simplex



Figs. 1-9, 11-19. *Lyramula simplex* from the Horton River region, Northwest Territories, Canada. Unless stated otherwise all photographs are from sample C-9610. Figs 1-5. Specimens exhibiting the common morphology of *L. simplex* var. *simplex*, Fig. 4 from sample C-9586; Figs 6-9, 11. Specimens of *L. simplex* var. *spinosa* with a spine, Fig. 9 from sample C-8596; Fig. 10, Specimen of *L. furcula*; Figs 12, 14. examples of distorted skeletons of *L. simplex*, Fig. 14 from sample C-8596; Figs 13, 15-19. Specimens of *L. simplex* var. *inflata* with a 'bulb' or inflation of the skeleton, Fig. 13 from sample C-8619; Fig. 17 from sample C-8621.

riety, divided by the small spine, diverge at a more acute angle than the smooth curve of non-spinose skeletons of *Lyramula simplex* var. *simplex*. The spine on specimens of this variety is short and blunt.

Remarks: Spine-bearing morphologies were noted in all seventeen samples over 80 m of section (distribution data provided in a range chart in McCartney et al., 2011b). This spinose variety comprised between 5 and 25% of the total number of *Lyramula simplex*. This variety is less common and less consistent in the upper 20 m of the section, which is of late Campanian to early Maastrichtian age.

Lyramula simplex var. *inflata*
McCartney, Harwood & Witkowski (this study)
Pl. 1, Figs 13, 15-19

Description: A simple U-shaped bar of hollow silica, with two incurved limbs the terminations of which usually point towards each other. The point where the two limbs meet is marked by an obvious inflated area. The cross-sectional diameter of the skeleton increases to several times the diameter of the limbs outside of the inflated region. The inflated area may take the shape of a sphere or teardrop-shaped 'bulb'.

Remarks: A specimen of *Lyramula simplex* with an inflation at the point where the two limbs meet was illustrated previously by Jousé (1951), with a form similar to that illustrated in Plate 1, Figure 4 of this study. Specimens reported herein are generally more pronounced than the specimen illustrated by Jousé, bearing a bulb-like ornamentation. More than fifty specimens with inflated central and bulbous structures were noted through most of the Horton River section. The relative abundance of this variety varied from 0 to more than 50% of all *L. simplex* specimens.

4. Discussion

Skeletons of *Lyramula simplex* are typically large (with limbs sometimes exceeding 80 μm) and have two limbs which curve towards the axis of the skeleton, and usually pointing towards the other limb. Specimens were usually larger and of more robust construction than co-occurring specimens of *L. furcula*. The distal ends of *L. furcula* limbs generally point away from one another and the terminations are relatively distant. All other *Lyramula* species observed in this stratigraphic section are smaller and easily distinguished from *L. simplex*.

In specimens of *Lyramula simplex* var. *spinosa*, the spine is located where the two limbs meet at an angle. Specimens of *Lyramula simplex* var. *simplex* bear a smooth curve (which is more characteristic) and do not have a spine. *L. simplex* var. *spinosa* may provide a clue to the rules of silicoflagellate skeletal design. McCartney and Loper (1989; see also McCartney et al., 1994), in their optimization modeling of silicoflagellate skeletal design, commented on general rules for silicoflagellates, where angular intersections nearly always comprise three elements. This is also observed in the corners of silicoflagellate basal rings, where rounded corners lack spines, but less rounded corners will bear a spine.

The presence of bulbs in *Lyramula simplex* var. *inflata* is more unusual and difficult to explain in silicoflagellate morphology. Expansions or inflation of basal or apical strut attachments were reported by Deflandre (1933) and Ichikawa et al. (1964) for *Dictyocha and Distephanus*. After considering several possible explanations for these structures, Deflandre (1933) concluded that the most reasonable hypothesis for these "encystments" was a parasite, perhaps feeding on the material in the hollow canals of the skeletal interiors. Similar expansion or inflation of strut attachment areas were observed within specimens of *Corbisema archangelskiana* in the lower part of the Horton River section (McCartney et al., 2011b).

Bulbous corners of the silicoflagellate skeleton distinguish the unusual Eocene genus *Hannaites* Mandra (1968), *Mesocena oamaruensis* (Martini and Müller, 1976) and *M. nodulifera* (Tsumura, 1963). It remains to be determined whether these occurrences are correlated in any way to the perturbations in the silica cycle reported for the Eocene (McGowan, 1989; Muttoni and Kent, 2007). Other unusual silicoflagellate taxa of comparable age include extremely large *Dictyocha grandis* (Shaw & Ciesielski, 1983; McCartney & Harwood, 1992) associated with the Middle Eocene Climatic Optimum (MECO of Bohaty & Zachos, 2003; Witkowski et al., 2008).

The distribution of *Lyramula simplex* may provide some clues to the occurrence of this variable morphology. This taxon is known from marine sections representing neritic and interior basin environments in Russia, California and Arctic Canada, but it is rare to absent in oceanic settings such as DSDP Sites 216, 275 (Bukry, 1975; Hajós and Stradner, 1975; Perch-Nielsen, 1975) and Alpha Ridge in the Arctic Ocean (Ling et al., 1983; Bukry, 1981, 1985), and shallow-water neritic sections on Devon Island, Arctic Canada (McCartney et al., 2011a). This suggests a higher abundance of this taxon in neritic and coastal environments, where its morphological variation and abundance may have been influenced by terrestrial run-off, lower salinity, and nutrients.

Other evidence of environmental stress at the time of deposition is the occurrence of teratoid skeletons of *L. simplex*, which were more abundant than for other *Lyramula* species. Two examples of distorted specimens are shown on Plate 1, Figures 12 and 14. High variability of silicoflagellate morphological elements, and the presence of teratoid skeletons were suggested to have been associated with low salinity environments by Frenguelli (1935), Dumitrică (1973) and Shitanaka (1983), among others. Thomas et al. (1980) showed that distorted or incomplete skeletons can result from growth in culture media that contain heavy metals. However, distorted skeletons are uncommon among silicoflagellates in general, suggesting that *L. simplex* may be more susceptible to such stress.

5. Conclusions

The presence of either a small spine or an inflated area or 'bulb' at the central angle of *L. simplex* is interpreted to result from this taxon's response to variable environmental conditions. Other features of this taxon are consistent in most specimens, suggesting the presence of a spine or 'bulb' results from environmental influences rather than genetic differences. Future studies may identify this variability as a useful tool to infer events of greater fluvial input into coastal and neritic settings. Future detailed studies of Cretaceous sediments from Arctic Canada may reveal a stratigraphic or paleobiogeographic correlation that would improve their potential value in chronostratigraphic division of the Upper Cretaceous, or in paleoecological reconstructions.

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