Two rare silicoflagellate double skeletons of the Star-of-David configuration from the Eocene

KEVIN MCCARTNEY1, KENTA ABE2, JAKUB WITKOWSKI3 & RICHARD W. JORDAN4
1Department of Environmental Studies, University of Maine at Presque Isle, Presque Isle, ME 04769, USA
2Graduate School of Science and Engineering, Yamagata University, 1-4-12 Kojirakawa-machi, Yamagata 990-8560, Japan
3Geology and Palaeogeography Unit, Faculty of Geosciences, University of Szczecin, ul. Mickiewicza 18, 70-383 Szczecin, Poland
4Department of Earth & Environmental Sciences, Faculty of Science, Yamagata University, 1-4-12 Kojirakawa-machi, Yamagata 990-8560, Japan
*Corresponding author (e-mail: kevin.mccartney@umpi.edu)

ABSTRACT – Two, rare double skeletons of Corbisema silicoflagellates have been observed from Early and Middle Eocene sediments. Both specimens are in the Star-of-David configuration, with the basal corners of each skeleton aligned with the middle of sibling basal sides. These specimens are of a species that has an elongate basal ring, which shows that skeletons are flipped 180° with respect to one another, rather than simply rotated.

KEYWORDS: silicoflagellates, double skeletons, Eocene

INTRODUCTION
The life cycle and biology of silicoflagellates are only partially understood — Loeblich et al. (1968) and Moestrup & Thomsen (1990) illustrated and discussed some basic biological parameters of living specimens, for example. One of the poorly documented aspects of silicoflagellate biology and fossil record is the formation of double skeletons, or doublets. Here, we focus on recent discoveries of unusual double skeletons from the Early and Middle Eocene.

Silicoflagellate double skeletons are rarely observed in the fossil record, since the two skeletons easily disarticulate during life, deposition and the processing of sediment samples. McCartney et al. (2010a) presented in this journal the first observed silicoflagellate double skeleton from the Cretaceous. This specimen was especially unusual because the basal rings of the sibling skeletons were rotated into a ‘Star-of-David’ configuration which is different from more typical double skeletons that have an alignment of the basal corners and spines. Two double skeletons of this configuration, also of the fossil genus Corbisema recorded here, were illustrated by Schulz (1928) from the Fur Formation of Denmark. Notably, however, other Corbisema double skeletons (Bachmann, 1970; Dumitrică, 1974; Bukry, 1987) are in the corner-aligned configuration.

Two more Corbisema double skeletons in the Star-of-David configuration have been recently observed and are presented in this paper. These specimens provide photographic evidence that the Star-of-David configuration persisted from the Late Cretaceous into the Cenozoic. Both specimens reported here are also of a species that has an elongate basal ring and thus show that the sibling skeletons are flipped 180° rather than rotated 30°, as could be interpreted from an equal-sided species of Corbisema (McCartney et al., 2010a). Thus, the newly discovered specimens provide additional information on how the sibling skeletons relate to one another in the Star-of-David configuration.

SPECIMENS FROM THE IVDEL’ REGION, RUSSIA
Sediment samples of Cretaceous to Palaeogene age originating from multiple sites located in the Urals region of Russia were studied by Jousé (e.g. 1949, 1951) and recently relocated in the collection of the Geological Faculty, Moscow State University (Witkowski et al., 2012). No precise locality and age data are available for these samples, other than catalogue cards that usually give a general indication of the sampling region and a broad age assignment.

During a survey of Palaeogene samples from the Jousé sample suite, a double skeleton of Corbisema hastata (Lemmermann) Frenguelli (Frenguelli, 1940) was observed (Fig. 1a). The specimen is partially filled with matrix, which obscures the apical structures and pikes. However, it is the matrix that holds the sibling skeletons together. The specimen was found in sample 28, which – according to its accompanying catalogue card – was collected in ‘Ivdel’ region, eastern slopes of Northern Urals’, which is located in the Sverdlovsk District. Despite many hours of careful search in numerous slides of the same sample, no further double skeletons were found.

The precise age of the Ivdel’ specimen is unknown. The catalogue card for sample 28 states ‘Eocene’. Gleser (1964, 1966) reported on silicoflagellates and diatoms from two wells in the Ivdel’ area, with siliceous microfossil-bearing sediments dated as Early through Late Eocene. The diatom assemblage in sample 28 comprises rare Solium exsculptum, which is indicative of Early Eocene age (Fenner, 1985). This is consistent with the absence of Distephanosira architecturals, a common Middle to Late Eocene zonal index species (Fenner, 1985). Therefore, an Early Eocene age seems appropriate for the double skeleton that we report from the Ivdel’ area.

SPECIMEN FROM THE LOMONOSOV RIDGE, ARCTIC OCEAN
A second specimen of C. hastata (Fig. 1b) has been found recently by KA in a sample from Integrated Ocean Drilling Program Leg 302 (also known as the Arctic Coring Expedition; ACEX). This specimen can be confidently dated as Middle Eocene in age (for detailed stratigraphy see Stickley et al., 2008). A detailed presentation of the silicoflagellates from this expedition is provided by Onodera & Takahashi (2009). Both skeletons are complete, with exterior surfaces covered with a reticulate ornamentation and the interior surfaces being smooth.

The major axes of the sibling skeletons roughly coincide, with the basal elements near the major axis corner of each skeleton in

contact with the short basal side of the other. There are six points of contact along the abbasal surfaces of the pair, with pikes of each skeleton roughly centred between the basal elements near each corner of the sibling. The basal sides of each skeleton rest in a plane with no deflection of the elements near the points of contact. Two of the pikes are visible. These are prominent, arch in the general direction of the apex of the sibling skeleton and appear to terminate between the basal corner and apex. Whereas the major axis spine of each skeleton appears to lie in the basal plane, the other two basal spines are shorter and point abapically.

**DISCUSSION**

Recent study of modern double skeletons (McCartney et al., unpublished observations) suggests that the skeletal morphology of the apical structure is transposed from the mother to the daughter skeleton through the centre of the cell. This produces nearly identical skeletons with the same sinistral rotations of the apical rings or bridge, as seen from apical view, often observed in Neogene and Recent silicoflagellates. In the Star-of-David skeletons observed thus far, this applies also to the basal ring, so that the corners of three-sided *Corbisema* and five-sided *Vallacerta* (McCartney et al., 2010b) are transposed across the centre of the cell to place the corners aligned with the middle of the opposite side of the sibling skeleton.

However, while modern silicoflagellates show a transposition of the apical elements across the cell to the sibling skeletons, the elements of the basal ring are apparently not transposed. If transposition included the basal ring in modern silicoflagellates, then in morphologies with an odd number of basal sides, each basal corner of the mother skeleton would be transposed across the cell to the daughter to be aligned with the mother’s opposite basal side. The fossil three-sided corner-aligned double skeletons, as well as Recent five- and seven-sided *Distephanus*, are connected at the basal sides, corners and spines. The differences between the corner-aligned and Star-of-David groups, however, may not be a simple transposition of the basal ring, but rather some other factor. Thus far, no corner-aligned three-sided silicoflagellate skeletons have been available for scanning electron microscope (SEM) examination. One of the key questions is how the pikes are positioned, if present. When observed from lateral view, three-sided silicoflagellates do not have the zig-zag basal ring, typical of modern *Dictyocha* and *Distephanus* (McCartney et al., unpublished observations) which helps project the pikes into the region of the sibling skeleton. Except for the *Ivdel’* specimen, which has the central area obscured by matrix, all the three-sided Star-of-David specimens have pikes, and most are prominent. Other three-sided silicoflagellates, such as *Corbisema archangelskiana* (Schulz) Frenguelli (Frenguelli, 1940) and *C. geometrica* Hanna (Hanna, 1928), have less prominent pikes or no pikes, and it remains to be determined whether these may be associated with the other configuration. Of the corner-aligned *Corbisema*, only the one illustrated by Bukry (1987), which is somewhat disarticulated, appears to have obvious pikes.

The rarity of fossil double skeletons in the literature suggests that less aggressive sample processing techniques should be used to reduce disaggregation of preserved specimens. Dumitrică (1974) observed double skeletons of several silicoflagellate taxa in strained material treated in HCl, but not H$_2$O$_2$. Samples treated with H$_2$O$_2$ did not yield double skeletons (Dumitrică, pers. comm. 2012). The specimen from *Ivdel’* shows that clay-rich samples with fine-grained matrix may help to hold the skeletons together. Examination of coprolites for double skeletons should also be pursued, although this is a time-consuming process and photography of specimens can be difficult.
CONCLUSIONS

Rare specimens of the Star-of-David configuration have been observed among three-sided silicoflagellates from the Palaeogene. These could represent a group of silicoflagellates distinct from other taxa that have corner-aligned basal rings, which is the only configuration found in modern waters. Unfortunately, at present the only way to distinguish between these groups is through the observations of double skeletons, which are extremely rare in the fossil record. In order to increase the likelihood of finding fossil double skeletons, more careful techniques for the preparation of sediments for study need to be developed.

ACKNOWLEDGEMENTS

We thank Y. Polyakova and M. Kulikovskiy for making the Jousé samples available, and J. Gregory for reviewing the manuscript. The Ivdel’ specimen was observed during a sabbatical to KM from the University of Maine at Presque Isle to do research at the University of Szczecin, and we are grateful to both institutions for their support. The Lomonosov Ridge sample came from the Integrated Ocean Drilling Program, Leg 302, for which RWJ was provided by Anhui Normal University. Financial support for JW was provided by the Foundation for Polish Science (START Programme).

Manuscript received 1 October 2013
Manuscript accepted 10 February 2014
Scientific Editing by John Gregory.

REFERENCES

Bachmann, A. 1970. Silicoflagellaten aus dem oberösterreichischen Egerien (Oberoligozän). Verhandlungen der Geologischen Bundesanstalt, 2: 275–305.

Bukry, D. 1987. Eocene siliceous and calcareous phytoplankton, Deep Sea Drilling Project Leg 95. Initial Reports of the Deep Sea Drilling Project, Scientific Results, 95. US Government Printing Office, Washington, DC, 395–415.

Dumitrică, P. 1974. Silicoflagelatele Miocene din Romania. Silicoflagelatele miocene din Romania. Teza de doctorat, Universitatea din Bucuresti, Facultatea de Geologie-Geografie, Bucuresti, 224pp.

Fenner, J. 1985. Late Cretaceous to Oligocene planktic diatoms. In Bolli, H.M., Saunders, J.B. & Perch-Nielsen, K. (eds) Plankton Stratigraphy. Cambridge University Press, Cambridge, 2: 713–762.

Frenquelli, J. 1940. Considerationes sobre los silicoflagelados fósiles. Revista del Museo de la Plata, Paleontología, 7: 37–112.

Gleser, Z.I. 1964. Silicoflagellatae fossils novae URSS. Novitates Systematicae Plantarum Non Vascularium, 1: 46–58.

Gleser, Z.I. 1966. Silicoflagellatophyceae. Nauka, Moskva (translated from Russian by Israel Program for Scientific Translations, Jerusalem, 1970), 363pp.

Hanna, G.D. 1928. Silicoflagellata from the Cretaceous of California. Journal of Paleontology, 1: 259–263.

Jousé, A.P. 1949. Algae diatomaceae aetatis supernectaceae ex arenis argillaceis systematis fluminis Bolschoy Aktay in declivitate orientali Ural Borealis. Notulae systematicae e Sectione Cryptogamica Instituti Nomine V.L. Komarovii Academiae Scientiarum U.R.S.S, 6: 65–78.

Jousé, A.P. 1951. Diatomeae et silicoflagellateae aetatis Creta superne e Montibus Uralensisibus Septentrionalibus. Notulae systematicae e Sectione Cryptogamica Instituti Nomine V.L. Komarovii Academiae Scientiarum U.R.S.S, 7: 42–65.

Loeblich, III, A.R., Tappan, H. & Loeblich, A.R. Jr 1968. Annotated Index of Fossil and Recent Silicoflagellates and Ehrbiids with descriptions and illustration of validly published Taxa. Geological Society of America, Memoirs, 106. 319pp.

McCartney, K., Harwood, D.M. & Witkowski, J. 2010a. A rare double skeleton of the silicoflagellate Corbisema. Journal of Micropalaeontology, 29: 185–186.

McCartney, K., Witkowski, J. & Harwood, D.M. 2010b. Early evolution of the silicoflagellates during the Cretaceous. Marine Micropaleontology, 77: 83–100.

Moestrup, O. & Thomsen, H.A. 1990. Dictyocha speculum (Silicoflagelateae, Dictyochoophyceae), studies on armoured and unarmoured stages. Biologiske Skrifter, 37: 1–22.

Onodera, J. & Takahashi, K. 2009. Taxonomy and biostratigraphy of middle Eocene silicoflagellates in the central Arctic Basin. Micropaleontology, 55: 209–248.

Schulz, P. 1928. Beiträge zur Kenntnis fossierer und rezenten Silicoflagellaten. Botanisches Archiv, 21: 225–292.

Stickley, C.E., Koç, N., Brumsack, H.-J., Jordan, R.W. & Suto, I. 2008. A siliceous microfossil view of middle Eocene Arctic palaeoenviron-ments: A window of biosilica production and preservation. Paleoceanography, 23: 1–19, PA1S14, http://dx.doi.org/10.1029/2007PA001485.

Witkowski, J., Harwood, D.M. & Kulikovskiy, M. 2012. Observations on Late Cretaceous marine diatom resting spore genera Pseudoaulacodiscus and Archaeangiothecium gen. nov. Nova Hedwigia Beih., 326–328: 78–94.
BiotecMicroslides has been manufacturing slides for the storage of microfossils and small zoological and botanical specimens since 1974.

Slides, with either black or white cell backgrounds are available in cardboard with aluminium holder and glass coverslide. Also available to order are double-depth single-cell slides with paper tops and either acetate or glass coverslip.

Slide dimensions 3” x 1” (76mm x 27mm)

- Pine Storage Cabinets (28 drawers) with or without glazed door
- Picking trays 3¾ x 3¼ (97mm x 84mm)
- 00 Picking brushes with sable or synthetic bristles