2012

Fragilariopsis tigris sp. nov., a New Late Pliocene Antarctic Continental Shelf Diatom with Biostratigraphic Promise

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ABSTRACT: A new species within the genus *Fragilariopsis*, *F. tigris*, is described and illustrated using light microscopy and scanning electron microscopy. This species is restricted to a single 8-meter-thick diatom unit within the 585-meter-long section of alternating diatomites and diamictites recovered in the upper portion of the ANtarctic geological DRILLing (ANDRILL) McMurdo Ice Shelf Project (MIS) AND-1B marine sediment core. This new taxon from a diverse, well-preserved diatom assemblage is inferred to be the youngest member of the well-documented, biostratigraphically useful *F. praeinterfrigidaria – F. interfrigidaria – F. weaveri* lineage and may represent a near-shore corollary to the open-ocean species *F. weaveri*. Based on available chronostratigraphic data from AND-1B, *F. tigris* appears to be restricted to the earliest late Pliocene (first occurrence datum ~3.2 Ma) and is extinct before 3.0 Ma.

KEY WORDS: Pliocene; Antarctica; diatom biostratigraphy; *Fragilariopsis*; ANDRILL

INTRODUCTION

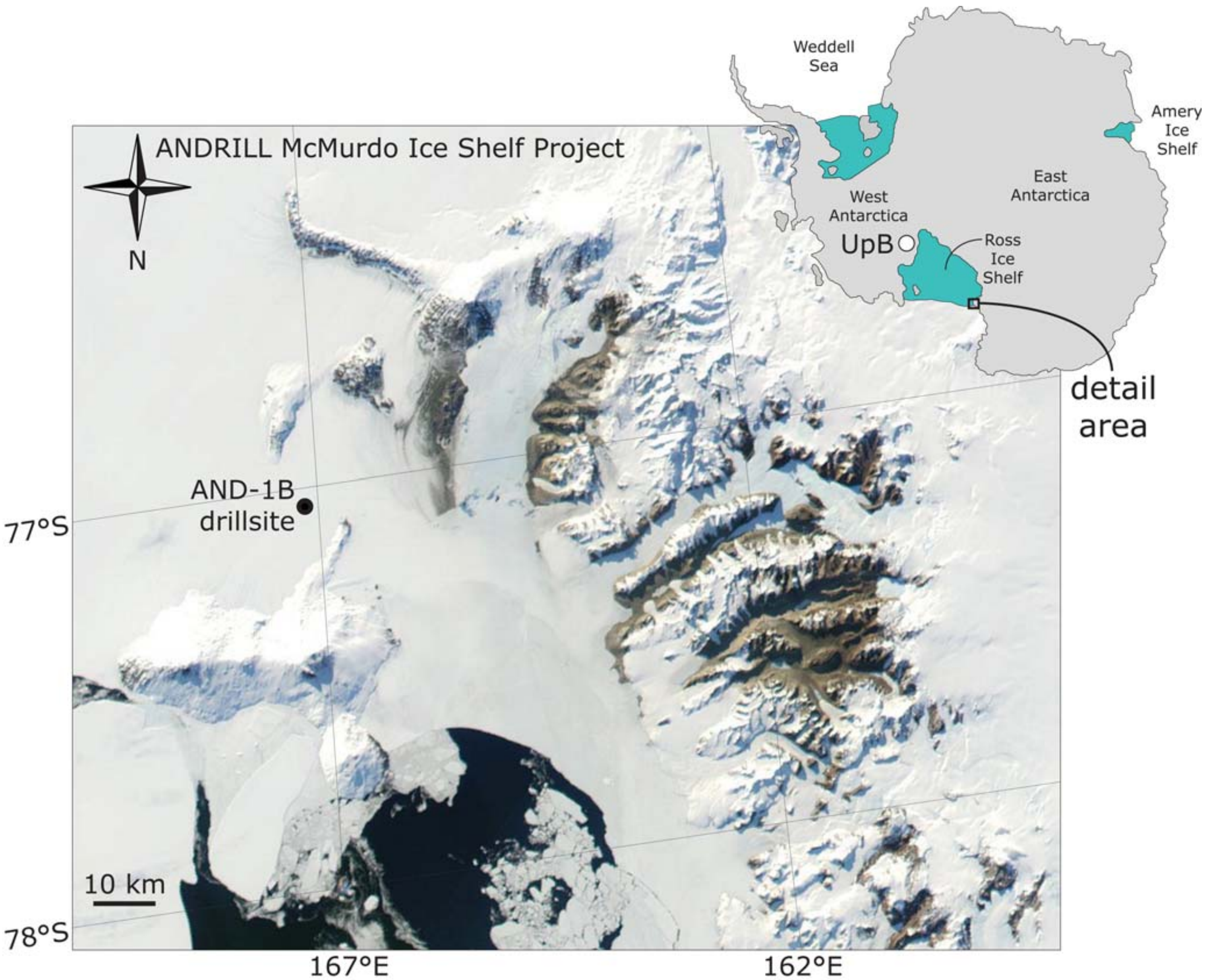
The marine sediment core collected by the ANtarctic geological DRILLing (ANDRILL) Program from Site AND-1B beneath the McMurdo Ice Shelf (MIS) provides the most comprehensive and well-preserved record to date of Neogene diatom evolution within the Antarctic near-shore environment. Thirteen diatom-rich lithologic units alternate with glacial sediments in the upper six hundred meters of AND-1B, providing direct evidence of orbitally-induced cycles in ice sheet extent and glacial proximity throughout the Pliocene and early Pleistocene. Each diatom-rich unit within this oscillating record has a biostratigraphically and ecologically distinct diatom assemblage (Scherer et al. 2007), and most are interpreted to record near-shore open marine conditions during the interglacial interval of a 40-thousand-year glacial/interglacial cycle (Naish et al. 2009). This unique record accumulated in an environment not previously sampled through Antarctic drilling, and diatom assemblages include numerous previously unknown and unnamed forms (Scherer et al. 2007). Six new diatom species are formally described and named from AND-1B (Winter et al. 2012; Sjunneskog et al. 2012). One of these new species, *Fragilariopsis tigris*, is distinctive in appearance, with affinities to the well-documented *F. praeinterfrigidaria – F. interfrigidaria – F. weaveri* lineage and an AND-1B range that is restricted to a single late Pliocene interglacial interval. This species may, therefore, provide a valuable biostratigraphic constraint for future drilling on the Antarctic continental shelf.

MATERIALS AND METHODS

Core AND-1B is located beneath the McMurdo Ice Shelf south of Ross Island, 77.889° S, 167.089° E, (text-fig. 1) at a water depth of 917 meters (Falconer et al. 2007). The upper 585 meters of the 1285-meter core comprise alternating diamictite and diatomaceous sequences with episodic volcanigenic rocks (Krissek et al. 2007; Naish et al. 2009). The diatomaceous material is divided biostratigraphically into thirteen distinct diatom units, DU XIII through DU I, which largely represent interglacial open-water conditions from the early Pliocene to the mid Pleistocene (Scherer et al. 2007; Winter et al. 2012).

F. tigris is described from DU IX (292 – 284 mbsf; text-fig. 2), based on light microscope (LM) morphometric analysis supported by scanning electron microscopy (SEM). Fourteen 2-cc samples were collected at ~50 cm intervals for microfossil analysis. Each semi-lithified sample was split across its 1-cm thickness, and the representative subsample was gently crushed and mixed, digested in 3% hydrogen peroxide for 12 hours in a 30° C water bath, triple-rinsed in nannopure water and centrifuged at 2000 rpm, then stored in nannopure water. To prepare slides, samples were agitated and allowed to settle for 10 seconds, then an aliquot of the suspended material was dried onto a cover slip, mounted using Norland Optical Adhesive #61 (refractive index = 1.56), and cured under UV light. The slides were examined on a Leica DM LB2 with Nomarski optics and equipped with 100x, 63x, and 40x oil-immersion objectives, attached to a SPOT Insight photomicrographic system, housed at the U.S. Geological Survey in Menlo Park, CA. Morphometric measurements were collected from LM images using the SPOT Basic software package. SEM images were obtained using an FEI Sirion XL30 scanning electron microscope housed in the Stanford Nanocharacterization Laboratory.

Many AND-1B DU IX samples contain moderately to heavily fragmented assemblages in which *F. tigris* was identified only from apical fragments. Morphometric data (text-fig. 3) were collected from whole *Fragilariopsis tigris* specimens encountered and imaged in several slide traverses of three samples with good preservation. In addition, data on valve width and costae density were collected from a small number of specimens that were missing a single apex but were otherwise intact. Supporting SEM images are from a single well-preserved sample at 288.76 mbsf. The work of Ciesielski (1983) provides a basis for the comparison of *F. tigris* to other Pliocene *Fragilariopsis* species within the same inferred lineage (text-fig. 4; text-fig. 5).



TEXT-FIGURE 1
Map of the southern Ross Sea and McMurdo Sound region. The filled circle indicates the location of the ANDRILL McMurdo Ice Shelf (MIS) AND-1B drillsite, and the open circle indicates the location of the UpB sample site discussed in the text.

Fragilariopsis tigris Riesselman **sp. nov.**
Plates 1, 2

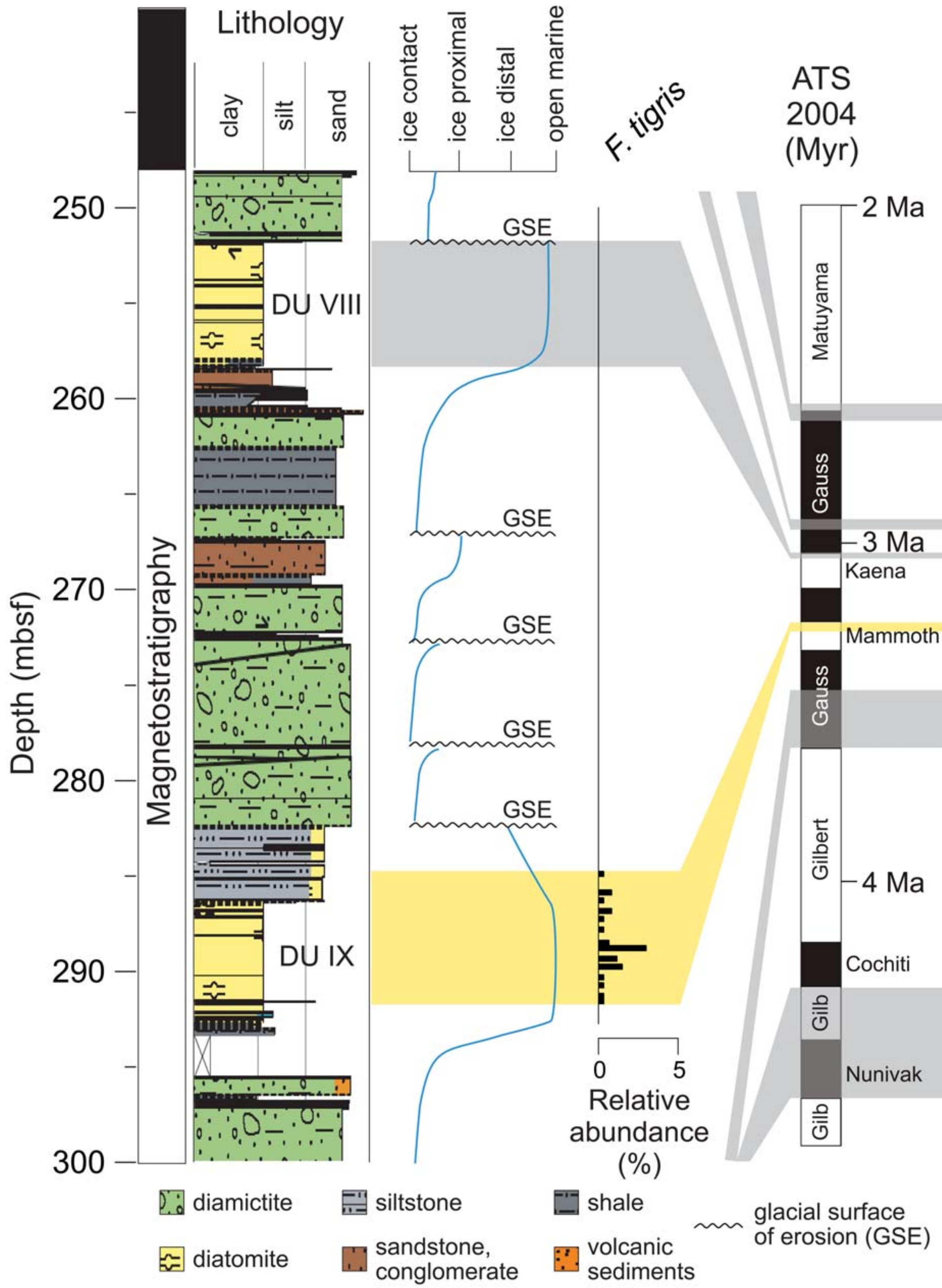
Nitzschia sp. A SCHERER 1991, p. 405, pl.III, fig. 8

Description

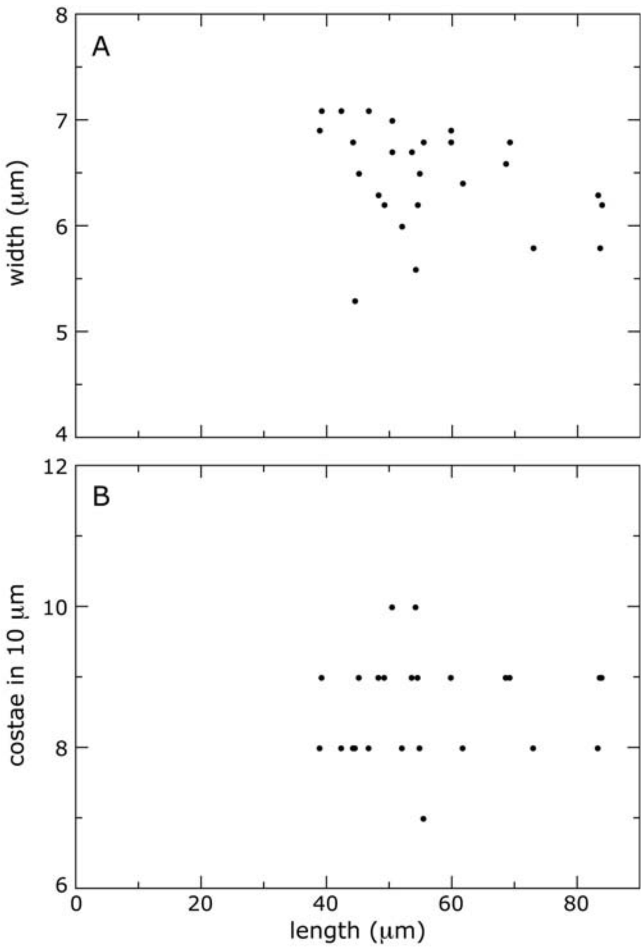
The valve outline is linear to lanceolate and heteropolar. One apex is obtusely rounded and the other tapers to an acutely rounded or pointed tip (Plates 1 and 2). The raphe is eccentric, located at the junction between valve face and mantle, and terminates near the tapered apex but short of the rounded apex (Plate 2, figs. 3 and 5). In some specimens, the tapered apex curves away from the raphid margin (Plate 1, fig. 2); many valves exhibit neither bilateral nor medial symmetry. The apical axis ranges from 38.0 to 83.9µm in length (mean 53.0µm; n=22) and the transapical axis ranges from 5.6 to 7.1µm at the widest point (mean 6.6µm; n=29; Table 1; text-fig 3A). In most specimens, transapical costae are visible across the valve face; these are parallel and straight to slightly oblique in the middle of the valve, becoming curved toward the blunt apex, at a density of 7–10 in 10µm (mean 9; n=29). The valve face is incompletely striated by punctae. Observed under SEM, these form clusters near the valve margin and decrease to irregularly spaced single or paired punctae in a linear arrangement across the middle portion of the valve (Plate 2, figs. 5 and 6). The internal relief of costae and marginal clusters of punctae give the margin a ribbed appearance under light microscopy. The number of fibulae is equal to or slightly greater than the number of costae (Plate 2; figs. 2 and 4).

Type specimens

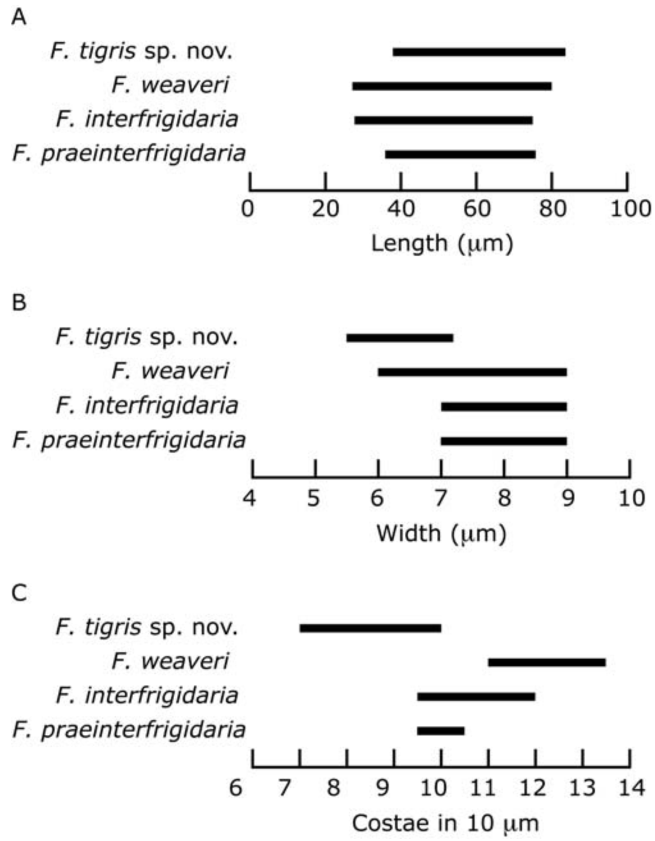
Holotype specimen: Plate 1, figure 6. Paratype specimen: Plate 1, figure 2. Type slide and sample material are deposited at the California Academy of Sciences.



TEXT-FIGURE 2
Summary of the AND-1B core from 248-300 mbsf. Magnetostratigraphy after Wilson et al. (2007). Lithostratigraphy after Krisek et al (2007). Glacial proximity curve after Naish et al. (2009); grounding line advances for five glacial/interglacial cycles are identified by glacial surfaces of erosion. *Fragilariopsis tigris* is only identified from DU IX. The bold yellow field marks the position of DU IX within the astronomically tuned timescale of (ATS) of Gradstein et al. (2004). Pale grey fields mark the ages of AND-1B diatomites from which *F. tigris* is absent (Winter et al. 2012). Full color version is available onine at micropress.org



TEXT-FIGURE 3
Valve measurements for whole *F. tigris* specimens from AND-1B: A) correlation between valve length and valve width; B) correlation between valve length and costae number.



TEXT-FIGURE 4
Morphometric comparison between the new species *F. tigris* and the other members of its proposed evolutionary lineage: A) valve length comparison; B) valve width comparison; C) comparison of costae density.

Type locality

AND-1B drillcore, 77.889° S, 167.089° E, McMurdo Ice Shelf in the southern McMurdo Sound, Ross Sea, Antarctica

Type level and age

Late Pliocene; AND-1B, 288.76 mbsf

Stratigraphic range

Fragilariopsis tigris is restricted to the lower portion of the late Pliocene *F. bohatyi* diatom zone (Winter et al. 2012). In AND-1B, *F. tigris* is limited to DU IX (291.50–284.90 mbsf), with peak abundance of 3% at 288.76 mbsf (Fig. 2).

Etymology

The epithet is from the Latin "tigris", in reference to the tiger-like nature of valve face striation, particularly evident under SEM; originally from the Old Persian "tigr", translated as "fast" or "arrowlike".

DISCUSSION

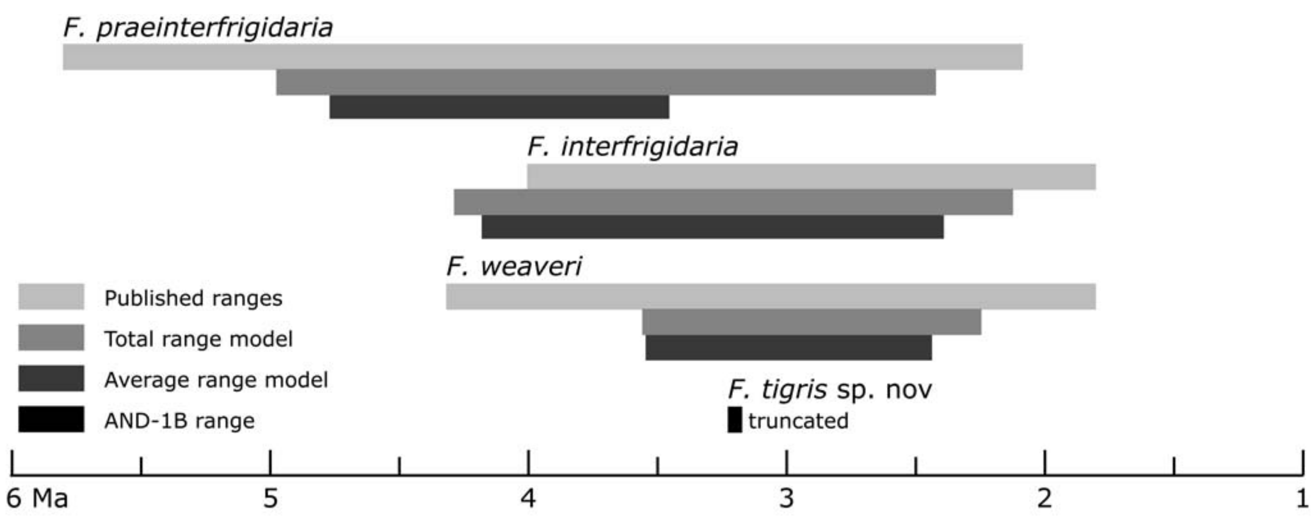
Age constraints and regional distribution

Fragilariopsis tigris appears in the AND-1B record in the horizon immediately above the unique diatom-bearing diamict DU X (347–296 mbsf), at the base of DU IX at 292 mbsf (Scherer et al. 2007). This transition corresponds to a First Occurrence Datum (FOD) of ~3.2 Ma based on chronostratigraphic and biostratigraphic data (Wilson et al. 2007; Naish et al. 2009; Winter et al. 2012). There is no evidence of glacial erosion separating DU X from DU IX, although a ~3m coring gap immediately below DU IX means that the possibility of a truncated FOD cannot be discounted (Krissek et al. 2007; text-fig. 2).

In AND-1B, *F. tigris* is last observed at 284.90 mbsf, in the uppermost DU IX assemblage examined. Because DU IX is interpreted to preserve a single interglacial interval within a 40 kyr-long glacial/interglacial cycle, this corresponds to an observed Last Occurrence Datum (LOD) that is also ~3.2 Ma. However, DU IX is unconformably overlain by ~25m of ice-proximal, grounding line, and subglacial siliciclastic facies. Within this siliciclastic sequence, four glacial surfaces of erosion (GSEs) mark the removal of intervening interglacial sediments by advancing grounded ice sheets on a cycle of 40 kyr,

TABLE 1
Fragilariopsis tigris valve measurements from AND-1B.

Depth	Specimen type	Length (μm)	Width (μm)	Interstriae in 10 μm	Illustration
289.75	whole valve	38.8	6.9	8	Plate 1, fig. 9
288.76	whole valve	39.1	7.1	9	Plate 1, fig. 10
289.75	whole valve	42.3	7.1	8	Plate 1, fig. 11
288.76	whole valve	44.1	6.8	8	Plate 1, fig. 12
288.76	whole valve	45.0	6.5	9	Plate 1, fig. 13
288.76	whole valve	46.5	7.1	8	-
288.90	whole valve	48.1	6.3	9	Plate 1, fig. 8
289.75	whole valve	49.0	6.2	9	-
288.76	whole valve	50.3	6.7	10	Plate 1, fig. 7
288.76	whole valve	50.3	7.0	10	Plate 1, fig. 6
289.75	whole valve	52.0	6.0	8	Plate 1, fig. 5
288.76	whole valve	54.0	5.6	10	Plate 1, fig. 4
289.75	whole valve	54.6	6.5	8	-
288.76	whole valve	55.4	6.8	7	-
288.76	whole valve	59.6	6.8	9	-
288.76	whole valve	59.8	6.9	9	-
288.76	whole valve	61.7	6.4	8	-
288.76	whole valve	68.6	6.6	9	Plate 1, fig. 3
288.76	whole valve	69.2	6.8	9	Plate 1, fig. 2
288.76	whole valve	83.2	6.3	8	-
288.76	whole valve	83.5	5.8	9	Plate 1, fig. 1
289.75	whole valve	83.9	6.2	9	-
288.76	apical fragment	54.5	6.2	9	-
288.76	apical fragment	-	7.2	9	-
288.76	apical fragment	-	7.6	8	-
288.76	apical fragment	-	6.1	8	-
288.76	apical fragment	53.3	6.7	9	-
288.76	apical fragment	72.7	5.8	8	-
288.76	apical fragment	44.4	5.3	8	-



TEXT-FIGURE 5
Age range for *F. tigris*, plotted with ranges for other members of its proposed evolutionary lineage. Published ages incorporate ranges from previously published Southern Ocean sites. Model ranges are from the CONOP diatom biochronology of Cody et al. (2008), and the reader is referred to that publication for a discussion of the differences between the total and average range models.

providing additional cyclostratigraphic control (Krissek et al. 2007; Mckay et al. 2009; Naish et al. 2009). From the youngest of these GSEs, at 267 mbsf, a continuous cycle of accumulation tracks the interglacial retreat of the Ross Ice Shelf, culminating in the open marine deposition of DU VIII at ~3.03 Ma, in which *F. tigris* is absent from the assemblage (text-fig. 2). It is therefore possible that *F. tigris* persisted beyond 3.2 Ma, but its extinction prior to 3.03 Ma is well constrained by its absence in well-preserved diatomaceous sediments of AND-1B.

Fragilariopsis tigris is probably conspecific with a taxon identified by Scherer (1991) as *Nitzschia* (?) sp. A. A single broad apex of Scherer's *Nitzschia* (?) sp. A, similar to Plate 1, fig. 10, was documented from a subglacial till sample collected beneath the Whillans Ice Stream (formerly Ice Stream B) at 83.478° S, 138.097° W (UpB), and additional smaller fragments of the species were also observed from that sample. The occurrence of *F. tigris* in AND-1B and in the UpB sample suggests that this species may have been endemic to the Ross Sea continental shelf in the late Pliocene.

Lineage

Fragilariopsis tigris has affinities to the Pliocene Antarctic evolutionary lineage *F. praeinterfrigidaria* (McCollum) Gersonde et Bárcena – *F. interfrigidaria* (McCollum) Gersonde et Bárcena – *F. weaveri* (Ciesielski) Gersonde et Bárcena, but differs from these three species in its distinctive heteropolar valve outline. *Fragilariopsis interfrigidaria* co-occurs with *F. tigris* at AND-1B; *F. praeinterfrigidaria* and *F. weaveri* do not.

All four species span a similar valve length range. *Fragilariopsis tigris* valve width is generally narrower than the width reported by Ciesielski (1983) for the other species, although there is significant overlap with *F. weaveri* (text-fig. 4). The costae density, size and arrangement of punctae, and lack of bilateral symmetry exhibited by some *F. tigris* specimens are most similar to *F. praeinterfrigidaria* (text-fig. 4), although some specimens with significantly reduced valve face punctation (e.g. Plate 1, figs. 9 and 12) are similar in appearance to *F. weaveri*. In fact, tapered-apex fragments of *F. tigris* were initially reported as *F. weaveri* from on-ice work.

The stratigraphic position of *F. tigris* in AND-1B overlaps with the published ranges of all three of the other species within the lineage. However, diatom ages have recently been refined by Cody et al. (2008), who used constrained optimization (CONOP) to correlate all recorded Antarctic FO and LO datums. Two resulting complementary models, which are based on different assumptions about reworking, yield independent estimates of average local ranges and total regional ranges. The range models shift the LOD of *F. praeinterfrigidaria* such that the ranges of *F. praeinterfrigidaria* and *F. tigris* overlap in the total range model, but not in the average local model (text-fig. 5; see Cody et al. 2008 for a comprehensive treatment of CONOP, its application to diatom biostratigraphy, and the differences between total and average range models). Because they co-occur in AND-1B, it is possible that *F. tigris* and *F. interfrigdaria* both evolved independently from *F. praeinterfrigidaria.* Its precise stratigraphic position in AND-1B and overall morphologic similarities may also indicate that *F. tigris* is a near-shore corollary to the open-ocean species F. *weaveri*. The narrow stratigraphic range of this new species in AND-1B should provide a useful biostratigraphic constraint for future Ross Sea drilling.

Paleoenvironmental considerations

Based on its identification in AND-1B and UpB, *Fragilariopsis tigris* appears to be restricted to an open-marine continental shelf environment, present in the McMurdo sound and the West Antarctic interior following the retreat of the Ross Ice Shelf and collapse of the West Antarctic Ice Sheet during late Pliocene interglacial intervals. Peak relative abundance data from a num-

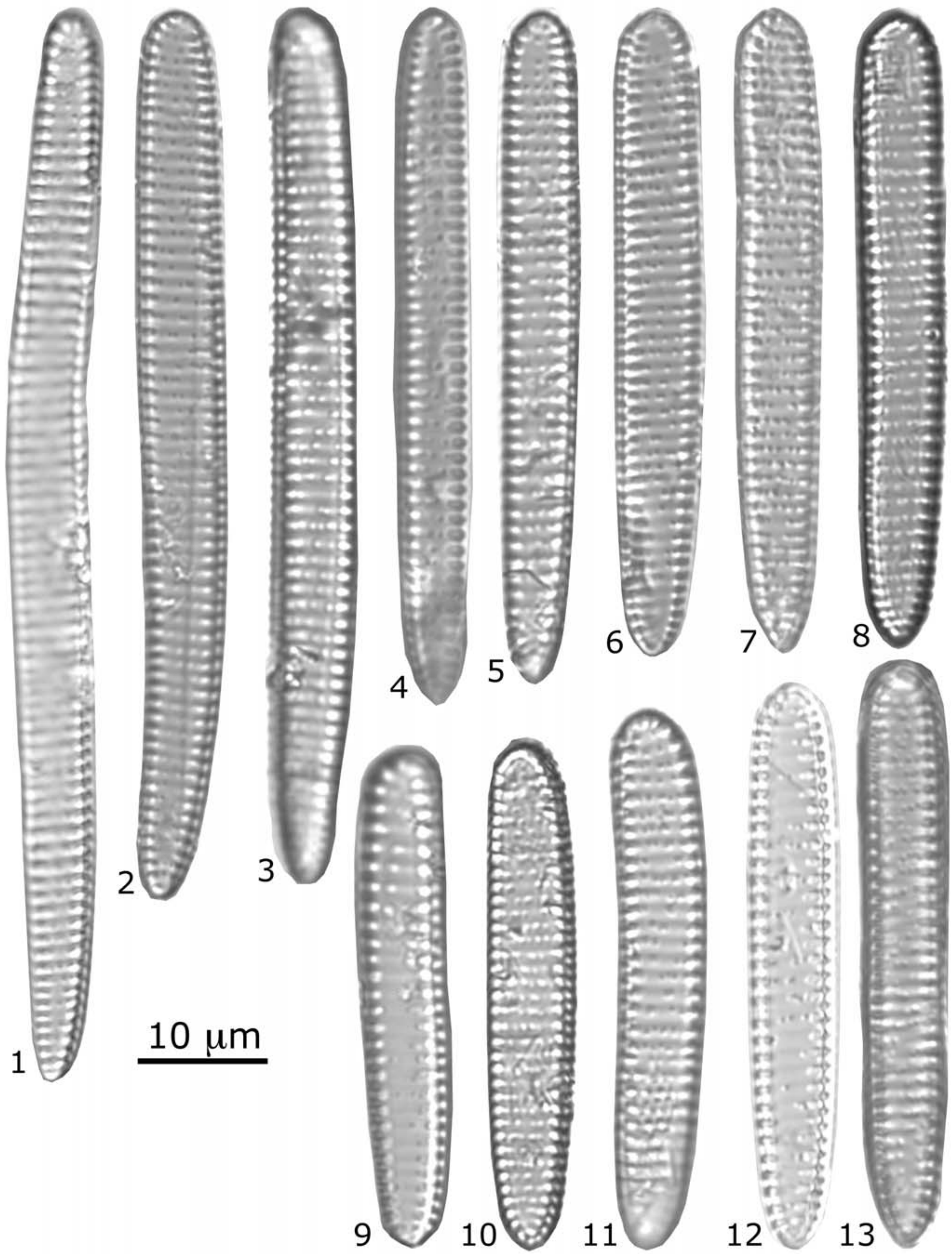
PLATE 1

Fragilariopsis tigris light micrographs from AND-1B, DU IX. Scale bar is 10μm for all specimens Holotype **(6)** and paratype **(2)** from type slide, deposited at the California Academy of Sciences.

1-4, 6-7, 10, 12-13 288.76 mbsf;

5, 9, 11 289.75 mbsf;

8 288.90 mbsf.


1
2
3
4
5
6
7
8
9
10
11
12
13
10 μm

ber of Pliocene Southern Ocean sites indicate that the coeval species *F. weaveri* had a strong ecological preference for subantarctic surface waters north of the polar frontal zone (PFZ) and remained present at greatly reduced numbers under the PFZ and in northern Antarctic surface waters (Fenner et al. 1991; Barron 1996). Given that *F. tigris* first appears in DU IX, inferred to record the onset of late Pliocene cooling in the Ross Sea (McKay et al. 2012; Riesselman and Dunbar, in press), the complete exclusion of *F. weaveri* in favor of *F. tigris* in AND-1B suggests selection pressure from temperature or other environmental factors.

SUMMARY

Fragilariopsis tigris sp. nov. Riesselman is described from Antarctic continental shelf sediments, and is documented with light and scanning electron microscopy. This species has an extremely short range in AND-1B; limited to a single interglacial interval at ~3.2 Ma, it may prove to be a valuable biostratigraphic marker for future Pliocene sections. *Fragilariopsis tigris* is the youngest member of the *F. praeinterfrigidaria* (McCollum) Gersonde et Bárcena – *F. interfrigidaria* (McCollum) Gersonde et Bárcena – *F. weaveri* (Ciesielski) Gersonde et Bárcena lineage, and appears to be restricted to near-shore sedimentary environments.

ACKNOWLEDGMENTS

The author gratefully acknowledges the ANDRILL Program for the award of an ANDRILL Graduate Fellowship, and the AND-1B on-ice diatomists D. Winter, C. Sjunneskog, and R. Scherer for their initial core characterization efforts; both were instrumental in allowing her to pursue this work. S. Starratt generously provided access to an exceptional light microscope and camera system, which was used for all LM images and morphometric characterization presented herein. The guidance of B. Jones was instrumental in acquiring SEM images. Recommendations from J. Barron, J. Self-Trail, and M. Jones significantly improved this manuscript.

This work was completed at Stanford University with support from the National Science Foundation under Cooperative Agreement No. 0342484 through subawards administered by the ANDRILL Science Management Office at the University of Nebraska-Lincoln, and issued through Northern Illinois University (for the MIS Project) as part of the ANDRILL U.S. Science Support Program. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government. Recommendations from J. Barron, J. Self-Trail, and M. Jones significantly improved this manuscript.

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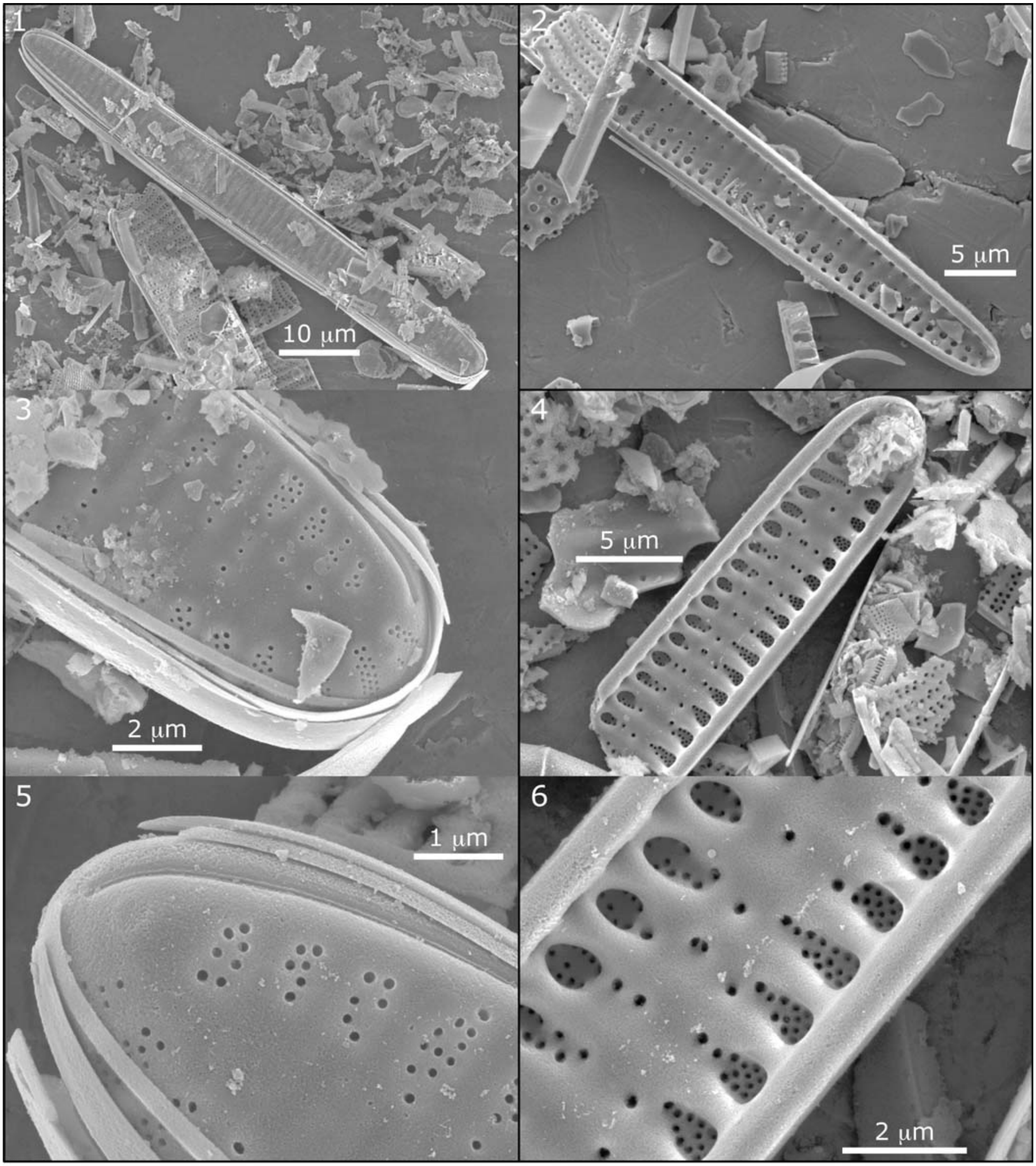
PLATE 2

Fragilariopsis tigris SEM micrographs from AND-1B, DU IX.
All specimens are from a well-preserved diatomite at 288.76 mbsf.
Black boxes group multiple images from a single specimen; scale bars as noted.

1,3,5 valve face exterior view with apical detail;

2,4,6 valve face interior view of broad and tapered apex fragments, including

6 detail of poroid distribution.


1
10 μm
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5 μm
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2 μm
4
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5
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6
2 μm

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Received January 27, 2012
Accepted September 12, 2012
Published November 2012