

3 Supporting Information for

4 **Ecological response to collapse of the biological pump following the mass**
5 **extinction at the Cretaceous-Paleogene boundary**

6 Johan Vellekoop^{1,2}, Lineke Woelders², Sanem Açikalin³, Jan Smit⁴, Bas van de
7 Schootbrugge¹, Ismail Ö. Yilmaz⁵, Henk Brinkhuis^{1,6}, Robert P. Speijer²

8
9 ¹ Marine Palynology, Laboratory of Palaeobotany and Palynology, Faculty of Geosciences, Utrecht
10 University Utrecht, 3584 CD, Utrecht, The Netherlands

11 ² Division of Geology, Department of Earth and Environmental Sciences, KU Leuven, B-3001,
12 Leuven-Heverlee, Belgium

13 ³ School of Civil Engineering and Geosciences, Newcastle University, NE1 7RU, Newcastle upon
14 Tyne, UK

15 ⁴ Department of Sedimentology and Marine geology, Faculty of Earth and Life Science, VU
16 University Amsterdam, 1018HV, Amsterdam, The Netherlands

17 ⁵Department of Geological Engineering, Middle East Technical University, Ankara, Turkey

18 ⁶Royal Netherlands Institute for Sea Research (NIOZ), Landsdiep 4, 1797 SZ, 't Horntje, Texel,
19 The Netherlands

20
21 **Contents of this file**

22 Text S1

23 Text S2

24 Text S3

25 Figures S1 to S4

Additional Supporting Information (Files uploaded separately)

Captions for Data Sets S1 and S2

Introduction

Supporting information includes additional information about the use of hexaperidinioids as a qualitative proxy for nutrient availability (Text S1), a detailed description of the procedures followed to arrive at estimated benthic foraminiferal accumulation rates and dinocyst accumulation rates for the Cretaceous-Paleogene boundary interval of the Okçular section, Turkey (Text S2) and a discussion on benthic foraminiferal diversity of the Okçular record (Text S3). Supporting information also includes photo plates of the most common benthic foraminiferal taxa (Figures S3 and S4). Datasets provide benthic foraminiferal and dinocyst counts (Data Sets S1 and S2). Details of the analyses are explained in the Materials and Methods section in the main article.

Text S1.

Previous studies have shown that in the Tethys in particular the hexaperidinioids show strong variations across the K-Pg boundary (Brinkhuis et al., 1998; Vellekoop et al., 2015). Based on statistical correlations between palynological records and other paleo-proxies, it has been suggested that this inferred heterotrophic group is indicative of high nutrient availability and/or low salinities. (Eshet et al., 1994; Brinkhuis et al., 1998; Sluijs and Brinkhuis, 2009).

Therefore, high abundances of this morphological group can be related to changes in trophic condition as well as to changes in salinity. Since the Okçular section is deposited at outer neritic to upper bathyal depths (Açikalin et al., 2015), this locality probably represents a relatively distal setting, with little freshwater input. Therefore, changes in relative abundances of hexaperidinioids are more likely to reflect changes in nutrient availability rather than changes in salinity. To nevertheless exclude the possibility that the signals in the palynological record can be attributed to changes in freshwater input, we tested for a significant correlation between relative abundances of hexaperidinioids and relative abundances of terrestrial palynomorphs. Pollen and spores are land-derived and can therefore be regarded as a proxy for the input of terrestrial-derived material. Since a hypothetical decrease in salinity would most likely be associated with increased riverine input, the input of terrestrial-derived material is expected to increase with decreasing salinity.

Our correlation shows that there is no significant relationship between the relative abundances of hexaperidinioids and the relative abundances of terrestrial palynomorphs, $r(31) = 0.0089$, $p > 0.05$ (Figure S1). Therefore, in this study, high abundances of hexaperidinioids are considered indicative of high nutrient availability in the upper water column, instead increased freshwater input.

Text S2.

To estimate the Benthic Foraminiferal Accumulation Rate (BFAR, number of benthic foraminifera per cm² per kyr), the number of benthic foraminifera (>63µm) per gram dry sediment were calculated. In the foraminiferal records of the Mudurnu-Göynük Basin there is a decrease in numbers of benthic foraminifera

74 across the K-Pg boundary, from 600-1200 foraminifera/gram in the Maastrichtian
75 to lowermost Danian values of 150-250 foraminifera/gram. Using the estimated
76 sedimentation rates for the studied interval based on the biostratigraphic age
77 model of Açıkalın et al. (2015) and the estimated range of densities for the
78 lithologies (mudstones, claystones and limestones) of the Taraklı Fm (2-2.5 g/cm³;
79 Manger et al., 1963) the concentrations of foraminifera may be used to estimate
80 the BFAR. The resulting estimated BFAR record shows a drastic decrease across
81 the K-Pg boundary, from 1800-7200 foraminifera/cm²/kyr in the latest
82 Cretaceous to 175-400 foraminifera/cm²/kyr in the earliest Paleocene. The
83 benthic foraminiferal accumulation rate does not fully recover until Zone P1b.

84 To estimate the dinocyst accumulation rates, here defined as the preserved
85 cysts that accumulated per cm² sea floor per kyr, the dinocyst concentrations in
86 cysts per gram dry sediment were calculated. In the palynological records of the
87 Mudurnu-Göynük Basin there is a strong increase in concentrations of dinocysts
88 across the K-Pg boundary, from Maastrichtian abundances of ~1000-2000
89 cysts/gram at Okçular, to lowermost Danian values of up to ~14000 cysts/gram,
90 representing a 7 fold increase across the boundary. These high concentrations
91 occur in the interval correlative to planktic foraminiferal Zones P0 and P α , above
92 which concentrations decrease again to ~2500-6500 cysts/gram. Using the
93 estimated sedimentation rates for the studied interval based on the
94 biostratigraphic age model of Açıkalın et al. (2015), the concentrations of
95 dinocysts (in cysts/ gram) may be used to estimate the dinocyst accumulation
96 rates. The resulting records show that the estimated dinocyst accumulation rate
97 shows a general increasing trend across the boundary interval, with no major
98 changes at the boundary itself, implying that the change in absolute

concentrations of dinocysts at Okçular is mostly related to the decrease in sedimentation rates across the K-Pg boundary (Açikalin et al., 2015).

Text S3.

Compared to the benthic foraminiferal records from the Bidart section (Alegret et al., 2004), the Walvis Ridge section (Alegret and Thomas, 2007), the Agost section (Alegret et al., 2003), and the El Kef section (Speijer and van der Zwaan, 1996), the Fisher alpha and Shannon H diversity of the benthic foraminiferal assemblages are lower in our study, also in the cases where the counted number of specimens is higher than 600. It could be argued that the number of specimens in our study (ranging from 245 to >500 specimens) may be too low to capture the full diversity of our record. However, as Fisher-alpha should in theory not be sensitive to number of specimens counted (Fisher et al., 1943), this is a strong indication that diversity in our study is systematically lower than at these other sites. Furthermore, when the number of species encountered in each sample is plotted against the number of specimens counted per sample (Figure S2), we see no trend towards higher numbers of species with increasing sample size. We thus argue that we do not have any indication that the number of specimens in our study may be too low to capture the full diversity.

122

123 REFERENCES

- 124 Açıkalın, S., Vellekoop, J., Ocakoğlu, F., Yilmaz, I. Ö., Smit, J., Altiner, S. Ö., Goderis, S., Vonhof, H.,
125 Speijer, R. P., Woelders, L., Fornaciari, E., Brinkhuis, H., 2015. Geochemical and
126 palaeontological characterization of a new K–Pg Boundary locality from the Northern
127 branch of the Neo-Tethys: Mudurnu – Göynük Basin, NW Turkey. *Cretaceous Research* 52,
128 251-267
- 129 Alegret L., Molina E., Thomas E., 2003. Benthic foraminiferal turnover across the
130 Cretaceous/Paleogene boundary at Agost (southeastern Spain): paleoenvironmental
131 inferences. *Marine Micropaleontology*, 48: 251-279.
- 132 Alegret L., Kaminski M.A., Molina E., 2004. Paleoenvironmental recovery after the
133 Cretaceous/Paleogene boundary crisis: evidence from the marine Bidart section (SW
134 France). *Palaios*, 19: 574-586.
- 135 Alegret L. and Thomas E., 2007. Deep-Sea environments across the Cretaceous/Paleogene
136 boundary in the eastern South Atlantic Ocean (ODP Leg 208, Walvis Ridge). *Marine*
137 *Micropaleontology*, 64: 1-17.
- 138 Brinkhuis, H., Bujak, J.P., Smit, J., Versteegh, G.J.M., Visscher, H., 1998. Dinoflagellate-based sea
139 surface temperature reconstructions across the Cretaceous-Tertiary boundary.
140 *Palaeogeography, Palaeoclimatology, Palaeoecology* 141, 67-83.
- 141 Eshet, Y., Almogi-Labin, A., Bein, A., 1994. Dinoflagellate cysts, paleoproductivity and upwelling
142 systems: A Late Cretaceous example from Israel. *Marine Micropaleontology* 23. 231-240.
- 143 Fisher, R. A., Corbet, S., Williams, C. B., 1943. The relationship between the number of species and
144 the number of individuals in a random sample of an animal population. *Journal of Animal*
145 *Ecology* 12 (1), 42-58.
- 146 Manger, G. E., 1963. Porosity and Bulk Density of Sedimentary Rocks: Contributions to
147 Geochemistry. USGS Bulletin 1144-E, 1963, 55 pp.
- 148 Sluijs, A., Brinkhuis, H., 2009. A dynamic climate and ecosystem state during the Paleocene-
149 Eocene Thermal Maximum: inferences from dinoflagellate cyst assemblages on the New
150 Jersey Shelf. *Biogeosciences* 6 (8), 1755-1781.
- 151 Speijer, R. P. and Van Der Zwaan, G. J. 1996. Extinction and survivorship of southern Tethyan
152 benthic foraminifera across the Cretaceous/Paleogene boundary, in *Biotic recovery from*
153 *mass extinction events*, edited by M. B., Hart, pp. 343–371, *Geolog. Soc. Spec. Publ.*, 102,
154 London.
- 155 Vellekoop, J., Smit, J., van de Schootbrugge, B., Weijers, J. W. H., Galeotti, S., Sinninghe Damsté, J. S.,
156 Brinkhuis, H., 2015. Palynological evidence for prolonged cooling along the Tunisian
157 continental shelf following the K-Pg boundary impact. *Palaeogeography, Palaeoclimatology,*
158 *Palaeoecology* 426, 216–228.

159

160

161 Figure S1

162 Relative abundances of hexaperidinioids of the Okçular section palynological samples
163 plotted against the relative abundances of sporomorphs within the same samples. This

plot indicates that the variations of the relative abundances of hexaperidinioids are likely not related to changes in freshwater input at this locality.

Figure S2

Number of specimens counted vs number of taxa encountered, for the 4 different stratigraphic intervals. Both within each stratigraphic interval, as well as between the different intervals, there is no clear relationship between number of specimens counted and number of taxa encountered.

Figure S3

Plate 1. SEM images of most common benthic foraminifera found in this study.

1 a, b, c. *Angulogavelinella avnimelechi* (Reiss). Okçular, 150 cm.

2 a, b, c. *Anomalinoides* cf. *midwayensis*. Okçular, -0.5 cm.

3 a, b, c. *Anomalinoides praeacutus* (Vasilenko). Okçular, 8-9 cm.

4 a, b, c. *Cibicidoides* cf. *hyphalus*. Okçular, 49-50 cm.

5 a, b, c. *Cibicidoides pseudoacutus* (Nakkady). Okçular, 8-9 cm.

6 a, b, c. *Cibicidoides* sp. 1. Okçular, 74-75 cm.

7 a, b, c. *Valvalabamina depressa* (Alth). Okçular, 49-50 cm.

8 a, b, c. *Pulsiphonina prima* (Plummer). Okçular, 99-100 cm.

9 a, b, c. *Gyroidinoides girardanus* (Reuss). Okçular, 350 cm.

10 a, b, c. *Osangularia plummerae* (Brotzen). Okçular, 29-30 cm.

Figure S4

Plate 2. SEM images of most common benthic foraminifera found in this study.

11 a, b, c. *Cibicidoides alleni* (Plummer). Okçular, -0.5 cm.

12. *Bolivinoidea draco draco* (Marsson). Okçular, -50 cm.

13. *Bulimina arkadelphiana* (Cushman and Parker). Okçular, -100 cm.

- 191 14. *Bulimina srobila* (Marie). Okçular, -0.5 cm.
- 192 15. *Sitella carseyae* (Plummer). Okçular, -0.5 cm.
- 193 16. *Eouvigerina subsculptura* (McNeil and Caldwell). Okçular, -50 cm.
- 194 17. *Coryphostoma midwayensis* (Cushman). Okçular, 350 cm.
- 195 18 a, b. *Dorothia oxycona* (Reuss). Okçular, 470 cm.
- 196 19. *Praebulimina reussi* (Morrow). Okçular, -100 cm.
- 197 20. *Gaudryina pyramidata* (Reuss). Okçular, 49-50 cm.
- 198 21. *Oolina orbignyana* (Kellough). Okçular, 150 cm.
- 199
- 200 .
- 201
- 202
- 203
- 204

Figure S1

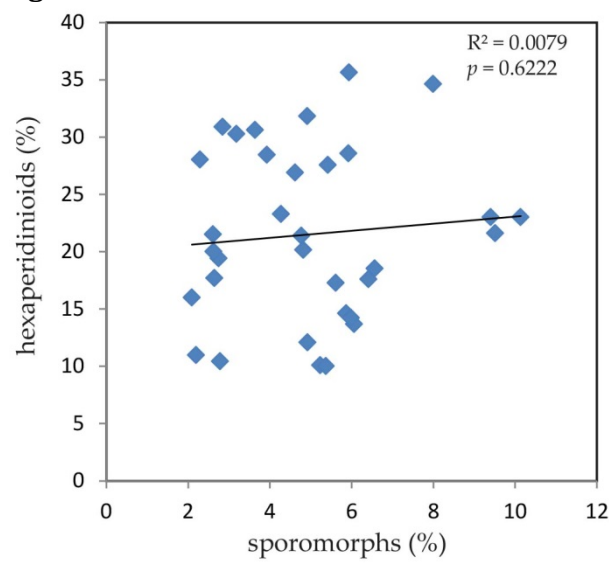
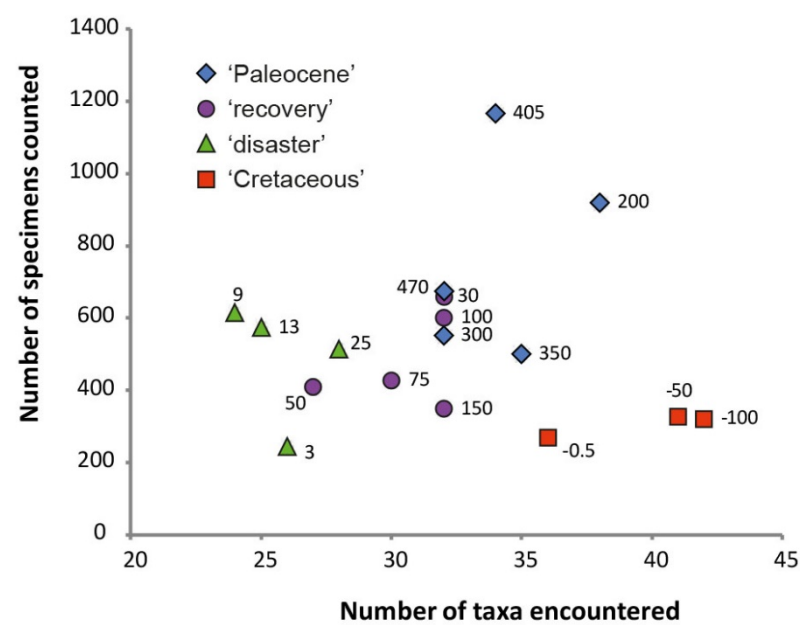
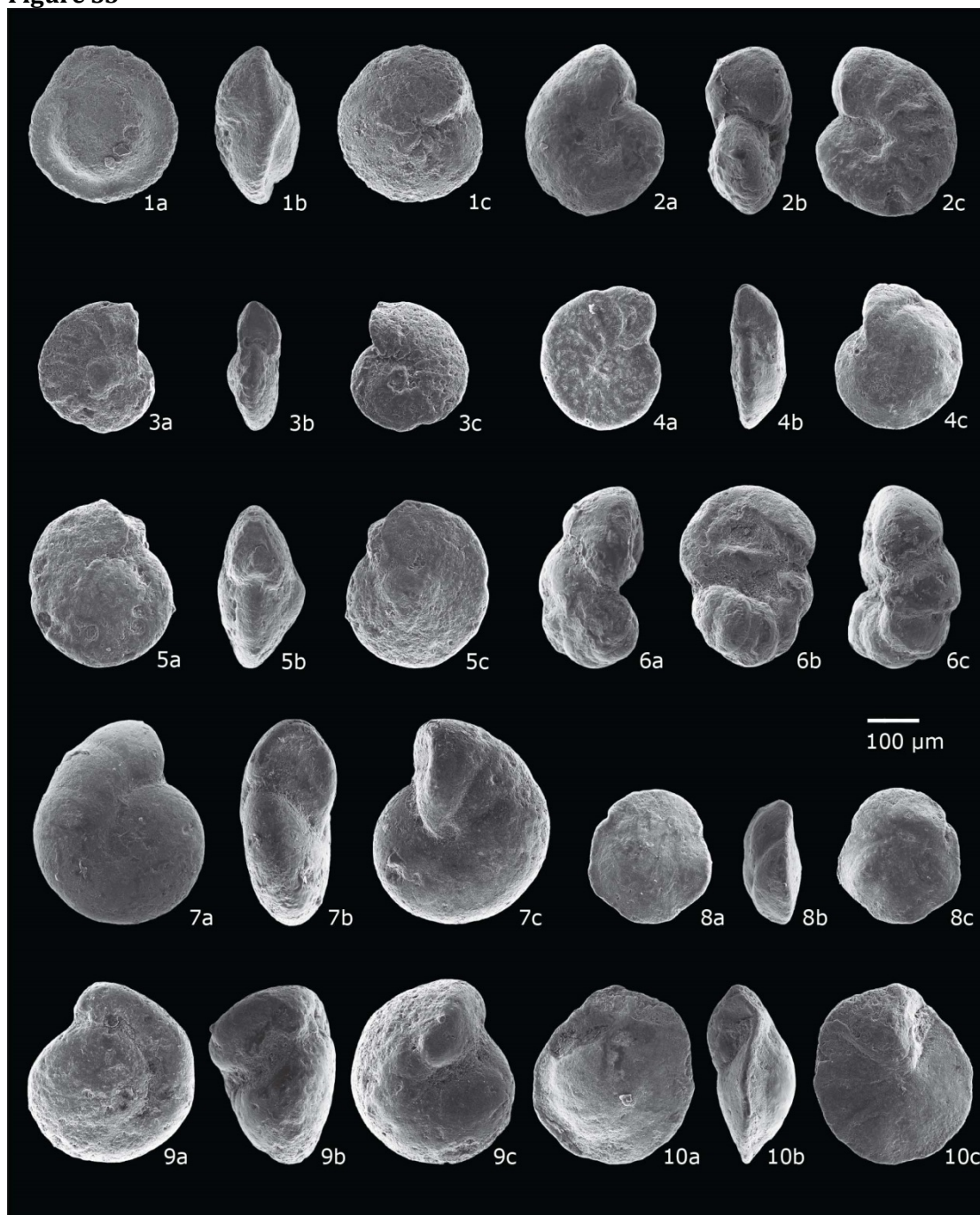
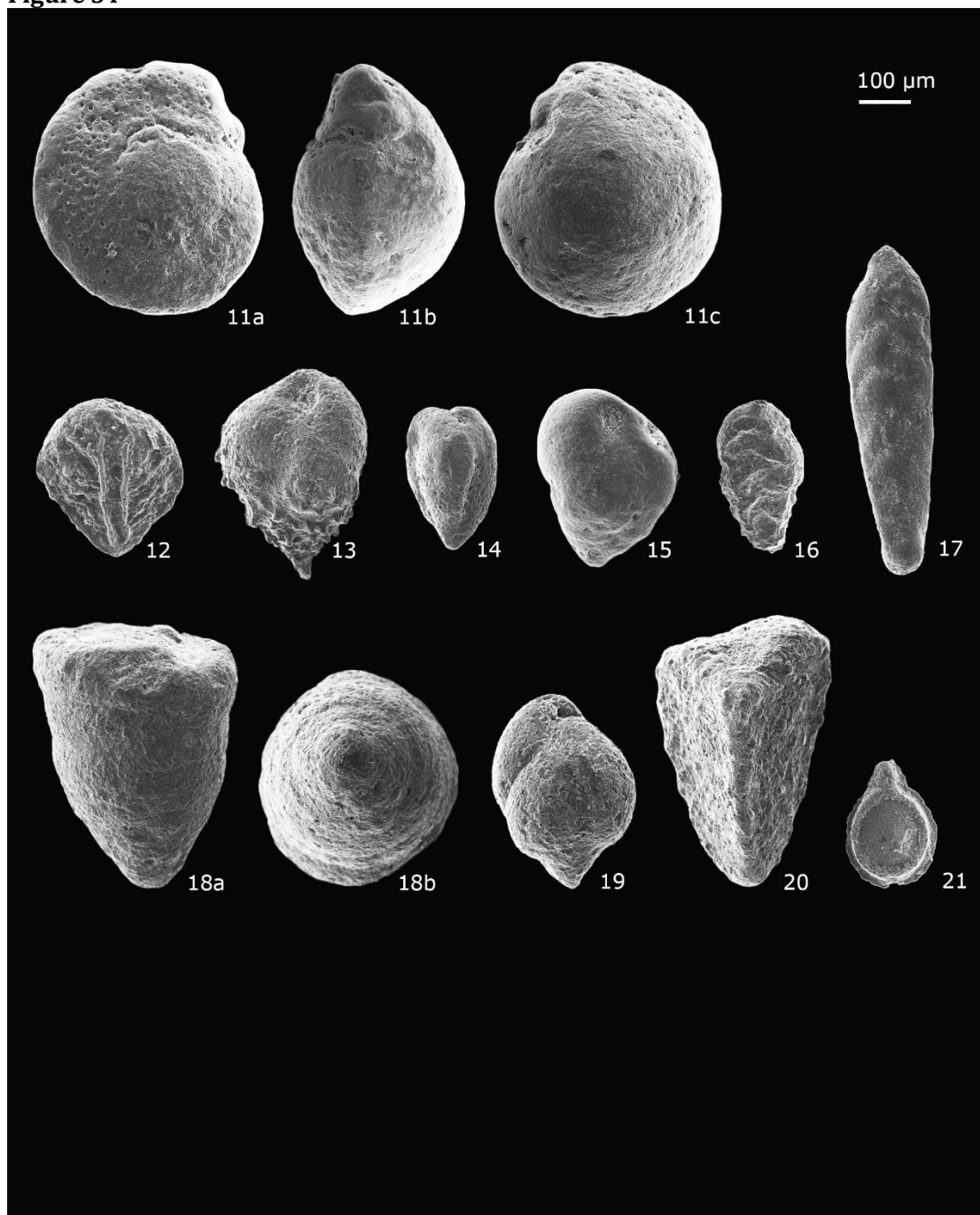


Figure S2





221 **Figure S4**



222
223

224

225 **Additional Supporting Information**

226 Captions for Data Sets S1 and S2

227

228 **Data Set S1**

229 Benthic foraminiferal counts of Okçular (Excell file)

230

231 **Data Set S2**

232 Palynological counts of Okçular (Excell file)

233