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7 Pteropoda (Mollusca, Gastropoda, Thecosomata) from the Eocene/Oligocene boundary  
8 interval of three cored boreholes in southern coastal Tanzania and their response to the  
9 global cooling event

10

11 Key words: planktic Gastropoda, *Altaspiratella*, *Heliconoides*, *Limacina*, *Bovicornu*, new  
12 species, geographical distribution, vertical ranges, Eocene-Oligocene transition (EOT)

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30 Laura J. Cotton

31 Naturalis Biodiversity Center, P.O. Box 9517, 2300 RA Leiden, The Netherlands; present

32 address: [Florida Museum of Natural History, 1659 Museum Road, University of Florida,](#)

33 [Gainesville, FL 32611, U.S.A and Department of Geological Sciences, University of](#)

34 [Florida, 241 Williamson Hall, Gainesville, FL32611, U.S.A .; lcotton@flmnh.ufl.edu](#)

35

36 Arie W. Janssen (corresponding author)

37 Naturalis Biodiversity Center, P.O. Box 9517, 2300 RA Leiden, The Netherlands;

38 [ariewjanssen@gmail.com](mailto:ariewjanssen@gmail.com)

39

40 Paul N. Pearson

41 Department of Earth and Ocean Sciences, Cardiff University, Main Building, Park Place,

42 Cardiff. CF10 3AT, United Kingdom; [PearsonP@cardiff.ac.uk](mailto:PearsonP@cardiff.ac.uk)

43

44 Rens van Driel

45 [Buys Ballotsingel 85A, 3112 JD, Schiedam, The Netherlands; rensvdriel@gmail.com](#)

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53 ABSTRACT

54 The Eocene - Oligocene Transition was a period of major climatic and oceanographic  
55 change, resulting in widespread biotic overturning. However, the record of many marine  
56 organisms remains patchy. Planktic Mollusca (Pteropoda) from three cored boreholes  
57 spanning the Eocene/Oligocene boundary (EOB) in southern coastal Tanzania are  
58 represented by eight species, three of which are introduced as new: *Heliconoides nikkieae*  
59 sp. nov., *Limacina tanzaniaensis* sp. nov. and *Limacina timi* sp. nov. Three of the other  
60 species can only be identified in open nomenclature. The two most commonly occurring  
61 species, *H. nikkieae* and *L. timi*, straddle the EOB without noticeable loss in abundance.  
62 Two species, *Limacina robusta* (Eames, 1952) and *L. tanzaniaensis* disappear before the  
63 EOB. The species *Bovicornu* aff. *eocenense* Meyer, 1886 disappears shortly after the  
64 EOB. Two species were only found in a single sample each, in the Eocene part of the  
65 succession. Response to changing environmental conditions seems to be demonstrated by  
66 two or three of the pteropod species only that become extinct before or shortly after the  
67 EOB.

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77 **Plain Language Summary**

78 A major cooling event took place between 33.5 and 34 Ma, known as the Eocene-  
79 Oligocene transition (EOT). The response of many marine micro-biota, such as  
80 foraminifera, has been well documented, however, records of other marine organisms,  
81 such as pteropods, are less well-known. Pteropods are planktic gastropods which spend  
82 their life in the water column, and are sensitive to changes in the ocean environment. Here  
83 we describe the assemblage and ranges of well-preserved pteropods through the EOT from  
84 three borehole records from Tanzania, an exceptionally understudied region. In total eight  
85 species were found in this material, three of which are new. The two most common  
86 species pass through the climatic event with no noticeable change in abundance. Three  
87 other species disappear during the transition, at a level similar to the planktic extinctions.  
88 The remaining species are too few to comment on. This demonstrates a likely response to  
89 the changing conditions, similar to some foraminiferal groups. Despite the small sample  
90 sizes, this study represents an important new record from an understudied region.

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93

## INTRODUCTION

94 The Eocene-Oligocene transition (EOT) was one of the most dramatic events of the  
95 Cenozoic, associated with major climatic disruption and widespread biotic turnover in  
96 both marine and terrestrial realms (see Coxall and Pearson, 2007 for review). High-  
97 resolution studies of the marine response have been carried out using planktic and benthic  
98 foraminifera, and nanno-fossils (e.g. Zachos et al., 1994; Molina et al., 1993; Diester-  
99 Haass et al., 2001; Lui et al., 2004; Wade and Pearson, 2008; Cotton and Pearson, 2011;  
100 Cotton et al., 2014). However, records of other marine groups are often patchy. Pteropods  
101 are planktic gastropods and are increasingly being used in studies of recent ocean records  
102 and climate change (Fabry, 1990; Wall-Palmer et al., 2012; Bednaršek and Ohman, 2015;  
103 references therein). Their aragonitic shells are susceptible to dissolution, making them  
104 excellent model organisms to study ocean acidification. However, palaeoecological data  
105 for older pteropod records are relatively uncommon, yet may add important information  
106 to the overall understanding of climatic impacts in the marine realm. Pteropods have a  
107 well-documented fossil record, but many regions remain understudied, and early well-  
108 preserved records are therefore exceptionally important (e.g., Janssen *et al.*, 2016).

109 The Eocene-Oligocene Transition (EOT) is an extended period of global oceanographic  
110 and climatic perturbation spanning between 33.5 - 34 Ma. The Eocene/Oligocene  
111 Boundary (EOB) is defined by the last occurrence of the planktic foraminiferal family  
112 Hantkeninidae at the Global Boundary Stratotype-Section and Point (GSSP) at  
113 Massignano, near Ancona, on the Italian Adriatic coast (Premoli Silva and Jenkins, 1993)  
114 which occurs at 33.7 Ma on the timescale of Cande and Kent (1995). However, an  
115 unreliable magnetostratigraphy and stable-isotope stratigraphy (Bodiselitsch *et al.*, 2004)

116 and lack of carbonate (macro)fossils (pers. observ. AWJ, August 1992) in the Massignano  
117 section prevented global correlation with climatic events. The additional fact that the  
118 occurrence of Hantkeninidae is mostly restricted to tropical and sub-tropical  
119 environments also made long-distance correlations (*e.g.*, to the North Sea Basin and in  
120 particular to the Priabonian stratotype) problematic. Subsequent studies of Deep Sea  
121 Drilling Project Site 522, showed that the extinction preceded the most positive oxygen  
122 isotopes of the EOT, representing the Early Oligocene Glacial Maximum (Zachos *et al.*,  
123 1994; Liu *et al.*, 2004). More recently this has been further refined.

124 The Kilwa District in southern Tanzania contains an apparently complete succession  
125 through the EOT, which was recovered by three Tanzanian Drilling Project boreholes  
126 (TDP 11, 12 and 17; Nicholas *et al.*, 2006; Pearson *et al.*, 2008). The dominant lithology  
127 consists of hemipelagic clays interspersed with debris flow limestones (Nicholas *et al.*  
128 2006). These clays contain exceptionally well preserved calcareous micro- and  
129 nannofossils, including aragonitic preservation (Pearson *et al.*, 2008; Wade and Pearson,  
130 2008; Bown *et al.*, 2008). This, coupled with the expanded nature of the sediments  
131 allowed for high resolution stratigraphy chemo-and biostratigraphy to be carried out and  
132 precise correlation to global records. This placed, for the first time, the extinction of the  
133 Hantkeninidae between the two positive isotope shifts of the transition (Pearson *et al.*,  
134 2008; Wade and Pearson, 2008); the first of which is attributed to temperature change and  
135 the second largely to ice-volume (Lear *et al.*, 2008). In addition, the site contains many  
136 other exceptionally well-preserved calcareous micro-fossils, including larger benthic  
137 foraminifera (Cotton and Pearson, 2011), bryozoans (Martino *et al.*, 2017),  
138 dasycladaceae, ostracodes and molluscs, including pteropods (Cotton *et al.*, in prep),

139 making Tanzania an exceptionally important site for the study of comparatively less  
140 ubiquitous fossils across the EOT. Studies of the molluscan record have shown that  
141 overall numbers of mollusc shells increase across the boundary (Cotton *et al.*, in prep),  
142 however, this study mainly examined the benthic forms. Here we present a detailed record  
143 of occurrences through the EOT interval and taxonomy of specifically the pteropod fauna  
144 from TDP 11, 12 and 17 (see Nicholas *et al.* 2006; Cotton and Pearson, 2011, for details  
145 on these boreholes). Though relatively few specimens were found due to the small sample  
146 size, the often excellent preservation and well-correlated nature of the record offers a  
147 unique insight into a region where no pteropod records were previously known.

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AWJ: tried to make that a bit more clear

148

#### MATERIAL AND METHODS

149

150 The Tanzania Drilling Project (TDP) was initiated in 2002 (Pearson *et al.*, 2004;  
151 Nicholas *et al.*, 2006, 2007) after preliminary field observations beginning in 1998  
152 (Pearson *et al.*, 2001) on numerous outcrops between the towns of Kilwa and Lindi,  
153 southern Tanzania, had demonstrated the presence of well-preserved microfossil  
154 assemblages of Cretaceous to Paleogene age. The TDP focused on generating litho- and  
155 biostratigraphic, geochemical, micropalaeontological and palaeoclimatic records, and  
156 resulted in recovery of over 40 cored boreholes, covering Cretaceous (Aptian) to  
157 Paleogene (Oligocene) sediments (Pearson *et al.*, 2004, 2006; Nicholas *et al.*, 2006;  
158 Jiminez-Berrucoso *et al.*, 2010, 2012, 2015). These sediments are formally defined as the  
159 Kilwa Group and were initially subdivided into four formations: The Nangurukuru,  
160 Kivinje, Masoko and Pande formations (Nicholas *et al.*, 2006), to which a fifth was  
161 recently added, the Lindi formation (Jiminez-Berrucoso *et al.*, 2015). The Pande

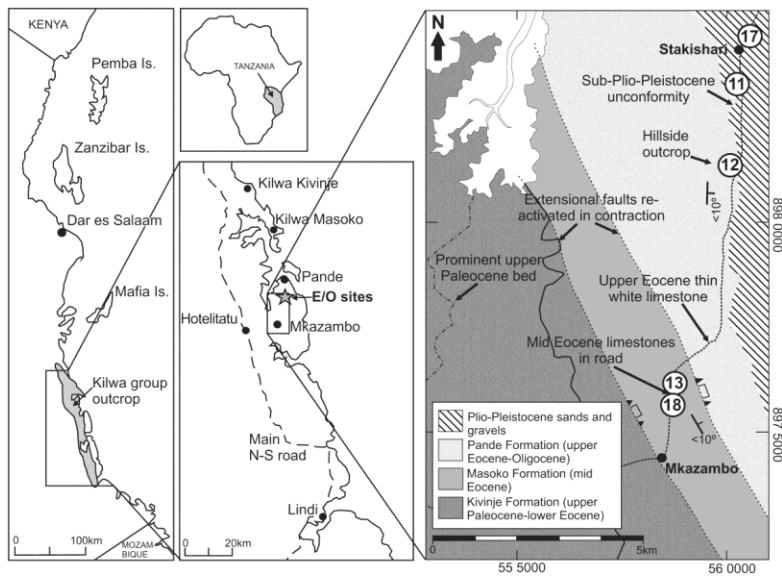


162 Formation contains an apparently conformable succession through the EOT and was  
163 recovered in three boreholes drilled approximately along strike of each other (Figure 1):  
164

165 TDP 11: South of Stakishari (Tanzania, Kilwa region), coordinates UTM 37L 560250  
166 8983211; pteropod specimens are available from four samples TDP11.26.2, 64-74 cm, to  
167 TDP11.33.2, 74-84 cm.

168  
169 TDP 12: South of Stakishari (Tanzania, Kilwa region), coordinates UTM 37L 560222  
170 8981309; pteropods are available from 16 samples TDP12.11.4, 20-26 cm, to TDP12.29.2,  
171 20-30 cm.

172  
173 TDP 17: Stakishari (Tanzania, Kilwa region), coordinates UTM 37L 560539 8984483;  
174 pteropod specimens available from 36 samples 17.15.1, 50-63 cm, to 17.41.3, 0-15 cm.  
175



176

177 **Figure 1.** Location and geological map of the Tanzanian Drilling Project

178 Eocene/Oligocene boundary sites (TDP 11, 12 and 17), additional Tanzanian Drilling

179 Project sites in the area are also shown, modified from Nicholas *et al.* (2006). After

180 Cotton and Pearson, (2011).

181

182 Based on micropalaeontological event correlations the three sections were given “composite

183 depths” to enable direct comparison of results between the three sites (Pearson *et al.*, 2008).

184 These composite depths are specified in the distribution tables following the systematical

185 part..

186 The meters added are, for TDP 17 cores 1-35: 0 m; for TDP17 cores 36-42: 12 m; for

187 TDP11 cores 1-28: 17 m, and for TDP11 cores 29-36: 20 m.

188 **The Eocene Tanzanian shelf is thought to have been narrow, much like today, and the three**

189 **boreholes are estimated to be approximately 50 km from the palaeo-shoreline (Kent et al.,**

190 1971; Nicholas *et al.*, 2006, 2007). Based on the sedimentary facies and smaller benthic  
191 foraminiferal assemblage the palaeo-depth is estimated to be approximately 300-500 m,  
192 although it is possible it is deeper than this (Nicholas *et al.*, 2006; 2007). The dominant  
193 sediment is dark green-grey clay with < 10% CaCO<sub>3</sub>.  
194 The half-round core-samples of the hemi-pelagic clays, varying in length from 1.5 to 15 cm,  
195 were washed through a 63 µm sieve and the residues dried (Lear *et al.*, 2008; Pearson *et al.*,  
196 2008; Wade and Pearson, 2008). Pteropods were then picked using a paintbrush under a  
197 binocular microscope.  
198 The Kilwa Group is characterised by excellent preservation of its carbonate microfossils,  
199 this extends to the pteropods, which is related to the high clay content and shallow  
200 maximum burial depth (Pearson *et al.*, 2001; Van Dongen *et al.*, 2006; Bown *et al.*,  
201 2008). However, the condition of pteropod specimens varies from perfect shell  
202 preservation to shells filled with pyrite and specimens preserved as pyritic internal  
203 moulds with partly or completely dissolved aragonitic shell material. Local dissolution  
204 may be related to pyritisation. Some specimens are badly deteriorated and indeterminate.  
205 Specimens are housed in the fossil holoplanktic mollusc collection of Naturalis  
206 Biodiversity Center, Leiden (The Netherlands), registered with RGM-registration  
207 numbers.

208

#### 209 **Scanning electron microscopy**

210 SEM micrographs were made by Renate Helwerda from uncoated specimens at 1.000 kv  
211 with a Jeol Field emission scanning electron microscope type: JSM-7600F at Naturalis  
212 Biodiversity Center, Leiden, The Netherlands.

213

214 **Micro - Computed Tomography**

215 Micro-computed tomography (Micro-CT or X-ray microtomography) scanning of the  
216 three holotypes (RGM 777415a, RGM 777428b and RGM 1007748b) was carried out by  
217 Dirk van der Marel, of Naturalis Biodiversity Center in Leiden, the Netherlands, using a  
218 Bruker SkyScan 1172 micro-CT scanner. 1601 projections of 3 -15 sec exposure were  
219 collected with a 2000x1336 detector, using a source voltage of between 80 and 140 kV.  
220 No filtration was used, and the scan provided a reconstructed dataset with 0.8 – 1.4  $\mu\text{m}$   
221 voxels.

222 The pteropod shells were segmented in Avizo 9.0.0. and surface files exported as .wrl.  
223 The files were subsequently edited in Meshlab 1.3.3. Laplacian smoothing was applied  
224 and Quadric Edge collapse Decimation used, reducing the polygon count by  
225 approximately a factor of 10. Files were saved as .ply and u3d for viewing as three  
226 dimensional PDFs.

227

228 **SYSTEMATICS (AWJ)**

229 Phylum **MOLLUSCA** Linnaeus, 1758

230 Class **GASTROPODA** Cuvier, 1795

231 Subclass **HETEROBRANCHIA** Burmeister, 1837

232 Superorder **PTEROPODA** Cuvier, 1804

233 Order **THECOSOMATA** de Blainville, 1824

234 Suborder **EUTHECOSOMATA** Meisenheimer, 1905

235 Superfamily **LIMACINOIDEA** Gray, 1847

**Commented [LC2]:** Do we need to remove this as suggested by the editors comments?  
A WJ: No, that would be quite unusual.

236 Family LIMACINIDAE Gray, 1847

237 Genus ALTASPIRATELLA Korobkov, 1966 (= *Plotophysops* Curry, 1982)

238

239 *Type species.* – “*Limacina elongatoides*” [sic] (Aldrich), by original designation of

240 Korobkov (1966, p. 74) = *Physa elongatoidea* Aldrich, 1887 = *Altaspiratella*

241 *elongatoidea* (Aldrich, 1887) (Eocene, early Ypresian, Wilcox Group, Hatchetigbee

242 Formation, Bashi Member; zone NP 10).

243

244

245 *Altaspiratella bearnensis* (Curry, 1982)

246 Figure 2.1-2

247

248 \*v 1982 *Plotophysops bearnensis* Curry, p. 40, pl. 1, figure 9a-c.

249 v. (1986) *Spiratella tutelina* Curr. – Merle, p. 43 (*non* Curry).

250 v. 1990b *Altaspiratella bearnensis* (Curry 1981) – Janssen, p. 68.

251 ? 1992 *Altaspiratella bearnensis* (Curry) – Hodgkinson *et al.*, p. 13, pl. 1, figures 1,

252 2.

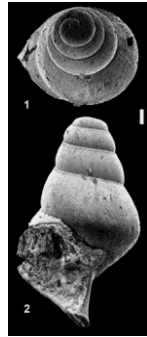
253 . (1996) *Altaspiratella bearnensis* (Curry, 1981) – Kunz, p. 164, pl. 30, figures. 1-3.

254 v. 2010 *Altaspiratella bearnensis* (Curry, 1982) – Cahuzac and Janssen, p. 24, pl. 2,

255 figures 1-4, pl. 3, figure 1.

256 v. 2013 *Altaspiratella bearnensis* – King *et al.*, pp. 192, 193.

257



258

259 **Figure 2.** *Altaspiratella bearnensis* (Curry, 1982); RGM 777374. TDP 12.28.1, 66-76  
260 cm; 1: apical view, 2: apertural view. Bar = 100  $\mu$ m.

261

262 *Material examined.* – TDP 12.28.1, 66-76 cm, depth 90.91-91.01 m below surface,  
263 composite depth 148.91-149.01 m (Table 2); RGM 777374 (1 specimen, Fig. 2.1-2, H =  
264 1.36, W = 0.80 mm).

265

266 *Description.* – Only available specimen with high conical shell, 1.7 times higher than  
267 wide, and apical angle of *c.* 40°. Four and a half slightly convex and comparatively high  
268 whorls, regularly increasing in diameter and separated by incised, oblique suture. Whorls  
269 attach below periphery of preceding whorl. Specimen incomplete, last whorl missing, in  
270 shell preservation, but filled with pyrite.

271

272 *Discussion.* – Two closely resembling *Altaspiratella* species are currently known.

273 *Altaspiratella elongatoidea* (Aldrich, 1887) occurred during the earliest Eocene  
274 (Ypresian, nannoplankton zones NP 9 and 10) of the USA (Hodgkinson *et al.*, 1992;  
275 Janssen *et al.*, in review); *A. bearnensis* (Curry, 1982), introduced from the Ypresian

276 (zone NP 12/13) of SW France, is also known from the USA (with some doubt) in rocks  
277 of middle Eocene, Lutetian age (zone NP 15). These two species differ only very slightly  
278 in the proportions of their early whorls. Of *A. elongatoidea* no specimens preserving  
279 apertural structures are known, so there might be differences in that respect as well.  
280 In the single available specimen from Tanzania apertural structures are missing and its  
281 apical whorls take a position in between the two known species mentioned above. This  
282 could be an indication that these two taxa represent a single, long-ranging species.  
283 However, as long as apertural structures cannot be compared it seems better to keep them  
284 apart and the one available Tanzanian specimen is here considered, for the time being, to  
285 be the youngest representative of the *A. elongatoidea* - *A. bearnensis* lineage. The  
286 specimen extends the vertical range to the Priabonian (Zones P 16-17, NP 19-20;  
287 Nicholas *et al.*, 2006, figure 16).

288

289 Genus HELICONOIDES d'Orbigny, 1835

290

291 *Type species.* – *Atlanta inflata* d'Orbigny, 1834, by subsequent designation of  
292 Herrmannsen (1846, p. 514) = *Heliconoides inflatus* (d'Orbigny, 1834) (Recent).

293

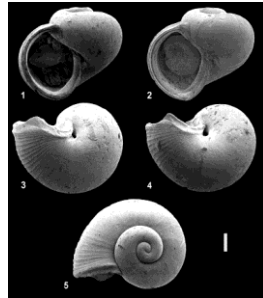
294 *Heliconoides nikkieae* sp. nov.

295 Figures 3.1-5; 4

296

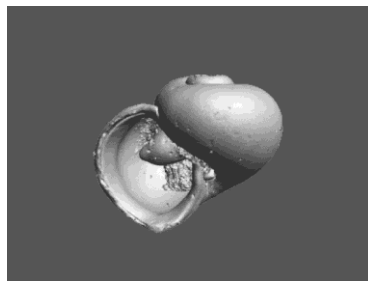
297 *Type material.* – Holotype RGM 777415a (Fig. 3.1); paratypes 1-2, RGM 777415b-c  
298 (Figures 3.3, 3-5) from the type locality. Kilwa Group, Pande Formation (upper Eocene,

299 Priabonian), biozones P 18 and NP 21; paratype 3, RGM 777 381 (Fig. 3-4), from TDP  
300 17.21.1, 9-20 cm, Kilwa Group, Pande Formation (early Oligocene, Rupelian), biozones  
301 P18 and NP 21.



302  
303 **Figure 3.** *Heliconoides nikkieae* sp. nov.; 1: **Holotype**, RGM 777415a, apertural view;  
304 2: apertural view, specimen lost; 3: **paratype 1**, RGM 777415b, umbilical view; 4:  
305 **paratype 3**, RGM 777 381, umbilical view; 5: **paratype 2**, RGM 777415c, apical view.  
306 Figures 3-1, -2, -3 and -5 from the type locality, TDP 17.36.1, 10-25 cm; Figure 3-4 from  
307 TDP 17.21.1, 9-20 cm. Bar = 100  $\mu$ m.

308



309  
310 **Figure 4.** *Heliconoides nikkieae* sp. nov.; **holotype**, RGM 777415a, 3dPDF.  
311



312 *Additional specimens.* – TDP 11 (2 specimens), 12 (1 specimen) and 17 (49 specimens,  
313 some of which with a query because of poor preservation) (Tables 1-3).

314

315 *Type locality.* – Stakishari (Tanzania, Kilwa region), cored borehole TDP 17, sample  
316 17.36.1, 10-25 cm, 104.00-104.10 m below surface, composite depth 116.00-116.10 m.

317

318 *Etymology.* – Named after Nikkie Elert, the author's second granddaughter. At age six she  
319 is, in many respects, more up-grown than many grown-ups. *Heliconoides* gender  
320 masculine (ICZN 1992, art. 30.1.4.4).

321

322 *Diagnosis.* – Very small limacinid of 2.5 whorls in low-conical spiral, about as high as  
323 wide, with large aperture, apertural margin externally thickened and internally doubled in  
324 some specimens (Figure 3-2), basal margin with denticle. Apertural margin preceded by  
325 about ten fine, margin parallel riblets.

326

327 *Description.* – Strikingly small limacinid of 2.5 whorls, height/width-ratio variable  
328 between *c.* 1.19 (holotype H = 0.62, W = 0.52 mm, Figure 3-1) and 0.89 (*e.g.*, H = 0.50,  
329 W = 0.56 mm, Figure 3-2), with depressed, low conical spire and distinct, incised suture.  
330 Shell surface smooth and shiny, growth lines invisible. Last whorl large, occupying  
331 almost entire shell height. Aperture relatively large, slightly higher than wide to almost  
332 circular, occupying 4/5th of entire shell height. Apertural margin externally thickened by  
333 narrow ridge, running all around margin, flexuous at base of shell, reaching umbilicus,  
334 internally (Figure 3-2) in some specimens. Protruding denticle on basal part of margin

335 (Figures 3-3 and -4). Marginal thickening preceded by about ten fine, margin parallel  
336 orthocline riblets. Shell base regularly rounded, umbilicus very narrow, *c.* 1/20th of shell  
337 diameter.

338

339 *Discussion.* – In general shape the new species resembles somewhat the holotype of  
340 *Limacina wechesensis* Hodgkinson (1992, p. 21, pl. 5, figures 4-6) from the Lutetian of  
341 Texas, USA, but that species has one whorl more and reaches double the size of *H.*  
342 *nikkieae*, does not have the apertural structures of that species and its umbilicus is  
343 considerably wider.

344 Size and apertural structures of the new species form a unique combination and cannot be  
345 compared to any limacinid currently known. The holotype was chosen from the sample  
346 with most specimens (13) of Priabonian age, but the species continues, in low numbers,  
347 well into the Rupelian part of the TDP 17 section.

348

349

350 Genus LIMACINA Bosc, 1817

351

352 *Type species.* – *Clio helicina* Phipps, 1774 by monotypy = *Limacina helicina* (Phipps,  
353 1774) (Recent).

354

355 *Limacina robusta* (Eames, 1952)

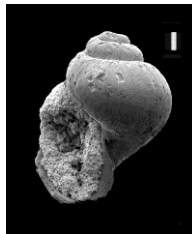
356 Figures 5, 6

357 \*1952 *Aplexa robusta* Eames, p. 152, pl. 6, figure 149.

358

359 *Type material.* – Holotype (Figure 6) in the Natural History Museum, London, NHMUK  
360 BM 68457, presented by the Burma Oil Co. Ltd, March 1950; Eames (1952) furthermore  
361 recorded 19 paratypes from the type locality.

362



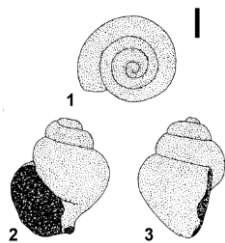
363

364 **Figure 5.** *Limacina robusta* (Eames, 195). TDP 17.37.1, 0-13 cm; RGM 777423b,  
365 apertural view. Bar = 100  $\mu$ m.

366

367 *Type locality.* – Rahki Nala (Pakistan, western Punjab), 255' above base, local zone 9.  
368 Lower Chocolate Clays; according to Afzal *et al.* (2009, p. 20) nowadays indicated as  
369 Rahki Nala (Pakistan, western Punjab), 255' above base, local zone 9. Lower Chocolate  
370 Clays; according to Afzal *et al.* (2009, p. 20) nowadays indicated as Kirthar Formation of  
371 late Lutetian - Priabonian age of late Lutetian - Priabonian age.

372



373

374 **Figure 6.** *Limacina robusta* (Eames, 1952), **Holotype**, Natural History Museum, London  
375 BM 68457. Rahki Nala (Pakistan, western Punjab); Kirthar Formation, Lower Chocolate  
376 Clays (late Lutetian – Priabonian); 1: apical, 2: apertural, 3: lateral view. Bar = 100  $\mu$ m.

377

378 *Material examined.* – TDP 11 (1 specimen), TDP 12 (1 specimen), TDP 17 (16  
379 specimens, all from the Priabonian), see Tables 1-3 for specification.

380

381 *Description.* – Most available specimens are juveniles and most in pyritic internal mould  
382 preservation. Largest and best preserved specimen (Fig. 5) higher than wide (H = 0.94, W  
383 = 0.72 mm) with four convex whorls rapidly increasing in diameter. Aperture large, oval,  
384 occupying more than half shell height. Base of shell regularly rounded with narrow  
385 umbilicus.

386

387 *Discussion.* – Most of the available specimens are poorly preserved and juvenile, but the  
388 illustrated Tanzanian specimen (Fig. 5)  
389 has a shell height of 0.94 mm, whereas the holotype of *Limacina robusta* has a shell  
390 height of 0.75 mm. Some of the smaller specimen have a somewhat wider apical angle  
391 than the illustrated specimen. In spite of these small differences the Tanzanian specimens  
392 are thought to represent the same species as the Pakistanian *L. robusta*, which has a  
393 comparable age and was described from a pre-eastern-Paratethys locality under influence  
394 of the Indian Ocean.

395 Initially the Tanzanian specimens were thought to represent *Limacina conica* (von  
396 Koenen, 1892, p. 994, pl. 62, figures 5-6), a species described from the “early Oligocene”

397 of two localities (Atzendorf, Unseburg) in the eastern part of Germany. However,  
398 specimens from Atzendorf (NP 21 interval), made available by Arnold Müller (Leipzig,  
399 Germany) differ in shape and reach far larger dimensions. Their apical angle is smaller,  
400 the whorls are more convex and the aperture remains smaller than half shell height.  
401 Several species described by Hodgkinson *et al.* (1992), from the Paleogene of the United  
402 States also resemble the Tanzanian shells. Especially similar is *Limacina smithvillensis*  
403 Hodgkinson (*in Hodgkinson et al.*, 1992, p. 19, pl. 3, figure 16) from the Lutetian of  
404 Texas. However, that species reaches a shell height of 1.5 mm, has less convex whorls, a  
405 wider apical angle and its aperture occupies just half the shell height. Finally, that species  
406 is considerably older (Lutetian, NP 15) than the Priabonian (NP 21) specimens from  
407 Tanzania. At first glance also *L. stenzeli* Garvie (*in Hodgkinson et al.*, 1992, p. 19, pl. 4,  
408 figure 1) from the NP13-14 interval (Ypresian) of Texas is similar. However, that species  
409 should be included in the genus *Heliconoides*, because of its reinforced apertural margin.

410

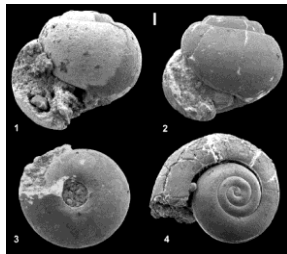
411 *Limacina tanzaniaensis* sp. nov.

412 Figures 7.1-4; 8

413

414 *Type material.* – Holotype (Fig. 7.1) RGM 777428b; paratype 1 (Fig. 7.2), RGM 777438;  
415 paratypes 2 and 3 (Figures 7.3-4) RGM 777416b-c. Kilwa Group, Pande Formation  
416 (Eocene, Priabonian, biozones P 18 and NP 21).

417



418

419 **Figure 7.** *Limacina tanzaniaensis* sp. nov. 1: **Holotype**, apertural view, RGM 777428b,  
420 TDP 17.38.2, 22-29 cm; 2: **paratype 1**, apertural view, RGM 777438, TDP 17.36.2, 80-  
421 95 cm; 3: **paratype 2**, umbilical view, RGM 777416b, TDP 17.36.1, 10-25cm; 4:  
422 **paratype 3**, apical view, RGM 777416c, same data as 3. Bar = 100  $\mu$ m.

423

424 *Additional specimens.* – Fourteen specimens from TDP 17 (Table 3), all from the  
425 Priabonian part of the section. Most specimens poorly preserved as pyritic internal  
426 moulds.

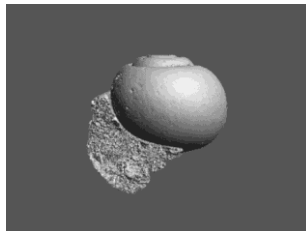
427

428 *Type locality.* – Stakishari (Tanzania, Kilwa region), cored borehole TDP 17.38.2, 22-29  
429 cm, 111.12-111.19 m below surface = 123.12-123.19 m composite depth.

430

431 *Diagnosis.* – Spherical limacinid of almost four whorls, apex flattened. Last whorl  
432 inflated, 95% of total shell height, aperture *c.* 75% of total shell height, margin simple,  
433 base of shell umbilicate.

434



435

436 **Figure 8.** *Limacina tanzaniaensis* sp. nov.; **holotype**, apertural view, RGM 777428b,  
437 3dPDF.

438

439 *Description.* – Limacine of spherical shape, measurements of holotype H = 0.92, W =  
440 1.00 mm, consisting of 3.75 moderately convex whorls with convex tangent. First two  
441 whorls flattened, last whorl very large, inflated, occupying 95% of total shell height.  
442 Aperture large, about 75% of total shell height, attaching on (holotype, Fig. 7.1) or  
443 slightly below (paratype 1, Fig. 7-2) periphery of penultimate whorl. Apertural margin  
444 simple, semicircular, inner margin and columella invisible as all specimens are in pyritic  
445 internal mould preservation. Base of shell regularly rounded, umbilicus present, 20-25%  
446 of shell diameter.

447

448 *Discussion.* – The available specimens demonstrate variability in height of the apex, in  
449 some the initial flattening continues to the third whorl, resulting in an only slightly raised  
450 apical shell part. There is some resemblance to the Ypresian species *Limacina heatherae*  
451 Hodgkinson in Hodgkinson *et al.* (1992, p. 17, pl. 2, figures 15-18). In that species,  
452 however, the whorls attach higher on the foregoing whorl, the aperture is narrower and its  
453 umbilicus smaller.

454

455

*Limacina timi* sp. nov.

456

Figures 9.1-4; 10

457

458 *Type material.* – Holotype (Fig. 9-1), RGM 1007748b; paratype 1 (Fig. 9-2),

459 RGM777408a, from TDP 17.34.1, 0-7 cm, 98.90-98.97 m below surface and composite

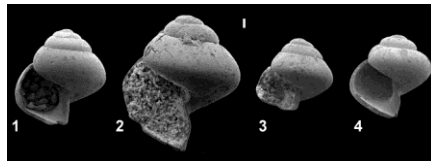
460 depth; paratype 2 (Fig. 9-3), RGM 777408b, TDP 17.34.1, 0-7 cm; paratype 3 (Fig. 9-4),

461 RGM 777414m TDP 17.36.1, 0-5 cm. Kilwa Group, Pande Formation (Eocene,

462 Priabonian); planktic foraminefera zone P 16-17, calcareous nannoplankton zone NP 19-

463 20.

464



465

466 **Figure 9.** *Limacina timi* sp. nov.; 1: **holotype**, RGM 1007748b, TDP 12.27.1, 35-45 cm;

467 2: **paratype 1**, RGM 777408a TDP 17.34.1, 0-7 cm; 3: **paratype 2**, RGM 777408b, TDP

468 17.34.1, 0-7 cm; 4: **paratype 3**, RGM 777414m TDP 17.36.1, 0-5 cm. Apertural views,

469 bar = 100  $\mu$ m.

470

471 *Additional specimens.* – Boreholes TDP 11, 12 and 17: 15 specimens (see Tables 1 and

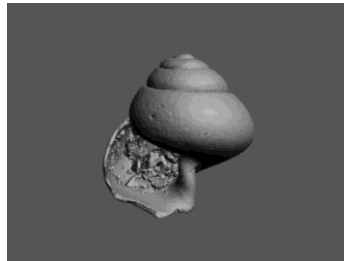
472 3).

473



474 *Type locality.* – South of Stakishari, Tanzania, Kilwa Region, cored borehole TDP 12,  
475 coordinates UTM 37L 560222-8981309, sample TDP 12.27.1, 35-45 cm = 89.60-89.70 m  
476 below surface = 147.60-147.70 m composite depth.

477



478

479 **Figure 10.** *Limacina timi* sp. nov.; **holotype**, RGM 1007748b, 3dPDF.

480

481 *Etymology.* – Named after Tim Janssen, the author's six year old second grandson. For  
482 him life is nonstop fun. Keep it that way, my friend!

483

484 *Diagnosis.* – Small limacine of 3.75 whorls, slightly higher than wide. Whorls rounded  
485 angular in juveniles, more regularly rounded in adults. Aperture lunate, somewhat higher  
486 than half shell height. Base imperforate.

487

488 *Description.* – Holotype (H = 1.04, W = 1.00 mm) a small, regularly coiled, conical  
489 limacine of 3.75 slightly convex whorls, separated by incised suture. Last whorl  
490 occupying 80% of shell height, slightly angular at periphery. Shell surface smooth,  
491 growth lines invisible. Aperture large, lunate, 65% of shell height, no apertural  
492 reinforcements present. Columellar side of aperture smooth, slightly concave internally,

493 straight externally. Base of shell regularly convex, umbilicus absent in holotype,  
494 extremely small or absent in juveniles. Angularity of whorls more clearly developed in  
495 juvenile specimens, resembling a rounded keel, but covered by following whorls  
496 attaching at the place of angularity, almost disappeared in adults. Juvenile specimens  
497 wider than high, in some of these the keel is rather strong and the apical angle wider  
498 (RGM 777425).

499

500 *Discussion.* – The angularity of especially juvenile specimens is not very clearly visible in  
501 the SEM images given here in Figures 9.3-4, but under light microscope, with  
502 illumination from left above it cannot be overlooked.

503 *Limacina timi* resembles somewhat the Ypresian species *L. gormani* (Curry, 1982)  
504 described from the Marnes de Gan Formation, of Gan, SW France (Curry, 1982; Cahuzac  
505 and Janssen, 2010). The same species or a closely related form was also described from  
506 the Stone City and Cook Mountain formations (Lutetian/Bartonian) of Texas, USA  
507 (Hodgkinson *et al.*, 1992, p. 19, pl. 3, figures 14-15) as *Limacina pygmaea* (*non* Lamarck,  
508 1805), in which also the juvenile whorls are angular and the base imperforate. The adult  
509 shell, however, reaches one and a half times the size of *L. timi*, has a different, more  
510 spherical shape and a distinctly wider apical angle. Subsutural crests (Cahuzac and  
511 Janssen, 2010, pl. 11, figure 2) as seen in *L. gormani* are not present in *L. timi*.

512 Adult specimens of *Limacina timi* also resemble *Heliconoides nemoris* (Curry, 1965),  
513 described from the Bartonian of the UK and also recorded from the Priabonian of Biarritz,  
514 SW France by Curry (1982) and Cahuzac and Janssen (2010). That species belongs to the  
515 genus *Heliconoides* because of its apertural reinforcements that are apparently absent in

516 *L. timi*, but also its apex is flattened and juvenile specimens have no angular periphery.

517 *Limacina timi* straddles the Eocene/Oligocene boundary.

518

519

520 *Limacina* sp. 1

521 Figures 11.1-2

522

523 *Material examined.* – Five specimens, all from the same sample TDP 17.37.1, 0-13 cm;

524 106.90-107.03 m below surface, 118.90-119.03 composite depth; RGM 777440a-c (Table

525 3).



526

527 **Figure 11.** *Limacina* sp. 1. 1: RGM 777440c, TDP 17.37.1, 0-13 cm, apical view; 2:

528 RGM 777440b, same data, apertural view. Bar = 100  $\mu$ m.

529

530 *Description.* – Low conical limacinid of 3.75 moderately convex whorls attaching on

531 periphery of foregoing whorls. Aperture semicircular, slightly more than half shell height,

532 Base regularly rounded, umbilicus *c.* 1/6th of shell diameter.

533

534 *Discussion.* – Three of the available specimens are juveniles in poor preservation. In  
535 specimen RGM 777440b (Fig. 11.2) the first whorl is missing. The two more adult  
536 specimens show a striking resemblance with a limacinid illustrated by Lokno and Kumar  
537 (2008, figure 3-2) from the Upper Disang Formation (Bartonian - Priabonian) of the Phek  
538 District, south-central Nagaland (Assam - Arakan Basin), northeastern India, indicated by  
539 these authors as “Limacinidae type A”. As these specimens were recorded from Indian  
540 Ocean Basin rocks of more or less similar age they could very well represent the same  
541 species as the Tanzanian ones. However, the material is insufficient for a reliable  
542 identification. Lokno and Kumar compared their specimens with “*Limacina pygmaea*”, as  
543 illustrated by Hodgkinson *et al.* (1992, pl. 3, figures 14-15), correctly stating that that  
544 name “most certainly is incorrect”, as Hodgkinson *et al.*’s species seems to be closely  
545 related to *L. gormani* (Curry, 1982) (see above) and not to *Limacina pygmaea*.

546

547 *Limacina* sp. 2

548 Figures 12.1-4

549

550 *Material examined.* – One specimen from TDP 12 (Table 2); 4 poorly preserved and  
551 presumably juvenile specimens in pyritic internal mould preservation, from TDP 17  
552 (Table 3).

553



554

555 **Figure 12.** *Limacina* sp. 2, RGM 777373, TDP 12.27.1, 35-45 cm; 1: apertural, 2: apical,  
556 3: oblique apical, and 4: umbilical views. Bar = 100  $\mu$ m.

557

558 *Description.* – Limacinid of very low conical shape with almost flat, slightly raised or  
559 slightly concave apical plane. Width of illustrated specimen 1.20 mm, height 0.86 mm.  
560 Whorls 3.75, regularly increasing in diameter. Aperture semicircular, occupying *c.* 80%  
561 or more of total shell height, reaching to far beyond base of preceding whorl. Apertural  
562 structures absent or not preserved. The apparently present groove along the apertural  
563 margin, as visible in Fig. 13.2-3, is considered to be caused by damage of the mould. Base  
564 perforated by umbilicus of 1/5th to 1/7th of shell diameter.

565

566 *Discussion.* – Several limacinids with an almost planorboid shell shape are known from  
567 the Eocene-Oligocene interval in Europe, Asia and the USA. Some of these are  
568 characterised by having a slightly concave apical plane, or, in other cases, by an irregular

569 development of early whorls. In the present specimens, however, the whorls are in a  
570 regular spiral and the apical plane is a bit raised, with the first 1.5 whorls flattened (Fig.  
571 12.3).

572 Very similar is a species from the early Oligocene of Japan, described as *Limacina*  
573 *karasawai* Ando (2011, p. 248, figures 3.1-2. This species was said to have three quarters  
574 of a whorl more than the Tanzanian specimen illustrated here, but we fail to see that from  
575 Ando's photographs. Also closely similar is *Limacina canadaensis* Hodgkinson (*in*  
576 Hodgkinson *et al.*, 1992, p. 16, pl. 2, figures 4-6), but its last whorl seems to be relatively  
577 lower. This species was collected from downhole contaminated cutting samples and could  
578 be anything between early Eocene and early Oligocene. An occurrence of similar age  
579 (earliest Oligocene) was described from the North Sea Basin and is also known from  
580 contemporaneous rocks (base of Viborg Formation) in Jylland, Denmark, as *Limacina*  
581 *mariae* Janssen (1989, p. 111, pl. 4, figures 2-5), but that species always has a concave  
582 apical spiral, has a somewhat wider umbilicus and reaches to over 2 mm shell width.  
583 Finally, as yet unpublished similar material is available from the Eocene - Oligocene  
584 interval in the NE United States and from the eastern part of Germany.

585 A reliable interpretation of all these forms depends on a larger material for comparisons  
586 and therefore the present specimens, apart from the illustrated specimen in poor  
587 condition, are left in open nomenclature.

588

589 *Limacinidae* indet.

590

591 *Material examined.* – One specimen from TDP 12.24.3, 0-10 cm; 10 specimens from  
592 TDP 17 (see Table 3).

593

594 *Description.* –These specimens are in internal pyritic mould preservation, more or less  
595 strongly deteriorated and cannot be identified any further.

596

597

598 Superfamily CAVOLINIOIDEA Gray, 1850 (1815) [= Hyaline Rafinesque, 1815]

599 Family CRESEIDAE Rampal, 1973

600 Genus BOVICORNU Meyer, 1886

601

602 *Type species.* – *Bovicornu eocenense* Meyer, 1886, by monotypy (early Oligocene, USA).

603

604 *Discussion.*– Shortly after its introduction by Meyer (1886) the validity of the genus

605 *Bovicornu* was denied by Dall (1892, p. 302), who considered both species introduced in

606 that genus by Meyer (1886, 1887) to belong to the caecid (benthic) genus *Meioceras*

607 Carpenter, 1858. Dall's point of view was followed, with doubts, by Cossmann (1912, p.

608 154-155), but rejected by later authors (Collins, 1934, p. 212; van Winkle Palmer, 1947,

609 p. 464; Hodgkinson *et al.*, 1992, p. 24). Indeed, in *Meioceras* the shell wall is

610 considerably thicker and its protoconch is utterly different, whereas in *Bovicornu* the shell

611 is thin-walled and the larval parts agree with species of the pteropod genus *Creseis*. Zilch

612 (1959, p. 49) followed Collins and included *Bovicornu* with a query in the cavoliniid

613 pteropods, considering it a possible synonym of *Euchilotheca* Fischer, 1882, which is also

614 a creseid genus, but its type species, *E. succincta* (Defrance, 1828), shows only very faint  
615 traces of spiralisation. We agree with Hodgkinson *et al.* that *Bovicornu* should be  
616 considered an independent genus in Creseidae.  
617 *Bovicornu* species demonstrate a certain resemblance with *Hameconia edmundi* Janssen,  
618 2008, described from the late Oligocene (Chattian) of SW France. In that species the  
619 bilaterally symmetrical shell has a curvature of *c.* 180°, but it is curved in one plain, not in  
620 a spatial spiral. The curvature is dorso-ventral, as is clear by the presence of lateral  
621 carinae. Its larval stage differs from *Bovicornu* in having separate protoconchs 1 and 2.  
622 Janssen and Maxwell (*in* Janssen, 1995, p. 164), Janssen (2008, p. 160) and Cahuzac and  
623 Janssen (2010, p. 111) included the genus *Hameconia* in the Sphaerocinidae family.

624

625

626 *Bovicornu* aff. *eocenense* Meyer, 1886

627 Figures 13.1-2

628

629 cf 1886 *Bovicornu eocenense* Meyer, p. 79, pl. 3, figure 12 (not figure 2).

630 cf 1892 *Meioceras eocenense* (Meyer) – Dall, p. 302.

631 cf 1912 *Bovicornu eocænense* [*sic*] Meyer – Cossmann, p. 155.

632 cf 1934 *Bovicornu eocenense* Meyer – Collins, p. 212, pl.9, figure 3, pl. 13, figure 5.

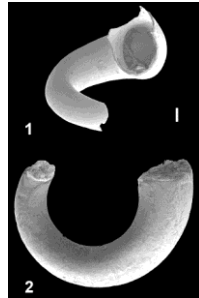
633 cf 1959 *Bovicornu eocenense* O. Meyer – Zilch, p. 49, figure 164.

634 cf 1992 *Bovicornu eocenense* Meyer – Hodgkinson *et al.*, p. 24, pl. 7, figures 9-10 (with  
635 additional synonymy).

636



637 *Type material.* – Holotype (H = 2,8, W = 0,7 mm) United States Natural Museum  
638 (Smithsonian Institution) nr. 644596.  
639



640  
641 **Figure 13.** *Bovicornu* aff. *eocenense* Meyger, 1886; 1. TDP 12.23.3, 89-96 cm; RGM  
642 777370, apertural view; 2. TDP 17.36.1, 20-35 cm, RGM 1007784, basal view. Bar = 100  
643  $\mu\text{m}$ .

644  
645 *Type locality.* – Red Bluff, USGS locality 5264, Mississippi, USA (Red Bluff Clay;  
646 Oligocene, Rupelian, NP 21).

647  
648 *Material examined.* – Only fragments were found, 2 from TDP 11, 9 from TDP 12 and 11  
649 from TDP 17 (see Tables 1-3 for details).

650  
651 *Description.* – Spatially spiralised tube with free volutions. Transverse section of tube  
652 circular, no surface ornamentation or growth lines visible. Only smaller fragments are  
653 available among which no complete aperture or protoconch. Diameter of tube doubles in  
654 about half a volution.

655

656 *Discussion.* – Two species of the genus *Bovicornu* are currently known and both are  
657 exclusively recorded from the USA. The older one of these, *B. gracile* Meyer, 1887 (p. 9,  
658 pl. 2, figure 17), of the Moodys Branch Formation, Texas, has an age of Bartonian (NP  
659 17). The other species, *B. eocenense* Meyer, 1886 (p. 79, pl. 3, figure 12), from the Red  
660 Bluff Formation of Mississippi, USA occurred during the Priabonian and early Rupelian  
661 (NP19-21) (Hodgkinson *et al.*, 1992, figure 3). In both species the shell is creseid, but  
662 instead of being straight or slightly curved, as in *Creseis* species, the tube demonstrates  
663 clear twisting in a wide spatial spiral that was said to be stronger in *B. gracile*.  
664 Hodgkinson *et al.* (1992), however, collected numerous specimens at both type localities  
665 and noted that in many specimens of both species the twisting is stronger and that the  
666 species cannot be distinguished on the degree of twisting. There is, however, a clear  
667 difference in protoconch morphology: an inflated bulb in *B. eocenense* and a more  
668 cylindrical shape in *B. gracile*. The holotypes of both species were re-illustrated in  
669 Hodgkinson *et al.* (1992, pl. 7, figures 9-10 and 11-12), reproduced herein as Figs 14.1-4.  
670 Although the few larger fragments from Tanzania seem to indicate a considerably  
671 stronger spirally twisted shell than in either of the holotypes it is preferred to indicate the  
672 Tanzanian species as related to the younger of the two American species and is indicated  
673 here as *Bovicornu* aff. *eocenense*. Once specimens preserving their protoconch become  
674 available this position might be revised.  
675



676

677 **Figure 14.** Holotypes of *Bovicornu eocenense* Meyer, 1886 (1, 2) and *B. gracile* Meyer,  
678 1887 (3, 4). Shell height of 1 = 2.8 mm, of 2 = 2.7 mm; 2 and 4 are magnifications of 1  
679 and 3, respectively. Photographs after Hodgkinson *et al.* (1992, pl. 7, figures 9-12).

680

681

682

## RESULTS

683 The number of specimens per species/per sample are specified in Tables 1-3. Vertical  
684 ranges of the species in the three Tanzanian sections are shown together in Figure 15.

685 Eight pteropod species are recognised, seven of them belonging to the Limacinidae and  
686 one (*Bovicornu*) to the Creseidae. Three of the limacinids are represented by a single or  
687 very few specimens only. Three species could only be identified in open nomenclature.

688 Three of the limacinid species are described as new.

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TDP Core section	Depth interval (cm)	Subsurface depth (m)	Composite depth (m)	<i>Heliconoides nikkeiae</i>	<i>Limacina robusta</i>	<i>Limacina timi</i>	<i>Bovicornu</i> aff. <i>eocenense</i>
700	11.26.2 64-74	82.14	98.14	<b>1</b>	-	-	-
701	11.32.1 33-40	89.63	109.63	-	<b>1</b>	-	-
702	11.32.3 64-72	91.94	111.94	<b>1</b>	-	<b>1</b>	-
703	11.33.2 74-84	94.04	114.04	-	-	-	<b>2</b>

700

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**Table 1.** Distribution of pteropod species in core TDP 11.

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TDP Core section	Depth interval (cm)	Subsurface depth (m)	Composite depth (m)	<i>Atlaspiratella bearnensis</i>	<i>Heliconoides nikkeiae</i>	<i>Limacina robusta</i>	<i>Limacina timi</i>	<i>Limacina</i> sp. 2	Limaciniidae indet.	<i>Bovicornu</i> aff. <i>eocenense</i>
712	12.11.4 20-26	38.20	96.20	-	-	-	<b>1</b>	-	-	-
713	12.12.1 23-31	38.23	96.23	-	<b>1</b>	-	-	-	-	-
714	12.14.1 47-48,5	44.47	102.47	-	-	-	-	-	-	<b>2</b>
715	12.14.1 51-53	44.51	102.51	-	-	-	-	-	-	<b>1</b>
716	12.14.1 56-58	44.56	102.56	-	-	-	-	-	-	<b>1</b>
717	12.14.3 23-31	46.23	104.23	-	-	-	-	-	-	<b>1</b>
718	12.18.3 65-76	58.65	116.65	-	-	-	<b>1</b>	-	-	-
719	12.19.1 22-34	59.22	117.22	-	-	-	<b>1</b>	-	-	-
720	12.21.1 37-48	65.37	123.37	-	-	-	<b>1</b>	-	-	-
721	12.23.3 89-96	73.89	131.89	-	-	-	-	-	-	<b>1</b>
722	12.24.3 0-10	76.30	134.30	-	-	-	-	-	<b>1?</b>	-
723	12.26.2 54-62	81.79	139.79	-	-	-	<b>1</b>	-	-	-
724	12.27.1 35-45	89,60	147,60	-	-	<b>1</b>	<b>1</b>	<b>1</b>	-	-
725	12.28.1 66-76	90.91	148.91	<b>1</b>	-	-	-	-	-	<b>2</b>
726	12.29.1 25-35	91.90	149.90	-	-	-	<b>1</b>	-	-	-
727	12.29.2 20-30	92.85	150.75	-	-	-	-	-	-	-

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**Table 2.** Distribution of pteropod species in core TDP 12.

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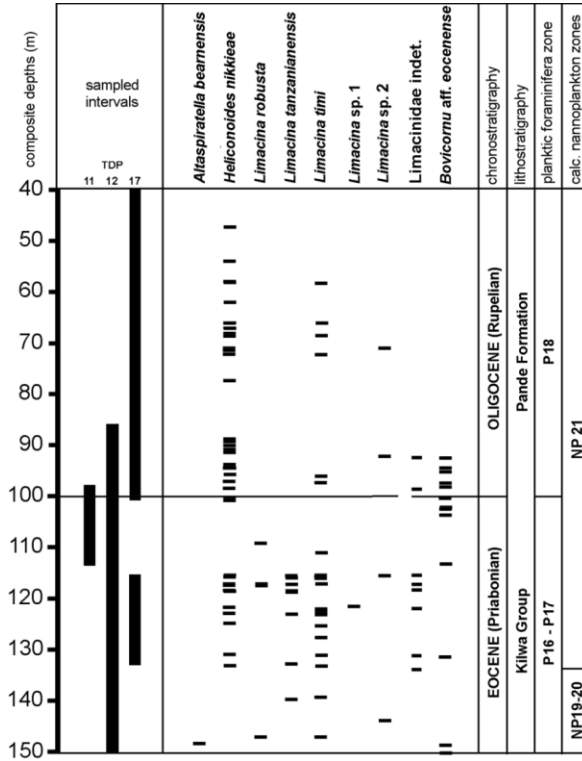
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TDF Core section	Depth interval (cm)	Subsurface depth (m)	Composite depth (m)	<i>Heliconoides nikkieae</i>	<i>Limacina robusta</i>	<i>Limacina tanzaniaensis</i>	<i>Limacina timi</i>	<i>Limacina</i> sp. 1	<i>Limacina</i> sp. 2	Limaciniidae indet.	<i>Bovicornu</i> aff. <i>eocenense</i>
17.15.1	50-63	47.95	47.95	<b>2</b>	-	-	-	-	-	-	-
17.17.2	0-14	54.45	54.45	<b>2?</b>	-	-	-	-	-	-	-
17.18.3	10-25	58.55	58.55	<b>2</b>	-	-	<b>1</b>	-	-	-	-
17.21.2	9-20	62.87	62.87	<b>1</b>	-	-	-	-	-	-	-
17.23.2	0-10	66.57	66.57	-	-	-	<b>1?</b>	-	-	-	-
17.23.3	0-13	67.54	67.5	<b>2?</b>	-	-	-	-	-	-	-
17.23.3	99-105	68.56	68.56	<b>2</b>	-	-	-	-	-	-	-
17.24.1	20-35	68.30	68.30	<b>5</b>	-	-	-	-	-	-	-
17.24.2	0-15	69.10	69.10	-	-	-	<b>1</b>	-	-	-	-
17.25.1	0-15	71.40	71.40	<b>2</b>	-	-	-	-	<b>1</b>	-	-
17.25.1	50-60	71.90	71.90	<b>1</b>	-	-	-	-	-	-	-
17.25.2	48-58	72.88	72.88	<b>1</b>	-	-	<b>1</b>	-	-	-	-
17.26.3	10-25	77.90	77.90	<b>2</b>	-	-	-	-	-	-	-
17.31.1	20-35	89.10	89.10	<b>2?</b>	-	-	-	-	-	-	-
17.31.2	0-15	89.90	89.90	<b>1</b>	-	-	-	-	-	-	-
17.31.3	0-15	90.90	90.90	<b>3?</b>	-	-	-	-	-	-	-
17.31.4	0-12	91.90	91.90	<b>1?</b>	-	-	-	-	-	-	-
17.32.1	10-25	92.00	92.00	<b>2?</b>	-	-	-	-	-	-	-
17.32.2	0-15	92.90	92.90	<b>3</b>	-	-	-	-	<b>1</b>	<b>1?</b>	<b>1</b>
17.32.4	14-20	95.04	95.04	<b>1</b>	-	-	-	-	-	-	<b>1</b>
17.33.1	3-18	95.93	95.93	<b>1</b>	-	-	-	-	-	-	<b>2</b>
17.33.3	0-15	97.90	97.90	<b>3</b>	-	-	<b>1</b>	-	-	-	<b>1</b>
17.34.1	0-7	98.90	98.90	<b>4?</b>	-	-	<b>2</b>	-	-	<b>3?</b>	<b>1</b>
17.34.2	91-99	100.81	100.81	-	-	-	-	-	-	-	<b>2</b>
17.36.1	0-5	103.90	115.90	<b>1</b>	-	-	<b>1</b>	-	<b>2?</b>	<b>1?</b>	<b>2</b>
17.36.1	5-13	103.95	115.95	-	-	<b>1</b>	-	-	-	-	-
17.36.1	10-25	104.00	116.00	<b>11</b>	-	<b>7</b>	-	-	-	-	<b>3</b>
17.36.2	52-59	105.42	117.42	-	<b>1</b>	-	-	-	-	<b>3?</b>	-
17.36.2	80-95	105.70	117.70	<b>3+5?</b>	<b>2</b>	<b>1</b>	<b>2?</b>	-	-	<b>2?</b>	-
17.37.1	0-13	106.90	118.90	-	<b>6</b>	-	-	<b>5</b>	-	-	-
17.37.1	32-47	107.22	119.22	-	<b>1</b>	-	-	-	-	-	-
17.38.1	25-35	110.15	122.15	-	-	<b>5</b>	<b>1</b>	-	-	-	-
17.38.2	22-29	111.12	123.12	-	<b>1</b>	<b>2</b>	-	-	-	-	-
17.38.2	62-70	113.52	123.52	-	-	-	<b>1</b>	-	-	-	-
17.41.1	8-18	119.48	131.48	-	-	<b>1</b>	<b>2?</b>	-	-	-	-
17.41.3	0-15	121.40	133.40	-	<b>1</b>	<b>1</b>	-	-	-	-	-

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**Table 3.** Distribution of pteropod species in core TDP 17 (question mark denotes poorly preserved specimens).



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778 **Figure 15.** Range chart of pteropods, combined data of TDP 11, 12 and 17, calibrated to  
 779 composite depths. Basic stratigraphical data mainly from Pearson *et al.* (2008, figure 16).

780

781

782 The stratigraphic ranges are remarkable. The two most commonly occurring species,  
 783 *Heliconoides nikkieae* and *Limacina timi* (both introduced herein), and the less frequently  
 784 represented *Limacina sp. 2* occur in comparable numbers both below and above the EOB

785 and do not seem to be influenced by changing environmental conditions. Two other  
786 species, *Limacina robusta* and *L. tanzaniaensis*, on the contrary, disappear some 10 m  
787 below the EOB, at a level close to the extinction of the *Turborotalia cerroazulensis*-group  
788 of planktic foraminifera and the first oxygen isotope step (Step 1 of Pearson *et al.*, 2008,  
789 Lear *et al.*, 2008) although improved sampling could of course extend the ranges up to the  
790 EOB or beyond. One species, *Altaspiratella bearnensis*, was found as a single specimen  
791 only in one of the lowermost samples. Finally, a single species (*Bovicornu* aff.  
792 *eocenense*), is irregularly distributed in the Eocene part of the sections, but disappears in  
793 the basal 10 m of the Oligocene. No pteropods are found exclusively in the Oligocene  
794 part of the record.

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#### DISCUSSION

797 The newly described taxa, as well as species recorded in open nomenclature, do not  
798 present clues that can be applied in long distance correlations. The present material from  
799 Tanzania furthermore originates from a very large area from which Paleogene pteropods  
800 have never been recorded previously. From the African continent only a late Eocene  
801 occurrence is known from Nigeria (Bende Ameki; Curry, 1965 and Naturalis collection)  
802 and some Eocene (Ypresian, Bartonian) material was collected from Egypt (Valley of the  
803 Kings) by the late Chris King (Naturalis Biodiversity Center collections, unpublished).  
804 The presence of *Altaspiratella bearnensis* is quite unexpected. That species is only known  
805 from the Aquitaine Basin in SW France (type locality, Ypresian) and from the southern  
806 USA (Ypresian and Lutetian). Its presence in the Tanzanian Priabonian is surprising. The

807 record, however, is based on a single incomplete specimen and better preserved material  
808 might prove that another species is involved.

809 The occurrence of *Limacina robusta* is interesting. That species was originally described  
810 from Pakistan, a locality under the influence of the Indian Ocean, what is equally the case  
811 for the Tanzanian material. If *Limacina* sp. 1 is indeed closely related to or even identical  
812 with ‘Limacinidae type A’ as described by Lokho and Kumar (2008) from northern India  
813 it similarly represents an interesting palaeogeographical occurrence on the Indian Ocean.

814 The creseid species *Bovicornu eocenense* is to date exclusively known from the United  
815 States and its vertical distribution includes the Priabonian and the Rupelian transition,  
816 which is consistent with its range in the Tanzanian material. However, the Tanzanian  
817 material is poorly preserved and better specimens might lead to another specific  
818 interpretation.

819 When compared with previous isotope and microfossils from the Tanzanian material it  
820 may be concluded that three pteropod species (*Heliconoides nikkieae*, *Limacina timi* and  
821 *Limacina* sp. 2) do not show clear response following the drastic climatic cooling at the  
822 EOB, but two species (*Limacina robusta* and *L. tanzaniaensis*) seem to disappear close to  
823 the cooling related step of the EOT, perhaps indicating a temperature sensitivity if a true  
824 disappearance. The last occurrence of these two taxa precedes that of the planktic  
825 foraminiferal family Hantkeninidae and the extinction level of the larger benthic  
826 foraminifera (Pearson *et al.*, 2008; Wade and Pearson, 2008; Cotton and Pearson, 2011).  
827 However, it is similar to the last occurrence of the planktic foraminifera *Turborotalia*  
828 (Pearson *et al.*, 2008; Wade and Pearson, 2008). In addition, the nannofossil assemblage  
829 has shown an increase in nutrient loving taxa close to the onset of the EOT (Dunkley

Commented [U3]: AWJ: previous isotope and microfossil data  
??



830 Jones *et al.*, 2008), suggesting nutrient increase in the water column as a potential  
831 contributing factor.

832 There are currently plans to re-core the EOB of Tanzania with wide diameter boreholes  
833 (Pearson and Hudson, 2014). Much larger samples and denser sampling may shed further  
834 light on the pteropod record across the EOB in the region.

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835

## 836 CONCLUSION

837

838 Here we have shown a small but important insight into pteropod fauna from both an  
839 under-represented geological time and geographic region. Eight species were identified,  
840 three of which were new. Two of the taxa show an apparent, at least, local extinction  
841 close to the first major cooling step of the EOT whilst the others seem unaffected, or have  
842 too few occurrences to tell. The occurrences of several taxa, though not enough for long  
843 distance correlation, are surprising with *Altaspiratella bearnensis*, and *Limacina robusta*  
844 only previously known from Europe and the U.S.A., and from the U.S.A., respectively.

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845 The occurrence of possible *Bovicornu eocenense* which is only previously known from  
846 Pakistan very tentatively suggests an Indo-Pacific connection. This therefore underlines  
847 the need for increased studies of older pteropod occurrences, particularly in that may be  
848 under-sampled but have good preservation potential. Furthermore it shows the importance

**Commented [U6]:** AWJ: better leave this out, as we do some long-distance correlation with *Limacina robusta*

**Commented [U7]:** No, *Bovicornu* aff. *eocenense*

**Commented [U8]:** AWJ: No, *Limacina robusta* should be here

**Commented [U9]:** AWJ: not so 'tentatively'... I think that quite clear. Better leave it out.

**Commented [U10]:** AWJ: I'd rather suggest to say Paleogene instead of older

**Commented [U11]:** AWJ: Here something seems to be missing. What did you want to say here?

849 of carrying out studies of less conventional micro-fossils on cores generally used for  
850 foraminiferal or nannoplankton studies. (or something like that?)

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853

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