

1 **Origin, migration pathways and palaeoenvironmental significance of Holocene**
2 **ostracod records from the north-eastern Black Sea shelf**

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21

22 **Abstract**

23

24 Micropalaeontological studies of the Black Sea, including ostracod records, have
25 suggested that early Holocene salinity values were between ~5-10 psu, contrasting
26 with present values of 18-22 psu. However, more precise palaeoenvironmental
27 reconstructions based on ostracod assemblages require additional information
28 related to their modern ecological affinities. This study uses modern species
29 information collected from samples with living fauna to interpret the fossil Holocene
30 assemblages of two sediment cores, Ak-2575 and Ak-521 collected from the north-
31 eastern outer shelf of the Black Sea. A total of 37 ostracod species are recorded in
32 the fossil assemblages, with two related to freshwater/oligohaline environments, 23
33 from Caspian-type environments, and 12 from environments similar to the
34 Mediterranean. Three distinct assemblage zones are identified from Caspian-type
35 dominating in the early Holocene up to 7.4 cal ka BP, a mixed assemblage of
36 Caspian-type and Mediterranean type from 7.4 to 6.8 cal ka BP and a progressive
37 dominance of Mediterranean species from 6.8 cal ka BP. It is very likely that the
38 dominant control of ostracod species occurrence during the period up to ~6.8 cal ka
39 BP is salinity. A range of factors including temperature, biotope and sedimentation
40 rates influenced the species distribution over the last 6.8 cal ka BP.

41

42 **Key Words**

43

44 Ostracod assemblages, salinity, brackish water, migration, Caspian Sea,
45 Mediterranean Sea, Sea of Azov, palaeoenvironment, Quaternary.

46

47 **Introduction**

48

49 The connection of the Black Sea with the Mediterranean has been episodic during
50 the Quaternary whereas fewer periodic intrusions of water from the Caspian Sea
51 have occurred via the Manych Corridor during the Pleistocene (Chepalyga, 2002,
52 2007; Bahr et al., 2008; Badertscher et al., 2011; Yanina, 2014). These intrusions
53 have greatly influenced the Black Sea environmental conditions eventually creating
54 the biota that is now inhabiting the basin (e.g. Mudie et al., 2002; Yanko-Hombach,
55 2007; Marret et al., 2009; Boomer et al., 2010). The present two-way connection
56 between the Black Sea and Marmara Sea was established in the early Holocene
57 (Grigor'ev et al., 1984; Yanko and Troitskaya, 1987; Hiscott et al., 2007; Soulet et al.,
58 2011a) creating a substantial salinity increase in the Black Sea. However,
59 quantitative estimation of such conditions as well as their timing have been heavily
60 debated (Ryan et al., 1997; Aksu et al., 2002; Ryan et al., 2003; Hiscott et al., 2007;
61 Ivanova et al., 2007, 2015; Yanko-Hombach et al., 2007, 2014; Marret et al., 2009;
62 Nicholas et al., 2011). Most of these studies have yielded well preserved macro- and
63 microfossil proxy records, providing insights of past environmental conditions during
64 the Holocene (Atanassova, 2005; Hiscott et al., 2007; Yanko-Hombach et al., 2007,
65 2014; Ivanova et al., 2007, 2012, 2015; Mudie et al., 2007; Verleye et al., 2009;
66 Boomer et al., 2010; Bradley et al., 2012; Mertens et al., 2012). However,
67 understanding the temporal and spatial changes in assemblages from a variety of
68 locations, taxonomic refinements (Boomer et al., 2010), and more information about
69 modern habitat preferences are a prerequisite for improving Holocene
70 palaeoenvironmental reconstructions, which is the case for ostracods. This
71 microfossil group is particularly suitable for palaeoenvironmental reconstruction

72 because they are abundant, inhabit a wide range of habitats, are sensitive to
73 environmental change, and their specific assemblage composition reflects definite
74 bottom water conditions (Athersuch et al., 1989; Schornikov, Zenina, 2014).

75

76 Two main migration pathways have been postulated to explain the composition of
77 Holocene Black Sea ostracod fauna. The first pathway (Figure 1) enabled the
78 migration of Caspian species during periodic intrusions of water during the
79 Pleistocene, via the Manych Corridor, with the last connection with the Caspian Sea
80 occurring during the Neoeuxinian transgression between 14-15 cal ka BP (Yanina,
81 2014). These species are tolerant of low-salinity environments such as the present
82 conditions in the Caspian Sea (Boomer et al., 2005). During periods of relative
83 higher salinity, for example in the Holocene or Eemian (Shumilovskikh et al., 2013),
84 the Caspian species did not inhabit the main body of the Azov-Black Sea basin, but
85 survived in low salinity refuges (Schornikov et al., 2011). The second pathway
86 (Figure 1A) allowed the migration of marine species during periods of connection
87 with the Mediterranean (Hiscott et al., 2007; Boomer et al., 2010). Improving our
88 knowledge about the ecological affinities of these two groups will enable to better
89 constrain environmental reconstructions from a period where the Black Sea was
90 isolated from other water bodies up to its reconnection.

91

92 This paper aims provide new insights on the Holocene environmental changes on
93 the north-eastern (Caucasian) Black Sea shelf based on ostracod data from two
94 gravity cores (Ak-521 and Ak-2575). We interpret the fossil ostracod data using
95 modern species and habitat information, from living fauna collected in the Caspian
96 Sea and Azov-Black Sea basin. The paper provides a more detailed examination of

97 the fossil data presented by Ivanova et al. (2015) using the newly collected modern
98 data. In addition, new fossil data with taxonomic revisions from core Ak 521, first
99 published at a lower resolution by Ivanova et al. (2007), are presented. Six species
100 of Caspian type are reported for the first time in the Black Sea fossil assemblages.
101 Five of these species, hypothesised to belong to genera of Caspian type, are not
102 found in the Caspian Sea. They are new undescribed species and shown in open
103 nomenclature.

104

105 **Regional Setting**

106

107 The Black Sea has a unique set of characteristics, with surface water salinity about
108 half of oceanic salinity ranging between 18-22 psu; Murray, 1991; Sorokin, 2002).
109 Strong stratification of the water column results in the appearance of a hydrogen
110 sulphide zone in the deep water. In the south-west, the Black Sea exchanges water
111 with the Marmara Sea, via the Bosphorus Strait, with outflowing brackish surface
112 water replaced by inflowing saline deep water. In the northeast, the Black Sea
113 exchanges water with the Sea of Azov, via the Kerch Strait (Figure 1). Compared
114 with the Black Sea, the Sea of Azov is geologically young and very shallow (less
115 than 10 m); it has a small surface area and much smaller volume. Therefore, it can
116 be considered as a gulf, or part of the Black Sea (Chepalyga, 2002). In this paper,
117 we use the term Azov-Black Sea basin. The Caspian Sea is the largest enclosed
118 body of water on Earth, with water depth ranging from quite shallow in the north (less
119 than 20m), to relatively deep in the south basin (1025m) (Kosarev, 2005). The Volga
120 River is the largest water inflow into the Caspian Sea and discharges into the North
121 Caspian basin. The Caspian Sea is closed with no outlet. In the 20th century, it has

122 experienced large changes in sea level with drops and increases of ~1-3 m observed
123 (Arpe and Leroy, 2007). The salinity is brackish with ranges between 1 to 13. The
124 salinity increases in a southward direction.

125

126 The two sediment cores were taken from the Caucasian Shelf (Fig. 1A, C) between
127 Arkhipo-Osipovka and Dzhubga. In this area, the shelf narrows to a width of 4 to 12
128 km and generally has a flat surface which slopes slightly ($0.2-0.6^\circ$) towards the shelf
129 break at depths of 100-120 m. The shelf can be divided three portions; a coastal area
130 that extends from the shoreline to depths of 25-30 m; a central shelf platform
131 between 30-70 m depth; and the outer shelf that ranges from a depth of 80 m to a
132 sharp shelf break at 95-105 m (Torgunakov et al., 2002).

133

134 The surface circulation on the north-eastern shelf is dominated by the counter-
135 clockwise rotating peripheral Rim Current (Bogatko et al., 1979; Öğuz, 1993). On the
136 outer shelf, two water masses are identified in the water column. A well-ventilated
137 surface water mass is present in the upper 50-90 m, above a strong seasonal
138 pycnocline. Salinity measurements at $\sim 44.53^\circ\text{N}$ and 37.93°E during February, May,
139 July and October 2015 show that annual salinity values vary between 17.5 and 19.4
140 psu (Fig. 2). Seasonal variability depends on depth, with <25 m measurements
141 having a range of ~ 0.5 psu, 25-75 m depths spanning <0.5 m, and >75 m ranging
142 between ~ 1 psu. Annual temperature values vary between 7.5°C and 25°C with
143 greatest variability at depths 0-50 m (Figure 2). At depths below 50 m variability
144 decreases to $\sim 2.5^\circ\text{C}$.

145

146 **Material and methods**

147

148 Two gravity cores, Ak-521 (44.26°, 38.54°, water depth -101m, 200 cm long) and Ak-
149 2575 (44.22°, 38.63°, water depth -99m, 186 cm long), were retrieved during cruises
150 of the RV *Akvanavt* in 2001 and 2007 respectively.

151

152 *Fossil Ostracod Analysis*

153

154 Samples were sieved through a 100 µm (Ak-521) or 63 µm (Ak-2575) mesh using
155 distilled water. For core Ak-2575, dry fractions (>2 mm, 0.1-2 mm and 0.063-0.1 mm)
156 were weighed to calculate the percent of each fraction in samples, and the total
157 number of ostracods per gram of sediment. The dry fractions 0.1-2 mm (both cores)
158 and 0.063-0.1 mm (Ak-2575 only) were analysed using a binocular microscope.

159 Ostracod valves were described to species level where possible. Ivanova et al.
160 (2007) briefly described a subset of 18 ostracod samples from Ak-521. In this paper,
161 we present the full ostracod record (37 samples), taxonomic revision of previously
162 published work (Table 1), integration with ecological data (Figure 1E; Table 2, Table
163 3), and species images (Supplementary Figure 1-3). Ostracod assemblages from
164 core Ak-2575 were analysed in 2 cm thick slices from 93 contiguous samples
165 (Supplementary data Table 1). Previously, ostracods from this core were briefly
166 described in Zenina et al. (2013) and Ivanova et al. (2015). SEM images were taken
167 using a Zeiss EVO 40.

168

169 The accumulation rate of ostracod valves (OAR) in AK-2575 was estimated using the
170 following equation:

171 Accumulation rate of valves (cm² per ka) = V * D * S.

172 Where, V = valve counts per gram of dry sediment from grain-size fractions between
173 63-2000 μm ; D = sediment wet density (1.4 g/cm^3); S = sedimentation rate (cm/ka)
174 which is based on the age model by Ivanova et al. (2015).

175

176 *Modern ostracod samples*

177

178 Nine samples collected from the Caspian Sea with a small dredge were analyzed
179 (Figure 1C). Samples I-VI were collected by M.A. Zenina between the 28th July to 1st
180 August 2014. Samples VII-IX were collected by E.I. Schornikov on 5th August 1956
181 (VII, VIII) and 16th July 1952 (IX). In this study, we also provide information about
182 ostracod fauna living in the Azov-Black Sea basin, and do not consider species living
183 only in Caspian Sea.

184

185 **Lithostratigraphy and chronostratigraphy**

186 The age model for the two gravity cores Ak-521 and Ak-2575 published by Ivanova
187 et al. (2015) is based on 19 calibrated radiocarbon dates (9 for Ak-521, 10 for Ak-
188 2575). Regional stratigraphic units with calibrated dates of their boundaries
189 (Balabanov, 2009, Ivanova et al., 2015) are also taken into account. The proposed
190 transgression phases include Neoeuxinian (11-10 cal ka BP), Bugazian (10–8.8 cal
191 ka BP), Vityazevian (8.8–7.8 cal ka BP), Kalamitian (7.8–6.9 cal ka BP),
192 Dzhemetinian (6.9–2.6 cal ka BP) and Nymphean (2.6–0 cal ka BP) (Balabanov,
193 2009).

194

195 Both cores were retrieved close to the shelf break and recovered similar sections of
196 Holocene deposits. This included ~0.5m thick coquina at their base composed of
197 semi-freshwater Caspian type mollusk shells (dominated by *Dreissena rostriformis*)
198 in its lower part and a mixed (Caspian + Mediterranean) mollusk fauna in the upper
199 part (Ivanova et al., 2007, 2015). The coquina marks a high-energy bottom
200 environment at the shelf edge which commenced at the end of the Neoeuxinian
201 stage as shown by the oldest date from the shelly mud layer underlying the coquina
202 in core Ak-521 (11.87 cal ka BP), and lasted up to ~7.4 cal ka BP according to the
203 age model (Ivanova et al., 2015). The sharp, possibly erosional, basal contact of the
204 coquina suggests a hiatus at its base. Another hiatus likely separates the *Dreissena*-
205 dominated coquina from the mixed-fauna one, both belonging to a slowly
206 accumulated high-energy shelf edge facies.

207

208 The gradual, although distinct, upper contact of the coquina reflects slowing down of
209 bottom hydrodynamics thus allowing deposition of fine-grained terrigenous mud
210 which was inhabited by *Mytilus galloprovincialis* (the *Mytilus* mud facies).

211 Sedimentation rates increased up to 95.2 cm/ka during the time interval 7.4-6.8 cal
212 ka, and to 111.1 cm/ka in the interval 6.8—6.5 cal ka BP (Ivanova et al., 2015).

213 Intercalation of the *Mytilus* mud by thin muddy *Mytilus* coquina beds suggests
214 pulsating sedimentation possibly related to alternation of extreme floods delivering
215 very large amounts of terrigenous suspended material to the shelf edge with periods
216 of depleted mud supply.

217

218 Sedimentation rates decreased during the interval 6.5-5.8 cal ka BP to values less
219 than 4.4 cm/ka. A hiatus likely occurs between the 6.27 and 3.59 cal ka dates that
220 separates the *Mytilus* mud facies from the overlying *Modiolus phaseolinus* mud
221 facies characterized by low sedimentation rates of 5.0 – 19.3 cm/ka. The *M.*
222 *phaseolinus* dominated shelly mud comprises uppermost parts of both core sections
223 up to the sediment surface. At present, it covers a wide area of the outer shelf
224 landward to depths of ~60 m.

225

226 **Results**

227

228 *Ostracod division into ecological groups based on their modern distribution*

229

230 The ostracods of Caspian type in the Azov-Black Sea region dwell in shallow water
231 (down to 5 m) (Fig. 1E, Table 2), but in the Caspian Sea they can inhabit
232 considerably greater depths (Table 3). For example, living specimens of *Graviacypris*
233 *elongata* were found in depths of 50-68 m in the Caspian Sea. Most of the species
234 found in both cores (Table 4) are abundant in silty-sandy mud. *Tyrrhenocythere*
235 *amnicola donetziensis* and *Euxinocythere virgata* were also quite numerous on
236 shelly ground in the Caspian Sea. *T. amnicola donetziensis*, *E. virgata*, *G. elongata*,
237 *Xestoleberis chanakovi*, *Sarmatina? cf. azeri* can inhabit depths of 30 m. These
238 species are found living in the Caspian Sea (Table 3). Owing to the lack of adequate
239 data on the ecology of Caspian type species, it is not yet possible to separate groups
240 solely based on habitat.

241

242 It is possible to differentiate ostracod species of Mediterranean type (Table 4) based
243 on habit preferences (Ivanova et al., 2014; Schornikov et al., 2014). Mud dwellers
244 include *Palmoconcha agilis*, *Cytheroma variabilis*, *Cytheroma marinovi*, *Bythocythere*
245 *sp.*, *Carinocythereis carinata*, *Paradoxostoma simile* and *Xestoleberis cornelii*.
246 Sandy mud dwellers include *Hiltermannicythere rubra*, *Leptocythere multipunctata*,
247 *Callistocythere diffusa* and *Pontocythere tchernjawskaa*. *Sagmatocythere rennata* is a
248 sand dweller.

249

250 ***Fossil distribution of ostracod species***

251

252 In total, 37 ostracod species were recorded in the samples taken from the two cores
253 (Table 4). These species can be split into three groups based on their habitat
254 preference type; two are freshwater/oligohaline taxa, 23 taxa are of Caspian type
255 and 12 taxa are of Mediterranean type. Both cores are subdivided into three sections
256 based on assemblage groupings. These sections appear to depend on the variation
257 in salinity and habitat type during the Holocene.

258

259 ***Assemblage I***

260 Assemblage I spans the interval from 11.9 to 7.4 cal ka BP which corresponds to
261 core depths 187-144 cm in Ak-2575 and 192-148 cm in Ak-521. The ostracod
262 abundance for core AK-2575 varies from >1 to 31 valves/g and ostracod
263 accumulation rates vary from 6.8 to 870.8 valves/ka yr. Twenty nine species are
264 identified for this period including 23 species of Caspian type. Two are of the
265 freshwater/oligohaline type and three species are the earliest Mediterranean
266 ostracods to appear in the Black Sea (Table 4; Fig. 3, 4). The most abundant

267 species are *L. lepida*, *Loxocaspia sublepida*, *Amnicythere martha*, *Euxinocythere*
268 *relicta*, *Amnicythere stepanaitysae* and *G. elongata*. The two freshwater/oligohaline
269 taxa are *Cypria lubeziensis*, which is only found in the deepest samples of core Ak-
270 521 (195-190 cm), and *Fabaeformiscandona* sp. which is recorded in both cores
271 between ~9.6-7.4 cal. ka BP. Strong polymorphism is exhibited in a number of
272 Caspian species, especially *A. stepanaitysae*, *L. lepida*, *E. relicta* and *A. martha*.
273 This is highlighted for *A. stepanaitysae* and *E. relicta* in Supplementary Figure 1-2.
274 The total number of species found per sample decreases towards the upper parts of
275 the interval of Assemblage I. Only three taxa, *L. lepida*, *L. sublepida* and *G.*
276 *elongata*, are found in the uppermost part of the assemblage interval, around 7.4 cal
277 ka BP (150-152 cm in Ak-2575 and 153-158 cm in Ak-521). In the youngest
278 samples, *L. lepida* increases in relative abundance. There are also Mediterranean
279 type species including *H. rubra*, *Palmoconcha agilis*, in both cores, and sparse
280 specimens of *L. multipunctata* in Ak-2575 are represented both by adult and juvenile
281 valves.

282

283 *Assemblage II*

284 Assemblage II occurs between 7.4-6.7 cal ka BP which corresponds to core depths
285 144-90 cm in Ak-2575 and 148-88 cm in Ak-521. This assemblage contains a
286 mixture of Caspian and Mediterranean species. The low number of ostracods
287 recorded in Ak-2575 (< 100 valves per sample), prevented determination of the
288 relative abundance of species. The ostracod abundance for core Ak-2575 is low (0 to
289 3 valves/g). Among the ostracods of Caspian type, *L. lepida* and *G. elongata* are
290 common. In contrast, *L. sublepida* is represented by only two valves in the sample
291 136-138 cm from Ak-2575. In both cores, the regular appearance of *L. multipunctata*

292 is noted from ~7.4 cal ka BP. Furthermore, the species composition in the two cores
293 is slightly different. For example, *P. agilis* was not recorded in core Ak-521.

294

295 Assemblage II can be further subdivided into two sub-assemblages occurring at 7.4-
296 7.1 cal ka BP (II-A) and 7.0-6.8 cal ka BP (IIB). The fauna of Caspian type prevails in
297 sub-assemblage (IIA) while taxa of Mediterranean type, such as *H. rubra*, *L.*
298 *multipunctata* (in both cores) and *P. agilis* (in core Ak-2575) are still only minor
299 components of the assemblage. Ostracod accumulation rates in the lower and
300 middle parts (122 to 96 cm) of Assemblage II is low (0 to 65.1 valves/ka yr), but in
301 the upper part (up to 90 cm, ~6.8 cal ka BP) it increases to 362 valves/ka yr.

302 In the upper part of IIA, *G. elongata* disappears from the record. In the interval 7.1-
303 7.0 cal. ka BP (122-116 cm in core Ak-2575) the record is barren. There is no data
304 from Ak-521 in this period because of the lower sampling resolution. In Sub-
305 assemblage II-B, species diversity of Mediterranean ostracods becomes higher.
306 Along with the taxa recorded in IIA, the fauna of this period also includes *S. rennata*,
307 *X. cornelii*, *C. marinovi* and *C. variabilis*. The only species of Caspian type found
308 during this period is *L. lepida*, which disappears from the record around ~6.8 cal ka
309 BP. The most typical species in Sub-assemblage IIA are *L. multipunctata* and *S.*
310 *rennata*. *H. rubra* increases in relative abundance upwards in the assemblage.

311

312 *Assemblage III*

313 Assemblage III spans the interval from 6.8 cal ka BP (90cm in core Ak-2575 and 88
314 cm in core Ak-521) to present (Fig 3-4). It is characterized by a depleted fauna of
315 Mediterranean type species, typical of water depths of >50 m. Accumulation rates
316 are relatively high at the oldest boundary before falling in younger samples. Two

317 species of Caspian type found in core Ak-2575 include a reworked valve of *X.*
318 *chanakovi* (found in sample 22–20 cm) and two reworked valves of *L. lepida* (found
319 in sample 84–82 cm). The ostracod abundance for core Ak-2575 in this period is
320 between >1 to 41 valves/g. Fauna of Mediterranean type in core Ak-2575 is more
321 diverse and is represented by 12 species, while in core AK-521 it only consists of
322 nine species (Fig 3; 4). However, this is most likely due to the more detailed study of
323 core Ak-2575. Indeed, species not recorded in Ak-521 samples such as *C. carinata*,
324 *C. diffusa* and *P. tchernjawsii* are noted as minor components in samples from core
325 Ak-2575.

326

327 The upward disappearance of the relatively shallow-water *S. rennata* and decrease
328 in abundances of *L. multipunctata* and *X. cornelii* coincide with the increased
329 occurrence of *P. agilis* and appearance of *Bythocythere* sp. in the uppermost part of
330 the cores. This section is split into two sub-assemblages in Ak-2575 depending on
331 the abundance and occurrence of these species. *X. cornelii* and *H. rubra* are the
332 most abundant species in Sub-assemblage IIIA during the interval 6.8–6.6 cal ka BP
333 (90–64 cm in Ak-2575). However, the two sub-assemblages cannot be identified in
334 Ak-521 because of the lower sampling resolution. Hence, the data indicates a similar
335 species diversity and relative abundance within this assemblage in both cores. The
336 abundance of the sandy mud dweller *L. multipunctata* decreases in the lower part of
337 the interval, whereas the mud dweller *P. agilis* gradually becomes more common in
338 the younger samples. In Ak-2575, two sub-assemblages are divided by a short
339 interval from 6.5 to 6.3 cal ka BP in which only rare valves of *P. agilis* and *H. rubra*
340 are found. The sub-assemblage IIIB from the interval 6.3–0 cal ka BP is of a
341 relatively colder type. This is indicated by considerable numbers of *P. agilis* generally

342 dominating the ostracod fauna, and by the recording of *Bythocythere* sp., which
343 prefers lower temperatures and inhabits modern assemblages of the Black Sea only
344 at depths of >70 m (Schornikov, 1969). *H. rubra* decreases in relative abundance
345 during this period. A short-term spike of maximal total ostracod abundance (up to 40
346 valves/g of dry sediment) occurs just above the hiatus, at ~4.2 cal ka BP.

347

348 **Discussion**

349

350 *Present-day ostracod distribution and implication for palaeoenvironmental*
351 *reconstruction*

352

353 This study investigated the present-day environmental ranges of Caspian-type
354 species. These species currently inhabit the main body of the Caspian Sea (Boomer
355 et al., 2005) but are limited in the Black Sea region to estuaries, rivers, lagoons and
356 lakes (this study, figure 1D, table 2; Schornikov, 1969, 2011; Opreanu, 2008). They
357 currently account for ~20% of all known ostracods in the Black Sea (Schornikov,
358 2012). These Caspian-type species have the highest relative abundance in early
359 Holocene sediment records in the BS (Hiscott et al., 2007; Boomer et al., 2010;
360 Bradley et al., 2011; Williams et al., 2011; Ivanova et al., 2015; this study, Figures 3
361 & 4). Currently environmental reconstructions are limited to suggesting that the early
362 Holocene Black Sea was similar to the modern Caspian Sea. The modern data
363 presented in this study allow some refinement of early-Holocene benthic
364 reconstructions in the Black Sea, a period where salinity and rates of change are
365 contested (see Yanko-Hombach et al., 2007; Bradley et al., 2012).

366

367 In-situ data show that ostracods of Caspian type previously found in shallow waters
368 (0- 5 m) in the Black Sea region (Schornikov 1969, 2011; Opreanu, 2008; Table 2;
369 Fig.1E) are able to inhabit considerably greater depths in the modern Caspian Sea
370 (Table 3). These two basins are known to be characterized by different salt
371 compositions, with chlorine type in the BS basin and sulphate–hydrocarbonate type
372 in the Caspian Sea (Neveskaya, 1965; Oceanographic tables, 1975). Our data
373 suggest that the different salt compositions may affect the ostracod species
374 distribution. Notably, species of Caspian type recently inhabiting mesohaline depths
375 in the Caspia Sea (Fig. 1D, Table 3) can tolerate less saline conditions in the Black
376 Sea basin (Fig. 1C, Table 2). This hypothesis is supported by previous findings with
377 other groups of animals (Morduhai-Boltovskoy, 1960).

378

379 In contrast to the Caspian type species located in the fringe areas of the Black Sea,
380 Mediterranean-type species inhabit the oxygenated, shallow-water areas that are
381 free of hydrogen sulfide pollution (Caraion, 1962; Schornikov, 1969, 2012) and
382 represent ~80% of reported ostracods in the modern Black Sea (Schornikov, 2012).
383 This fauna consists of species that can tolerate marine conditions in the
384 Mediterranean Sea, as well as brackish salinities and lower temperatures of the
385 Black Sea. For many Mediterranean species, the low salinity (half that of the
386 Mediterranean Sea), and low temperatures are the main barriers to migration into the
387 Black Sea, and thus the Black Sea fauna is a depleted representative of modern
388 Mediterranean fauna. Fauna of the Sea of Azov is further depleted, relative to the
389 Black Sea, due to the lower salinity in the shallow sea, being 1.3 times lower than
390 that of the Black Sea (Caraion, 1962; Schornikov, 1969).

391

392 Studies of Black Sea ostracods have referred to endemic marine species (Briceag &
393 Ion, 2014), e.g. *Pontocythere bacescoi* (Caraion, 1960). The finding of *P. bacescoi*
394 valves in the northern part of the Aegean Sea (Schornikov, 1969) suggests that this
395 species is not endemic to the Black Sea. Indeed, it is unlikely that any
396 Mediterranean-type species are endemic to the Azov-Black Sea basin. The Caspian-
397 type ostracods discussed in this study are likely endemic to the Ponto-Caspian
398 region. Studies of late Quaternary Black Sea and Caspian Sea ostracod
399 assemblages illustrate that they have strong affinities to the Neogene assemblages
400 of the eastern Paratethyan basin (Boomer, 2012). Partial or total isolation from the
401 global ocean and generally intense freshwater input from rivers favoured endemism
402 of the ostracod fauna.

403

404 Periodic connections between the Black Sea and the Caspian Sea in the Quaternary
405 allowed species migration between the two basins (Chepalyga et al., 2007;
406 Badertscher et al., 2011). They were last connected ~15-14 cal ka BP (Yanina,
407 2014) and therefore any major migration of Caspian-type ostracods occurred prior to
408 the start of the Holocene, although some of this group were present in the Black Sea
409 prior to this connection (Boomer et al., 2010). Therefore, this means that
410 assemblage change in Holocene ostracod records (this study; Hiscott et al., 2007;
411 Boomer et al., 2010; Bradley et al., 2011; Williams et al., 2011; Ivanova et al., 2015)
412 is a reflection of the migration and/or expansion of Mediterranean-type ostracod
413 populations. This process was driven by the input of water from the Marmara Sea,
414 commencing in the early Holocene (see below) and highlighted by various authors
415 as the dominant control of environmental changes in the Black Sea (Yanko-
416 Hombach et al., 2007; Marret et al., 2009; Nicholas et al., 2011; Soulet et al., 2011a).

417

418 ***Palaeoenvironmental records from the NE shelf***

419

420 The data collected from cores Ak-521 and Ak-2575 provide detailed information
421 about the benthic paleo-environments at the NE Black Sea shelf edge throughout the
422 Holocene. Estimates of water depth in the early Holocene are difficult to quantify
423 using ostracods because of the lack of modern species information. However, the
424 depth was shallower than present but increased until ~4 cal ka BP which
425 corresponds to sea-level curve estimates for the Black Sea (Balabanov et al., 2007;
426 Brückner et al., 2010). The ostracod records show that prior to ~7.4 cal ka BP, the
427 shelf was covered in low salinity water but salinity values increased until ~5.7-4 cal
428 ka BP. The increases in water depth and salinity are linked to the establishment of
429 the two-way flow through the Bosphorus in the early Holocene (Grigor'ev et al., 1984;
430 Yanko and Troitskaya, 1987; Mudie et al., 2004, 2007; Hiscott et al., 2007; Yanko-
431 Hombach et al., 2007).

432

433 Following establishment of the two-way flow in the Bosphorus, the data support other
434 studies from around the basin (e.g. Mertens et al., 2012) that suggest changes in
435 global sea-level was the main factor in controlling water level and salinity in the Black
436 Sea. These changes would have been moderated by changes in the precipitation-
437 evaporation budget and discharge from major rivers (Giosan et al., 2012). River
438 inflow of the Danube, Dnieper and Dniester is responsible for ~85% of runoff into the
439 modern Black Sea (Likhodedova and Konikov, 2007) and therefore disproportionately
440 affects the NW Black Sea. However, our records are not sensitive enough to detect
441 these secondary controls on water depth and salinity on the NE Shelf. The

442 boundaries between the assemblages and sub-assemblages are indistinct. The data
443 in this study do not find evidence of any rapid changes in environmental conditions
444 that were hypothesised by Ryan et al., (2003).

445

446 *Transformation of the Neoeuxinian environment towards the Holocene marine*
447 *environment (Assemblage I)*

448

449 The Caspian-assemblage present between 9.6-7.4 ka cal BP suggests that salinity
450 values ranged between 6 and 11 psu, sea level was greater than 50m, and salt
451 composition was similar to Caspian Sea water (Nevessakaya, 1965; Chepalyga,
452 2007; Yanko-Hombach et al, 2007, 2014; Ivanova et al., 2007, 2012, 2015). A
453 significant portion of the sediment sequence is represented by a coquina. This
454 coquina is rich in ostracod valves belonging to different ecological groups, possibly
455 due to a variety of biotopes alternating during the very slow and discontinuous
456 coquina deposition in a high-energy bottom water environment. Reworking of
457 ostracod valves might also contribute to the observed high species diversity in the
458 coquina. In Ak-521, Assemblage I contains species of the Caspian type such as
459 *Amnicythere* sp.1, *Loxocaspia* cf. *immodulata*, *Euxinocythere?* sp., *Amnicythere?* sp.
460 1, *Amnicythere* sp. 2, which were previously not recorded in either the Black Sea or
461 the Caspian Sea (Agalarova et al., 1961; Mandelstam et al., 1962; Caraion, 1962,
462 1967; Schornikov, 1969; Stancheva 1989a, 1989b, Boomer et al., 2005, 2010;
463 Yanko-Hombach et al., 2014; Leroy et al., 2014). In the younger sections of this
464 assemblage there is a gradual disappearance of certain species including *T.*
465 *amicola donetziensis*, *E. baquana*, and *E. relicta*. This suggests that salinity was
466 increasing throughout the early to mid-Holocene.

467

468 The reason for this increase in salinity is linked to the greater input of higher salinity
469 water into the Black Sea from the Mediterranean Sea, via the Marmara Sea (see
470 Hiscott et al., 2007; Mertens et al., 2012) and a rise in sea level (Balabanov et al.,
471 2007). This increase was potentially moderated by the higher levels of precipitation
472 discussed by Göktürk et al. (2011). However, detailed information about past
473 climates of the NE Black Sea region is lacking. In comparison to Western Europe,
474 there are very few studies concerning the Holocene climate conditions for the BS
475 region. The European palaeoclimate reconstructions from Mauri et al. (2015) provide
476 some insights on winter and summer conditions for different time slices from the
477 onset of the Holocene but it is based in a low number of palynological records
478 around the BS. Benthic salinity of less than 2 psu, suggested by Soulet et al.,
479 (2011b) is unlikely because the freshwater/oligohaline component is poorly
480 represented, with only two species of ostracods present.

481

482 Although Caspian fauna dominate in the early Holocene, the first Mediterranean
483 ostracods appeared on the NE Black Sea shelf at least by ~9.6 cal. ka (Fig. 3, 4).
484 They were represented by *P. agilis*, *H. rubra* and *L. multipunctata*, although the total
485 number of valves is low. In shallower areas, the species composition of the first
486 Mediterranean ostracods is more diverse due to the greater variety of habitats. *C.*
487 *diffusa*, *Callistocythere mediterranea* (Müller, 1894) are recorded in sediment, *C.*
488 *variabilis*, *C. marinovi* and *Cytherois* spp. are found together with the species of
489 Caspian type on the NE shelf (Schornikov collections). This suggests that saline
490 water inputted from the Mediterranean reached the north-eastern shelf relatively
491 quickly after the initial establishment of the two-way flow. This suggestion is

492 supported by the persistent occurrence of euryhaline dinoflagellate cysts and rare
493 specimens of foraminifer *Ammonia tepida* from 9.6 cal ka BP in Ak-2575 (Ivanova et
494 al., 2015) as well as by the foraminiferal data from the NW and SE shelves (Yanko-
495 Hombach et al., 2014).

496

497 *Co-existence of Mediterranean and Caspian fauna (Assemblage II)*

498

499 At about 7.4 cal ka BP, salinity reaches a critical limit of ~11-12, and the salt
500 composition of water changes from the Caspian type to the normal oceanic type
501 (Nevesskaya, 1965; Chepalyga, 2002; Yanko-Hombach, 2007). These conditions
502 are unsuitable for the majority of the Caspian type fauna. However, they are also not
503 optimal for Mediterranean ostracods, since the salinity is at the lower limit of their
504 tolerance (Schornikov, 1969). This explains the low ostracod abundance just after
505 the transition between Assemblage I and Assemblage II. Soft shelly mud started to
506 accumulate over the coquina at the NE shelf edge owing to a decrease in bottom
507 water dynamics and increase in fine-grained terrigenous material supply. These
508 environmental changes coincided with the beginning of the large-scale migration of
509 the Mediterranean ostracod fauna to the Black Sea shelf that characterized
510 Assemblage IIA development.

511

512 The data presented in this study assume ecological conditions that allowed the
513 coexistence of Mediterranean and Caspian species (Ivanova et al., 2007, 2012,
514 2015). According to other studies, after the onset of two-way circulation in the
515 Bosphorus Strait, ostracod valves of both fauna types occur simultaneously over an
516 extended period of time (Stancheva, 1989b; Yanko-Hombach et al., 2014; Ivanova et

517 al, 2007, 2015). Living specimens of Caspian and Mediterranean types are not
518 reported together in the same samples from the Black Sea and Sea of Azov. Along
519 with the fauna of Mediterranean type, only *C. torosa* was found in the Sea of Azov.
520 This species is able to coexist with representatives of the Caspian type.

521

522 However, in different areas of the Black Sea, the appearance of Mediterranean
523 species and thus the lower boundary of the mixed assemblage seem to be slightly
524 diachronous. According to the data from the Bulgarian shelf, this level corresponds
525 to the Bugazian/Vityazian boundary (Stancheva, 1989b). Hiscott et al. (2007) discuss
526 the transition from the Caspian to the Mediterranean type on the SW shelf from 7.3
527 to 6.0 cal ka BP. Using calibration procedures in Ivanova et al. (2015), this
528 corresponds to ~7.9 to 6.2 cal ka BP. Note that the datum level of the large-scale
529 migration of Mediterranean species cannot be ascertained using the quantitative
530 data on their occurrence (Yanko-Hombach et al., 2014). The less abundant
531 occurrence of Mediterranean ostracods during the large-scale migration event can
532 possibly be explained by their slower migration rates into the Black Sea compared to
533 molluscs, as most part of Podocopa are benthic animals without any pelagic
534 ontogenetic stages.

535

536 The Caspian-type ostracod fauna prevails over the Mediterranean fauna throughout
537 the Assemblage IIA interval. This occurs at a very low level of total ostracod
538 abundance (Fig. 4), likely due to dilution by rapidly accumulating shelly mud of the
539 *Mytilus* mud facies (Ivanova et al., 2015). Moderate OAR values support this
540 assumption for core Ak-2575. However, a persistent presence of authigenic gypsum
541 crystals suggests that episodic upwelling of the anoxic deep water onto the shelf

542 edge might suppress populations of the ostracod fauna. In Ak-521, gypsum crystals
543 are rare and the ostracod fauna is more abundant.

544

545 The gradual transition from Assemblage IIA to IIB at about 7.1 – 7 cal ka BP is
546 expressed by a disappearance of most Caspian-type ostracod species except for *L.*
547 *lepida*. Relatively high diversity and abundance of species of Mediterranean type in
548 the IIB interval (from Ak-2575) indicate that an increase in salinity should exceed the
549 limits of tolerance for species of Caspian type. In this context, the late disappearance
550 of only one ostracod species *L. lepida* and its late occurrence in significant amounts
551 (ten valves per sample) needs further investigation, as a salinity of ~18 psu was
552 reported at that period (Mertens et al., 2012). It is unlikely that *L. lepida* could *in situ*
553 coexist with a relatively diverse Mediterranean fauna for such a long time because of
554 the significantly different tolerances to salinity conditions (absolute value and salt
555 composition balance). Thus, we assume that the specimens of *L. lepida* found in
556 younger samples are reworked from shallow-water areas where it could inhabit low-
557 salinity conditions. In the early Holocene and late Pleistocene, this species was one
558 of the most abundant (Stancheva, 1982a, b; Boomer et al., 2010). Moreover,
559 reworked valves of the Caspian type ostracods occur in grab samples together with
560 recent ostracods mainly near the southern extremity of the Crimean Peninsula at
561 depths of 60–100 m, in the near-Bosporus area at a depth of 105–415 m
562 (Schornikov, 2011), and in our grab and drag samples from the NE shelf edge, at
563 depths of 80-100 m.

564

565 Assemblage IIB differs from IIA because of the higher diversity of Mediterranean-
566 type ostracod fauna. It contains more stenohaline species along with euryhaline

567 species, which previously dominated. Thus, it demonstrates a migration event via the
568 Bosphorus Strait related to increases in salinity. Significant changes in bottom-water
569 temperature are documented by variations in the species composition of
570 Assemblage II. *S. rennata* occurred in significant numbers at the point when
571 Mediterranean type species increased. At present, this species inhabits depths of 15
572 to 30 m (Schornikov, 1969) where the bottom water temperature is significantly
573 higher over the year than on the outer shelf (Fig. 1). Abundant *L. multipunctata* occur
574 within the same time interval in both cores, although at present it is usually much
575 abundant in shallower depths.

576

577 Hence, Assemblage II suggests that the bottom water temperature was considerably
578 warmer than at present on the outer shelf during the colonization by Mediterranean
579 fauna (7.4-6.7 cal ka BP). However, it is not clear when the warm climatic conditions
580 responsible for the bottom water warming commenced. The warm period during the
581 mid Holocene (7.4–6.7 cal ka BP) as highlighted by our ostracod records is identified
582 for winter conditions (1 to 2 °C above modern pre-industrial conditions) from
583 reconstructed climate conditions by Mauri et al., (2015). In addition, warm and humid
584 climates were estimated from the pollen record from Yenicağa Lake in northern
585 Anatolia (Bottema et al., 1995), Lake Van in central Anatolia (Wick et al., 2003; Litt et
586 al., 2009), Northern Anatolia (Shumilovskikh et al., 2012) and Georgia (Kvavadze
587 and Connor, 2005), as well as from the Bulgarian Black Sea shelf (Filipova–
588 Marinova, 2006). According to Shumilovskikh et al. (2012), a warm and humid phase
589 occurred in Northern Anatolia at ~8.5-5 cal ka BP.

590

591 *Onset of the recent bottom environment on the NE Black Sea shelf (Assemblage III)*

592

593 Assemblage III consists of only Mediterranean-type species. The composition of
594 Mediterranean type fauna in both transitional (II) and marine (III) assemblages is
595 very impoverished because both studied cores were collected from a relatively deep
596 area (99-101 m) covered with rather uniform soft shelly silty mud. On shallower
597 areas of the eastern shelf, upper Holocene ostracod assemblages are much more
598 diverse (Schornikov et al., 2014).

599

600 Salinity almost reaches present-day values during the gradual end of the
601 Assemblage II phase. Further development of the ostracod fauna mainly depended
602 on changes in the bottom water temperature and sedimentation processes.
603 Disappearance of relatively warm-water *S. rennata* and the decrease in abundance
604 of *L. multipunctata* at ~6.8 cal ka BP indicate a gradual reduction in bottom water
605 temperature. Other explanations seem unlikely, as there is no evidence of large
606 salinity changes and the biotope (soft silty-pelitic mud) is similar both below and
607 above this level (Fig. 5A). Therefore, the above mentioned changes in composition
608 of the ostracod fauna likely reflect a climate (and bottom water) cooling trend.
609 However, the accumulation rate of ostracod valves (OAR) sharply accelerated at the
610 transition from Assemblage IIIA (Fig. 4d). This suggests high productivity of the
611 ostracod fauna, although concentration of valves in sediments is rather low owing to
612 their dilution by rapidly accumulated terrigenous mud.

613

614 Sedimentation rates slowed down after the very rapid terrigenous mud accumulation
615 related to the Kalamitian high sea level stand (Ivanova et al., 2007, 2015). The hiatus
616 (>1000 years) which likely corresponds to erosion during the Kundukian regressive

617 phase (Chepalyga, 2002) separates assemblages IIIA and IIIB. This correlates with
618 *Mytilus* mud and *M. phaseolinus* mud facies respectively. Ostracod abundance and
619 OAR increased during the transition from IIB to IIIA reflecting favourable conditions
620 for ostracods, and fall to almost zero values after ~6.5 cal ka BP, according to the
621 data from core Ak-2575 (Fig. 5E). The short period of suppressed ostracod fauna
622 before the hiatus might be related to an anoxic water upwelling event.

623

624 The species composition of Assemblage III suggests the cooling trend continued up
625 to the time of the modern assemblage onset at ~5.7 - 4 cal ka BP, although water
626 conditions were still somewhat warmer than present. Increasing percentages of *P.*
627 *agilis* during the time interval from 6.7 to 4 cal ka BP and appearance of
628 *Bythocythere* sp. at about 4 cal ka BP confirms this suggestion. *Bythocythere* sp. is
629 found in modern assemblages of the Black Sea only at depths of >70 m (Schornikov,
630 1969). Therefore, its presence serves as an evidence of bottom water temperature
631 reduction to present values. The changes in species composition were simultaneous
632 with the gradual transition from *Mytilus* mud to *Modiolus phaseolinus* mud facies
633 (Ivanova et al., 2015). *P. agilis* is the most abundant ostracod species on the modern
634 *M. phaseolinus* mud (Schornikov, 1969). Changes in Assemblage III may be caused
635 either by facies replacement that was accompanied by the slowing down of mud
636 sedimentation rates (and thus, also OAR, Fig.4d) or by some bottom water cooling.
637 Formation of modern assemblages at ~5.7- 4 cal ka BP indicates the onset of
638 environmental conditions close to present.

639

640

641 **Conclusions**

642 Ostracod records of cores Ak-521 and Ak-2575 are generally synchronous and
643 represent the response of ostracod assemblages at the NE Black Sea shelf edge to
644 the major Holocene paleoenvironmental events. During the period ~ 11.8 to 7.4 cal
645 ka BP, the ostracod fauna of Caspian type was represented by a relatively diverse
646 range of species. However, the first Mediterranean migrants already appeared at
647 about 9.6 cal ka BP. A significant portion of the sediment sequence in this period is
648 represented by a coquina that is rich in ostracod valves belonging to different
649 ecological groups. This is potentially explained by a variety of biotopes alternating
650 during the very slow coquina deposition interrupted by hiatuses, in a high-energy
651 bottom water environment that resulted in washing away of mud, reworking of
652 mollusc shells in the coquina, as well as ostracod valves. Many species in the
653 Caspian assemblage are in common with those in the modern Caspian Sea.

654

655 The composition of Mediterranean type fauna in the *Mytilus* mud facies overlying the
656 coquina is very impoverished compared to that from shallower areas, likely because
657 of a uniform biotope represented by shelly silty mud. A transitional assemblage
658 occurs between 7.4-6.8 cal ka BP that contains a mixture of both Caspian and
659 Mediterranean-type species. This occurs at a very low level of total ostracod
660 abundance, likely due to high accumulation rates of the mud. The Caspian-type
661 ostracod fauna dominates over the Mediterranean type until ~7.1 cal ka BP. After
662 this period, Mediterranean fauna became more abundant. Remains of the Caspian-
663 type fauna found in sediments younger than about ~7.1 cal ka BP were likely
664 reworked from shallower freshened areas. They were unlikely to reside together with
665 a diverse range of Mediterranean species, which occupy bottom conditions with a
666 salinity much higher than the tolerance level for the Caspian species. After 6.8 cal ka

667 BP, ostracod fauna presented only by Mediterranean-type species became more
668 abundant.

669

670 Changes in the ostracod fauna of the NE Black Sea shelf edge during the Holocene
671 reflect the increase in bottom water salinity after the opening of the two-way
672 circulation through the Bosphorus Strait and a bottom water cooling trend starting
673 from the mid-Holocene optimum (at ~6.8 cal ka BP) to recent conditions. The bottom
674 water temperature was considerably warmer than at present on the outer shelf
675 during the active colonization by Mediterranean fauna (~7.4 to 6.8 cal ka BP). After
676 6.8 cal ka BP, warmer-water assemblages were gradually replaced by colder-water
677 ones. The cooling trend continued up to the onset of the modern assemblage ~5.7 -
678 4 cal ka BP when water conditions were still somewhat warmer than present. The
679 modern ostracod assemblage is typical of the *M. phaseolina* mud facies on the outer
680 shelf.

681

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683

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697

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1012

1013 **List of figures**

1014

1015 Figure 1. The study region. A – Overview of study area; B- Ponto-Caspian basins
1016 during the Late Pleistocene in time of connection of Neoeuxinian (Black Sea) Basin
1017 and Khvalynian (Caspian) Basin (adopted from Yanina, 2014); C- Location of cores
1018 Ak- 2575 and Ak- 521; D – Sample locations in Caspian Sea, E - Modern distribution
1019 of fauna of Caspian type in Azov-Black Seas basin from (Schornikov 1969, 2011;
1020 Opreanu, 2008 and new data from the Kuban Delta)..

1021

1022 Figure 2. Variation in temperature and salinity with depth at four time intervals from
1023 44.53°N and 37.93°E on north-eastern Black Sea shelf.

1024

1025 Figure 3. Occurrence of ostracods in core Ak-2575. Lithology and calendar ages are
1026 based on Ivanova et al. (2015). 2σ range for the calibrated radiocarbon dates
1027 2610(2360-2800); 3590 (3390-3830); 6270(6000- 6450), 6510(6300-6690);
1028 6820(6600-7030); 7150 (6910-7330); 7415 (7250-7580); 7520 (7410-7680); 9440
1029 (9270-9540); 9550 (9470-9690) (all cal yr BP).

1030

1031 Figure 4. Occurrence of ostracods in core Ak-521. Lithology and calendar ages are
1032 based on Ivanova et al. (2015). 2σ range for the calibrated radiocarbon dates 4540
1033 (4280–4830), 6120 (5920–6302), 6410 (6270–6640), 6870 (6650–7160), 7420
1034 (7170–7620), 8740 (8380–9130), 8710 (8350–9130), 9150 (8700–9500), 11,870
1035 (11,250–12,430) (all cal. yr BP). Sediment and ostracod occurrence legend in Figure
1036 3.

1037

1038 Figure 5. Lithology, stratigraphy, benthic ostracod diversity and assemblages from
1039 (1) Ak-2575 and (2) Ak-521. (A) lithology (see Fig. 3 for sediment type); (B) calibrated
1040 ages of AMS-14C dated levels (see Fig.3 for 2σ range, cal yr BP); (C) grain size; (D)
1041 ostracod taxa per sample and ecological affinities overview; (E) accumulation rates
1042 of ostracod valves (OAR), valves/ka yr, (F) ostracod abundance; (G) ostracod
1043 assemblages; (H) stratigraphy; (I) lithology (see Fig. 2 for sediment type); (J)
1044 calibrated ages of AMS-14C dated levels (see Fig. 4 for 2σ range, cal years BP); (K)
1045 ostracod taxa per sample and ecological affinities overview; (L) ostracod
1046 assemblages; (M) stratigraphy. (A-D, F, H-J, M) from Ivanova et al. (2015); *Ne* –
1047 Neoeuxinian (11.8-10 cal ka BP), *Bg* – Bugazian (10–8.8 cal ka BP), *Vt* –
1048 Vityazevian (8.8–7.8 cal ka BP), *Kl* – Kalamitian (7.8–6.9 cal ka BP), *Dz* –
1049 Dzhemetinian (6.9–2.6 cal ka BP).

1050

1051 Figure 6. Holocene ostracod assemblages and major events affecting the faunal
1052 changes.

1053

1054

1055 **List of tables**

1056

1057 Table 1. Revised ostracod taxonomy A- for Ak-521 from Ivanova et al., (2007), B-
1058 Ak-2575 from Ivanova et al., (2015) and C- fauna of Caspian type from Opreanu
1059 (2008).

1060

1061 Table 2. Modern distribution of ostracod species of Caspian type in Azov-Black Sea
1062 basin based on literature data (Schornikov, 1967, 2011; Opreanu, 2008)

1063

1064 Table 3. Modern distribution of some collected ostracod species in Caspian Sea.
1065 I-IX samples (see Fig. 1C), * - species is found living; without * - only valves and
1066 shells; I-IX– sample numbers, S, t, O2, pH are noted only for sites with living
1067 ostracods

1068

1069 Table 4. Species composition of ostracod fauna from the NE outer shelf.

1070 Occurrence of species: +++ - abundant, ++ - common, + - rare. *Bg* – Bugazian (10–
1071 8.8 cal ka BP), *Vt* – Vityazevian (8.8–7.8 cal ka BP), *Kl* – Kalamitian (7.8–6.9 cal ka
1072 BP); Dzhemetinian (6.9–2.6 cal ka BP) according to Balabanov (2007). M- species of
1073 Mediterranean type, C – species of Caspian type; F/O – freshwater-oligohaline
1074 species. I, IIA, IIB, IIIA, IIIB- Assemblages (see Fig. 3-4)

1075

1076 **Supplementary data**

1077 Table 1. Ostracod species occurrence in core Ak-2575

1078

1079 Figure I. SEM images of ostracod species

1080 1 - *Graviacypris elongata* (Schweyer, 1949), right valve (RV) of male, AK 2575, 154-

1081 156 cm. 2 - *G. elongata*, left valve (LV) of female, AK 2575, 150-152 cm. 3 -

1082 *Bythocythere* sp., RV of male, AK 2575, 28-30 cm. 4 - *Bythocythere* sp., LV of

1083 female, AK 2575, 24-26 cm. 5 - *Fabaeformiscandona* sp. sensu Schornikov, 2011,

1084 RV of A-1, 158-158 cm. 6 - *Fabaeformiscandona* sp., RV of A-1, 174-176 cm. 7 -

1085 *Leptocythere multipunctata* (Seguenza, 1884), RV of female, AK 2575, 126-128 cm.

1086 8 - *L. multipunctata*, RV of female, AK 2575, 110-112 cm. 9 - *L. multipunctata*, LV of

1087 male, AK 2575, 106-108 cm. 10 - *Amnocythere stepanaitysae* (Schneider in

1088 Mandelstam et al., 1962), RV of female, AK 2575, 156-158 cm. 11 - *A. stepanaitysae*,

1089 LV of female, AK 2575, 180-182 cm. 12 - *A. stepanaitysae*, RV of female, AK 2575,

1090 156-158 cm. 13 - *A. stepanaitysae*, LV of female, AK 2575, 156-158 cm. 14 -

1091 *Amnocythere resupina* (Stepanaitys in Mandelstam et al., 1962), RV of male, AK

1092 2575, 156-158 cm. 15 - *A. stepanaitysae*, LV of female, AK 2575, 166-168 cm. 16 -

1093 *A. resupina*, RV of female, AK 2575, 156-158 cm. 17 - *A. resupina*, LV of female, AK

1094 2575, 160-162 cm. 18 - *Amnocythere striatocostata* (Schweyer, 1949), RV of female,

1095 AK 2575, 176-178 cm. 19 - *A. striatocostata*, LV of male, AK 2575, 180-182 cm. 20 -

1096 *Amnocythere hilda* (Stepanaitys, 1960), LV of female, AK 2575, 180-182 cm. 21 - *A.*

1097 *hilda*, LV of female, AK 2575, 180-182 cm. Bar: 1-19 - 100 μ m, 20-21 - 60 μ m

1098

1099 Figure 2. SEM images of ostracod species

1100 1 - *Euxinocythere relictata* (Schornikov, 1964), right valve (RV) of female, AK 2575,
1101 156-158 cm. 2 - *E. relictata*, left valve (LV) of female, AK 2575, 156-158 cm. 3 - *E.*
1102 *relictata*, RV of female, AK 2575, 182-184 cm. 4 - *E. relictata*, LV of female, AK 2575,
1103 166-168 cm. 5 - *E. relictata*, RV of female, AK 2575, 182-184 cm. 6 - *E. relictata*, LV of
1104 male, AK 2575, 166-168 cm. 7 - *Amnocythere* sp. 1, RV of male, AK 2575, 158-160
1105 cm. 8 - *Amnocythere* sp. 1, LV of female, AK 2575, 158-160 cm. 9 - *Amnocythere* sp.
1106 2, RV of female, AK 521, 165-170 cm. 10 - *Amnocythere* sp. 2, LV of female, AK 521,
1107 165-170 cm. 11 - *Amnocythere* sp. 2, RV of A-1, AK 521, 165-170 cm. 12 -
1108 *Amnocythere* sp. 2, LV of A-1, AK 521, 165-170 cm. 13 - *Amnocythere?* sp., RV of
1109 female, AK 521, 165-170 cm. 14 - *Amnocythere?* sp., RV of male, AK 521, 165-170
1110 cm. 15 - *Amnocythere martha* (Livental in Agalarova et al., 1940), RV of female, AK
1111 2575, 160-162 cm. 16 - *A. martha*, LV of male, AK 2575, 160-162 cm. 17 -
1112 *Amnocythere volgensis* (Negadaev, 1957), RV of female, AK 521, 170-175 cm. 18 -
1113 *A. volgensis*, LV of male, AK 521, 190-195 cm. 19 - *Euxinocythere?* sp., RV of 190-
1114 195 cm. 20 - *Euxinocythere baquana* (Livental, 1938), RV of female, AK 2575, 154-
1115 156 cm. 21 - *Euxinocythere virgata* (Schneider, 1962), RV of male, AK 2575, 156-
1116 158 cm. 22 - *E. virgata*, LV of female, AK 2575, 156-158 cm. 23 - *Euxinocythere*
1117 *bosqueti* (Livental, 1929), LV of female, AK 521, 170-175 cm. Bar: 1-23 - 100 µm.

1118

1119 Figure 3. SEM images of ostracod species

1120 1 - *Cytheroma marinovi* Schornikov, 1969, right valve (RV) of female, AK 2575, 30-
1121 32 cm. 2 - *C. marinovi*, left valve (LV) of male, AK 2575, 32-34 cm. 3 - *Pontocythere*
1122 *tchernjawsii* Dubowsky, 1939, RV of A-1, AK 2575, 14-16 cm. 4 -
1123 *Hiltermannicythere rubra* (Müller, 1894), RV of female, AK 2575, 40-42 cm. 5 -
1124 *Tyrrhenocythere amnicola donetziensis* (Dubowsky, 1926), RV of A-1, AK 2575 182-

1125 184 cm. 6 - *T. amnicola donetziensis*, LV of A-1, AK 2575, 172-174 cm. 7 -
1126 *Carinocythereis carinata* (Roemer, 1838), LV of A-2, AK 2575, 32-34 cm. 8 -
1127 *Sagmatocythere rennata* (Schornikov, 1965), RV of male, AK 2575, 90-92 cm. 9 - S.
1128 *rennata*, LV of female, AK 2575, 90-92 cm. 10 - *Loxocaspia lepida* (Stepanaitys,
1129 1962), RV of female, AK 2575, 150-152 cm. 11 - *L. lepida*, LV of male, AK 2575,
1130 150-152 cm. 12 - *L. sublepida* (Stancheva, 1989), RV of female, AK 2575, 150-152
1131 cm. 13 - *L. sublepida*, LV of male, AK 2575, 150-152 cm. 14 - *L. cf. immodulata*
1132 (Stepanaitys, 1958), RV of female, AK 521, 172-175 cm. 15 - *L. cf. immodulata*, LV
1133 of male, Ak 521, 180-185 cm. 16 - *Sarmatina?* cf. *azeri* (Agalarova, 1961), RV of
1134 female, AK 2575, 152-154 cm. 17 - *S.?* cf. *azeri*, LV of female, AK 2575, 152-154
1135 cm. 18 - *Loxocaspia? edita* (Schneider, 1962), RV of male, AK 521, 172-175 cm,
1136 100 µm. 19 - *Paradoxostoma simile* Müller, 1894, RV of female, AK 2575, 8-10 cm,
1137 100 µm. 20 - *Xestoleberis chanakovi* Livental in Schweyer, 1949, RV of female, AK
1138 2575, 156-158 cm. 21 - *Xestoleberis cornelii* Caraion, 1963, RV of male, AK 2575,
1139 80-82 cm. Bar: 1-2 - 60 µm, 3-21 - 100 µm.
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1141