1 **Origin, migration pathways and palaeoenvironmental significance of Holocene**

2 **ostracod records from the north-eastern Black Sea shelf**

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Abstract

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

Key Words

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

Introduction

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

129 break at depths of100-120 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 ~44.53°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 ~2.5°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 (cm^2 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 tchernjawskii*. *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

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

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

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; Schnornikov, 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 (Nevesskaya, 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

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

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

417

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 disproportionally

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   *amnicola 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* (Műller, 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 Bosporus 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

species, which previously dominated. Thus, it demonstrates a migration event via the

Bosporus Strait related to increases in salinity. Significant changes in bottom-water

temperature are documented by variations in the species composition of

Assemblage II. *S. rennata* occurred in significant numbers at the point when

Mediterranean type species increased. At present, this species inhabits depths of 15

to 30 m (Schornikov, 1969) where the bottom water temperature is significantly

higher over the year than on the outer shelf (Fig. 1). Abundant *L. multipunctata* occur

within the same time interval in both cores, although at present it is usually much

abundant in shallower depths.

Hence, Assemblage II suggests that the bottom water temperature was considerably

warmer than at present on the outer shelf during the colonization by Mediterranean

fauna (7.4-6.7 cal ka BP). However, it is not clear when the warm climatic conditions

responsible for the bottom water warming commenced. The warm period during the

mid Holocene (7.4–6.7 cal ka BP) as highlighted by our ostracod records is identified

for winter conditions (1 to 2 °C above modern pre-industrial conditions) from

reconstructed climate conditions by Mauri et al., (2015). In addition, warm and humid

climates were estimated from the pollen record from Yenicağa Lake in northern

Anatolia (Bottema et al., 1995), Lake Van in central Anatolia (Wick et al., 2003; Litt et

al., 2009), Northern Anatolia (Shumilovskikh et al., 2012) and Georgia (Kvavadze

and Connor, 2005), as well as from the Bulgarian Black Sea shelf (Filipova–

Marinova, 2006). According to Shumilovskikh et al. (2012), a warm and humid phase

occurred in Northern Anatolia at ~8.5-5 cal ka BP.

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 Bosporus 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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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

Supplementary data

Table 1. Ostracod species occurrence in core Ak-2575

Figure I. SEM images of ostracod species

1 - *Graviacypris elongata* (Schweyer, 1949), right valve (RV) of male, AK 2575, 154-156 cm. 2 - *G. elongata*, left valve (LV) of female, AK 2575, 150-152 cm. 3 - *Bythocythere* sp., RV of male, AK 2575, 28-30 cm. 4 - *Bythocythere* sp., LV of female, AK 2575, 24-26 cm. 5 - *Fabaeformiscandona* sp. sensu Schornikov, 2011, RV of A-1, 158-158 cm. 6 - *Fabaeformiscandona* sp., RV of A-1, 174-176 cm. 7 - *Leptocythere multipunctata* (Seguenza, 1884), RV of female, AK 2575, 126-128 cm. 8 - *L. multipunctata*, RV of female, AK 2575, 110-112 cm. 9 - *L. multipunctata*, LV of male, AK 2575, 106-108 cm. 10 - *Amnicythere stepanaitysae* (Schneider in Mandelstam et al.,1962), RV of female, AK 2575, 156-158 cm. 11 - *A. stepanaitysae*, LV of female, AK 2575, 180-182 cm. 12 - *A. stepanaitysae*, RV of female, AK 2575, 156-158 cm. 13 - *A. stepanaitysae*, LV of female, AK 2575, 156-158 cm. 14 - *Amnicythere resupina* (Stepanaitys in Mandelstam et al., 1962), RV of male, AK 2575, 156-158 cm. 15 - *A. stepanaitysae*, LV of female, AK 2575, 166-168 cm. 16 - *A. resupina*, RV of female, AK 2575, 156-158 cm. 17 - *A. resupina*, LV of female, AK 2575, 160-162 cm. 18 - *Amnicythere striatocostata* (Schweyer, 1949), RV of female, AK 2575, 176-178 cm. 19 - *A. striatocostata*, LV of male, AK 2575, 180-182 cm. 20 - *Amnicythere hilda* (Stepanaitys, 1960), LV of female, AK 2575, 180-182 cm. 21 - *A. hilda*, LV of female, AK 2575, 180-182 cm. Bar: 1-19 - 100 µm, 20-21 - 60 µm

Figure 2. SEM images of ostracod species

1100 1 - *Euxinocythere relicta* (Schornikov, 1964), right valve (RV) of female, AK 2575,

1101 156-158 cm. 2 - *E. relicta*, left valve (LV) of female, AK 2575, 156-158 cm. 3 - *E.*

1102 *relicta*, RV of female, AK 2575, 182-184 cm. 4 - *E. relicta*, LV of female, AK 2575,

1103 166-168 cm. 5 - *E. relicta*, RV of female, AK 2575, 182-184 cm. 6 - *E. relicta*, LV of

1104 male, AK 2575, 166-168 cm. 7 - *Amnicythere* sp. 1, RV of male, AK 2575, 158-160

1105 cm. 8 - *Amnicythere* sp. 1, LV of female, AK 2575, 158-160 cm. 9 - *Amnicythere* sp.

1106 2, RV of female, AK 521, 165-170 cm. 10 - *Amnicythere* sp. 2, LV of female, AK 521,

1107 165-170 cm. 11 - *Amnicythere* sp. 2, RV of A-1, AK 521, 165-170 cm. 12 -

1108 *Amnicythere* sp. 2, LV of A-1, AK 521, 165-170 cm. 13 - *Amnicythere*? sp., RV of

1109 female, AK 521, 165-170 cm. 14 - *Amnicythere*? sp., RV of male, AK 521, 165-170

1110 cm. 15 - *Amnicythere 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 *Amnicythere 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 *tchernjawskii* Dubowsky, 1939, RV of A-1, AK 2575, 14-16 cm. 4 -

1123 *Hiltermannicythere rubra* (Műller, 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