ANALYSIS OF VEGETATION-ENVIRONMENT RELATIONSHIPS IN THE BAY OF SOZOPOL, BULGARIAN BLACK SEA COAST BY THE CCA METHOD

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ABSTRACT. A 2.20 m long sediment core, belonging to profile of square “D” in the Bay of Sozopol, Bulgarian Black Sea coast, was analysed for diatoms, chrysophycean stomatocystae, dinocysts and pollen. The main objective of this study is to present a mathematical model, based on Canonical Correspondence Analysis (CCA), of the palaeoenvironmental changes in salinity and tidal exposure and to test our hypothesis about the successive phases in the development of the bay during the Eneolithic and Early Bronze age.

KEY WORDS: diatoms, pollen, canonical correspondence analysis, Black Sea coastal deposits, the Late Holocene, palaeoecology

INTRODUCTION

Mathematical models can be used as a perfect combination of ecological, cultural, geological and climatic variables, recalculated to a certain archaeological period in a certain local area. The main objective of this study is to present a mathematical model of the palaeoenvironmental changes in salinity and tidal exposure, based on different microfossil groups (diatoms, chrysophycean stomatocystae, pollen and dinocysts). This model is impossible without the use of an experimental database, containing all the information, archaeological, geological and palaeoecological, collected during the underwater excavation of settlements in the harbour of Sozopol, Bulgarian Black Sea coast, carried out between 1990 and 1993. The history of these settlements gives more information about the genesis of the Thracian tribal community from the end of the Eneolithic to the end of the Early Bronze Age (Draganov 1995).

STUDY AREA

The study area included two zones of investigation: Sozopol 1 and Sozopol 2. Eight more or less connected squares, 5 by 5 meters in size, were excavated in these zones. Three of the squares contained only Early Bronze age material (A, C, E); two contained Early Bronze age material and, under a hiatus, Eneolithic material (B and F), and three contained only Eneolithic material (D, G, H). A complete synthesis of the results of diatom and pollen analysis of the profile of square “D” have been previously published (Ognjanova-Rumenova 1995, Ognjanova-Rumenova & Popova 1996, Ognjanova-Rumenova & Zaprianova in press, Filipova-Marinova in press).

RESULTS AND DISCUSSION

A total of 119 diatom taxa have been identified (Appendix 1). The diatom flora consists of recent species.
Only 6.8% of the determined taxa are of unknown ecology. On the basis of species composition and the relationships between the ecological groups two local diatom assemblage zones have been distinguished in the diagram (Ognjanova-Rumenova 1995): Diatom zone A (2.20–0.70 m) – the diatom flora indicates fresh-brackish sedimentary conditions, the dominant taxa are epiphytic; Diatom zone B (0.70–0.10 m) – the diatom flora marks marine-brackish sedimentary environment.

Additional data about chrysophycean stomatocystae, dinocysts and pollen, found in the material from profile of square “D”, allowed us to perform canonical correspondence analysis (CCA) with quantitative and explanatory variables in order to find direct relationships among the investigated fossil groups (Ter Braak 1986). The successions of all these plant groups with known ecology may be used as “external” explanatory variables in CCA. The primary result of CCA is an ordination diagram, i.e. a graph with a coordinate system formed by ordination axis (i.e. the synthetic gradient extracted by CCA). This biplot diagram is informative and reveals correlations between diatom succession and successions.
of other fossil groups (Fig. 1). The diagram consists of the following elements: points of species, samples and arrows for quantitative “external” environmental variables. All determined diatom species are displayed on the CCA-ordination diagram, independently of their too crowded disposition. CCA has been carried out on 15 samples (Appendix 2), which were included to pollen analysis. Consequently, each species point in diagram is at the centroid (weighted average) of the sample points in which it occurs. The centroid principle then implies that the species occurring in a particular sample are scattered around the point of sample. The importance of the “external” variables is proportional to the length of the environmental vector in the biplot. The interpretation of the axes is unambiguous (Table 1): the first axis is defined by the ratio: arboreal/non-arboreal pollen type (AP:NAP) and it reflects the human influence; the second – by the acritarch – Cymatosphaera globulosa (Dino 2), a planktonic, euhaline species, which distribution depends on the rise of the sea level. The diatom taxa are further differentiated on the third axis, determined by Dino 3 – Spiniferites ramosus, a stenohaline, cool-water species and the ratio diatom frustules/chrysophycean stomatocystae expressed changes in trophy (the eutrophication) during the bay development.

The main results of the CCA analysis is that there is a good correspondence between the diatom taxa and ratio AP:NAP from the pollen analysis. This arrow is the longest on the biplot and some samples with a high positive score on that axis are projected on it. This proportion is connected with the human influence – land use and eutrophication in the bay. All these samples determined the sediment level (0.10–0.60 m), which corresponds to the local pollen assemblage zone PAZ-S2 (Filipova-Marinova in press). It is characterized by decrease of tree and shrub taxa in pollen diagram, due to the quantity diminution of Quercus (up to 18%). A great variety of anthropophytic elements is remarkable: Plantago lanceolata, Centaurea cyanus, Polygonum aviculare, Cirsium, etc. Among pollen of cereals there are: Cerealia-type and Triticum.

Although the chrysophycean arrow is short and the variance accounted for by the ordination diagram is small, statistical test shows a significant correlation between diatoms and chrysophycean species. This finding proves once more that the ratio diatom frustules/chrysophycean stomatocystae is an useful characteristic and can be used to study Quaternary brackish-marine history of the Black sea. The Lingulodinium machaerophorum centroid (Dino 1) is located positively along the Chrysophycean arrow with marine, mesohalobous and halophilous diatoms grouped around it: Mastogloia baldijakiana Grun., M. pusilla Grun., Hyalodiscus scoticus var. griseolus Pr. Lavr., Diploneis smithii (Breb.) Cl., etc. The centroid of Spiniferites ramosus (Dino 3) is situated very near to Dino 1. The diatom taxa, which are scattered around it are also marine and mesohalobous, i.e. Lyrella abrupta (Greg.) Mann and Gyrosigma balticum (Ehr.) Rab. Sample 9 (0.90 m) is projected next to these centroids, which are surrounded with diatoms, characteristic for more saline environment. Probably, this level corresponds to the stage of marine influx. The sea level rose and the littoral cleyey sediments have been replaced by more terrigenous sediments. The decrease of Chaetoceros spp. resting spores is explained by this influx of marine-brackish water and the decrease of nutrients. This had probably triggered the development of the second diatom assemblage (Ognjanova-Rumenova 1995). These data mark the time of the Black sea Post-Eneolithic transgression (Draganov 1995).

Most of the samples are scattered very close to each other (11–21 samples; 1.10–2.10 m). This is again evidence of monotonous conditions in the palaeoenvironment at the beginning of the sediment formation.

The CCA demonstrates statistically that the palaeoenvironmental features characterizing the profile “D” are common to all the diagrams under study (diatoms, chrysophycean stomatocystae, pollen and dinocysts).

### Table 1. Canonical coefficients and intraset correlations of the external (environmental) variables with the four axes of canonical correspondence analysis

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<th>Correlation coefficients</th>
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<td>Axis 1 2 3 4</td>
<td>1 2 3 4</td>
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<tr>
<td>Chrysophycean stomatocystae</td>
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<td>-0.141 0.077 0.747 -0.547</td>
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<td>Dino 1</td>
<td>0.025 -0.053 0.176 0.146</td>
<td>-0.131 0.177 0.253 -0.049</td>
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<tr>
<td>Dino 2</td>
<td>0.469 0.53 -0.07 0.116</td>
<td>0.425 0.803 -0.206 -0.184</td>
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<tr>
<td>Dino 3</td>
<td>-0.235 0.37 0.313 0.533</td>
<td>-0.038 0.217 0.792 0.346</td>
</tr>
<tr>
<td>AP:NAP ratio</td>
<td>0.849 -0.361 0.161 -0.003</td>
<td>0.698 -0.425 -0.024 0.455</td>
</tr>
</tbody>
</table>

REFERENCES

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**APPENDIX 1**

List of the diatom species codes in Fig. 1 and their ecological parameters.

I. “Habitat” spectrum: pl – planktonic species; ep – periphytic-epiphytic species; be – periphytic-deep water species.

II. Halobion spectrum: m – marine species; mhb – mesohalobous species; hl – oligohalobous-halophilous species; i – oligohalobous-indifferent species; hb – oligohalobous -halophilous species.

III. Geographical distribution: c – cosmopolitan species; n-a – north-alpine species; b – boreal species; t – tropical species.

IV. Saprobion spectrum: kseno – xenosaprobic species; L-B meso – mesosaprobic species; oligo – oligosaprobic species.

1. **Thalassiosira baltica** (Grun.) Ostenf. – I pl, II mshb
2. **Cyclotella caspia** Grun. – I pl, II mshb, III c
3. **Paralia sulcata** (Ehr.) Cleve – I pl, II m, III c
4. **Melosira moniliformis** (O.Mull.) Ag. – I ep, II mshb, III c
5. **Aulacoseira italic**a (Ehr.) Sim. – I pl, II i, III c, IV oligo – B
6. **A. granulata** (Ehr.) Sim. – I pl, II i, III c

7. **A. islandica** (O.Mull.) Sim. – I pl, II i, III n-a
8. **Hyalodiscus scoticus** (Kutz.) Grun. – I pl, II mshb, III c
9. **H. scoticus** var. **griseolus** Pr.-Lavr. – I pl, II mshb
10. **Coccosidiscus radiatus** Ehr. – I pl, II m, III c
11. **Actinocyclus octonarius** Ehr. – I pl, II mshb, III c
12. **A. tenellus** (Breb.) Andr. – I pl, II mshb, III c
13. **Pleurosigma laevis** (Ehr.) Comp. – I ep, II mshb, III c
14. **Cerataulus turigidus** (Ehr.) Ehr.– I ep, II m, III c
15. **Chaetoceros** sp.
16. **Raphoneis** sp.
17. **Fragilaria construens** f. **subsalina** (Hust.) Hust. – I ep, II hl, III c
18. **F. fasciculata** (Ag.) Lange-Bert. – II ep, II hl, III c
19. **F. leptostauron** var. **martyi** (Herib.) Lange-Bert. – I ep, II i, III b
20. **F. tabulata** var. **grandis** Mer. – I ep, II m, III t
21. **Aridsonia crystallina** (Ag.) Grun. – I ep, II mshb, III c
22. **Toxarium undulatum** (Bail.) Round – I ep, II mshb, III t
23. **Asterionella formosa** Hassall – I pl, II i, III c, IV oligo-B
24. **Dimerogramma marinus** (Greg.) Ralfs – I ep
25. **D. minor** (Greg.) Ralfs – I ep, II m
26. **D. minor** var. **nana** (Greg.) V.H. – I ep, II m
27. **Grammatophora marina** (Lyg.) Kutz. – I ep, II m
28. **G. oceanea** Ehr. var. **macilenta** (W.Sm.) Grun. – I ep, II m
29. **Lichmophora** sp.
30. **Lyrellia abrupta** (Greg.) Mann – I ep, II m, III c
31. **Navicula arenariaiformis** Pant. – I be, II hl, III b
32. **N. capitata** var. **lueneburgensis** (Grun.) Patr. et Reim. – I be, II hl, III b, IV L-meso
33. **N. cohnnii** (Hilse) Lange-Bert. – I be, II i, III c
34. **N. digitoriadiata** (Greg.) Ralfs – I be, II mshb, III c
35. **N. humerosa** Breb. – I ep, II m, III c
36. **N. hyalina** Donk. – I ep, II m
37. **N. meniscus** Schum. – I be, II hl, III c
38. **N. palpebralis** Breb. – I ep, II m
39. **N. pennata** var. **pontica** Mereschk. – I ep, II mshb
40. **N. pi Cleve – I be, II mshb
41. **N. protracta** var. **elliptica** Gallik – I be, II mshb, III b
42. **N. rhynchocephala** Kutz. – I be, II i, III c, IV L-B
43. **N. salinarum** Grun. – II mshb, III c, IV B-L
44. **Navicula** sp.
45. **Sellaphora populata** (Kutz.) Mann – I be, II i, III c
46. **Trachyneis aspera** (Ehr.) Cleve – I ep, II m
47. **Stauroneis aspera** (Ehr.) Cleve – I ep, II mshb
48. **Gyrosigma balticum** (Ehr.) Rab. – I ep, II mshb, III c
49. **Pinnularia braunii** var. **amphicephala** (A.Mayer) Hust. – I be, II hl, III n-a
50. *P. viridis* var. *leptogongyla* (Grun.) Cl. – I be, II i, III b
51. **Caloneis** amphiisbaena f. subsalina (Donk.) Werff. et Huls – I ep, II hl
52. *C. bacillum* (Grun.) Cleve – I be, II i, III b
53. *C. liber* (W.Sm.) Cleve – I be, II m
54. **Diploneis** bombus Ehr. – I ep, II m, III c
55. *D. didyma* (Ehr.) Ehr. – I ep, II mshb, III c
56. *D. interrumpa* var. *heeri* (Pant.) – Hust. II mshb
57. *D. notabilis* var. *tenuera* Pr.-Lavr. – I ep
58. *D. papula* (Schmidt) Cleve – I ep, II m
59. *D. smithii* (Breb.) Cleve – I be, II mshb, III b
60. *D. smithii* var. *pumila* (Grun.) Hust. – I be, II mshb, III b
61. *D. subadvena* Hust. – II m, III t
62. **Mastogloia** angulata Lewis – I ep, II m, III t
63. *M. baldijkiana* Grun. – I ep, II m
64. *M. braunii* Grun. – I ep, II mshb, III c
65. *M. eurythraea* Grun. – I be, II m
66. *M. pumila* (Cl. et Moller) – I ep, II m, III c
67. *M. pusilla* Grun. – I ep, II mshb, III c
68. *M. smithii* Thwaites – I ep, II mshb, III c
69. **Scoliopleura** tumida (Breb. ex Kutz.) Rabenh. – II mshb
70. *Cocconeis* disculus (Schum.) Cleve – I ep, II i, III n-a
71. *C. distans* Greg. – I ep, II hl, III c, IV oligo-B
72. *C. neodiminuta* Krammer – I ep, II i, III b, IV kseno
73. *C. pediculus* Ehr. – I ep, II hl, III c, IV B
74. *C. placentula* Ehr. – I ep, II i, III c, IV L
75. *C. placentula* var. *euglypta* (Ehr.) Grun. – I ep, II i, III b, IV oligo
76. *C. placentula* var. *lineata* (Ehr.) V.H. – I ep, II i, III b, IV oligo
77. *C. quarrnerensis* (Grun.) Schmidt – I ep, II m, III c
78. *C. scutellum* Ehr. – I ep, II m, III c
79. *C. scutellum* var. *minutissima* Grun. – I ep, II mshb
80. **Achnanthes** brevipes Ag. – I ep, II mshb, III c
81. *A. brevipes* var. *intermedia* (Kutz.) Cleve – I ep, II mshb
82. *A. delicatula* ssp. *hauckiana* (Grun.) Lange-Bert. – I ep, II mshb, III b
83. *A. longipes* Ag. – I ep, II m, III c, IV oligo-B
84. *A. longipes* var. *lata* Ag.
85. **Rhicosphenia** abbreviata (C.Ag.) Lange-Bert. – I ep, II hl, II c, IV B-L
86. *Cymbella* gracilis (Ehr.) Kutz. – I ep, II hb, III n-a, IV kseno
87. **Amphora** angusta Greg. – I ep, II mshb
88. *A. crassa* Greg. – II m
89. *A. aff. catarinaria* Cholnoky
90. *A. exigua* Greg. – I ep, II mshb
91. *A. holsatica* Hust. – I ep, II mshb, III c
92. *A. libyca* Ehr. – I ep, II i, III c
93. *A. obtusa* Greg. – II m, III t
94. *A. ovalis* (Kutz.) Kutz. – I ep, II i, III c, IV oligo-B
95. *A. pediculus* (Kutz.) Grun. – I ep, II i, III c, IV oligo-B
96. *A. proteus* f. *ambigua* Pr.-Lavr. – I ep, II mshb
97. *A. proteus* var. *oculata* Perag. et Perag. – I ep, II mt
98. *A. spectabilis* Greg. – II m
99. **Amphora** sp. 1
100. *Amphora* sp. 2
101. **Epithemia** solex Kutz. – I ep, II i, III c
102. *E. turgida* (Ehr.) Kutz. – I ep, II i, III c
103. *E. turgida* var. *granulata* (Ehr.) Grun. – I ep, II i, III b
104. *E. turgida* var. *westernmannii* (Ehr.) Grun. – I ep, II hl, III b
105. **Rhopalodia** gibba (Ehr.) O.Mull. – I ep, II i, III c, IV L
106. *R. gibberula* (Ehr.) O.Mull. – I ep, II hl, III c
107. *R. musculus* (Kutz.) O.Mull. – I ep, II mshb
108. *Nitzschia* circumcorta (Bail.) Grun. – I ep, II mshb, III c
109. *N. compressa* (Bail.) Boyer – I ep, II mshb, III n-a
110. *N. constriucta* (Kutz.) Ralfs – I ep, II mshb
111. *N. granulata* Grun. – I be, II m, III c
112. *N. hungarica* Grun. – I ep, II mshb
113. *N. sigma* (Kutz.) W. Smith – I ep, II mshb, III c
114. **Hantzschia** amphioxys (Ehr.) Grun. – I be, II i, III c
115. *Bacillaria* paulliifera (O.Mull.) Hend. – I ep, II mshb, III c
116. *Suriella* striatula Turpin – I be, II mshb
117. *S. striatula* var. minor R.Tynni – I ep
118. **Campylodiscus** daemeliamus Grun. – II mshb, III t
119. *C. fastuosus* Ehr. – I ep, II m, III c

**APPENDIX 2**

List of samples codes:

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