Research Article

Migration Routes of the Aptian to Turonian Ostracod Assemblages from North Africa and the Middle East

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Quantitative paleobiogeography is a powerful tool for detecting the migration routes of microfossils. This is factual and applicable when we select appropriate analyses for proper problems in the following manner. The quantitative study of 43 selected ostracod species (total of 136 species) from 11 countries of North Africa and the Middle East led to the detection of two migration routes in the late Early to early Late Cretaceous times. The first route of migration was from east to west during the intervals of Aptian-Albian to Cenomanian. While in the Turonian time, reduced oxygen conditions prevailed and minimized the east-west migration. The second route was from north to south for the duration of Aptian-Albian to Cenomanian. On the other hand, four ostracod biofacies, each with its distinctive environmental conditions, have been identified in the studied countries ranging in age from Aptian to Turonian.

1. Introduction

Several authors studied the Cretaceous ostracods of the Middle East and North Africa and the paleoenvironmental factors that affected their distribution. However, the pioneer works of Reymont in the sixties of the twentieth century [1–3] opened the way to understand the relation between these ostracods and the associated paleoenvironmental conditions. As a result, researchers focused their studies on these regions [4–15].

Elewa [14] concluded that there are two main biogeographical provinces that were connected during the Maastichtian to early Eocene intervals of North and West Africa and the Middle East through the Trans-Saharan Seaway. He, furthermore, proved stability of ostracod habitats in the studied regions [16], and no turnover across the K/Pg boundary can be noticed by ostracods (for details on the mass extinction at the K/Pg boundary, refer to [17–22]) as well as the P/E boundary [23]. A close situation has been established by Elewa [24] who studied the ostracod migrations during the middle and late Eocene of Egypt and recorded reduced ostracod migration activity along the shores of Tethys.

Conversely, planktonic foraminifers have shown somewhat different situation, where Nishi et al. [25] detected extinction of the foraminiferal marker *Morozovella lehneri* at lower stratigraphic level in the Eastern Desert of Egypt than in Sinai and the Nile Valley during the middle Eocene, demonstrating the consequence of paleoenvironmental changes on the existence and abundance of *Morozovella lehneri*.

The authors of this paper dealt with investigating the paleobiogeographical and paleoecological inferences of the ostracod assemblages of North Africa and the Middle East with the aid of multivariate data analyses (see [24], for more details on using these techniques to interpret paleoenvironments). They aim to determine the ostracod migration routes, together with the important environmental factors that affected ostracod migrations during the Cretaceous (Aptian to Turonian).

2. Methods and Techniques

One hundred thirty-six ostracod species from Egypt and the surrounding countries of North Africa and the Middle East have been counted from collected samples and published

FIGURE 1: Paleogeographic map of the studied regions showing the two routes of migration of the Aptian to Turonian ostracod assemblages (modified after [32]).

data of different authors who previously studied the Aptian-Albian ostracods of the studied regions (see [10, 15, 26, 27]). These ostracod species were examined to select the ostracod species suitable for multivariate faunal analyses (Figure 1). The investigations revealed 43 ostracod species ranging in age from Aptian to Turonian (the ages were defined according to the published literatures). The first step is started with eliminating the rare species (e.g., ostracod species that only occur in three or fewer number of the countries in this region). In general, the data from countries having ostracod faunas that cannot be correlated with those of Egypt (e.g., Saudi Arabia, Iraq, and Pakistan) were excluded from the analyses. Yet, these countries could help in explaining the ostracod migration routes of the studied regions. Besides, the countries containing less than three ostracod species were omitted as well. The resulting matrix of 43 ostracod species from 11 countries (Table 1) was subjected to principal coordinate analysis (PCOA; based on Euclidean distance measure of similarity index), to distinguish the paleogeographical provinces of the investigated countries. Then, principal component analysis (PCA; based on correlation matrix) was carried out on the same data matrix to verify the results obtained by PCOA. Afterward, detection of the migration routes of ostracod assemblages and understanding of their causes were attempted using R-mode cluster analysis, based on the correlation coefficient of similarity, which applied to presence/absence data.

We used the PAST statistical package, version 2.17b of November, 2012 (see [28], for details) to analyze our data.

3. Ostracod Provinces of the Studied Regions

Forty-three selected species in 11 countries (Table 1) were subjected to multivariate data analyses to locate the ostracod

FIGURE 2: Principal coordinate 1 versus principal coordinate 2 of the studied 11 countries.

provinces of the studied regions of North Africa and the Middle East.

First of all, principal coordinate analysis technique was applied to the presence/absence data matrix, to differentiate between the paleogeographical provinces of the studied countries.

From Figure 2 it is clear that there are two distinguished provinces, one of them represents the South Tethyan Province (STP) of Elewa [14]. This distinguished province is represented by Egypt, Israel, Tunisia, Algeria, and Morocco.

TABLE 1: The studied data matrix.

No.	Ostracod species	Morocco	Algeria	Tunisia	Libya	Egypt	Israel	Jordan	Lebanon	Iran	Oman	Kuwait
1	<i>Cytherella parallela</i>	1	1	0	0	0	1	1	0	0	0	0
2	<i>Cytherella ovata</i>	1	1	0	0	0	1	0	0	0	0	0
3	<i>Cytherella aegyptiensis</i>	1	1	0	0	1	1	0	0	0	0	0
4	<i>Paracypris mdaouerensis</i>	1	1	1	0	0	1	0	0	0	0	1
5	<i>Monoceratina trituberculata</i>	1	1	1	0	0	1	0	0	0	0	0
6	<i>Bythoceratina tamarae</i>	0	1	0	1	1	1	0	0	0	0	0
7	<i>Brachycythere angulata</i>	0	1	1	1	1	0	0	0	0	0	0
8	<i>Mauritsina coronata</i>	0	0	1	0	1	1	0	0	0	0	0
9	<i>Ordoniya ordoniya</i>	0	0	1	1	1	0	0	0	0	0	0
10	<i>Paracosta pervinqueri</i>	1	1	1	0	0	1	0	0	0	0	0
11	<i>Amphicytherura distincta</i>	1	1	1	0	0	1	0	0	0	0	0
12	<i>Ovocytheridea reniformis</i>	1	1	1	0	1	0	1	0	0	0	0
13	<i>Spinoleberis kasserinensis</i>	1	1	1	0	0	1	0	0	0	0	0
14	<i>Veeniacythereis jezzineensis</i>	0	0	0	0	1	1	0	1	0	1	1
15	<i>Oertliella? tarfayaensis</i>	1	1	1	0	0	0	0	0	0	0	0
16	<i>Reticulocosta boulhafensis</i>	1	1	1	0	0	0	0	0	0	1	0
17	<i>Cythereis algeriana</i>	1	1	1	0	0	1	0	1	1	1	1
18	<i>Cythereis magner</i>	1	1	1	0	0	0	0	0	0	0	0
19	<i>Xestoleberis tunisiensis</i>	0	1	1	0	1	0	0	0	0	0	0
20	<i>Pontocyprilla recurva</i>	0	1	1	1	1	0	0	0	0	0	0
21	<i>Actinocythereis coronata</i>	0	1	1	1	1	0	0	0	0	0	0
22	<i>Krithe echolsae</i>	0	0	1	0	1	1	0	0	0	0	0
23	<i>Cytherella gambiensis</i>	0	1	1	0	1	0	0	0	0	0	0
24	<i>Dolococytheridea atlantica</i>	0	1	1	0	1	1	0	0	0	0	0
25	<i>Peloriops ziregensis</i>	0	1	1	0	1	1	1	0	0	1	1
26	<i>Cythereis namousensis</i>	0	1	1	0	1	1	0	0	0	0	0
27	<i>Veeniacythereis maghrebensis</i>	0	1	1	0	1	1	0	0	0	1	1
28	<i>Metacytheropteron berbericum</i>	1	1	1	0	1	1	0	0	1	1	0
29	<i>Peloriops pustulata</i>	0	0	1	0	1	1	0	0	0	1	1
30	<i>Centrocythere tunetana</i>	0	1	1	0	1	1	0	0	0	0	0
31	<i>Bairdia yousefi</i>	0	1	1	0	1	0	0	0	0	0	0
32	<i>Amphicytherura (Sondagella) falloti</i>	0	1	1	0	1	0	0	0	0	0	0
33	<i>Cytherura gruendli</i>	0	1	1	0	1	0	0	0	0	0	0
34	<i>Paracypris dubertreti</i>	1	1	0	0	1	1	0	1	0	0	0
35	<i>Sinaiella halaliensis</i>	0	0	1	0	1	1	0	0	0	0	0
36	<i>Rehacythereis zoumoffeni</i>	0	0	0	0	1	1	0	1	0	0	0
37	<i>Schuleridea baidarensis</i>	0	0	0	0	1	1	0	1	0	1	0
38	<i>Centrocythere sanninensis</i> MTA	0	0	1	0	1	1	0	1	0	0	0
39	<i>Centrocythere sanninensis</i> MTB	0	0	1	0	1	1	0	1	0	0	0
40	<i>Hiltermannia majestica</i>	0	0	0	0	1	1	0	0	1	0	0
41	<i>Rehacythereis btaterensis interstincta</i>	0	0	0	0	1	1	0	1	0	0	0
42	<i>Rehacythereis btaterensis btaterensis</i>	0	0	1	0	1	1	0	1	0	0	0
43	<i>Veeniacythereis streblolophata</i>	0	0	1	0	1	0	0	0	1	0	1

However, the analysis could subdivide this province into two provinces: the East South Tethyan Province (ESTP) comprising Egypt and Israel and the West South Tethyan Province (WSTP) including Tunisia, Algeria, and Morocco. In the meantime, from the same graph, the second distinguished province is represented by Lebanon, Jordan, Kuwait, Oman,

and Iran; this province is named herein as the Asian Province (ASP). It is obvious that Libya has unreal strong affinity to the Asian Province. This could be attributed to the frequent occurrences of the studied ostracods, where the countries of the STP are represented in the current study by more diverse species than the countries of the ASP and Libya (Table 1).

TABLE 2: Summary of principal coordinate analysis.

Coordinate axis	Eigenvalue	Percent (%)	Cumulative percent
1	40.516	38.688	38.688
2	21.28	20.319	59.007
3	15.021	14.343	73.350
4	8.3071	7.9321	81.2821
5	5.3118	5.0721	86.3542
6	4.059	3.8757	90.2299
7	3.3866	3.2337	93.4536
8	3.1666	3.0237	96.4773
9	2.2634	2.1612	98.6385
10	1.4161	1.3522	99.9907

TABLE 3: Summary of principal component analysis.

PC	Eigenvalue	% variance	Cumulative percent
1	16.7933	39.054	39.054
2	8.79787	20.46	59.514
3	6.21374	14.451	73.965
4	3.27228	7.6099	81.5749
5	2.11814	4.9259	86.5008
6	1.6999	3.9533	90.4541
7	1.38916	3.2306	93.6847
8	1.24925	2.9052	96.5899
9	0.902841	2.0996	98.6895
10	0.563524	1.3105	100.000

Accordingly, to establish the stability of the obtained results, the principal component analysis technique, based on correlation coefficient matrix, on the same data matrix, is applied.

It is worth mentioning that the results of the principal coordinate analysis (Table 2 and Figure 2) and principal component analysis (Table 3; Figure 3) techniques are exactly the same, indicating the stability of results obtained. Note that only the first and second coordinate axes of the principal coordinate analysis are represented in plot (Figure 2), as they together account for more than 59% of the total variance (Table 2). Also the same for PCA (Figure 3), as the 1st and 2nd principal axes account for more than 59% of the total variance (Table 3).

Decisively, the principal coordinate and principal component analyses were effective in clarifying variations between the studied countries according to their ostracod associations.

4. Ostracod Migration Routes (History and Causes)

In the present study, R-mode cluster analysis based on the correlation coefficient of similarity using the paired-group method was applied to the data matrix. By means of this technique 4 main ostracod biofacies could be observed (Figure 4).

FIGURE 3: 1st principal component axis versus 2nd principal component axis of the studied 11 countries.

Biofacies A (Figure 4) consists of a large number of species, most of which consistently occur in Egypt and Israel (in this study: the Egyptian Type Fauna), which

FIGURE 4: Dendrogram resulted from cluster analysis based on the correlation coefficient of similarity for 43 ostracod species from 11 countries of the studied regions. Biofacies A represents common Albian-Cenomanian ostracods of Egypt and Israel (in this study: the Egyptian Type Fauna); biofacies B represents common Cenomanian ostracod species of Kuwait and Oman (in this study: the Arabian Type Fauna); biofacies C represents common Aptian-Albian ostracods of Lebanon and Iran (in this study: the Eastern Type Fauna); biofacies D represents common Cenomanian-Turonian ostracod assemblages of Morocco, Algeria, and Tunisia (in this study: the Western Type Fauna).

mainly represent the Albian-Cenomanian fauna of the studied assemblage. The most important species of this group are *Ordoniia ordoniya* (number 9 in Figure 4), *Mauritsina coronata* (number 8 in Figure 4), *Xestoleberis tunisiensis* (number 19 in Figure 4), *Krithe echolsae* (number 22 in Figure 4), and *Pontocyprilla recurva* (number 20 in Figure 4). Elewa and Morsi [23] and Elewa [29] defined most species mentioned for this group to inhabit an outer shelf to upper bathyal depths.

Biofacies B (Figure 4) consists of the species that consistently took place in the successions of the Cenomanian of Kuwait and Oman (in this study: the Arabian Type Fauna). These species are *Peloriops ziregensis* (number 25 in Figure 4), *Veeniacythereis maghrebensis* (number 27 in Figure 4), and *Peloriops pustulata* (number 29 in Figure 4). Elewa [13] recorded *Peloriops ziregensis* to represent the open marine, shallow water associations implying a shallow ramp facies belt, without major influence of wave activity. It is remarkable that the Arabian Type Fauna has been recorded from the South Tethyan Province as well as the Asian Province, indicating the domination of the shallow marine ostracod assemblages in these provinces during the Cenomanian time.

Biofacies C (Figure 4) is represented by a group of species that are common in Lebanon and Iran (in this study: the Eastern Type Fauna). This group stands for the Aptian-Albian interval and comprises species belonging to

the genera: *Rehacythereis* (e.g., *R. btaterensis btaterensis*, number 42 in Figure 4, and *R. btaterensis interstincta*, number 41 in Figure 4), *Centrocythere* (e.g., *C. sanninensis* MTA, number 38 in Figure 4, and *C. sanninensis* MTB, number 39 in Figure 4), *Veeniacythereis* (e.g., *V. jezzineensis*, number 14 in Figure 4), and *Schuleridea* (e.g., *S. baidarensis*, number 37 in Figure 4). Rosenfeld and Raap [26] stated that the environment of deposition of *Centrocythere sanninensis* MTA is shallow (littoral), warm, marine environment with water depths not exceeding 200 m, while for *Centrocythere sanninensis* MTB is deeper and could possibly even extend to 1000 m. Elewa [13] concluded that MTB could tolerate a wider range of salinity than MTA, indicating the fluctuation of salinity levels in the Eastern Type fauna.

Biofacies D (Figure 4) represents the Cenomanian-Turonian ostracod assemblages of Morocco, Algeria, and Tunisia (in this study: the Western Type Fauna). This group includes the following species: *Oertliella? tarfayaensis* (number 15 in Figure 4), *Cytherella parallela* (number 1 in Figure 4), *Cytherella ovata* (number 2 in Figure 4), *Cytherella aegyptiensis* (number 3 in Figure 4), *Amphicytherura distincta* (number 11 in Figure 4), *Monoceratina trituberculata* (number 5 in Figure 4), and *Paracypris dubertreti* (number 34 in Figure 4). The aforementioned species of this group probably indicate reduced oxygen conditions (see [30, 31]).

Alternatively, Libya and Jordan enclose ostracod assemblages of these four biofacies.

From the abovementioned results it can be concluded that there were two routes or directions of ostracod migrations in North Africa and the Middle East during the late Early to early Late Cretaceous (Aptian to Turonian) times (Figure 5).

The first direction was from the east (Lebanon and Iran) in the Aptian-Albian times to the west through Israel and Egypt to Tunisia, Algeria, and Morocco for the duration of the Cenomanian time. In the Turonian time, minimized oxygen conditions prevailed and reduced the east-west migration.

The second direction of migration was started from the north (Lebanon and Iran) during the Aptian-Albian times and extended to the south (Saudi Arabia, Kuwait, and Oman) during the Albian-Cenomanian times.

It is prominent that each of the abovementioned four ostracod biofacies has its distinct environmental conditions that caused the migration of the studied ostracod species.

The history of migration of the studied ostracods began in the Aptian-Albian times depending on oscillation in both sea level and salinity. These unbalanced environmental conditions forced the deep marine ostracod species to migrate westward during the Albian-Cenomanian times towards Egypt, where the outer shelf to upper bathyal marine conditions succeeded. In the Cenomanian, shallow water conditions dominated in the south of the Asian Province and allowed shallow ostracod species to migrate from the north and prevail. During the Turonian times, the worse environmental situation, which is represented by the low oxygen content of water, resulted in the survival of those ostracod species that are able to endure oxygen diminution within the Western Type Fauna of North Africa (e.g., Morocco, Algeria, and Tunisia).

FIGURE 5: Timing and pattern model showing the migration routes of the studied Aptian to Turonian ostracod assemblages.

5. Conclusions

The studied ostracods range in age from Aptian to Turonian and represent the following countries: Jordan, Israel, Lebanon, Kuwait, Oman, and Iran in the east through Egypt and the other North African countries in the west (Figure 2).

The data differentiate between two main geographical provinces connected through the Trans-Saharan Seaway, termed the South Tethyan Province (STP), which is subdivided into the Eastern South Tethyan Province (ESTP) and the Western South Tethyan Province (WSTP) and the Asian Province (ASP). Meanwhile, the ostracods of Egypt belong to the Eastern South Tethyan Province (ESTP).

The obtained results indicate the existence of a shallow marine transcontinental connection between the Eastern South Tethyan Province (ESTP) and the Western South Tethyan Province (WSTP) of the studied countries of North Africa and the Middle East during the Aptian-Turonian times. Another connection between the north and the south is noticed within the ostracod species of the Arabian Peninsula during the Aptian-Cenomanian times.

These results support the results of Luger [27], who established an increasingly uniform pan—South Tethyan ostracod province (North Africa and the Arabian Peninsula) through the Aptian to Cenomanian times.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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