Matrix Provenance of Upper Miocene Gypsiferous Sandstones in the Mediterranean Area

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Mit 2 Figuren und 4 Tabellen

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Abstract

Gypsiferous conglomeratic sandstones of Upper Miocene (Messinian) age were sampled at eastern and central Mediterranean sites. An evaluation of the heavy mineral suites in the 0.15–0.25 mm fraction shows a statistically very significant common denominator of decreasing relative presence of individual species with distance from a putative eastern point of origin. This strengthens the postulate of an anticlockwise longshore current driven by the Coriolis effect along the north shore of the Mediterranean Sea in Messinian time. A tributary flowed through what is now the Aegean Sea; this tributary was previously indicated only by the presence of central European brackish water mollusks and phytoplankton in evaporitic sediments of Greece, Italy and Spain. While Aegean and central Mediterranean samples contain iron oxides among the heavy minerals, west of Sicily one finds only pyrite and marcasite indicating anoxic conditions in the latter.

Introduction

In Upper Miocene time the Mediterranean area became the site of extensive evaporite deposition, of which remnants are known from Spain, Italy, Albania, Greece, Turkey, Tunisia, and Algeria; to this day the evaporites are inadequately explored in the offshore to map their extent in detail. When very thick Upper Miocene evaporites were encountered in several boreholes of the Deep-Sea Drilling Project, Legs 13 and 42A, the question arose where the source of the waters might have been that precipitated these salts. Several potential passages into the Mediterranean area could be considered with varying degrees of probabilities, but none offers sufficient evidence to exclude all others (SONNENFELD, 1985; SONNENFELD and FINETTI, 1985). This study tries to elucidate the possible water circulation in this sea. Upper Miocene conglomeratic sandstones were evidently deposited by waters moving into and around the evaporite basin. Either they represented a series of river mouths, or they were part of the bedload of a continuous current moving anticlockwise along the northern rim of the ancestral Mediterranean Sea. In the former instance, there should be no similarity between samples from one locality to another. There was, however, some evidence to

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believe that sands from the various localities did indicate a common carrier. A more thorough study of the sandstone fraction was thus indicated.

Sample Collection and Analysis

Sample Locations

To evaluate the direction of bedload movement, samples of the fine grained matrix of gypsum bearing conglomeratic sandstones were first collected from a selected number of localities. The boulder component of the conglomerates is probably of local origin, but the finer matrix may contain components sedimented by the longshore current. The results of this preliminary investigation have been reported by SONNENFELD et al. (1978). A second more detailed set of samples was collected from the Dardanelles through the Aegean Sea to Crete, from the Ionian islands to Toscana and Romagna in Italy, from the Molise Belt to Calabria and Sicily at 309 localities (Fig. 1). Sample locations less than 5 km apart were then averaged to reduce the number of sites to 141. Dating of the sites was based on the work of earlier studies (GRADSTEIN and VAN GELDER, 1971; BESENECKER, 1973; DERMITZAKIS, 1977; FORTUIN, 1977; HEIMANN, 1977; MEULENKAMP, 1980; a. o.) or on the personal experience of colleagues (M. DERMITZAKIS for Greece, G. RICHTER-BERNBURG for Sicily, D. SAVELLI for Urbino, C. ORSZAG-SPERBER and M. ROUCHY for circum-Balearic sites). The total pyritization of the circum-Balearic samples eliminated them from a statistical analysis of the heavy mineral suites. Similarly, samples from Cyprus were excluded as having potentially a different source.

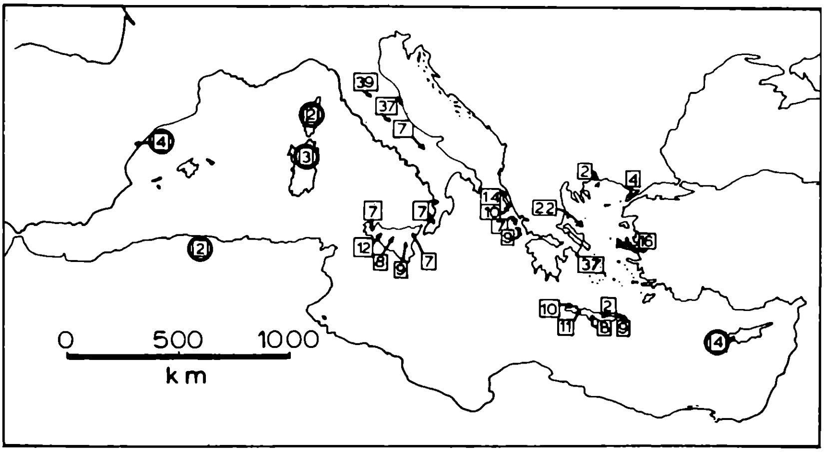

Fig. 1: Location map of sampling areas.
Squares: Number of sites within a given area.
Circles: Sampling sites not used in statistical analyses.

Analytical methods

Heavy minerals were separated from the 0.125–0.150 and the 0.150–0.250 mm fraction of each sample by heavy media separation, and the proportion of different heavy minerals was determined with the aid of petrographic and binocular microscope. Only the coarser fraction was used in the analysis, since the identification of the heavy minerals in the finer fraction was somewhat less certain. Sixteen variables determined from 141 sampling points give a total of 2,256 data points as sampling base for multivariate statistical analysis. The analysis was done on the entire sample group, as well as on the Aegean and Ionian samples separately from the Italian and Sicilian samples. To break down the sampling sites into smaller groupings would not have provided statistically significant sets.

Statistical analysis

The results of a heavy mineral analysis at each locality were grouped and their means were determined (Table 1). These data were used as input for subsequent statistical analyses. Some comment on the nature of data and its effect on statistics is warranted. The data shown in Table 1 is a closed set – i. e., represents means of percentages, and as such the variables have been manipulated so that their total is 100. This in unavoidable.

To determine the relationship of the mineral assemblages between localities and with distance, three types of multivariate statistical analyses were conducted: 1. multiple correlation, 2. factor analysis, and 3. stepwise regression analysis. The means obtained above were used, in order to normalize the data set and thus to minimize the influence of any one locality on the results due to the difference in the number of samples taken at that locality. Distance was measured counterclockwise along the northern Mediterranean coast with the Dardannelles taken as point 0.

Multiple Correlation Analysis

The results of multiple correlation are given in Table 2. Each correlation is given a probability or significance rating: The probability of $t = 0.05$, for instance, indicates that the significance of the correlation is at the 95 percentile level. This is taken as the cut-off. All correlations having a probability of less than 0.05 are considered significant and are given in the table. The above statistics are not too meaningful by themselves, except to indicate relative relationships between particular mineral suites. For instance, four heavy mineral suites show a significant correlation with distance.

Factor Analysis

A factor analysis provides a means of determining the interrelationships of groups of minerals. In this case, it corroborates the correlation matrix of Table 2, which is to be expected. It is, however, useful in itself, as it reveals additional members of the factor groupings. The results of the

Loc	Dist	Ap	E–Zo	Gar	H–L	M–C	M–I	P–Am	Rut	SAS	Tou	Zir	Ign	Meta	Ratio
1	205	3.1	12.8	10.9	13.4	4.4	15.3	15.9	5.3	6.9	0.0	11.9	64.4	35.6	2.3
2	455	0.0	33.8	5.0	3.8	5.0	6.3	6.3	0.0	5.0	1.3	30.0	77.5	18.8	8.1
3	775	3.6	5.9	9.0	1.4	7.3	1.4	19.5	4.5	18.6	0.9	28.2	64.1	36.5	12.1
4	930	1.7	0.0	3.3	0.0	0.0	3.3	1.7	0.0	33.3	1.7	55.0	63.3	36.7	9.4
5	1275	0.0	3.8	1.3	0.0	5.0	3.8	3.8	0.0	33.8	0.0	48.8	60.0	40.0	4.8
6	1385	1.7	22.2	9.4	0.6	1.1	6.1	15.0	0.0	5.0	1.1	38.3	84.4	16.2	18.6
7	2055	0.0	18.8	12.5	3.8	2.5	3.8	7.5	1.3	3.8	5.0	41.3	77.5	22.5	3.7
8	2816	0.0	11.7	15.8	2.5	4.2	9.2	15.8	2.5	24.2	2.5	11.7	53.3	46.7	1.4
9	3786	2.1	28.6	8.6	2.9	4.3	1.7	10.7	0.4	13.9	1.9	24.3	69.7	29.6	4.0
10	3827	0.0	15.0	15.0	0.0	25.0	12.5	15.0	2.5	0.0	0.0	15.0	60.0	40.0	1.7
11	3883	3.1	10.0	17.9	1.2	27.5	1.9	9.2	0.2	6.5	3.1	19.4	46.9	53.1	1.1
12	3886	0.0	24.4	17.5	1.9	7.5	3.8	10.6	0.0	12.5	1.3	21.9	61.9	39.4	4.4
13	3920	1.3	13.1	17.5	0.6	29.4	0.0	8.1	0.0	4.4	5.6	19.4	47.5	51.9	1.2
14	4369	0.0	7.5	35.0	0.0	0.0	5.0	10.0	0.0	12.5	0.0	30.0	52.5	47.5	1.1
15	4415	1.9	11.9	12.3	0.4	13.1	1.2	14.2	1.9	15.8	1.9	25.8	58.8	41.6	9.5
16	4642	0.7	12.1	12.1	0.0	1.4	5.0	14.3	1.4	35.7	2.1	15.0	50.7	49.4	15.1
17	4735	2.3	9.5	12.7	1.4	10.5	4.1	9.5	0.0	35.0	1.4	14.1	40.9	59.5	0.9

Table 1. Means of heavy mineral data, grouped by location

Legend to Tables 1–4:

Loc = Location
Dist = Distance
Ap = Apatite
E-Zo = Epidote, Zoisite
Gar = Garnet
H–L = Hematite, Limonite
M–C = Mica, Chlorite
M–I = Magnetite, Ilmenite
P–Am = Pyroxene, Amphibole
Rut = Rutile
SAS = Staurolite, Andalusite, Sillimanite
Tou = Tourmaline
Zir = Zircon
Ign = Igneous minerals (Ap, E–Zoi, M–I, P–Am, Zir)
Meta = Metamorphic minerals (Gar, H–L, M–C, SAS)
Ratio = Ratio of Igneous to Metamorphic minerals

	E–Zo	H–L	Rut	P–Am	Tou	Zir	Ign	Meta	Ratio	Dist
E–Zo								–0.587 0.003		
Gar										0.600 0.011
M–Il		0.596 0.012	0.530 0.029		–0.491 0.045					
P–Am						–0.622 0.008				
Rut		0.590 0.013		0.723 0.001						
SAS	–0.545 0.024									
Zir							0.498 0.042	–0.490 0.046		–0.488 0.047
Ign								–0.997 0.000	0.493 0.045	–0.646 0.005
Meta									–0.474 0.054	0.655 0.004

Table 2. Significant correlation coefficients (.05)
Blank spaces indicate no correlation.
Number above the line = R, correlation coefficient
Number below the line = t, error probability

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
Ap	0.04003	0.36803	−0.33216	0.72180
E–Zo	−0.43960	0.03126	0.74487	−0.09941
Gar	0.54064	0.27603	0.37147	−0.37987
H–L	−0.50021	0.61168	−0.03718	0.12525
M–C	0.54468	0.21609	0.39506	0.43373
M–I	−0.38024	0.63908	−0.09272	−0.45502
P–Am	−0.02524	0.80152	0.00664	−0.01713
Rut	−0.26156	0.81038	−0.31464	0.16272
SAS	0.28912	−0.31940	−0.78566	−0.16371
Tou	0.27642	−0.24625	0.46717	0.52764
Zir	−0.41814	−0.78885	−0.24268	0.08092
Ign	−0.92325	−0.17189	0.24794	0.02570
Meta	0.92671	0.18133	−0.26753	−0.02648
Dist	0.82996	0.02057	0.31582	−0.22667

Table 3. Factor Analysis of Heavy Mineral Means

═══ Primary Group members

——— Secondary Group members

analysis are given in Table 3. Four factors were obtained; each of the factors represents a certain relationship or dependence of the heavy minerals and distance to each other. The degree of dependence is represented by the decimal: the higher the number, the higher is the contribution of the mineral to the group. The sign indicates a direct or an inverse relationship to the group. The factor number indicates the strength of the relationship. Factor 1 indicates a stronger relationship than does factor 2 between the members of the group.

A factor analysis shows the following relationships: The grouping in factor 1 is dominated by three variables, igneous and metamorphic minerals, and distance. The igneous minerals decrease and metamorphic minerals increase with distance from the Dardanelles. Garnet and mica-chlorite, being members of the metamorphic group, each show a significant but somewhat lower positive relationship to distance, while zircon, epidote-zoisite, magnetite-ilmenite and hematite-limonite groups show inverse relationships.

The above seems to indicate that a dominantly metamorphic source of minerals existed in the east, while a dominantly igneous source or sources existend in the central Mediterranean area during Messinian time.

In factor 2 rutile and pyroxene-amphibole show a strong positive relationship to each other. A lower, but significant, positive relationship exists for magnetite-ilmenite and hematite-limonite associations. Zircon alone shows a strong negative relationship in the group. The relationship seems to group black or dark iron-rich minerals. As they increase, the light coloured non-iron minerals, such as zircon, decrease.

There are two strong members found in factor 3, staurolite-sillimanite-andalusite and epidote-zoisite. The latter has a positive relationship, the former a negative one. This reinforces the findings of factor 1, where igneous minerals decrease as metamorphic minerals increase.

Apatite and tourmaline are the strongest, positively associated members of factor 4. Mica-chlorite also shows a weaker, positive association. A weak, negative or inverse, relationship is shown by magnetite-ilmenite and garnet. No clear explanation of this rather weak factor group is offered.

Stepwise regression analysis

A stepwise analysis compares the chosen variable (the dependent variable) against the remaining variables, and chooses those that correlate best with it in a stepwise or progressive fashion. Distance along the rim of the Mediterranean basin, starting at the Bosporus where the northernmost sample came from, was taken as a dependent variable, and was compared to the various heavy mineral fractions taken as independent variables. Thus a model is built up that gives a mathematical relationship of the dependent variable (both as straight distance and as logarithm of distance); in this manner it shows the interrelationships of the various heavy minerals to each other and to distance. Independent variables were the individual heavy mineral types, as well as certain groups and ratios of the heavy minerals.

A stepwise regression analysis with distance as the dependent variable was performed in order to determine whether a significant relationship exists between distance on one hand, and the observed heavy minerals on the other. The analysis determines which minerals, in what order and to what degree, are related to distance from the Dardanelles.

Table 4 shows the result of the regression analysis, beginning with one variable model (simple correlation) and ending with a four variable model. It is interesting to note the progression of the model. One variable model gives the metamorphic suite as significantly correlatable with distance. In a two-variable model, the epidote-zoisite mineral group improves the model significantly. The three-variable model has added hematite-limonite. The igneous group has been added in the four-variable model. It improves the three-variable relationship but slightly. However, it is interesting to note that the addition of the igneous group has radically changed the relative importance of the individual minerals in the relationship: epidote-zoisite is now the principal determinant of the relationship and the metamorphic group is now third, behind hematite-limonite.

The four-variable model relationship has been plotted in Fig. 2, to show graphically the derived relationship. For each sampling point (distance), a value representing the heavy mineral suite was calculated according to the four-variable model equation. The points so obtained

One-Variable model	R Sq. = 0.429	Prob. = 0.0043
Distance = – 666.7		
Distance = + 88.2 (metamorphic minerals)		= 0.0002
Two-Variable model	R Sq. = 0.632	Prob. = 0.0009
Distance = – 3830		
Distance = + 132.2 (metamorphic minerals)		= 0.0002
Distance = + 101.9 (epidote, zoisite)		= 0.0150
Three-Variable model	R Sq. = 0.765	Prob. = 0.0002
Distance = – 3223		
Distance = + 123.1 (metamorphic minerals)		= 0.0001
Distance = + 111.3 (epidote, zoisite)		= 0.0030
Distance = – 193.2 (hematite, limonite)		= 0.0174
Four-Variable model	R Sq. = 0.831	Prob. = 0.0001
Distance = – 49758		
Distance = + 134.5 (epidote, zoisite)		= 0.0006
Distance = – 186.7 (hematite, limonite)		= 0.0116
Distance = + 583.5 (metamorphic minerals)		= 0.0188
Distance = + 463.7 (igneous minerals)		= 0.0525

Table 4. Stepwise Regression Analysis Equations

were plotted in Fig. 2, and the line of best fit through the points was calculated. The equation and trace of this line are given in the figure. Although there is some clustering (bi-modal distribution) of the points, it is felt that the regression is valid. The figure shows rather forcefully that a significant relationship exists between selected minerals and distance that cannot be explained by chance alone.

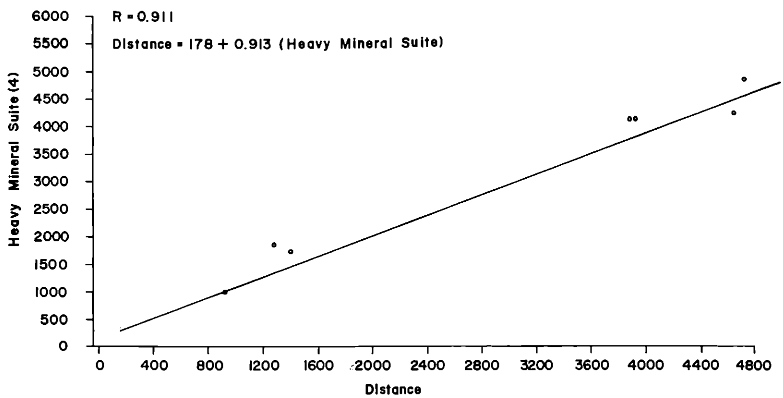

Fig. 2. Calculated Heavy Mineral Suite (4) vs. Distance

Fig. 2: Calculated heavy mineral suite (four-variable model) vs. distance.

Interpretation of statistical analysis

The various statistical analyses given above suggest that the distribution of the heavy minerals as a function of distance along what is perceived as the shoreline of the Messinian Mediterranean Sea is not random. This is shown by the stepwise regression analysis, and also by the factor analysis. The factor analysis indicates a decrease in the metamorphic and darker, iron-rich minerals, and a progressive increase in igneous and light-coloured minerals with distance. The distribution of the calculated heavy mineral suite with distance (Fig. 2) also shows a positive and significant relationship. The relationship of distance to heavy minerals can be explained in two opposing ways:

1. A progressive change in the character of source rocks along the coast. The analyses indicates that the rocks in the east would be predominantly metamorphic, and those in the west predominantly igneous. The sediments delivered to the sea reflect local conditions only.

2. A current carrying constant bedload. The changes in the heavy mineral suite are due to abrasion and weathering of the minerals.

Not much is known about the nature of provenance rocks of Messinian time. To assume that their heavy mineral content reflected a progressive change with distance is perhaps more demanding than assuming a constant current. There is no doubt that the heavy mineral assemblage reflects local input, but the underlying cause for their distribution would appear to be due to a steady, one-directional current.

Statistical analyses say nothing about the direction of the current. This must be determined on other evidence, presented below.

Discussion

Messinian sandstones

Although Messinian halite and anhydrite occurs in grabens of the northern Aegean Sea, the conglomeratic sandstones are generally free of gypsum through the Aegean region. Sandstones with desiccation cracks that underlie and overlie a 5 cm bed of somewhat calcitized anhydrite occur only on the SW coast of the island of Chios (SONNENFELD et al., 1983).

Samples from Crete, the Ionian islands, the Marche, Umbria, Molise and Calabria districts of Italy, and Sicily have a gypsiferous matrix. An assertion by SENIN et al. (1977) that the variation in mineral composition of bottom sediments, which can be attributed to degradation and within the aqueous medium exceeds the variation determined by differences in the petrographic composition of the provenance area, appears to hold. Local influences on the heavy mineral composition appear to be too small to overpower the regional trends.

Samples from Sardinia, Corsica, the Catalonian province of Spain, and Algeria are said to be Messinian sandstones, but they are without a gypsum matrix. They show a dearth of heavy minerals except for abundant euhedral crystal aggregates of pyrite and marcasite. It is significant that none of the Sicilian, Italian, Greek, or Turkish samples contained any pyrite.

There are thus three types of Messinian sandstones:

a) Those at localities in the Aegean Sea, that contain a variety of oxides as heavy minerals and sparse or no gypsum cement.

b) Those at localities on Crete, the Ionian islands, Italy and Sicily, with the same set of oxides as heavy minerals and common gypsum cement.

c) Those at localities in Sardinia, Corsica, Catalonia and Algeria, i. e. essentially around the rim of the western Mediterranean Balearic Sea, that contain hardly any oxides as heavy minerals but iron sulfides instead. They are also devoid of any gypsum cement.

The statistical analyses on the sub-sets of heavy minerals also indicated an internal consistency within these three divisions of Messinian sandstones.

An assumption that sands in Corsica and around the Balearic Sea have always been devoid of any heavy oxides is not tenable. They have evidently been stripped of any gypsum and iron oxides, as Messinian evaporites still occur farther out from present shores. Anaerobic bacteria utilize gypsum under concurrent production of hydrogen sulfide. This would have led to a neoformation of authigenic pyrite and marcasite crystal druses and fossil fragment replacements. Post-depositional anaerobic conditions are thus indicated around the basin fringes of the Messinian Balearic Sea. It is noteworthy that this distribution of anoxic environments is opposite to the sapropel distribution in Quaternary sediments in Mediterranean deeps (PERISORATIS et al., 1980; CITA and PODENZANI, 1980; ROSSIGNOL-STRICK et al., 1982) and probably represents an earlier phase of anoxic conditions. In contrast, sandstones in the Aegean, eastern and central Mediterranean regions remained in an oxygenated environment after deposition to this day, as both the oxides and the gypsum are preserved. An oxygenated environment precludes the existence of continuous density stratification along the north rim of the Messinian evaporite basins separating anoxic bottom waters from well oxygenated surface brines. The limit of the interface must have been further offshore. Cliffy coasts have not been documented around any Phanerozoic evaporite basin. On the contrary, broad sebkha-type flats of iron-rich red beds with a pronounced fining towards the shores and then grading to shallow marine carbonate or gypsum shelves are common in many instances. This is due to the requirement of halite precipitating evaporite basins to maintain a free water surface equal to a multiple of the area of rock salt precipitation (SONNENFELD, 1984; SONNENFELD and FINETTI, 1985).

A progressive decrease in maximum grain size exists in the gypsiferous conglomerates from Aegean and Levantine sites to Crete and thence to the Ionian islands, Italy, Sicily, Corsica and Catalonia (SONNENFELD, 1974, 1975, 1977). This could be explained by lower gradients of tributaries in the west, steeper gradients in the east. Yet there is no reason to assume that, at this time, the mountains of eastern Greece and Turkey were steeper than mountains in western Greece, Italy or Sicily. Instead, the direction of grain size diminuition and heavy mineral depletion points towards a westward, anticlockwise current. This is corroborated by the direction of current cross bedding in various localities (as discussed in SONNENFELD, 1974, 1977; cf. also GRADSTEIN and VAN GELDER, 1971).

Messinian currents

The rotation of the earth creates vertical and horizontal Coriolis components which impart a westward direction to any surface current along the Mediterranean north shore. Unless the direction of the earth rotation has changed, the grain size diminuition thus represents the direction of surface currents without bottom counter currents. The sequence from heavy minerals in well oxidized sandstones in the Aegean Sea to heavy minerals in gypsiferous sandstones around the Adriatic and Ionian Seas to pyrite replacing other iron oxides around the Balearic Sea indicates a gradation to progressively more reducing environments. A current in the present Mediterranean Sea moves along the African coast to the Levant, along the Turkish and Greek coasts into the Adriatic Sea and thence via Sicily to the French coast. At Reggio di Calabria at the tip of Italy the top 30 m of Mediterranean waters move north into the Tyrrhenian Sea at an average velocity of 4.3 cm/s, the surface waters at 6 cm/s (DEFANT, 1961). Even without taking into consideration the greater force of a gypsum precipitating current, such a current is quite capable of moving sand in excess of 0.5 mm in diameter (DAVIS et al., 1976; BLATT et al., 1980). Only where water depths exceed 30 m is a measurable counter current moving eastward today through the various straits. All available evidence points only towards a westward moving current in Messinian time, not to an eastward movement. If such an eastward counter current did not appear to have moved the sands in Messinian time, the sandy shelves must then have been too shallow for such a counter current to form.

Fossil evidence

The brackish Paratethys Sea, a body of water to the NE of the Mediterranean Sea, experienced a water surplus in Messinian times due to an excess of runoff by northern rivers. Some of the Paratethys waters must have drained into the Mediterranean Sea, since the Bosporus was much wider at that time (CVIJIĆ, 1908). In the northwestern Aegean Sea some Messinian evaporites are known to occur. However, the flow might well have been an intermittent one, as even the sandstones on the island of Chios appear to be predominantly derived from a tributary freshwater source (BESENECKER, 1973). Such a flow direction is also suggested by the presence of brackish-water pelecypods and other fossil groups belonging to a Ukrainian and Romanian provenance in these gypsiferous sediments in eastern Greece, Toscana, Sicily, and Catalonia (RUGGIERI, 1967; GILLET, 1959); similar faunas were also encountered in a borehole sunk into the middle of the Balearic basin about 40 m beneath the top of the gypsum sequence (SCHRADER and GERSONDE, 1978). As a matter of fact, the Messinian neostratotype at Pasquasia-Capodarso in central Sicily consists of two principal gypsum beds separated and overlain by beds of marly clays with abundant brackish-water ostracods, followed by a third minor bed of gypsum overlain by a few more centimeters of marl and more brackish ostracodes (BENSON, 1975). The observed faunal assemblages migrated alive to their present sites of deposition, possibly from temporary refuges in estuaries. The contamination of Messinian evaporitic sediments by major quantities of brackish and fresh waters, as indicated by isotope studies (e. g. NESTEROFF, 1973; LONGINELLI and RICCHIUTO, 1979; KUSHNIR, 1982) indicates periodic floodings from freshwater sources. In contrast, an absence of an Atlantic benthonic fauna in Messinian sediments east of the island of Mallorca in the western Balearic Sea off the coast of Spain is significant, since neither waterfalls nor narrows pose effective barriers to faunal migration. The repeated resettling of Messinian Porites corals, that alternate with stromatolites in both Greece and coastal Spain, indicate a break with Atlantic faunas, as all corals had died out along the Atlantic coast several million years earlier, in mid-Miocene time (ESTEBAN, 1979).

Had the inflow from the Paratethys been continuous through the Aegean Sea and had it been dragged as a floating freshwater wedge along the north coast of the Messinian Mediterranean Sea, brines underneath the wedge would have become anoxic and neither gypsum nor heavy mineral oxides would have remained stable. On the other hand, drainage from circum-Balearic lands provided such freshwater wedges and thus induced local anaerobic conditions which resulted in gypsum decomposition. As long as we have little knowledge about the distribution of North African drainage towards the Mediterranean Sea prior to the burial of the Saharan landscape in desert sands, we cannot estimate the effects of freshwater drainage into the Balearic basin.

Conclusion

The distribution of the heavy mineral assemblage along the north rim of the Messinian Mediterranean Sea shows a definite grouping and relationship with distance. This suggests that they were deposited by a common current. The westerly direction of the current is suggested by the existing currents of the Mediterranean Sea, by heavy mineral distribution, by oxidation states of iron, and by fossil assemblages.

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Zusammenfassung

Gipsführende konglomeratische Sandsteine obermiozänen Alters (Messinian) wurden von verschiedenen Lokalitäten des östlichen und zentralen Mediterrangebietes aufgesammelt und untersucht. Das Schwermineralspektrum der Fraktion 0,15–0,25 mm zeigt einen gemeinsamen Trend der Abnahme des Auftretens der einzelnen Mineralarten mit zunehmender Entfernung von einem vermuteten Herkunftsort im Osten. Dies unterstützt die Annahme einer küstenparallelen Meeresströmung im Gegensinn des Uhrzeigers zur Zeit des Messinian als Folge des Coriolis-Effektes. Die heutige Ägäis war ein Seitenarm, der damals nur durch das Auftreten von zentraleuropäischen Brackwasser-Mollusken und Phytoplankton in evaporitischen Sedimenten Griechenlands, Italiens und Spaniens erkennbar war. Während im östlichen und zentralen Mittelmeer Eisenoxide neben den Schwermineralien vorkommen, findet man westlich von Sizilien nur Pyrit und Markasit als Indikatoren eines reduzierten Milieus.

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Artikel/Article: Matrix Provenance of Upper Miocene Gypsiferous Sandstones in the Mediterranean Area. 23-37