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Significance of rare reproduction occurrences among recent nodosariids and other benthic foraminifera

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Abstract

Rare morphologies of nodosariids and other benthic foraminifera reported from various locations and depths in the seas present data valuable in interpreting both past and recent environmental conditions. A few abnormal nodosariids and other benthic foraminifera have been found at the Saros Gulf, near the island of Bozcaada, at the Edremit Gulf (northern Aegean Sea) and Gökova Gulf (southern Aegean Sea) off the coast of W Turkey. The unusual morphology of these foraminifera, "improbable" and rare, is mysterious clues to the natural survival of such organisms. Environmental conditions such as temperature and trace elements may play an important role in stimulating such unusual test occurrences. Warm-water sources in deep-sea environments carry rare trace elements that cause unusual appearances of benthic foraminifera during reproduction. These remarkable and rare specimens found by chance provide data relevant to the reproduction history of nodosariids and other benthic foraminifera.

Key words: Abnormal forms, *Amphicoryna, Astacolus, Pyramidulina, Adelosina, Peneroplis, Rosalina, Euuvigerina*, Turkey.

Resumen

Significado de la presencia de morfologías raras durante la reproducción en los nodosaridos actuales y otros foraminíferos bentónicos.

La presencia de morfologías raras en nodosaridos y otros foraminíferos bentónicos recogidos en distintas zonas y profundidades marinas proporcionan datos valiosos para interpretar las condiciones ambientales pasadas y recientes. Se han encontrados unos pocos ejemplares anormales a cierta distancia de la costa occidental de Turquía, en el Golfo de Saros, cerca de la isla de Bozcaada, en el Golfo de Edremit (Egeo septentrional) y en el Golfo de Göcova (Egeo meridional). La morfología inusual de esos foraminíferos, rara e "improbable" es una pista enigmática de la supervivencia natural de tales organismos. Ciertas condiciones ambientales, como la temperatura, y los elementos traza pueden jugar un papel importante en la estimulación de estos inusuales fenómenos. Las fuentes de aguas cálidas en los medios marinos profundos transportan elementos traza raros que producen la aparición de apariencias morfológicas inusuales durante la reproducción en los foraminíferos bentónicos. Estos llamativos y raros especímenes proporcionan datos relevantes sobre la historia reproductiva de los nodosaridos y otros foraminíferos bentónicos

Palabras clave: Formas anormales, *Amphicoryna, Astacolocus, Pyramidulina, Adelosina, Peneroplis, Rosalina, Euuvigerina,* Turquía.

Introduction

Although studies of recent foraminiferal reproduction described in the literature reflect investigations through 95 years, the reproduction of fossil benthic and planktonic foraminifera has only been undertaken during the past 40 years. Detailed investigations of peculiar occurrences, such as twin and triplet forms of fossil foraminifera, began as recently as 1950. A brief review of the literature is necessary to evaluate and understand the problems. Let us look at the reproduction of Holocene foraminifera in respect to abnormal occurrences throughout the principal foraminiferal genera and species focusing on the Holocene adhesive twin and triplet forms.

Le Calvez (1953) and Grell (1958) have illustrated the reproduction methods of primitive forms of recent foraminifera. Other scholars have also investigated the reproduction and life cycles of Holocene foraminifera. Examples of recent foraminifera and researchers responsible are as follows: *Peneroplis pertusus* (Forskål), Winter (1907); *Elphidium crispum* (Linnaeus), Myers (1938) and Le Calvez (1953); *Glabratella patelliformis* (Brady), Myers (1938) and Grasse (1953); *Spirillina vivipara* Ehrenberg, Myers (1936); *Patellina corrugata* Williamson, Myers (1935a, b); *Rubratella intermedia* Grell *and Rotalia heterocaryotica* Grell, Myers (1938) and Berthold (1971); and *Amphistegina gibbosa* d'Orbigny, Harney et al. (1998). For benthic fossil foraminifera, Cassan & Sigal (1961) recorded the first data on schizogonic reproduction. The studies of Meriç (1966a, 1970, 1973, 1976, 1996) and Meriç et al. (1997) have followed. Some of Meriç's studies (1964, 1966b, 1967, 1971, 1975, 1976) and that of Meriç & Görmüş (1997) introduce a new interpretation of the asexual reproduction of megalospheric individuals. However, many questions related to features of reproduction still remain unanswered, especially among benthic genera such as *Pleurostomella, Anomalina, Cassidulina* and *Nonion*. Furthermore, the reproduction cycles of different genera of the Buliminacea and Nodosariacea superfamilies also remain unknown (Loeblich & Tappan 1964, 1988). There is still insufficient data on these forms.

Let us now summarize the literature on adhesive twin and triplet forms of Holocene foraminifera. Le Calvez (1950) described twin forms of *Planorbulina mediterranensis* D'Orbigny as polyvalent individuals. Valuable scientific contributions are coming from various localities (Arnal 1955, Rötgerr & Spindler 1976, Debenay & Pages 1987, Debenay 1990, Sharifi et al. 1991, Almogi-Labin et al. 1992, Yanko et al. 1994, 1998, Meriç 1996, Geslin et al. 1998, Stouff et al. 1999, Meriç et al. 2001a, b). Adhesive twin fossil morphology in Turkey has been handled by Meriç (1972, 1976, 1979, 1992b), Inan & Meriç (1995), Inan et al. (1996), Meriç & Görmüş (1999, 2000), Matsumaru et al. (2000) and Görmüş & Meriç (2000). There is relatively little data on fossil planktonic twins and triplets in the literature. Boltovskoy (1982) first introduced the matter, and Nazik (2002) has recently dealt with the subject as well.

All the literature cited, however, deals with the occurrences of twin and triplet forms among the same species. Only a few of those studies illustrate forms with linear twin-triplet configurations (Loeblich & Tappan 1964, 1988, 1994, Cimmerman & Langer 1991). Neither has the researchers taken adhesive twins of different species of one genus, and of different genera into account, nor to say, and linear twins and triplet occurrences of different forms. Thus, the main object of this paper is linear abnormal occurrences displaying the adhesion of different genera among nodosariids and other benthic foraminifera. Furthermore, the occurrences may provide new evidence on the environmental conditions during their formation. As a result, a more precise palaeoenvironmental approach to abnormal occurrences is proposed.

Materials and Methods

The remarkable specimens previously illustrated from various localities (Fig. 1) are most interesting. In addition, we introduce more specimens with unusual linear configurations from the Saros Gulf, Bozcaada and Edremit Gulf in the N Aegean Sea, and Gökova Gulf in the S Aegean Sea off W Turkey (Fig. 2). The specimens are from samples of surface sediments

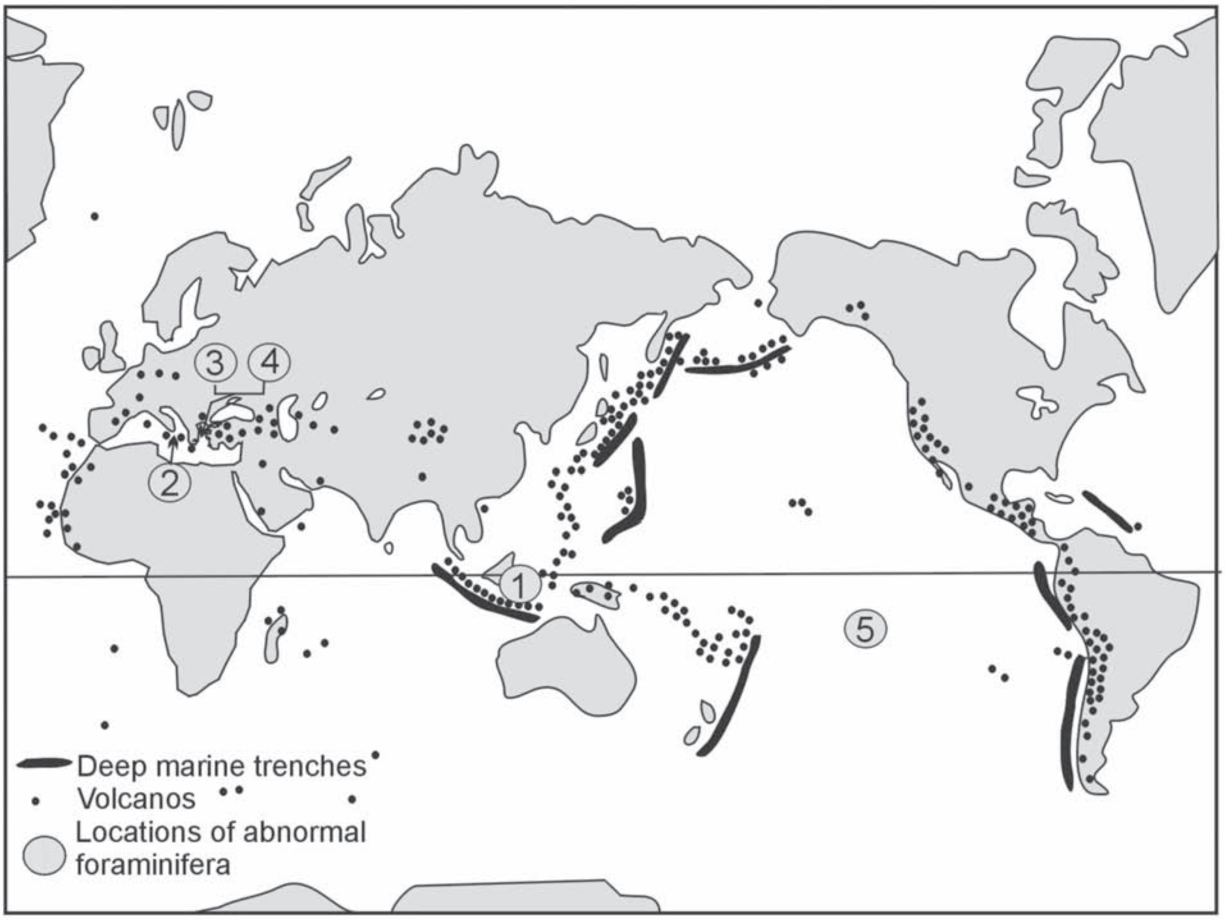

Figure 1. Distribution of volcanos, deep marine trenches (after Stowe 1979) and find spots of abnormal nodasariid and other benthic foraminifera. 1, The Timor Sea (Loeblich & Tappan 1988, 1994); 2, The Tyrrhenian Sea (Cimerman & Langer 1991); 3-4, The Aegean Sea (Saros Gulf and Bozcaada, this work); 5, An anonymous site in the Pacific Ocean (Loeblich & Tappan 1964).
Figura 1. Distribución de volcanes, de fosas marinas profundas (Stowe 1979) y de los puntos de hallazgo de nodasaridos anormales y de los otros foraminiferos bentonicos. 1, Mar de Timor (Loeblich & Tappan 1988, 1994); 2, Mar Tirreno (Cimerman & Langer 1991); 3-4, Mar Egeo (Golfo de Saros y Bozcaadajo); 5, Un lugar en el Océano Pacífico (Loeblich & Tappan 1964).

exposed on the sea bottom. After washing and drying the samples, the specimens were picked from the detrital sediments. Our interpretation of linear twin and triplet forms of the same and different nodosariid species is based on these new Turkish specimens as well as the previously known occurrences throughout the world (Fig. 1). In particular, we seek the cause for such occurrences. The organisms from Turkey have been examined with the scanning electron microscope of Arçelik Company, Turkey. All new examples of the abnormal forms discussed here are housed in the Geological Department of the Istanbul University, under safekeeping by the first author.

Unusual Occurrences

Abnormal occurrences and Siamese benthic foraminifera worldwide

A few recent nodosariid foraminifera display linearly formed twin or triplet individuals such as *Amphicoryna sublineata* (Brady) (Fig. 3a); *Amphicoryna separans* (Brady) (Figs. 3d, f); *Amphicoryna scalaris* (Batsch) (Fig. 3g); and *Amphicoryna separans* (Brady) (Fig. 4a). Although described in the literature as representing the same species, no comment is given on their formation. Figures 1, 2 and 5 here show the find spots of these rare specimens as well as their schematic views including the twin-triplet formations.

The specimen of *Amphicoryna sublineata* (Brady) from the Timor Sea was found in shelly deposits at a depth of 86.87 m (sample no. V 219) (Loeblich & Tappan 1994). Judging from the external features, the upper part of the specimen is *A. meringella* Loeblich & Tappan and the lower part is *A. sublineata* (Brady). The test includes one globular chamber. The first

Figure 2. Sampling locations of foraminifera from the Aegean Sea.
Figura 2. Lugares de muestreo de foraminiferos en el Mar Egeo.

individual displays coarse longitudinal ribs, while the abnormal formation part (above) has a smooth finely granulated surface. The external morphological characteristics of the two adhering species are different (Fig. 3a). Normal and abnormal individuals can be compared in their different morphologies as seen in Figure 3. Therefore, the form contains abnormal individuals of the genus *Amphicoryna.*

Twins of *Amphicoryna separans* (Brady) from the west Timor Sea have been reported from sands at a

Figure 3. a, *Amphicoryna sublineata* (Brady). External view, adhered two *Amphicoryna* individuals, *Amphicoryna sublineata* at lower part and *Amphicoryna meringella* Loeblich & Tappan at upper part, x130, the Timor Sea (from Loeblich & Tappan 1994, pl. 128, fig. 13); b, *Amphicoryna meringella*. External normal individual view, x104, the Timor Sea (from Loeblich & Tappan 1994, pl. 128, fig. 1); c, *Amphicoryna sublineata*. External normal individual view, x82, the Timor Sea (from Loeblich & Tappan 1994, pl. 128, fig. 9); d, *Amphicoryna separans* (Brady). External abnormal view, x234, the Timor Sea (from Loeblich & Tappan 1994, pl. 127, fig. 10); e, *Amphicoryna separans*. External normal view, x142, the Timor Sea (from Loeblich & Tappan 1994, pl. 127, fig. 13); f, *Amphicoryna seperans*. External abnormal view, x67, the Timor Sea (from Loeblich & Tappan 1994, pl. 127, fig. 5); g, *Amphicoryna scalaris* (Batsch). External view, x68, the Tyrrhenian Sea (from Cimerman & Langer 1991, pl. 54, fig. 6). Reprinted with permission from the Slovenska Akademija Znanosti in Umetnosti; On this figure, the pictures a-f are reprinted with permission from the Cushman Foundation for Foraminiferal Research.

Figura 3. a, *Amphicoryna sublineata* (Brady). Vista externa de dos individuos adheridos de *Amphicoryna*, *Amphicoryna sublineata* en una parte inferior y *Amphicoryna meringella* Loeblich & Tappan, en la parte superior, x130, del Mar de Timor (Loeblich & Tappan 1994, pl. 128, fig. 13); b, *Amphicoryna meringella*. Vista externa de un individuo normal, x104, Mar de Timor (Loeblich & Tappan 1994, pl. 128, fig. 1); c, *Amphicoryna sublineata*. Vista externa de un individuo normal, x82, Mar de Timor (Loeblich & Tappan 1994, pl. 128, fig. 9); d, *Amphicoryna separans* (Brady). Vista externa de un ejemplar anormal, x234, Mar de Timor (Loeblich & Tappan 1994, pl. 127, fig. 10); e, *Amphicoryna separans*. Vista externa de un individuo normal, x142, Mar de Timor (Loeblich & Tappan 1994, pl. 127, fig. 13); f, *Amphicoryna seperans*. Vista externa de un ejemplar anormal, x67, Mar de Timor (Loeblich & Tappan 1994, pl. 127, fig. 5); g, *Amphicoryna scalaris* (Batsch). Vista externa de un ejemplar anormal, x68, Mar Tirreno (Cimerman & Langer 1991, pl. 54, fig. 6) (con permiso del Slovenska Akademija Znanosti en Umetnosti). (Las figuras a-f se reimprimen con el permiso de la fundación de Cushman Foundation for Foraminiferal Research).

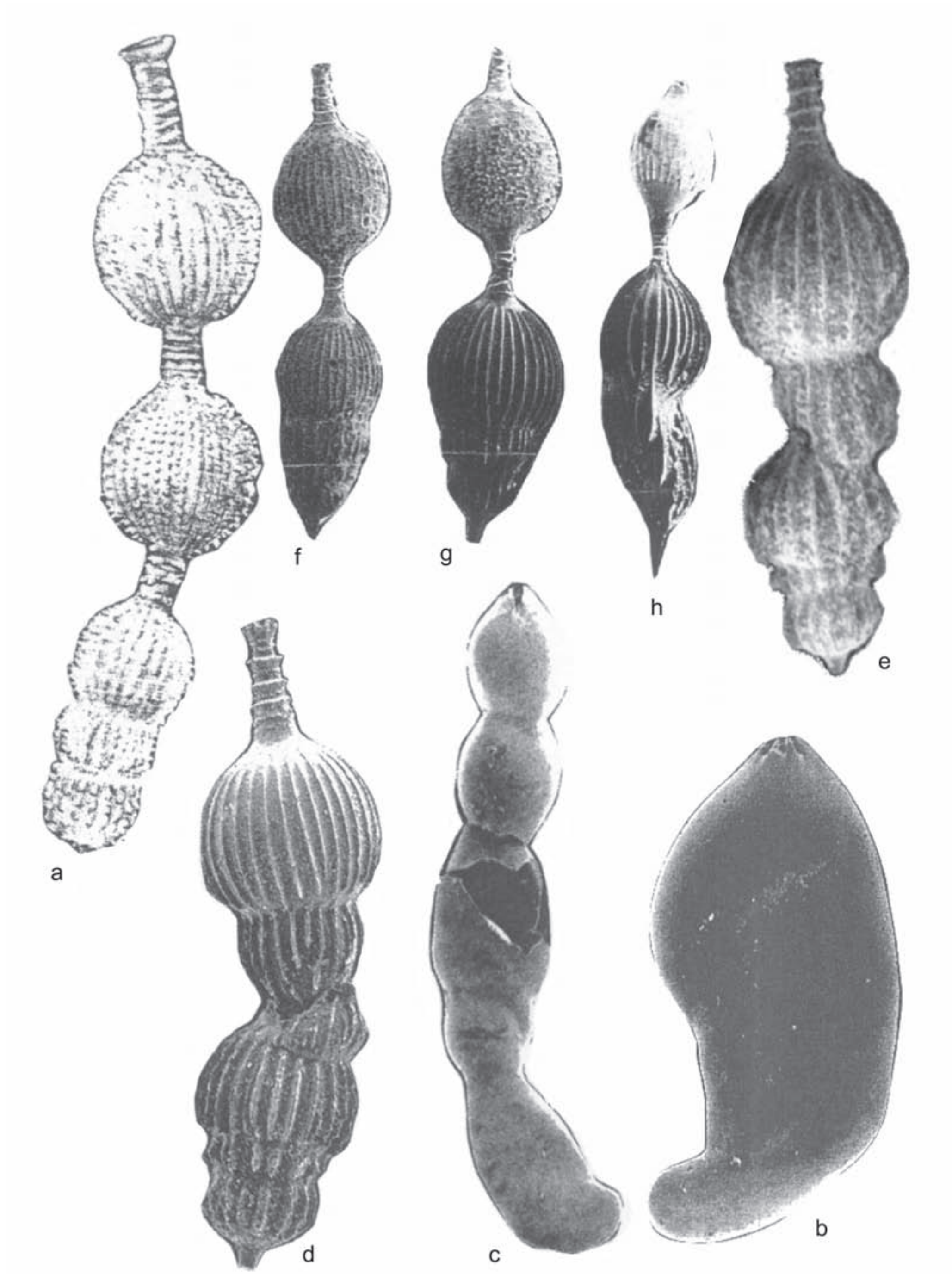

Figure 4. a, *Amphicoryna separans* (Brady). External view, x38, from the Pacific Ocean (from Loeblich & Tappan 1964, fig. 401,2). Reprinted with permission from the Geological Society of America; b, *Astacolus crepidulus* (Fichtel & Moll). Normal individual, external view, x95, the submarine spring of Harmantaş in the Saros Gulf, northern Aegean Sea; c, *Astacolus crepidulus*. Abnormal individual, external view, x75, the submarine spring of Harmantaş in the Saros Gulf, northern Aegean Sea; d, *Amphicoryna scalaris* (Batsch). Abnormal individual, external view, x132, station 10 in the Saros Gulf, northern Aegean Sea; e, *Amphicoryna scalaris*. Abnormal individual, external view, x139, station 7 in the Gökova Gulf, southern Aegean Sea; f-h, *Amphicoryna scalaris*. Abnormal individuals, external views, x55, west off Corsica Island, Western Mediterranean Sea. f-g, form A (megalospheric). 8, form B (microspheric) (from Bizon & Bizon 1984, pl. 8, figs. 2-4). Reprinted with permission from the Association des Techniciens et Professionnels du Pétrole.

Figura 4. a, *Amphicoryna separans* (Brady). Vista externa, x38, Océano Pacífico (Loeblich & Tappan 1964, fig. 401.2). (Reimpreso con el permiso de la Geological Society of America); b, *Astacolus crepidulus* (Fichtel & Moll). Vista externa de un individuo normal, x95, fuente submarina de Harmantaş en el Golfo de Saros, Mar Egeo septentrional; c, *Astacolus crepidulus*. Vista externa de un individuo anormal, x75, fuente submarina de Harmantaş en el Golfo de Saros, Mar Egeo septentrional; d, *Amphicoryna scalaris* (Batsch). Vista externa de un individuo anormal, x132, estación 10 en el Golfo de Saros, Mar Egeo septentrional; e, *Amphicoryna scalaris*. Vista externa de un individuo anormal, x139, estación 7 en el Golfo de Gökova, Mar Egeo meridional; f-h, *Amphicoryna scalaris*. Vista externa de individuos anormales, x55, al oeste de la isla de Córcega, Mar Mediterráneo occidental. f-g, forma A (megalosférica). h. forma B (microsférica) (Bizon & Bizon 1984, pl. 8, figs. 2-4). (Reimpreso con el permiso del Association des Techniciens et Professionnels du Pétrole).

depth 177.32 m (sample no. V 230) (Loeblich & Tappan 1994). The specimen comprises two different parts. The first individual has two inflated globular chambers with longitudinal patterns, while the second abnormal part includes longitudinal ribs. The aperture neck of the abnormal part is longer than that of the first. This specimen is an abnormal linear formation of *Amphicoryna* (Fig. 3d).

Another example of *Amphicoryna separans* (Brady) comes from shelly mud deposits 292.48 m below the surface of the Timor Sea (sample no. 260) (Loeblich & Tappan 1994; Fig. 3f). Although the initial part represents an individual with three chambers, the second part only includes one globular chamber (Fig. 3f). The small first chamber, the medium sized, globular second chamber and the inflated third chamber are all related to the first individual. The second part consists of a single medium-sized globular chamber. The aperture neck of the second part is longer. The external morphological features of both are similar. Coarse longitudinal ribs are clear on the surface of the test. This example represents an abnormal linear formation of identical species of *Amphicoryna* (Fig. 3f).

Another sample showing abnormal linear morphology comes from the Porta di Ponenete near Vulcano Island in the Tyrrehenian Sea. It was collected from soft sediments at a depth of 130.00 m (sample no. Vu 9) (Cimerman & Langer 1991). This example of the species *Amphicoryna scalaris* (Batsch) also includes two individuals of identical species. Differentiation of the two individuals is based on the number of its chambers. The first individual consists of three globular chambers with coarse longitudinal ribs. Its chambers increase in size in the last. A final globular chamber belongs to the second abnormal formation. The chamber has a longer aperture neck (Fig. 3g). Three specimens of *Amphicoryna scalaris* (Batsch) from west off Corsica Island (Bizon & Bizon 1984) show similar abnormalities (Figs. 4f-h). The tests of the second individuals differ in the ornamentation from the first individuals. These kinds of features are similar to the examples of the Timor Sea.

In addition to the examples above, Loeblich & Tappan (1964) have published an interesting triplet form of *Amphicoryna separans* (Brady) from an undisclosed site in the Pacific Ocean. The first individual includes three globular chambers of more or less the same size with coarse longitudinal, rather granular ribs. The abnormal parts display only one globular chamber. This remarkable form shows an abnormal linear formation of identical species of *Amphicoryna.* The latter has a longer aperture neck (Fig. 4a). Two more specimens showing abnormalities are related to *Pyramidulina pauciloculata* (Cushman) (Figs. 6b, c). They were reported from the Timor Sea (Loeblich & Tappan 1994).

The abnormal individuals of nodosariids described above include identical species of their genus. When the causes of unusual occurrences are evaluated in terms of living conditions at the locations of these Siamese twins, the chemical content of the water and the temperature of the substrata are striking features. The Timor Sea comprises many islands related to a subduction plate zone. Because of subduction there have been collisions and volcanic activity along the plate boundary. One abnormal nodosariid individual is from the Tyrrhenian Sea, near Vulcano Island, where it is clear that volcanic activity (the Etna and Stromboli volcanoes are nearby) may have affected the organic life of the region. These examples suggest that submarine springs and warm waters rich in trace elements play important roles in the formation of these organisms.

Results

Abnormal Occurrences and Siamese Benthic Foraminifera in Turkey

While all abnormal individuals reported from other parts of the world belong to the genus *Amphicoryna*, we have also found abnormal morphologies among different genera of the nodosariids and other benthic foraminifera in Turkey (Fig. 2). The foraminifera families found to comprise abnormal forms now include Hauerinidae, Peneroplidae, Euuvigerinidae and Nodosariidae.

The first specimen is a triplet? form of *Astacolus crepidulus* from recent sediments in Saros Bay in the northern Aegean Sea (Figs. 2, 4c). When compared to its normal form (Fig. 4b), this triplet form is very different. The adhering part is lightly compressed, with the abnormal triplet including two parts belonging to an identical species and a third adhesive individual of a different genus. The test of the *Astacolus crepidulus* (Fichtel & Moll) is elongate in outline and moderately compressed, triangular in cross section. Its periphery is rounded. The first part of the test displays a spiral coil tight in plan, followed by curved uniserial chambers with depressed sutures. The individuals have a smooth surface. The wall is calcareous. The aperture is radial at the edge of the last chamber. The individual of the upper part is not an *Astocolus* although it is also a nodosariid form. Its test is straight with two globular chambers (uniserial globular to elongate chambers with a smooth surface). The two chambers are more or less equal in size. The

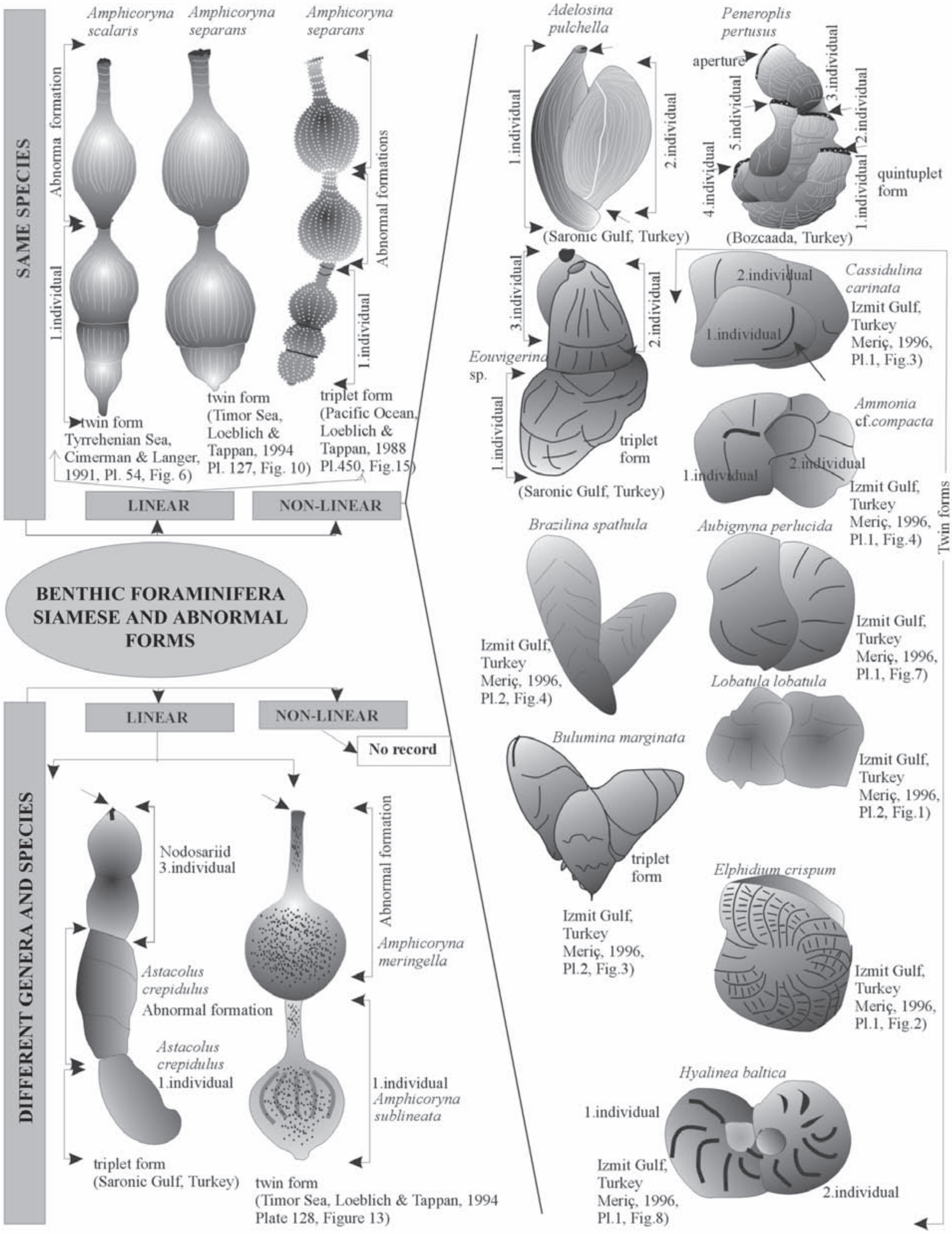

Figure 5. Overview of abnormal forms within benthic foraminifera. The forms are separated into two groups depending on whether the forms consist of individuals from the same or different species. The forms are also recogniced as linear or non-linear configurations.

Figura 5. Descripción de formas anormales dentro de los foraminíferos bentónicos. Las formas se separan en dos grupos dependiendo de si están constituidas por individuos de la misma o de distinta especie. Las formas también se reconocen como configuraciones lineares o no lineares.

Figure 6. a, *Amphicoryna scalaris* (Batsch). External view, x114, station 20 in the Saros Gulf, northern Aegean Sea; b-c, *Pyramidulina pauciloculata* (Cushman). Both from V-230, x51 and x43 respectively, the Timor Sea (from Loeblich & Tappan 1994, pl. 117, figs. 7-8); d, *Adelosina pulchella* d'Orbigny. Twin form, external view, x96, the submarine spring of Harmantaş in the Saros Gulf, northern Aegean Sea; e, *Peneroplis pertusus* Forskål. Quintuplet form, external view, x166, station 11 near Bozcaada, northern Aegean Sea; f, *Peneroplis planatus* (Fichtel & Moll). Abnormal form, external view, x67, station 5 in the Edremit Gulf, northern Aegean Sea; g, *Rosalina* sp. Abnormal form, external view, x70, station 3 in the Edremit Gulf, northern Aegean Sea; h, *Euuvigerina* sp. triplet? form, external view, x122, station 16 in the Saros Gulf, northern Aegean Sea.

Figura 6. a, *Amphicoryna scalaris* (Batsch). La vista externa, x114, estación 20 en el Golfo de Saros, Mar Egeo septentrional; b-c, *Pyramidulina pauciloculata* (Cushman). Ambos de V-230, de x51 y de x43 respectivamente, Mar de Timor (Loeblich & Tappan 1994, pl. 117, figs. 7-8); d, *Adelosina pulchella* d'Orbigny. Forma gemela, vista externa, x96, fuente submarina de Harmantaş, Golfo de Saros, Mar Egeo septentrional; e, *Peneroplis pertusus* Forskål. Forma quintuple, vista externa, x166, estación 11 cerca de Bozcaada, Mar Egeo septentrional; f, *Peneroplis planatus* (Fichtel & Moll). Vista externa de una forma anormal, x67, estación 5 en el Golfo de Edremit, Mar Egeo septentrional; g, forma anormal de *Rosalina* sp., vista externa, x70, estación 3 en el Golfo de Edremit, Mar Egeo septentrional; h, *Euuvigerina* sp. Forma ¿triple?, vista externa, x122, estación 16 en el Golfo de Saros, Mar Egeo septentrional.

Table 1. Sampling numbers and water depths of individuals of *Amphicoryna scalaris* (Batsch) collected from Saros Bay (Meriç et al. in press).
Tabla 1. Profundidades de los distintos puntos de captura de *Amphicoryna scalaris* (Batsch) en la bahía de Saros.

Sampling numbers	**10**	**12**	**13**	**14**	**20**	**22**	**25**	**27**	**28**	**29**	**30**	**34**	**36**	**40**	**72**	**80**
Water depth (m)	68.5	214.7	156	84	92	118.5	188	144.8	115.5	92	90.5	82	74	77.3	500	98

wall is calcareous. The aperture of the unidentified nodosariid genus is radial, located at the centre of the final chamber (Fig. 4c).

The second abnormal form was also found in the Saros Bay, at station 10 (Fig. 2). It is an abnormal form of *Amphicoryna scalaris* (Batsch) (Figs. 4d, e). The form includes two adhesive individuals. The first individual includes four globular chambers with coarse longitudinal ribs. The test is straight and uniserial. The third chamber increases in size, but the last chamber appears poorly developed due to the adhesion of the second individual with two globular chambers. A long aperture neck opening at the end of the second individual is clearly seen. Close examination shows that the adhesive part is different not only from that of the first individual here, but also from the other abnormal *Amphicoryna* forms mentioned above. Its history of development may be differently interpreted. The adhesive part might have been affected by different environmental factors. However, the linear adhesion is interesting. We would interpret the adhering part as an incomplete chamber of the first individual during reproduction.

Another unusual example of *Amphicoryna scalaris* (Batsch), our third specimen, comes from station 20 in the Saros Bay (Figs. 6a, b). The first four globular chambers are related to the first individual of the Siamese twin. Typical coarse longitudinal ornamentation and depressed sutures are clear. The test is straight and uniserial. The second individual is comprised of one globular chamber with a long aperture neck. The fourth abnormal individual of the *Amphicoryna scalaris* (Batsch) from station 7 in the Gökova Gulf, S Agean Sea also shows abnormalities.

Individuals of *Amphicoryna scalaris* (Batsch) were found in 16 out of 80 samples (Table 1), excluding those from the stations 10 and 20 in the Saros Bay. This data shows that the individuals of *Amphicoryna scalaris* (Batsch) appear at water depths from 68.5 to 500 metres. That implies an open shelf to deep-sea environment. Their appearances are commonly normal. Among the thousands of *Amphicoryna scalaris* (Batsch) specimens collected, three abnormal morphologies are worthy of mention.

Our fifth specimen is from recent sediments at Harmantaş in the Saros Bay (Fig. 2). The sediments were collected 20.10 metres below the sea surface. This twin development of *Adelosina pulchella* d'Orbigny presents a striking configuration of reverse adhesion. The aperture of the individual on the left (Fig. 2) is clear, and the final long compressed chambers with coarse longitudinal ornamentation are also distinct. The second individual's aperture adheres to the back of the first individual. The long compressed chambers of the second individual match the surface of those of the first (Fig. 6d). This twin was found in fossilliferous sediments with abundant benthic foraminifera.

The sixth specimen, also from the Saros Bay, belongs to *Euuvigerina* sp. (Fig. 6h). From station 16 this triplet form of *Euuvigerina* displays both linear and horizontal adhesion. The test of each individual is straight. However, appearance of the Siamese triplet is nonlinear due to its morphology. The third individual adheres to one side of the second one (Fig. 6h).

The last two examples of abnormal individuals were found in rich association of benthonic foraminifera in a single locality (Saros Bay, N Aegean Sea). Only few foraminifera here present unusual features. The following data describe their environment: 20.10 metres below sea level; temperature, 18.50°C; salinity, 35.64 ‰; density of oxygen, 5.2 mg/l; and pH 7.69. These data reflect an environment with relatively high temperatures and alkaline chemical composition. The fault system here is the primary reason for these diverse environmental conditions.

Our seventh abnormal specimen from Turkey belongs to *Peneroplis pertusus* (Forskål) (Fig. 6e). It is from the area near Bozcaada in the northern Aegean Sea (Fig. 2). It represents a quintuplet form. Contacts between the first four individuals are less clear than that of the fifth adhesive individual. They all adhere to form a ball. The individuals are spiral in plan at the initial part, later uniserial in coiling. The elongate chambers bear coarse longitudinal pattern. The test periphery is rounded and compressed. The length of the elongate chambers is greater than their heights. There are numerous apertures in the last chambers (Fig. 6e). Another abnormal formation of *Peneroplis planatus* (Fichtell & Moll) is from station 5 in the

Table 2. Heavy metal concentrations in surface sediments from the Dikili and Candırlı bays at the west coast of Turkey (Ergin et al. 1993).
Tabla 2. Concentraciones de metales pesados en los sedimentos superficiales en las bahías de Dikili y de Candırlı en la costa occidental de Turquía (Ergin et al. 1993)

Loc.	Zn μg/L	Cr μg/L	Ni μg/L	Cu μg/L	Co μg/L	Mn μg/L	Fe %
T52	19	9	13	3	2	103	0.59
T53	27	32	30	6	7	172	1.18
T54	37	42	36	11	5	441	2.20
T55	81	73	43	34	9	352	3.07
T56	58	58	35	14	12	377	3.58
T57	98	103	118	27	19	716	4.23
T58	84	161	70	16	12	704	2.98
T59	53	68	62	11	9	388	2.58
T80	93	101	50	21	12	337	3.16
T81	56	65	36	16	9	269	2.99
T82	60	74	52	18	9	343	3.69

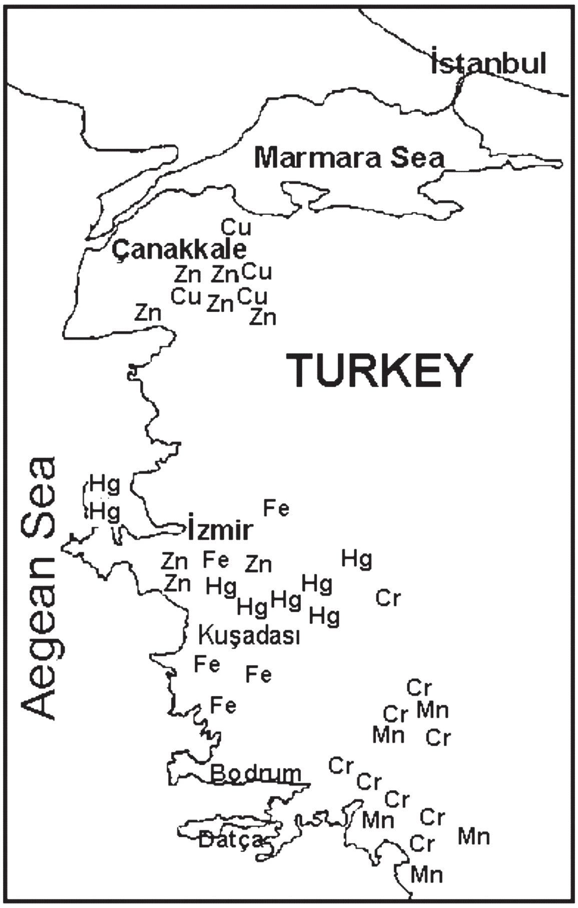

Figure 7. Mineral and ore occurrences along the west coast of Turkey (Evans 1971, MTA 1989, Ergin & Yemenicioğlu 1997).
Figura 7. Ocurrencias y mineral surgente a lo largo de la costa del oeste de Turquía (Evans 1971, MTA 1989, Ergin & Yemenicioğlu 1997).

Edremit Gulf, N Aegean Sea (Fig. 6f). *Rosalina* sp. from station 3 in the Edremit Gulf, N Aegean Sea also shows abnormal formation (Fig. 6g).

Only one nodosariid individual shows that abnormal linear occurrences may represent different genera (*Astacolus* and an unidentified nodosariid genus in Fig. 4c). The others represent identical species of one genus. As a whole, their significance lies in linear attachment as well as the adhesion of different genera. As shown in the previous examples from other parts of the world, environmental conditions such as chemistry and temperature may play an important role. The Aegean Sea resembles the Timor Sea region geomorphologically and tectonically. In the Aegean Sea, volcanic activities formed many graben and horst systems during the Neogene and Quaternary periods. Submarine springs and volcanic rocks are principal sources of trace elements and temperature alteration. The results of warmer temperatures and diverse chemistry may be summarized as follows: (1) the presence of rare forms *Laevipeneroplis karreri* (Wiesner)*, Peneroplis pertusus* (Forskål)*, P. planatus* (Fichtel & Moll)*, Sorites orbiculus* (Forskål) and *Amphistegina lobifera* Larsen in the samples collected east and south of Gökçeada, being unusual for the northern Aegean Sea (Avşar & Meriç 2001); (2) occurrences of *Laevipeneroplis karreri, Peneroplis pertusus* and *P. planatus* east and south of Bozcaada, forms also foreign to the region (Meriç et al. 2002); (3) an abundance of *Coscinospira hemprichii* Ehrenberg, *Laevipeneroplis karreri, Peneroplis pertusus*, *P.*

planatus and *Sorites orbiculus* at a depth of 2.5 m and temperature of 55-58 ºC near a thermal spring in Çeşme (Izmir) Ilıca Bay (Avşar & Meriç 2001); and (4) abnormal views of *Peneroplis* test in the latter area, first recorded by Sözeri (1966) and Sellier de Civrieux (1970).

Discussion

Environmental Interpretation

The Timor Sea (western Pacific Ocean), Tyrrhenian Sea, the Pacific Ocean and the Aegean Sea are a great distance from one other. The same abnormal forms of nodosariids and other benthic foraminifera are found in all these waters. To understand the reasons for such abnormal occurrences (twins, triplet and quintuplets) from a developmental point of view, we wish to discuss these rare phenomena by reviewing literature as well as including our new observations from Turkey, a method permissible considering the random character of the phenomena. Obviously, the history of formation includes many complex factors, both physical (temperature, depth, composition of substrata, sea currents, etc.) and chemistry (distribution and proportion of the elements, Eh and pH values) as well as the biological environment (biological interaction). Let us first discuss the chemical characteristics and temperature in the environments producing abnormal examples during reproduction, and then cite other selected examples from other localities that indicate the mutation of normal life.

A warming of the seawater and increase in biodiversity in deep-sea environments may be caused by (1) a chemical composition altered by magmatic bodies and deep-sea volcanism, (2) any sudden temperature changes, (3) tectonic-plate boundaries and fracture systems such as faults, and (4) muddy volcanic debris rich in gases.

Examination of the composition of seawater reveals more than 70 different elements dissolved in the sea. According to their concentration in the seawater, these are classified as (1) major elements, (2) minor elements, (3) trace elements, and (4) oligo elements (Ivanoff 1972, Tait 1981). Major elements represent more than 100 mg/l (ppm), while minor elements range between 1-100 mg /l (ppm), and trace elements are less than 1 mg/l (ppm). Oligo elements are minor catalysts or trace elements that effect organisms. The major elements are comprised of more than 99 % dissolved cations [Na^+ (30.61 %), Mg^{2+} (3.69 %), Ca^{2+} (1.16 %), K^+ (1.10 %)] and anions [Cl^- (55.04 %) and SO_4^{2+} (7.68 %)]. The primary ions are Cl^- and Na^+, making up 85 % of the ions, which indicates that seawater is a salt solution. The ratio of Cl^-/ SO_4^{2+}, Na^+/Mg^{2+}, Cl^-/Na^+ does not change in decreases and increases of seawater salinity. It varies only in very low salinity (< 24.7 %), when the seawater character also breaks down (Ivanoff 1972, Tait 1981).

Minor elements include Br (68 mg/l - ppm), C (28 mg/l), B (4.5 mg/l), Sr (8 mg/l), Si (3 mg/l) and F (1.4 mg/l). Trace elements are N, V, Li, Fe, Nb, Rb, Zn, Co, P, Mo, Cd and Hg (Ivanoff 1972, Tait 1981); some of which are essential to support life. For instance, N and P are necessary during the normal life cycle of plants. Fe is important for all animal life. Some organisms accumulate and store necessary minor and trace elements in their bodies. For example, in some *Ascidia* species, vanadium (V) is a million times higher concentrated than in the surrounding seawater. Various sea algae retain a variety of trace elements in their structure. Some fish and bivalves may also store Ni, Zn and Hg.

In addition, 13 oligo elements are critical for organic life. They must be present in the seawater in certain proportions. Extremely high or low values may result in deaths or mutations. These elements are Fe, Ti, Zn, Cu, V, Br, B, Mg, F, Al, As, Co and Ra (Ivanoff 1972, Tait 1981).

Magmatic bodies such as volcanic dykes and chimneys are the principal source of minor or trace elements, while fractures such as fault systems release hot springs into the deep-sea waters, thus providing environmental conditions suitable for certain organisms. $Radon^{222}$ and $Helium^3$ isotopes released from magmatic bodies have also been reported in the deep-sea water. Another interesting factor is the presence of H_2S in warm deep-sea waters.

Nevertheless, organic life continues in deep-sea environments provided with suitable living temperatures and food sources. The energy source is chemical. For example, H_2S and S bacteria provide a food source for some organisms. At the same time, the temperature in the deep-sea environment is also critical for organic life. Temperature generally increases around volcanic dykes and chimneys. Whereas the normal seawater temperature in deep-sea environments averages 2°C, for it is always higher close to submerged volcanic chimneys. The reasons for higher temperatures here is the volcanic activities along plate boundaries and fracture, particularly fault systems. Water heated to about 350-400ºC by magma is here released into the seawaters by thermal springs, providing suitable conditions for organisms even in deep-sea environments (e.g., Rona 1992).

The above mentioned chemical composition and temperature would suggest that the occurrence of only a few abnormal foraminifera within an area benthic life may be associated with changes in temperature and the composition of elements. Observations have shown element changes in the seawater of the locations studied. Coastal areas of western Turkey contain high concentrations of minor and oligo elements (Fig. 7), which may leach into the sea (Table 2). The environment of abnormal individuals is the same as that of the other associated benthic foraminifera. Major element and sudden temperature changes would lead to mass killings. Thus, the occurrence of just a few abnormal individuals must be related to minor, trace or oligo elements in their vicinity at the time of reproduction.

Over the past 25 years, the eastern Pacific highlands and the mid-Atlantic rifts have been investigated. Mysterious organic assemblages occur around fractures of hydrothermal origin (Corliss & Ballard 1977, Ballard & Grassle 1979, Enright et al. 1981, Lutz & Haymon 1994, Binns & Deckker 1998, Lutz 2000). The following examples serve to illustrate how important chemical composition and temperature are for the life of deep-sea environments. (1) Occurrence of gastropods, bivalves, crabs and shrimps around the volcanic chimneys near the Bismark Islands. Massive S bodies (including Cu, Sn, Ag and Au) are seen 2,000 m below the sea surface in these hydrothermal areas of the Bismark Sea. Organisms, which are depending on the heat and the source of S, are abundant around the volcanic chimneys until a distance of about 200 meters (Binns & Deckker 1998).

(2) Around the Galapagos Islands near the Cocos-Nazka plate boundary, abundant organisms live at hot water springs with a temperature of 350°C at a depth of 2,500 m (Corliss & Ballard 1977). The rich life in the warm waters provided by this hydrothermal system is interesting, in particular the bivalves, worms, crabs, octopi and fish of unusual appearance living in temperatures of 3-23°C (Corliss & Ballard 1977, Ballard & Grassle 1979).

(3) Large red worms at the Galapagos Islands have been reported from the well known “Garden of Eden” (Corliss & Ballard 1977), where the temperature of the seawater is about 17-20°C. The worms associated with fish and crabs appear as a forest. A differentiation of the size of the worms to the east and the west of Galapagos Islands has been related to the separate sources of the submarine thermal springs in their environments.

The Chance Factor

As indicated in Gretener (1967), those rare events defined as having a low probability due to essential interplay of various particular factors have a definite significance in geology. Events that are all too commonly confused are those labelled impossible and improbable. The first is an event that no observational or theoretical evidence justifies. The second, on the contrary, is an event that is physically possible, but dependent upon a rare coincidence of unrelated situations; it is consequently highly unlikely (Gretener 1967). From this point of view, abnormal linear occurrences of nodosariids fall within the second category. Such improbable events among the foraminifera of the world may be summarized as follows:

Reproduction samples of the genus *Orbitoides* from various localities were accidentally discovered during preparation of thin-sections (Cassan & Sigal 1961, Meriç 1966b, 1970, Neumann & Poisson 1970, Meriç et al. 1997). Reproduction samples of *Dizerina anatolica* Meriç from Koyulhisar-Sivas, *Discocyclina archiaci* (Schlumberger) from Amasya and twin or triplet individuals of orbitoids from Upper Cretaceous and Tertiary sediments in Turkey were also discovered by chance (Meriç 1964, 1966b, 1971, 1972, 1975, 1976, 1992a, Meriç & Görmüş 2000). Furthermore, Van der Vlerk (1966) and Butterlin (1971) have also reported twins of *Lepidocyclina* (*Pliolepidina*) *pustulosa* (Douvillé) and *Lepidocyclina* (*Pliolepidina*) *ariana* Cole and Ponton.

Findings of twin and triplet forms of foraminifera are rare. Among such a multitude of normal individuals, these few unusual forms must be taken into account when interpreting their past. In conclusion, the importance of these mysterious individuals lies in the possibility that a historical approach might suggest guidelines for the future development of such organisms.

Conclusions

This study emphasizes Siamese forms of different species and genera for the first time. In particular, the triplet linear form of nodosariids from Turkey is an extreme phenomenon worthy of note. The Siamese twins and abnormal individuals in benthic foraminifera raise the two following questions in particular. One of them is why adhesion tends to be linear. The second is why different genera adhere to each other. The linear adhesive forms of nodosariids and other benthic foraminifera presented from various localities through the world provide remarkable data about their living conditions. These improbable phenomena are believed to be the result of chemical change in the environment. With temperature providing a suitable environment for such organisms, some abnormal individuals may be related to the chemical composition of the seawater during reproduction. Examples of abnormal foraminifers presented in this article support chemical effects as one of the main causes of such unusual formations. Particularly hydrothermal springs may introduce suitable or unsuitable elements for organisms in deep-sea environments. Unsuitable elements introduced during the reproduction of foraminifers may cause abnormal occurrences. Current events also show that minor and trace elements affect an organism's life, particularly in the reproduction stage.

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