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Morphology and distribution of the marine diatom *Azpeitia africana* (Janisch ex A. Schmidt) G. Fryxell & T. P. Watkins in the South China Sea*

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Abstract The purpose of the present paper is to study the morphological structure and variability of *Azpeitia africana* and to determine its geographical distribution in the surface sediments of the South China Sea (SCS). Sediment samples were collected with grabs or box corers in one cruise in 2001 and two cruises in 2007. The sampling stations were located between 3°56.61′–20°59.37′N and 108°30.68′–116°46.70′E, where the water depth ranged from 72 m to 4 238 m. The diatom was observed by phase contrast microscopy and scanning electron microscopy. Microscopical observation showed that *A. africana* had circular valves with the areolar lines radiating from the eccentric ring. The central rimoportula had an external tube recessed on the edge of a central ring. The marginal rimoportulae were not evenly spaced, and they were positioned more closely together in one quadrant than in the others. *Azpeitia africana* is the most abundant diatom species in the southern region of the SCS, and accounted for 0.9%–5.6% of all diatom species in the Xisha Islands area. Average cell density of *A. africana* was 1.1×10^5 valves/g. The percentage abundance of *A. africana* was low (0%–2.5%) in the northern regions of the SCS and the Sunda Shelf, and it was not detected in the northwestern continental shelf (shallow water area) and northern Kalimantan Island shelf. Our results suggested that *A. africana* is a typical warm water species and that it could be used as an indicator of the warm Pacific Ocean water, including the Kuroshio Current, flowing into the SCS.

Keyword: diatom; morphology; *Azpeitia africana*; South China Sea (SCS)

1 INTRODUCTION

The genus *Azpeitia* was created and discussed in detail by Peragallo from the Osuna-Seville (Spain) fossil material (Tempère and Peragallo, 1915). Originally, *Azpeitia* Peragallo was described as a monotypic genus, with its type species being *A. antiqua*. Many of the species belonging to *Azpeitia* were originally placed in *Coscinodiscus* (Fryxell et al., 1986). According to Fryxell et al. (1986) the genus *Azpeitia* is characterized by valves with a nearly central rimoportula, often on the edge of an annulus; a ring of rimoportulae on the edge of the valve mantle; specialized areolae patterns on the mantle differing from those on the valve face; and two or more hyaline girdle bands including a wide valvocopula. There are 26 named species in Guiry and Guiry (2018) at present, as well as 4 infraspecific names. Of the species names, 23 have been accepted taxonomically. Fryxell et al. (1986) described *A. africana* and *A. barronii*. Almost all *Azpeitia* species have a warm water distribution in tropical/subtropical waters (Fryxell et al., 1986; Shiono and Koizumi, 2002; Seeberg-Elverfeldt et al., 2004; Jiang et al., 2006;

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Barron and Bukry, 2007; Garcia and Odebrecht, 2012; Barron et al., 2014; Chakraborty and Ghosh, 2016). The only exception is *A. tabularis*, which has radiated into austral cold water masses and is especially abundant in the Subantarctic Zone northwards and southwards of the Antarctic Convergence, although it is uncommon near ice (Fryxell et al., 1986; Garcia and Odebrecht, 2012; Ren et al., 2014). Ren et al. (2014) reported the distribution of *A. tabularis* in the North Pacific Ocean where summer sea surface temperatures ranged from 7°C to 27°C.

Azpeitia includes fossil and living marine species, ranging from the Eocene to the Recent. Most species are found in the middle Miocene, and only six extant species have been found: *A. africana*, *A. barronii*, *A. endoi*, *A. neocrenulata*, *A. nodulifera* and *A. tabularis* (Fryxell et al., 1986; Garcia and Odebrecht, 2012).

Because *A. africana*, in common with other members of *Azpeitia*, has an external cribrum, an internal foramen, rimoportula positioned on the edge of a central annulus, and a marginal ring of rimoportulae, Fryxell et al. (1986) transferred *A. africana* from *Coscinodiscus*. *A. africana* is common in equatorial and tropical marine waters (Fryxell et al., 1986; Jiang et al., 2006; Garcia and Odebrecht, 2012). It has been reported that *A. africana* has an occurrence range from the Late Pleistocene to Recent in the South China Sea (SCS) (Lan et al., 1995) and it commonly appears in SCS surface sediments (Jiang et al., 2004, 2006). However, the morphological description of *A. africana* in the SCS is inadequate, as is the original description, and the fine structure has not been observed at all with EM. Therefore, the morphological structure and distribution patterns of *A. africana* in SCS surface sediments remain unclear. The present paper studies the morphological structure and variability of *A. africana* and determines its geographical distribution in SCS surface sediments, increasing our knowledge of marine diatom diversity and ecological distribution information in the SCS, and providing essential information for paleoceanographical reconstructions of the SCS.

2 MATERIAL AND METHOD

2.1 Sampling and sample processing

We studied the morphology and distribution of the marine diatom *A. africana* from 62 samples in the uppermost 1 cm of sediment in the SCS. The sediment samples were collected with a grab or a box corer during cruises on R/Vs *Ocean-4* in 2000–2001, *Shiyan-3* in 2007 and *Yanping-2* in 2007. The sampling stations were located between 3°56.61′–20°59.37′N and 108°30.68′–116°46.70′E (Table 1, Fig.1). The water depths of sampling stations ranged from 72 m to 4 238 m. Optical microscope samples were prepared according to Håkansson (1984). Samples were treated with 10% HCl to remove calcareous matter and then treated with 30% H_2O_2 (1–2 h in a water bath at 60°C) to remove organic material. Samples with high proportion of clay were washed repeatedly by suspending and dispersing the material in distilled water in a 100-mL beaker. The supernatant was decanted off after at least 3 h, and the aliquot of the suspension was shaken, smeared on a cover slip and dried. After the materials were completely dry, samples were mounted with Naphrax. Samples for scanning electron microscopy (SEM) were prepared according to Huang et al. (1998). The coverslip was placed in dilute sulfuric acid and boiled for 30 min, then soaked in alcohol for 1 week. The sample liquid was dropped on a coverslip, and the sample was observed under the JEM-100CX II SEM (JEOL, Akishima-shi, Japan) after sputtering with gold for 25–30 s.

2.2 Diatom data processing

Diatoms were identified and counted with an Olympus BX-51 (Olympus, Tokyo, Japan) microscope using phase contrast at a magnification of 1 000×. The fine structure of *A. africana* was observed using a JEM-100CXII scanning electron microscope. The absolute number of diatom valves per gram of sediment was calculated as:

$$\text{number of valves/g}=((N\times(S/s))\times(V/v))\times1000/w,$$

where N is the number of diatom valves observed; S is the total number of separated rows per slide; s is the number of rows in which diatoms were counted; V is the total volume; v is the volume of solution placed onto cover slip; and w is the dry weight of the sample. Relative abundances of individual taxa are given as percentages (Abrantes et al., 2007).

3 RESULT

3.1 Morphology

Azpeitia africana (Janisch ex Schmidt) G. Fryxell & T. P. Watkins (Plate I)

Coscinodiscus africanus Janisch ex Schmidt, *Atlas der Diatomaceenkunde* 15, pl. 59, figs. 24, 25.1878; Jin et al., 1982, p. 28; Fryxell et al., 1986, p. 19, figs

Table 1 Details of diatom sampling in surface sediments of the South China Sea

Station	Latitude (N)	Longitude (E)	Water depth (m)	Station	Latitude	Longitude	Water depth (m)
ABS	18°41.09′	112°28.65′	471	SA09-087	04°46.09′	110°43.38′	112
C163	20°59.37′	114°52.48′	98	SA09-089	04°46.27′	111°16.58′	101
C175	20°54.05′	113°15.61′	73	SA09-091	04°45.80′	111°49.99′	114
C226	20°43.21′	112°47.13′	72	SA09-098	04°13.09′	111°49.92′	78
C245	20°43.23′	114°35.40′	100	SA09-100	03°56.61′	112°06.29′	62
C253	20°37.80′	112°47.15′	77	SA12-01	16°09.62′	109°40.12′	875
C258	20°37.87′	113°15.62′	83	SA12-04	16°10.18′	110°04.22′	1 010
C260	20°37.81′	113°26.97′	85	SA12-10	17°20.75′	109°39.97′	138
C294	20°32.47′	114°12.51′	99	SA12-29	17°20.83′	110°52.06′	1 665
NS2007-04	09°58.40′	113°22.29′	2 189	SA12-32	17°55.94′	110°15.46′	138
NS2007-08	12°00.59′	111°00.32′	2 946	SA13-01	16°09.82′	109°29.72′	635
NS2007-19	09°29.61′	116°46.70′	2 150	SA13-11	16°10.73′	112°15.65′	1 076
NS2007-204	09°51.34′	115°36.05′	1 446	SA13-19	15°53.88′	111°42.12′	1 180
NS2007-22	07°48.56′	115°59.80′	2 589	SA13-48	15°05.76′	112°15.01′	1 820
NS2007-29	05°23.02′	110°52.09′	181	SA13-49	14°49.67′	109°46.63′	377
NS2007-41	08°00.21′	110°51.68′	1 865	SA13-51	14°49.61′	110°35.35′	800
NS2007-47	11°11.93′	110°23.97′	1 609	SA13-53	14°49.90′	111°09.37′	1 565
NS2007-Q7	18°23.83′	111°28.22′	1 184	SA13-55	14°49.06′	111°41.37′	1 211
SA08-020	09°10.41′	109°20.70′	1 071	SA14-19	12°08.29′	110°35.74′	2 300
SA08-023	09°10.26′	110°10.51′	2 012	SA14-21	12°08.20′	111°10.20′	2 614
SA08-026	09°10.28′	110°59.96′	2 091	SA14-24	12°07.86′	112°13.98′	4 238
SA08-074	07°31.21′	108°30.68′	108	SA14-62	10°30.01′	109°46.04′	350
SA08-077	07°31.27′	109°19.85′	423	SA14-65	10°29.99′	110°35.47′	1 920
SA08-081	07°31.10′	110°27.46′	1 838	SA14-68	10°30.31′	111°25.46′	3 772
SA08-084	07°31.37′	111°16.51′	1 960	SA14-71	10°30.62′	112°15.46′	4 070
SA08-087	07°32.07′	112°06.43′	1 860	YSJD18	11°39.58′	113°02.77′	3 700
SA09-043	05°52.03′	108°30.75′	101	YSJD25	10°18.22′	113°45.55′	2 226
SA09-046	05°52.27′	109°20.53′	139	YSJD66	09°00.29′	111°53.24′	1 731
SA09-049	05°52.33′	110°10.13′	354	YSJD69	08°57.82′	112°40.69′	2 353
SA09-052	05°51.79′	110°59.41′	1 123	YSJD72	08°57.82′	113°30.69′	1 813
SA09-055	05°52.28′	111°49.57′	1 432	YSJD75	11°59.84′	113°24.64′	4 185

XVII, XVIII SEM; XXXII-1, 2 LM; Lan et al., 1995, p. 16, pl. 5/28, 29; Guo et al., 2003, p. 83, Fig.52.

Description: The valve is disc-shaped, flat, with radial areolae in decussating arcs and diameters of 30–95 μm. There is an eccentric ring with areolae arranged in lines near the center of the valve; areolae radiate from this eccentric ring rather than from the geometric center of the valve; 4–6 areolae in 10 μm (Plate Ia). There are between 8 and 10 marginal striae in 10 μm. A rimoportula is located on the edge of the eccentric ring of areolae proximal to the geometrical center of the valve, with its slit aligned with a radial row of areolae (Plate Ia, b). This nearly central rimoportula, with an external tube, is recessed externally and is somewhat more flared than the marginal rimoportulae (Plate Ia, b). The marginal rimoportulae are not evenly spaced with 3–8 μm apart, more closely appressed in one quadrant of the valve (Plate Ia, b, c). A curved external slit leads to each marginal rimoportulae. The slits begin in opposite directions at the midpoint of closely packed processes, 180° from that point, and they meet on the side of the valve, facing the same direction (Plate Id). Fryxell et al. (1986) term these poles "the 0° point" and the "180° point"; these slits spiral away from the "0° pole" and toward the "180° point". In addition,

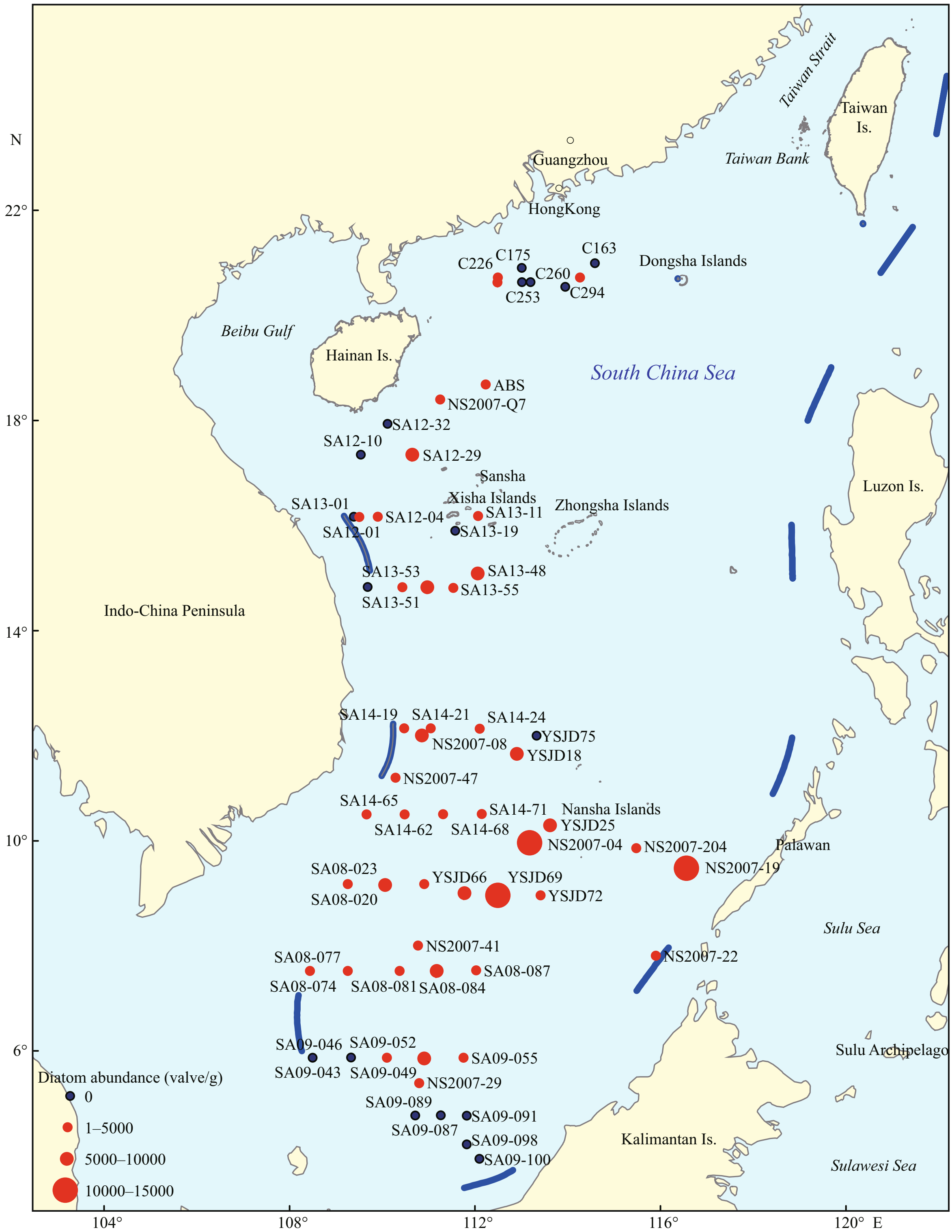

Fig.1 Locations of sampling sites and *Azpeitia africana* abundance distribution in surface sediments of the South China Sea

Map drawing No. GS(2016)2891 (accessed from the National Administration of Surveying, Mapping and Geoinformation of China).

the marginal rimoportulae are not evenly spaced but are denser in a sector defined by the plane through the "0° pole" and "180° point" poles and the nearly central rimoportula (Plate Id, e, f). This uneven distribution also lends polarity to the valve.

3.2 Geographical distribution of *A. africana* in the SCS

Diatom valve abundance and the relative abundance of *A. africana* (percentage contribution of *A. africana* to total diatom valve abundance) are shown in Table 2

Table 2 Diatom valve abundance and relative abundance of *Azpeitia africana* (percentage contribution of *A. africana* to total diatom valves) in surface sediments of different stations in the South China Sea

Station	Diatom abundance (valve/g)	*A. africana* (%)	Station	Diatom abundance (valve/g)	*A. africana* (%)
ABS	5.1×10^2	0.9	SA09-087	2.6×10^2	0.0
C163	1.9×10^2	0.0	SA09-089	0.7×10^2	0.0
C175	6.4×10^2	0.0	SA09-091	2.6×10^3	0.0
C226	3.8×10^2	1.1	SA09-098	1.6×10^5	0.0
C245	6.5×10^2	2.4	SA09-100	1.4×10^5	0.0
C253	2.1×10^2	1.2	SA12-01	4.1×10^4	2.8
C258	6.6×10^2	0.0	SA12-04	2.4×10^4	3.3
C260	6.3×10^2	0.0	SA12-10	3.1×10^3	0.0
C294	2.2×10^2	0.0	SA12-29	1.8×10^5	3.1
NS2007-04	3.5×10^5	4.2	SA12-32	3.0×10^3	0.0
NS2007-08	2.2×10^5	4.3	SA13-01	3.1×10^3	0.0
NS2007-19	3.3×10^5	3.0	SA13-11	3.9×10^4	3.1
NS2007-204	1.2×10^5	3.3	SA13-19	6.9×10^4	0.0
NS2007-22	4.5×10^4	8.1	SA13-48	1.5×10^5	4.0
NS2007-29	1.3×10^3	4.4	SA13-49	2.3×10^3	0.0
NS2007-41	6.3×10^4	2.4	SA13-51	9.7×10^4	3.0
NS2007-47	1.3×10^5	2.5	SA13-53	2.0×10^5	3.8
NS2007-Q7	5.9×10^4	5.6	SA13-55	7.0×10^4	4.1
SA08-020	3.5×10^4	1.8	SA14-19	2.3×10^4	2.7
SA08-023	3.4×10^5	1.9	SA14-21	1.5×10^5	2.9
SA08-026	2.1×10^5	1.8	SA14-24	3.2×10^4	1.4
SA08-074	0.8×10^2	1.3	SA14-62	4.8×10^3	2.2
SA08-077	9.8×10^2	2.3	SA14-65	1.6×10^5	3.0
SA08-081	2.2×10^5	2.1	SA14-68	2.2×10^5	1.8
SA08-084	2.5×10^5	2.3	SA14-71	1.5×10^5	2.6
SA08-087	9.5×10^4	2.8	YSJD18	6.2×10^5	1.4
SA09-043	2.6×10^2	0.0	YSJD25	3.1×10^5	1.8
SA09-046	0.8×10^2	0.0	YSJD66	4.1×10^5	1.4
SA09-049	2.6×10^3	2.5	YSJD69	3.8×10^5	3.8
SA09-052	1.6×10^5	4.5	YSJD72	9.0×10^4	2.9
SA09-055	1.4×10^4	2.7	YSJD75	2.5×10^5	0.0

* Partial data was cited from Wu et al. (2013).

and Fig.1. It was shown that *A. africana* is abundant and widely distributed in the SCS, being observed in samples from 43 of the 62 stations, an occurrence rate of 69.4%. The relative percentage of *A. africana* to total diatom cell abundance was high, with a maximum value of 8.1% in Station NS2007-22.

Azpeitia africana was more abundant in the southern region of the SCS, and was concentrated in the area 7°48.56′–9°58.40′N, 113°22.29′–116°46.70′E. Its abundance accounted for 0.9%–5.6% of all species in the Xisha Islands area. The lowest abundance of *A. africana* (0%–2.5%) was in the northern regions of the SCS and the Sunda Shelf, areas easily affected by coastal currents because of the shallow depth. The species was not detected on the northwestern continental shelf (shallow water area) and northern Kalimantan Island shelf (SA09-087, SA09-089, SA09-091, SA09-098, SA09-100).

Table 3 Morphological differences between *Azpeitia africana* and *A. barronii*

Structure	*A. africana*	*A. barronii*
Valve	Flat	Flat in center but sloping sharply to mantle
Areolae	With radial areolae in decussating arcs	Sublinear pattern
Central rimoportula	External tube is recessed	External tube is raised
Marginal rimoportulae	Long axis of slits lying parallel to margin	Long axis of slits not to tangent to valve margin
External slits of process	Reaching into the mantle	Reaching into curled ridge at the distal rim of the valve

4 DISCUSSION

4.1 Morphological characteristics of *A. africana*

Azpeitia africana was originally described as the new species *Coscinodiscus africanus* by Janisch ex Schmidt (1874–1859). According to Janisch ex Schmidt, it was distinguished by “an eccentric” structure in valve. The “an eccentric” in valve is inferred to be the external opening of central rimoportula near the valve center. Hustedt (1928) also reports *A. africana* (as *C. africanus*) that shows a large, coarse valve with radial rows of areolae of irregular sizes but with the larger ones in the middle of a radius. Marginal processes were shown, with diameters of 30–90 µm, 6 areolae in 10 µm, marginal processes 5–6 µm apart, and 8 striae in 10 µm at the margin. Simonsen (1974) shows that marginal processes are not evenly spaced, the slits start in opposite directions at the midpoint of closely packed processes and they meet on the opposite side of the valve, facing the same direction. Fryxell et al. (1986) make the new combination *A. africana* from all Gulf Stream warm core rings, moving it out of the genus *Coscinodiscus*. Diameters given for *A. africana* by Fryxell et al. (1986) are 33–76 µm, a narrower range than that observed in our sample materials (which are 30–95 µm). Whereas Fryxell et al. (1986) report 5–10 areolae in 10 µm, we found a range of 4–6 areolae in 10 µm. They report the distance between the two marginal rimoportulae as 3–6 µm, but we found a larger variation of 3–8 µm. The marginal striae (8–10 in 10 µm) were the same as Fryxell et al. (1986) describe. Fryxell et al. (1986) find that the genus *Azpeitia* has five living species; however, there is a distinct difference between *A. africana* and the other living species of *Azpeitia*.

In the living species, *A. africana* is very similar to *A. barronii*. They have unevenly spaced marginal rimoportulae positioned closer together in one quadrant than in the others. Fryxell et al. (1986) think that this character is of more recent origin than in the previously mentioned *Azpeitia* species (*A. tabularis*, *A. neocrenulata*, *A. nodulifer*, *A. barronii*). The patterns on the processes of *A. africana* as seen from the inside are similar to those of *A. barronii*: one large central rimoportula with an external tube adjacent to the center. In these two species, the external openings of the labiate processes are elongated slits with siliceous elaborations. Although the geographical distribution of the two species is similar (both are found in warm marine waters), there are distinct morphological differences between *A. africana* and *A. barronii* (Table 3).

According to Fryxell et al. (1986), this species is similar to *A. tabularis*. In these two living species, the external opening of the nearly central rimoportula is reduced. *A. tabularis* has the opening flush with the internal areola walls, and the external opening of the central rimoportula has little or no external projection. *A. africana* has a recessed opening. The areolae of *A. africana* are very similar to those of *A. tabularis*, sometimes partly occluded by radial threads, forming a basket-shaped covering. They differ in that *A. africana* is a warm water species, while *A. tabularis* is a cold-water species.

4.2 Ecology and distribution of *A. africana*

Azpeitia africana is a warm water, marine planktonic species found in most surface sediment samples collected from the stations in the SCS. The water depths ranged from 72 m to 4 238 m. It was recorded as *C. africanus* in Late Quaternary sediments from the SCS (Lan et al., 1995), and in surface sediments from the SCS (Jiang et al., 2004). It was recorded as *C. africanus* in the East China Sea (ECS) (Liu, 2008), and Jin et al. (1980) described *C. africanus* as a representative species in the ECS. In addition, Fryxell et al. (1986) found it in all warm Gulf Stream cores, as well as in plankton tows from the Central Pacific and Gulf of Mexico. *Azpeitia africana* is also often recorded from fossil material, from the upper Pliocene to Holocene sediments in the tropical Eastern Pacific (Barron, 1980). Burckle (1978) correlates the first occurrence of *A. africana* (*C. africanus*) with the late early Pliocene. It is also found in North Atlantic sediments (Baldauf and Barron, 1982) and Indian Ocean sediments (Schrader, 1974).

4.3 The environmental significance of *A. africana*

Previous studies have shown that *A. africana* is typical of tropical planktonic diatoms, widely distributed in the Western Pacific (Jousé et al., 1969) and Eastern Pacific (Jousé et al., 1971). The diatom complexes in the surface sediment layer of the Pacific Ocean can be divided into Arctoboreal diatom complex, Northboreal diatom complex, Subtropical diatom complex, Tropical diatom complex, Equatorial diatom complex, Subantarctic diatom complex and Antarctic diatom complex. Of these, the Tropical diatom complex and Equatorial diatom complex may reflect the characteristics of diatoms found in the North Equatorial Current and its branch, as well as in the Kuroshio Current (Jousé et al., 1971). The main composition of the Equatorial diatom complex in this research comprised *A. africana*, which was widely distributed in surface sediments in the SCS (Jiang, 1987; Jiang et al., 2004; Ran and Jiang, 2005), as well as in the areas of inflow of the warm Kuroshio Current in the ECS (Jin et al., 1980).

Ran and Jiang (2005) showed that there was a higher content of *A. africana* in the northeastern area of the SCS, where it accounts for 5% of diatom abundance. In the central and southern areas of the SCS, *A. africana* content was about 2.33%–4.10% of diatom abundance and the lowest percentage (0%–1.71%) was in the western and southeastern regions. Similarly, our results show that *A. africana* had the highest value of relative valve abundance in the southern area of the SCS, reaching 0.9%–5.6%. In our research, *A. africana* was more abundant in the southern region of the SCS, concentrated in the area of 7°48.56′–9°58.40′N, 113°22.29′–116°46.70′E. *Azpeitia africana* can be used as an indicator of the intrusion of the Kuroshio Current and Indian Ocean water (Ran and Jiang, 2005). As an indicator species, *A. africana* is prevalent in the area of the Kuroshio Current in surface sediments, indicating that its distribution is not only affected by the waters of the SCS, but also by those of the ECS (Jin et al., 1980). The climate and surface-water circulation in the SCS were largely controlled by monsoons driven by differential warming in adjacent continents and oceans (Wytki, 1961), resulting in abnormal rain and wind in the summer and winter of monsoon years. The northeast and southwest monsoons change the surface-water circulation regularly, bringing water into the SCS from the Western Pacific, including probably the warm Kuroshio Current (Wytki, 1961) through the Bashi Strait north of Luzon, and Indian Ocean surface water across the Sunda Shelf in summer (Wang and Abelmann, 2002). In this study, *A. africana* was shown to be a widely distributed species in the SCS, and its relative abundance was relatively higher in the southern region of the SCS. This may be attributed to the effect of the southwest monsoon which prevails during the summer, from the Java Sea to the south tropical Indian Ocean waters through the Cary Mata Strait, Gaspar Strait and the Malacca Strait, and into the SCS through the Sunda Shelf.

Our results suggest that the warm water planktonic species *A. africana* could be used as a good indicator of the intrusion of the Kuroshio Current and Pacific Ocean warm water in paleoenvironment reconstruction, and also support previous studies on the environmental indicators of *A. africana*.

5 CONCLUSION

This study observed the morphological features of the marine diatom *A. africana* from the SCS by LM and SEM. The main morphological characteristics of *A. africana* are: the valve is disk-shaped, with an eccentric ring of almost linear areolae near the center of the valve, the lines of areolae radiating from the eccentric ring. A central rimoportula has an external tube recessed on the edge of a central ring. The marginal rimoportulae are not evenly spaced, and are positioned closer together in one quadrant than in the others.

Our studies on the geographical distribution and ecological characteristics of *A. africana* have shown that this tropical planktonic species was the dominant diatom throughout the SCS, although its distribution was uneven. *A. africana* was more abundant in the southern region of the SCS and the Xisha Islands area, and was in low abundance or even absent in the shallow water area of the continental shelf and northern Kalimantan Island shelf. In paleoceanographic reconstructions of the area, *A. africana* may be used as an ideal indicator of the warm Pacific Ocean water, including the Kuroshio Current flowing into the SCS. Our results have provided a basis for further paleoceanographic research in the SCS.

6 DATA AVAILABILITY STATEMENT

The data sets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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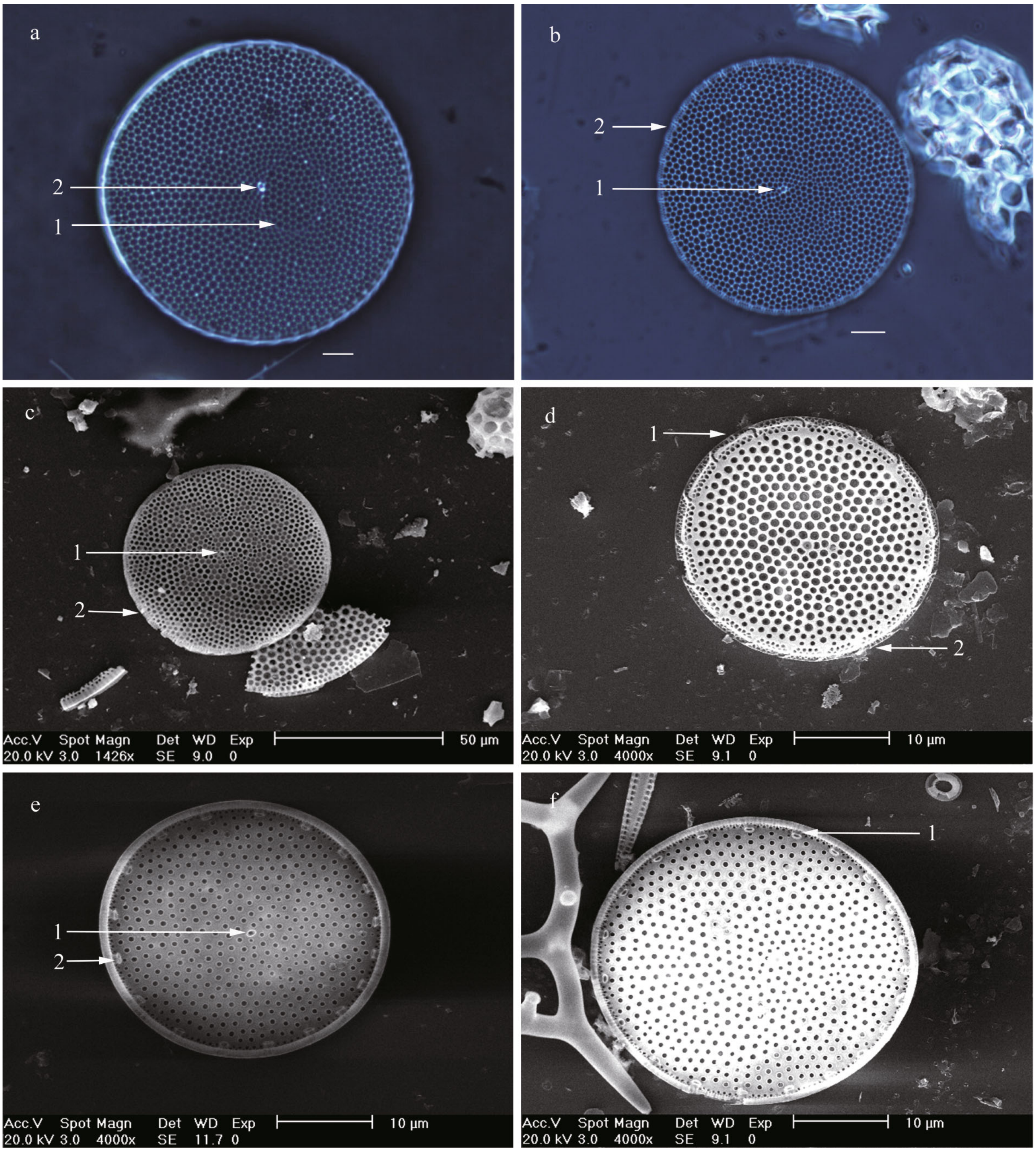

Plate I *Azpeitia africana*, LM (a, b) and SEM (c–f)

Scale bars=50 µm (c) or 10 µm (a, b, d, e and f). External view of value shown in a, b and c. Internal view of valve shown in d, e and f. a. external view, showing external opening of the central rimoportula near the center of the valve, on the edge of an eccentric ring of linear areolae; other areolae radiating from this ring (1. eccentric ring; 2. external opening of the central rimoportula); b. external view of recessed tube of the central rimoportula, areolae with decussating rows in spiraling arcs (1. recessed tube of the central rimoportula; 2. external openings of marginal rimoportulae); c. external view, showing slits on mantle leading into marginal rimoportulae at enlarged pore adjacent to modified ridge (1. external opening of the central rimoportula; 2. slits); d. external openings of the marginal rimoportulae, which are elongated slits with siliceous elaborations; slits on margin radiating from "0° point", pointing in opposite directions. At the "180° point", two adjacent marginal slits meet (1. 180° point; 2. 0° point); e. internal view, showing unevenly spaced marginal rimoportulae, more closely spaced in right quadrant of valve; and central rimoportula with an external tube recessed on the edge of an eccentric ring (1. central rimoportula; 2. marginal rimoportulae); f. internal view, showing unevenly spaced marginal rimoportulae, more closely spaced in right quadrant of valve, marginal rimoportulae with ends only slightly flared (1. marginal rimoportulae).

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