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# Late Neogene radiolarian absence event in the southern South China Sea and its paleoceanographic implication

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**Abstract**

Down-core variations of radiolarians at ODP Site 1143 in the southern South China Sea (SCS) are presented for the last 12 Myr. The fluctuations of radiolarian abundances since the Late Miocene can be divided into three stages: a high abundance stage at 12–5.96 Myr, a radiolarian absent stage at 5.96–3.30 Myr and a gradual increasing stage after 3.30 Myr. The three stages correspond to the forming and vicissitudes of the Western Pacific Warm Pool (WPWP) and the Eastern Asian Summer Monsoon (EASM). The radiolarian absence event (RAE) was also absent of diatom and occurred nearly simultaneously with the closures of the Panama Isthmus and the Indonesian seaway, which probably caused the reorganization of oceanic circulation systems. Accompanied this circulation reorganization was the weakening of the WPWP and the EASM, which probably led to a weakened upwelling in the southern SCS. In addition dissolved silica (Dsi) content in surface seawater might be very low during 5.96–3.30 Myr due to the "biogenic bloom" event, which consumed a large amount of Dsi in the surface seawater. All these factors together might lead to a great decrease of siliceous production in the southern SCS and consequently caused the RAE. Moreover, the dissolution of siliceous skeletons might also influence the abundance of radiolarians.


*Keywords:* Southern South China Sea; Late Neogene; Radiolarian absence event

## 1. Introduction

Radiolarians are useful proxies for the reconstruction of paleoceanography and paleoenvironment. Their distributions usually relate to specific hydrographic environments, and their skeletons composed of opal are well preserved in marine sediment. Most radiolarians widely live in nutrient-rich seawater, and need plentiful dissolved silica (Dsi) to form their siliceous skeletons [1], so their growth is controlled by the concentration of Dsi. Usually, the concentration of Dsi in surface seawater is under saturation, and Dsi supplemented to the ocean mainly originates from the weathering of silicate rocks on the continent, such as sandstone and flint gravel [2–4], transported by river runoff. In addition, amorphous biogenic silica dissolution in the form of siliceous frustules in the benthic layer [5,6], and the aeolian flux [7] are also sources of Dsi in surface seawater. For example, upwelling driven by monsoon could bring a large amount of nutrients from deep water to the sea surface, resulting abundant radiolarians and diatoms accumulated in the sediments [8].

Previous studies on radiolarians in the South China Sea (SCS) concentrated mainly on taxonomy in surface sediments [9] and radiolarian biostratigraphy [10,11], and generally focused on the northern SCS. The ODP Site 1143, drilled in the southern SCS [12], is a good location for paleoceanographic and micropaleontologic study in this area. Based on the distribution of radiolarians during the last 1.20 Myr, Yang et al. [13] found an ecological transition

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at 0.47 Myr. Chen et al. [11] studied the distribution of radiolarian during the Late Miocene and discussed its relations with the development of the Eastern Asian Summer Monsoon (EASM). In this paper, we give a continuous record of radiolarian distribution over the whole core of Site 1143 for the last 12 Myr, and report an obvious radiolarian absence event (RAE) happened at 5.96–3.30 Myr in the southern SCS. Also we try to give a preliminary discussion on its origin in the context of tectonism, environmental evolution and nutrition supply.

## 2. Material and methods

ODP Site 1143 (9°21.72′N, 113°17.11′E) is located in the southern SCS at a water depth of 2772 m (Fig. 1). Three holes were cored to a meter composite depth (mcd) of about 512.4 mcd [12]. The lithology of the recovered section at this site is divided into two subunits: Subunit I (1–160.0 mcd) consists of nannofossil carbonate ooze, several ash layers, and occasionally foraminifer ooze turbidites; Subunit II (160.0–512.4 mcd) is characterized by a higher carbonate content and an increase in the frequency of turbidites compared with Subunit I [12]. The turbidites of Subunit II are mainly composed of foraminifer sand, except for the biosiliceous laminae appearing in the interval of 439.74–460.08 mcd.

Previous studies by Yang et al. [13] and Chen et al. [11] have shown radiolarian distribution patterns in the upper part (0–59.64 mcd) and lower part (260–512.4 mcd) of ODP Site 1143. In this study, we selected a total of 88 samples from the middle part (60–260 mcd) for radiolarian analysis. Samples were taken at a 40–60 cm interval between 60 and 95 mcd and at about 6–10 m interval between 95 and 260 mcd. Preparation of the slides followed the technique of Chen et al. [11] All the radiolarian individuals were identified and counted under a binocular microscope due to an extremely low radiolarian abundance.

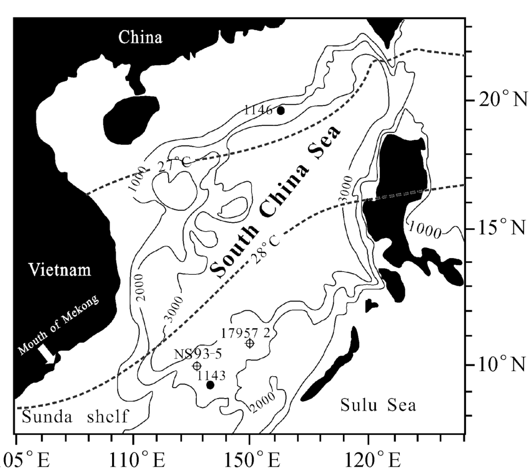


Fig. 1. Locations of ODP Sites 1143 and 1146, cores NS93-5 and 17957-2 in the South China Sea. The dash lines indicate the multi-annual sea surface isotherms. Solid lines mark the isobaths. The 28 °C surface isotherm is approximately regarded as the northern boundary of the present WPWP.

## 3. Revised chronological framework

Numerous nannofossil, foraminiferal, radiolarian and polarity chron events have been identified at ODP Site 1143 [11,12,14,15], which were calibrated to the time scale of Berggren et al. [16] and Sanfilippo and Nigrini [17]. The Brunhes/Matuyama polarity reversal is at the depth of 43.2 mcd [12] which gives an age control point of 0.78 Myr [18]. In this paper, we present an age model for Site 1143 mainly based on oxygen isotope [19,20] and the newly revised biostratigraphy [11,15]. The chronological framework for the upper part (0–190.77 mcd) of ODP Site 1143 uses the astronomically tuned age model of Tian et al. [19,20], from which a total of 191 oxygen marine isotope stages were identified for the last 5 Myr (from MIS 1 to MIS T1) (Fig. 2) and compared with a newly compiled $\delta^{18}O$ curve of the last 6 Myr by Shackleton [18]. The age model for the lower part (190.77–510 mcd) of ODP Site 1143 is established based on the biostratigraphy of planktonic foraminifera, calcareous nannofossils and radiolarians [11,12,15]. The overall sediment sequences of ODP Site 1143 approximately span the last 12 Myr.

## 4. Results and discussion

### 4.1. The radiolarian absent event

Combined with previously analyzed radiolarian data [11,13], we present a continuous record of down-core vari-

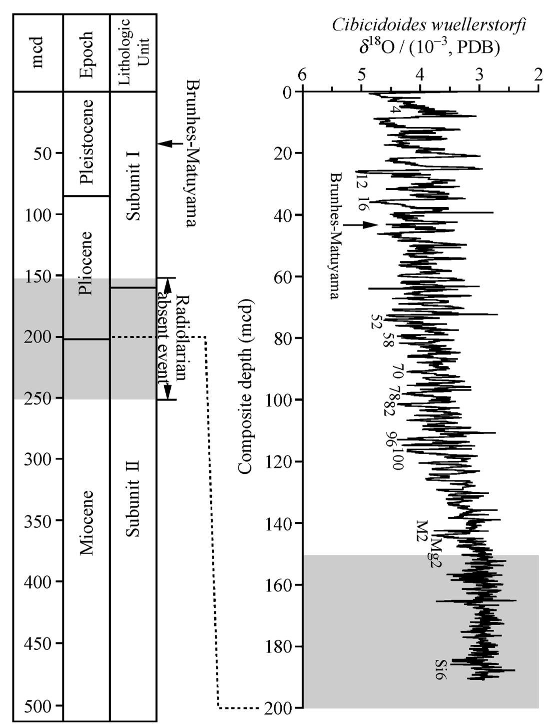


Fig. 2. Lithostratigraphic, paleomagnetic and oxygen isotopic records [12,19,20] at ODP Site 1143 in the southern South China Sea. Shaded area marks the RAE intervals.

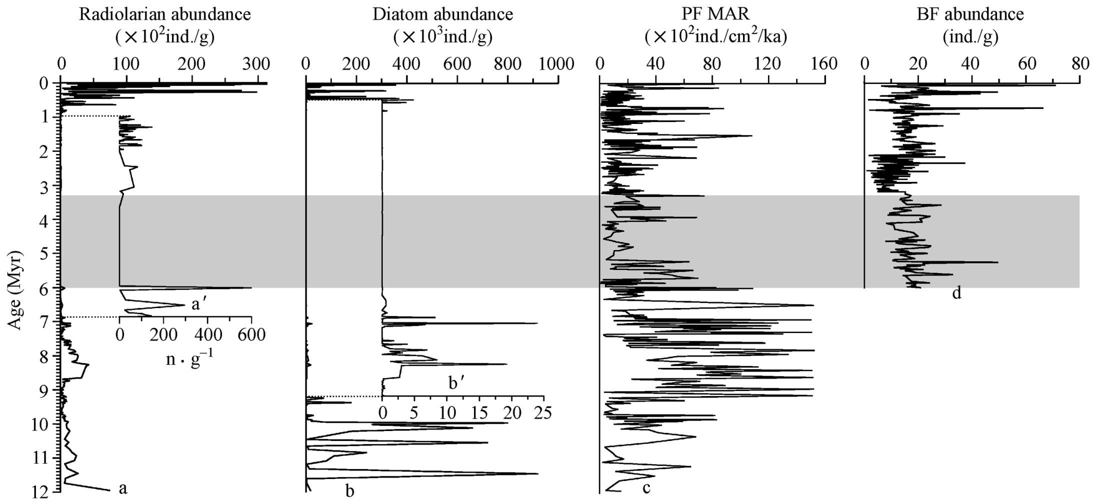


Fig. 3. Microplanktonic distributions in the sediments of ODP Site 1143. a and a′ indicate radiolarian abundances, the data of Late Miocene and mid Pleistocene radiolarian abundances are from Ref. [11] and [13]; b and b′ indicate diatoms abundances, the data of diatom are from Ref. [21]; (c) planktonic foraminiferal (PF) mass accumulation rates (MAR) (after Ref. [14]); (d) benthic foraminifers (BF) abundances, the data of BF come from Ref. [23].

ations of radiolarian abundance in ODP site 1143 (Fig. 3(a)). The abundance of radiolarian shows obvious variations along the whole core and can be subdivided into three stages since the Late Miocene (Fig. 3(a)): (1) At 12–5.96 Myr there was a high radiolarian abundance stage. Radiolarians experienced a period of high abundance and high diversity during 12–7.6 Myr (averaged > 1200/g), then the abundance of radiolarians showed a decreasing trend during 7.6–5.96 Myr (from 1670 ind./g at 7.6 Myr to zero at 5.96 Myr). (2) A radiolarian absence stage at 5.96–3.30 Myr. During this stage radiolarians disappeared in the sediments (Fig. 3(a)), so we call this stage the radiolarian absence event (RAE). (3) A gradually increasing stage after 3.3 Myr, when the abundance of radiolarians began to recover, but it remained very low values till 1.0 Myr (usually lower than 150 ind./g), after that time the abundance showed a gradual increasing trend and radiolarians became prosperous after 0.47 Myr.

During the period of RAE, diatom was also absent in the sediments, and this lasted for much longer time than that of radiolarian (Fig. 3(b)), from 6.3 to 0.47 Myr [21,22]. The content and the mass accumulation rate (MAR) of opal also showed low values consistently (Fig. 4) during the RAE period, suggesting a very low siliceous production during this time interval. The MAR of planktonic foraminifera also had relatively low values (Fig. 3(c)), while the abundance of benthic foraminifera [23] had relatively high values at this time (Fig. 3(d)). Calcareous nannofossils were abundant in the whole core of Site 1143 and nearly unchanged since the Late Miocene [12].

However, there have been no RAE recorded in other regions up to now. Many studies on radiolarians and diatoms from the Pacific Ocean showed that siliceous planktons continuously occurred during the Late Neogene sediments. For example, the data reports of Core 62, DSDP Leg 7 [24] and Core 462, DSDP Leg 61 [25] in western equatorial Pacific showed that the Late Neogene radiolarians were well preserved, although with common to few abundance. The scientific results of ODP Leg 186 in northwestern Pacific [26] indicated that diatoms were continuously distributed along the whole core since the Late Miocene. And a continuous radiolarian biostratigraphy for the Late Neogene [27–31] has already been established in the east equatorial Pacific, the northern Pacific and the northwestern Pacific. All the above studies suggest that the RAE in the southern SCS between 5.96 and 3.3 Myr is just a local event.

### *4.2. The vicissitudes of the WPWP: evidence from the radiolarian record*

Tectonic and paleoceanographic evolution can greatly affect the global climates. Before 10 Myr, when Australia did not drift northward, the Indonesian seaway connecting the equatorial Pacific and the Indian Ocean was still open, and the westward warm equatorial current water of the Pacific Ocean could flow into the Indian Ocean directly. However, with the closure of Indonesian seaway during the Late Miocene to mid Pliocene [32], the westward warm equatorial Pacific current water was blocked by lands and accumulated in the western equatorial Pacific, which resulted in a relative high sea surface temperature (SST) and a deepened thermocline at this area [33], and consequently the WPWP developed [34]. The Panama Isthmus emerged during Late Miocene to early Pliocene [35,36] and finally closed at about 3.2 Myr [37–39], which terminated the exchange of surface water between the Atlantic and Pacific oceans [40]. When the trade wind prevailed, upwelling would develop and thermocline would shoal in the eastern equatorial Pacific [34,40], which might cause an E–W thermocline gradient in the equatorial Pacific

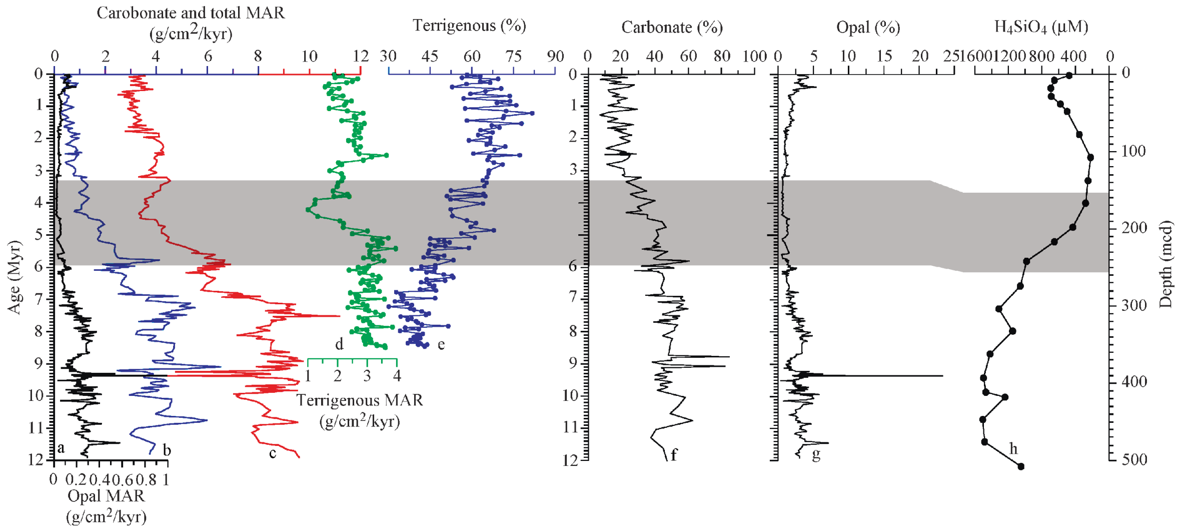


Fig. 4. Variations of mass accumulation rates of opal (a), carbonate (b), total sediments (c) and terrigenous (d), weight percents of terrigenous (e), carbonate (f), opal (g) in bulk samples, and silica record of the interstitial water (h) at ODP Site 1143 in the southern SCS. Shaded area marks the RAE period. The data of opal come from Ref. [47]. The data of carbonate, total sediment and silica in the interstitial water come from Ref. [12], and the data of terrigenous sediment from Ref. [45].

Ocean. This thermocline gradient between the east and west Pacific is important for the full development of the WPWP [38]. Based on an opposite change in the relative abundance of deep-dwelling planktonic foraminifera species between Site 1143 and Site 1146 of the SCS, Jian et al. [38] concluded that the WPWP probably formed initially during 11.5–10.6 Myr, then weakened or became extremely unstable during 10.6–3.6 Myr, and finally developed to its present extent at about 3.6–3.3 Myr. According to SST estimates from transfer function of planktonic foraminifera, Wang [39] found that the area with winter SST larger than 27 °C was apparently enlarged after 3.2 Myr in the northern Pacific Ocean, which suggests that the WPWP was formed at about 3.2 Myr.

Eastern Asian Summer Monsoon (EASM) and El Nino-Southern Oscillation (ENSO) are considered to have a close relationship with the WPWP [41]. The WPWP affects the intensity of EASM directly, because it supplies water vapor and latent heat for the development of the EASM [42]. In the southern SCS, the EASM usually acts as a driver forces upwelling. Therefore, the evolution of the WPWP might indirectly influence the living environment of radiolarian fauna in the southern SCS. ODP Site 1143 is located within the area of the WPWP, where the radiolarian evolution during the last 12 Myr corresponded to the vicissitudes of the WPWP. When the WPWP initially formed during 11.5–10.6 Myr [38], the radiolarians had a high abundance and diversity; when the WPWP was weakening or undeveloped during 10–3.6 Myr [38], the abundances of radiolarians decreased rapidly and even disappeared, except for a period of high radiolarian abundance during 8.7–7.6 Myr, which probably correspond to the "biogenic bloom" event popular in the Pacific area [43,44]. Since 3.6 Myr, when the WPWP had finally formed, the abundance of radiolarians exhibited a gradually increasing trend. Therefore, it can be implied that the WPWP affected the radiolarian productivity through controlling the strength of the EASM.

### *4.3. The causes of the radiolarian absence event*

Previous studies proposed that the abundance of radiolarians in sediments could be influenced mainly by three factors: the surface paleoproductivity of siliceous planktons, the dilution of carbonate, volcanic deposits or terrestrial input and the dissolution of biogenic opal. Here, we will discuss these factors according to their different exhibition in successive stages of the radiolarian abundance at Site 1143.

#### *4.3.1. Surface paleoproductivity*

During the Late Neogene, the closure of Indonesian seaway and Panama Isthmus terminated the surface seawater exchange between the Pacific and the Atlantic [40], and between the Pacific and the Indian Oceans, which led to a reorganization of the oceanic circulation system. These strong tectonics during this period might cause unstable oceanic environments, and greatly changed the living environment of radiolarian fauna in the southern SCS. Additionally, the WPWP was undeveloped [38], and the EASM was weakened [45,46] during the period of RAE, resulting in no or weakly developed upwelling in the southern SCS, which was supported by low MAR (Fig. 3(c)) and fragmentation ratio of planktonic foraminifera [14]. Consequently, the siliceous surface productivity during the Late Neogene could also be influenced greatly.

The "biogenic bloom" event resulting from enhanced upwelling is popular in the west equatorial Pacific and the Indian Ocean during the Late Miocene to Early Pliocene [43,44]. At Site 1143, peak values of MAR of planktonic foraminifera (Fig. 3(c)) and carbonate (Fig. 4(b)) occurred between 9.1 and 6.8 Myr, high abundance values of radiolarian occurred during 8.7–7.6 Myr (Fig. 3(a)), peak values of diatom abundance during about 11.5–9.9 Myr (Fig. 3(b)), and high content of MAR of opal [47] during 12–7.6 Myr (Fig. 4(a) and (g)). All these proxies probably indicate that the "biogenic bloom" event also occurred in the southern SCS in the Late Miocene. In the present world ocean, more than 40% of the entire primary production is attributable to diatoms [48], and mass propagation of diatom can deplete the Dsi in seawater [49]. So we speculate that the Dsi in surface seawater of the southern SCS might be largely consumed by the Late Miocene "biogenic bloom" event, hence causing an insufficiency of Dsi in surface seawater during the period of RAE. Together with the weakened EASM, and no or weak upwelling, they might lead to a great decrease of siliceous production in the southern SCS and consequently caused the RAE.

*4.3.2. Variations of carbonate content and terrestrial inputs*

In an upwelling environment, when the upwelling develops, the sources of the sediment are mainly composed of biogenic matter. On the contrary, when the upwelling disappears, the sources are usually composed of mixtures of biogenic and terrestrial matters. Therefore, the amount of terrestrial input and other biogenic matter may directly affect the abundance of radiolarians in sediments.

Through comparisons of the content and MAR of opal (Fig. 4(a) and (g)), carbonate (Fig. 4(b) and (f)), total sediment (Fig. 4(c)) and terrestrial input (Fig. 4(d) and (e)) among the three stages, we found that: (1) During the period of RAE, both MAR of carbonate and total sediment dropped greatly, but the values are still higher than those in the Quaternary; (2) the variations of the content and MAR of opal are similar to those of terrestrial input, both showing higher values during the Late Miocene, lower values during the RAE period and higher values again during the Quaternary; (3) the content of carbonate decreased gradually since the Late Miocene, opposite to the trend of terrestrial matter content. Wang [50] studied the distribution of radiolarians in core 17957-2 from the southern SCS and claimed that the strong siliceous dissolution and the dilution of carbonate and volcanic ashes were responsible for two low radiolarian abundance events. However, we think the dilution is not the main cause for radiolarian absence at Site 1143, because the MARs of both terrestrial input and carbonate show lower values in the RAE than those at other stages.

Recent study on core 17964 from the southern SCS by Jian et al. [51] showed that the increased input of terrigenous nutrients at lowered sea level might contribute to a high sea surface productivity. Based on the studying results of core NS 93-5 from the southern SCS, Wei et al. [52] also suggested that terrestrial input is important for siliceous phytoplankton production, but not for calcareous phytoplankton production. At Site 1143, some relationship was observed between radiolarian abundance and the content of terrestrial matter. For example, the content of terrestrial matter increased during the Quaternary with the increased abundance of radiolarian. This can be explained the fact by that the nutrients (especially Dsi, 80% of Dsi in the oceans originate from riverine runoff each year [53]) also increased with increased terrestrial input during the Quaternary, which was advantageous for the siliceous plankton.

*4.3.3. The dissolution of biogenic opal*

Dsi in seawater column is extremely unsaturated. It causes opaline skeletons to suffer from the dissolution not only during their setting to the sea floor but also after their deposition on the surface of the seabed [54]. But the dissolution process is usually slow when the suspended biogenic silica is wrapped by organic coating or adsorbing cations. Once siliceous skeletons are exposed to the seawater, the dissolution process will be faster. Usually strong biosiliceous dissolution in the benthic layer is known to be an important supply of oceanic nutrients [6]. At Site 1143, after the successional bloom of diatoms and radiolarians in the Late Miocene, Dsi in surface seawater could be largely consumed and extremely deficient. This would limit the production of siliceous planktons. On the other hand, the very low concentration of Dsi would lead to a more soluble environment for biogenic silica. The content of silicic acid in interstitial water can be used to reflect the strength of dissolution. At Site 1143, the content of silicic acid in interstitial water shows lower values during the radiolarian absence sediment intervals than that in the other two stages (Fig. 4(h)), indicating that biogenic opal was little influenced by the early diagenesis [55] after depositing at the seabed. Therefore we think that the dissolution is not a direct cause for the RAE.

## 5. Conclusions

Radiolarian abundance in the last 12 Myr shows large variations in the core samples from ODP site 1143. Based on it, three stages are defined: (1) A high abundance stage at 12–5.96 Myr; (2) a radiolarian absence stage (RAE) at 5.96–3.3 Myr; (3) a gradually increasing stage after 3.3 Myr. These radiolarian stages correspond to the time of the forming and vicissitudes of the WPWP and the EASM, suggesting that the WPWP might affect the radiolarian productivity through controlling the intensity of the EASM.

The RAE in the southern SCS during 5.96–3.3 Myr is just a local event, with the absence of diatom. Through analyzing the oceanic tectonism and the evolution of paleoceanography during the Late Neogene, together with sedimentary characteristics of Site 1143, we suggest that the main cause for this RAE may be the great decrease of siliceous production in the southern SCS during this period. The closures of the Panama Isthmus and the Indonesian seaway during the Late Miocene to mid Pliocene probably caused a reorganization of oceanic circulation systems.

Accompanying this circulation organization is the weakening of the WPWP and the EASM, which probably leads to a weakened upwelling in the southern SCS. And also Dsi in surface seawater might be depleted by the "biogenic bloom" event, caused extremely deficient Dsi in surface seawater during 5.96—3.3 Myr, and consequently led to a rapid decrease of siliceous production in the southern SCS. In addition, the dissolution of siliceous skeletons might also influence the abundance of radiolarian.

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