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# Middle and Late Tertiary Palaeogeography and Palaeoenvironment on the Northern Continental Margin of the South China Sea

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## Abstract

Based essentially on research results of calcareous nannofossils, combined with some other microfossil data and several secondary depositional breaks, this paper discusses the criteria of division and comparison of the middle and late Tertiary marine sediments, palaeogeographical and palaeoenvironmental evolution and palaeoclimates on the northern continental margin of the South China Sea, comprising the Tainan basin, Pearl River Mouth basin, Southeast Hainan basin and Beibu Gulf basin. Study shows that the upper Oligocene to Pliocene strata in the whole area consist essentially of marine sediments except in the Beibu Gulf basin. They include littoral, neritic and deltaic sediments as well as carbonate rock-bioherm limestone. The sea advanced from southeast to northwest. During the transgression there appeared three culminations coinciding to the stages of deposition of nannofossil zones NN4–5, NN11 and 13–15.

The northern continental margin of the South China Sea, strictly speaking, refers to the continental crustal borderland of the South China microplate that extends under water, including the Tainan basin, the Pearl River Mouth basin, the Southeast Hainan basin and the Beibu Gulf basin as well as the uplift zones between them. The Beibu Gulf basin, in accordance with its geological features, is an intraplate downfaulted-downwarped basin (Li et al., 1983). At present, however, the Beibu Gulf basin is commonly included when the Cenozoic geology on the northern margin of the South China Sea is discussed. So this practice is followed here. There is appreciable difference in geological structure between the northern part of the South China Sea and the South China continent. The NEE-trending structure predominating in the former intersects with the NE and NNE structure system developing in the latter. This is their major difference resulting from their tectonic evolution since the late Oligocene (Feng et al., 1982). This paper mainly deals with the late Oligocene to Pliocene biostratigraphy, transgression stages and sedimentary environments of this region.

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## I. Some Remarks on the Stratigraphic Division and Correlation

Certain achievements have been made in the Tertiary biostratigraphic study on the northern continental margin of the South China Sea. The book "Tertiary in the Northern Continental Shelf of the South China Sea" published in 1981 (South China Sea Branch of Petroleum Corporation of the P.R.C., 1981) not only gives a relatively detailed division and discussion of different stages of the Tertiary, but also presents a correlation of the Tertiary strata in various basins. Since the 1980s, as the study and exploration were carried out in a more deep-going and extensive way, our understanding of the stratigraphy and sedimentary characteristics since the late Oligocene has been perfected. The middle and upper Tertiary

**Table 1. Biostratigraphical Correlation of the Middle-Upper Tertiary on the Northern Margin of the South China Sea**

| CHRONOSTRATIGRAPHY | | | NANNO FOSSIL ZONE | | REGIONALIZATION | | | |
|---|---|---|---|---|---|---|---|---|
| SERIES | | STAGE | ① | ② | BEIBU GUEF BASIN | SOUTHEAST BASIN | PEARL RIVER MOUTH BASIN | TAINAN BASIN |
| PLIOCENE | U. | Piacenzian | NN17 | *D. pentaradiatus* | Wanglougang Fm. | ? Yingehai Fm. | Wanshan Fm. | Peiliao sh. |
| | | | NN16 | *D. tamalis* | | | | Zhutouchi Fm. |
| | L. | Zancilian | NN15 | *R. pseudoumbilica* | | | | Maopu sh. |
| | | | NN14 | *C. rugosus* | | | | Yunshuixi Fm. |
| | | | NN13 | | | | | |
| | | | NN12 | *C. acutus* | | ? | | |
| MIOCENE | U. | Messinian | NN11 | *D. quinqueramus* | Dengloujiao Fm. | Huangliu Fm. | Yuehai Fm. | Tang'enshan ss. |
| | | Tortonian | NN10 | *D. variabilis* | | | | |
| | | | NN9 | | | ? | | Nanzhuang Fm. |
| | M. | Serravallian | NN8 | *C. caolitus* | | | | |
| | | | NN7 | *small Helicosphaera* | Jiaowei Fm. | Meishan Fm. | Hanjiang Fm. | |
| | | | NN6 | | | | | |
| | L. | Langhian | NN5 | *S. heteromorphus* | | | | Heshe Fm. |
| | | | NN4 | *H. ampliaperta* | Xiayang Fm. | Sanya Fm. | Zhujiang Fm. | |
| | | Burdigalian | NN3 | *S. belemnos* | | | | |
| | | Aquitanian | NN2 | *S. conicus* | | | | ? |
| | | | NN1 | | | | | |
| OLIGOCENE | U. | Chattian | NP25 | *S. ciperoensis* | Weizhou Fm. | Lingshui Fm. | Zhuhai Fm. | |
| | | | NP24 | *S. distentus* | Nonmarine deposits or missing | | | ? |
| | L. | Rupelian | NP23 | Weizhou | | | | |

1 Standard Tertiary and Quaternary calcareous nannoplankton zonation (Martini, 1971).

2 Zonation in the northern South China Sea (Duan et al., 1987).

Note: The hachured area denotes the absence of continental sediments or strata.

* See the footnote on the next page.

stratigraphic division and correlation of various major negative units in the north of the South China Sea based essentially on data of calcareous nannofossils are summarized in Table 1, for which the following explanations are necessary.

1. Exploration shows that marine calcareous nannofossils such as *Sphenolithus distentus* and *Sphenolithus ciperoensis* of the typical late Oligocene marine zoning are present in the Zhuhai Formation in the offshore area of the Pearl River Mouth basin and in the Linshui Formation of the Southeast Hainan basin. The marine Zhuhai Formation and Linshui Formation are of limited distribution and there exists a distinct depositional break between it and the underlying continental Eocene yielding mainly sporo-pollen. This suggests that the Himalayan folding phase that led to the termination of deposition on the Cretaceous- early Tertiary red basin of the South China continent accompanied by magmatic activity had wide influence througthout the northern continental margin of the South China Sea.

2. Up to the present 15 zones① and several secondary depositional breaks have been recognized in the upper Oligocene to Pliocene strata in this region. Among the 15 nannofossil zones, those equivalent to zones NN11 and NN13–15 established by E. Martini (1971) are the most widespread. In combination with data of other fossils and depositional breaks, the 15 zones may serve as important markers for the stratigraphic division and correlation of the middle and upper Tertiary on the northern margin of the South China Sea.

3. The correlation shows that various formations of the upper Oligocene in various basins of this region are quite dissimilar. In some places the upper boundary of the Zhuhai Formation corresponds to the top of zone NP25 containing nannofossils and can serve as the boundary between the late Oligocene and the early Miocene. In the Southeast Hainan basin, according to an analysis of nannofossils from hole Y9, the Linshui Formaiton yields *Sphenolithus ciperoensis,* an element of the late Oligocene NP25 zone, and its overlying Sanya Formation yields early early Miocene elements. It is believed thus that the upper boundary of the Linshui Formation in southeastern Hainan can be correlated with that of the marine Zhuhai Formation. There generally occurs overlap of marine Burdigatian deposits, suggesting that the upper boundary of the Zhuhai Formation there lies at a highet level than in the east. The Weizhou Formation in the Beibu Gulf is a stratigraphic unit that straddles the boundary. The biostratigraphic analysis of the Southwest Weizhou depression and Wushi depression suggests that the nannofossils of the Xiayang Formation in this region belong to zones NN4–NN5 and that the foraminifera assemblage is *Globorotalia jiaweiensis- Cassigerilla chipolensis.* They can only correlate with those of part of the Zhujiang Formation or Sanya Formation. The lower boundary of the Xiayang Formation bearing marine fossils is not stratigraphically lower than the lower boundary of the nannofossil-bearing NN3 zone. In the Beibu Gulf basin, the Xiayang Formation overlies unconformably the Weizhou Formation (seismic horizon $T_2$). The lower boundary of the Xiayang Formation, i.e., the upper boundary of the Weizhou Formation can not represent the boundary betwęen the upper and lower Tertiary unless the sediments equivalent to nannofossil zones NN2–NN1 have been entirely denuded (which has not been reported).

① Duan Weiwu and Huang Yongyang, 1987. Tertiary calcareous nannofossil biostratigraphy in the northern South China Sea. In: Proceedings of the International Symposium on Petroleum Geology in the Continental Shelf of the Northern South China Sea, Vol. I , pp.273–191 (in Chinese). Edited by the Editorial Board of PETROLEUM OF CHINA sponsored by Petroleum Society of Guangdong Province.

The Weizhou Formation can not totally be correlated with the Linshui Formation or the marine Zhuhai Formation.

4. The depositional break between the late part of the middle Miocene and the early part of the late Miocene has its regional characteristics on the northern margin of the South China Sea. Except for some deep Miocene depressions, this depositional break, called the Dongsha movement by Chen Sizhong et al. [1], may be traced from southern Taiwan to the Beibu Gulf.

5. The depositional break between the Miocene and Pliocene, despite representing a very short span of time, is very distinct in the peripheral or uplift areas of these major basins, and is of certain significance in regional correlation.

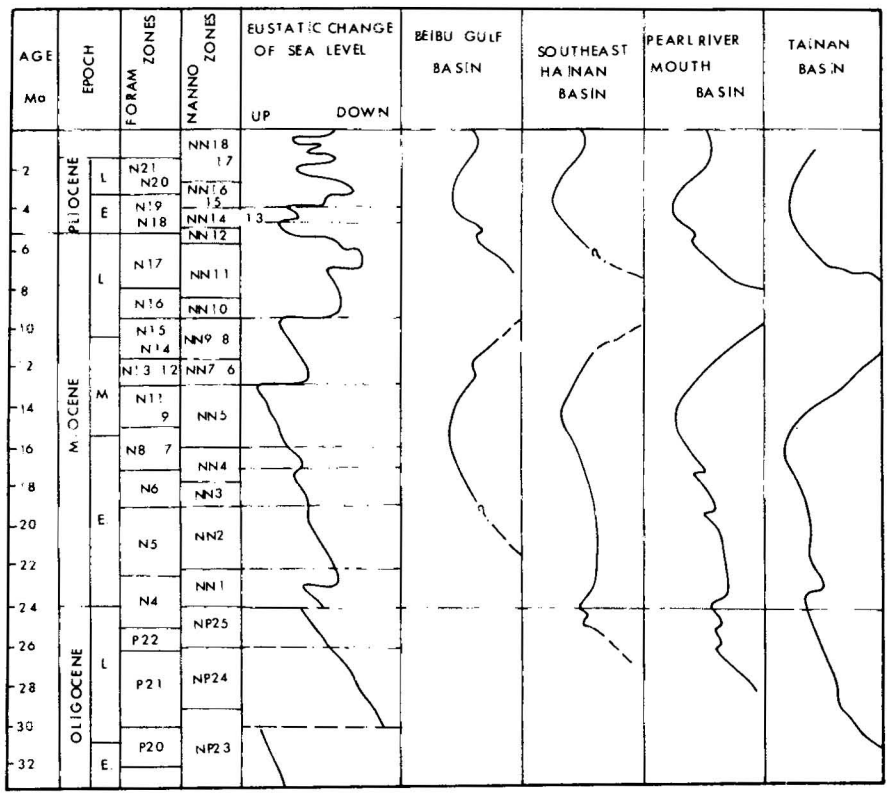


Fig. 1. Comparison of relative sea level changes in the mid-late Tertiary on the northern continental margin of the South China Sea.

6. From Shenhu to the north slope of the Dongsha uplift along the north side of the Southeast Hainan basin, there occurs a best-developed carbonate rock-bioherm zone known so far in the north of the South China Sea. Its existence is undoubtedly directly re-

1 Chen Sizhong, Li Zesong and Zou Yechu, 1987. Major oil-generation characteristics and exploration direction in the Pearl River Mouth Basin. In: Proceedings of the International Symposium on Petroleum Geology in the Continental Shelf of the northern South China Sea, Vol. I, pp.4–11 (in Chinese). Edited by the Editorial Board of PETROLEUM OF CHINA sponsored by Petroleum Society of Guangdong Province.

lated to the early Tertiary uplift and late Oligocene transgression in the above-mentioned areas. With the exception of shoal limestone in the lower part of the Linshui Formation that is of late Oligocene age, other carbonate rock-bioherms are essentially of early Miocene-early middle Miocene age, i.e., not later than the Langhian stage or the time when nannofossil zone NN5 was deposited. The arguments are as follows:

i) Restudy of nannofossil data from holes Y6 and Y9 indicates carbonate rocks bearing large benthonic *Nephrolepidina* stratigraphically all lie below the erosional surface of late middle Miocene age. For example, in hole Y9, the 1185–1265 interval yields nannofossils of zone NN11, while the elements of zone NN5 are found in the 1295–1345 m interval. Zones NN6–NN10 are absent. In this hole, *Nephrolepidina* limestone lies at depths of 1310 m and 1550 m, both of which are below the depositional break, and therefore it should not be earlier than early middle Miocene in age.

ii) Exploration has revealed that there exists a facies change between dark-coloured argillaceous rocks of the early Miocene Zhujiang Formation and the major intervals of carbonate rock-bioherm. Their deposition should be closely related to the transgression peak in the early middle Miocene.

7. Correlation of middle-late Tertiary strata of various basins is mainly based on nannofossil data from several drill holes, and by reference to limited nannofossil data from southeastern Hainan and the Beibu Gulf basin, the curves showing the relative sea level changes in various major negative units on the northern margin of the South China Sea were drawn, and a comparison was made between them and global eustatic curves of P.R. Vail et al. (1977). The curves showing the transgression or regression of sea water since the late Oligocene in the South Taiwan basin are essentially based on data of Huang Tingchang (1982) (Fig. 1).

## Ⅱ. A Brief Account of Palaeogeography and Palaeoenvironment

Appreciable changes had taken place on the northern continental margin of the South China Sea in respect to the palaeogeographical framework and depositional environment since the late Oligocene as compared with the early Tertiary. Exploration shows that except the Beibu Gulf basin and its vicinities and the western Pearl River Mouth basin, the upper Oligocene to Pliocene strata of the whole region are made up mainly of marine deposits, including littoral, neritic, deltaic and carbonate-bioherm limestone deposits. During the late Eocene-early Oligocene, the whole South China Continent, including the northern continental margin of the South China Sea uplifted concomitantly with the final closure of the Tethys, when the ancient coastline roughly ran from the south of Gaoxiong (Kaohsiung) through the southeast flank of the Dongsha uplift and the southern part of the Pearl River Mouth basin and then turned southwards to the east side of the Xisha uplift. But, on the basis of the latest drilling data, there could exist marine clastic sediments of Eocene age on the northeastern margin of this area. The sea probably invaded from north via the Penghu-Nanri basin that was arranged in a NE-SW direction (Fig. 2–A). The Himalayan movement that occurred in the middle-late Eocene resulted in late Eocene to early Oligocene short-term erosion in this area, and afterwards the area entered the stage of continuous subsidence. The upper Oligocene Chattian stage of this area developed essentially on the background of denudation and planation. The sediments that probably consist of

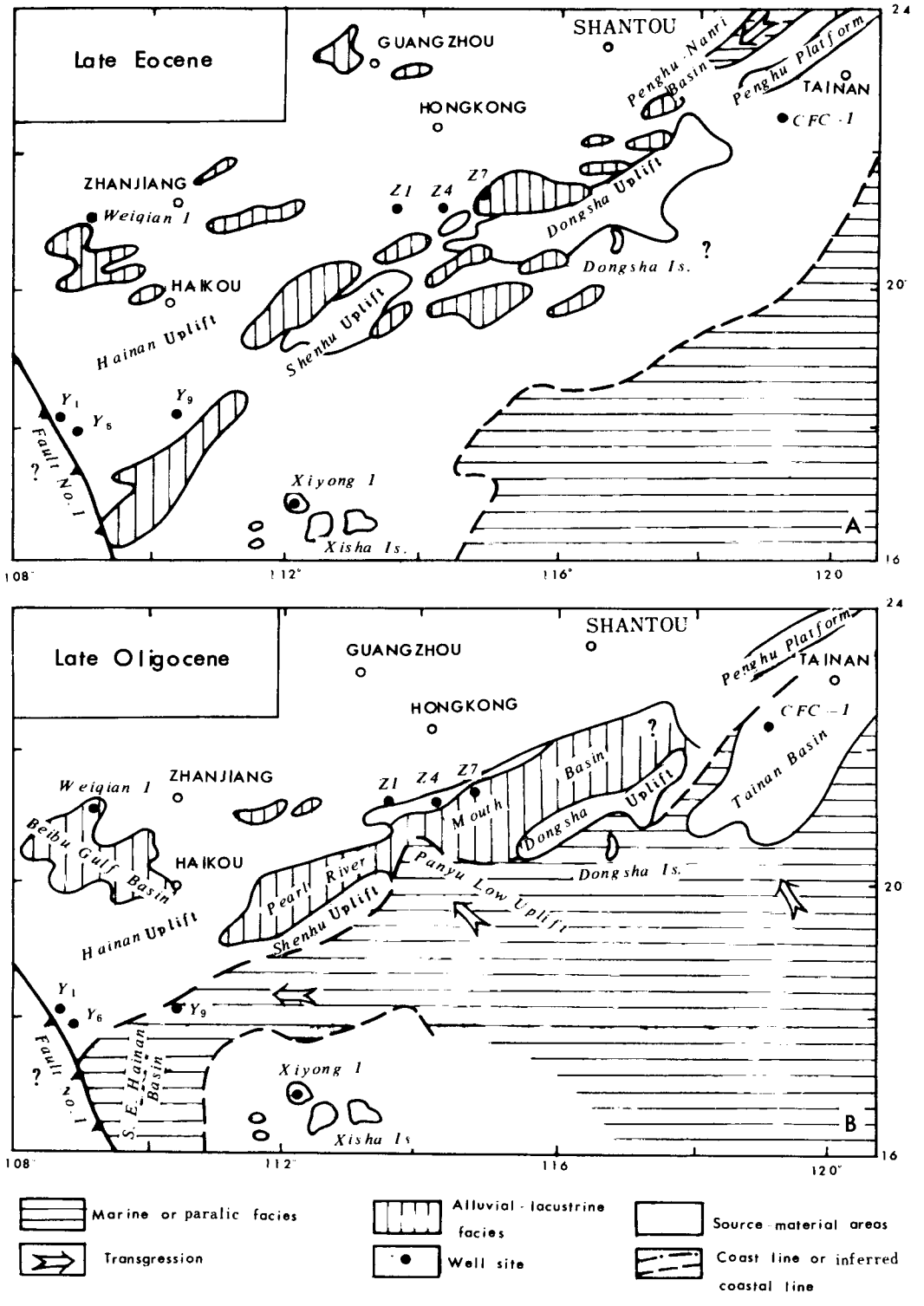


Fig. 2. Sketch map showing early Tertiary palaeogeography on the northern margin of the South China Sea.

marine shale and fine sandstone bearing nannofossilsof the latest early Oligocene zone NP23 were deposited in the Tainan basin first (Huang, 1982). Then the sea advanced towards the northwest. In hole CFC–1 southeast of Gaoxiong, the stratigraphic horizon of Oligocene sandstone and shale bearing foraminifera of zone N2 unconformably overlying the Middle Cretaceous is equivalent to the upper part of nannofossil zone NP24 of late Oliogocene age. The strata of nannofossil zones NP24 and NP25 have a tendency to overlap from east to west in the southern part of the Pearl River Mouth basin and the SoutheastHainan basin. The upper Oligocene formations consist mainly of neritic sandstone and mudstone and littoral coal measures from the Southeast Hainan basin through the southern part of the Pearl River Mouth basin to the west coast of Taiwan. During the late Oligocene, sea water could possibly for the first time enter the north flank of the Pearl River Mouth basin through the Panyu low uplift between the Shenhu and Dongsha uplifts (Fig. 2B). The marine Zhuhai Formation is of limited distribution and the littoral sediments in its lower part have barrier-type features. No evidence of Oligocene transgression has been found so far on the western side of the Yinggehai No.1 fault.

The depositional environment of the Weizhou Formation in the Beibu Gulf has long been an open question. The Weizhou Formation, composed of mottled clastic rocks with greyish green or light brown mudstone, is widespread in the Beibu Gulf basin and its surrounding areas, and is highly varied in thickness. Small amount of glauconite occurs intermittently in the Weizhou Formation (particularly in its upper part), as shown by the cores from several offshore and onshore boreholes. Glauconite is an important facies mineral, but it is very rare in the strata and can not serve as an indication of a marine environment. Furthermore, lithostratigraphic division and correlation are the main approaches in the stage of reconnaissance, and some possible errors can not be ruled out in local stratigraphic division. The palaeontological characteristics of sedimentary rocks are a sensitive marker for reflecting the environment. The analysis is as follows: 1) Sporopollen: The Weizhou Formation is rich in spores and pollen, which are characterized by hilly temperate deciduous and coniferous plants, and certain amount of pollen from coastal mangrooves are also contained in the assemblage. All of these suggest the nearshore character of the depositional areas. 2) Ostracods: They are characterized by non-marine *Chinocythere*, with fresh-water and brackish *Cyprinatus* and *Candona*. 3) Gastropods: *Sinomelania leei* is found in the lower member of the Weizhou Formation. It is usually found to be associated with fresh- water *Melania* in the Baishe basin. Terrestrial *Enteroplax?* sp. is also present. Gastropods in the upper part of the Weizhou Formation are characterized by mixed occurrences of marine and continental forms. 4) Foraminifers: *Parrotalia* sp. is reported to occur in the upper part of the Weizhou Formation as shown by the cores from the 800–900 m interval in Weiqian hole No. 1. On the basis of the above-mentioned palaeontological data, one can see that the general characteristics of the Weizhou Formation is entirely different from those of the Linshui Formation in the Southeast Hainan basin or the marine Zhuhai Formation in the Pearl River Mouth basin.

The earliest Miocene sediments within the region exhibit distinct features of regression, which was associated with the global sea level fall, especially in the northern hemisphere (Müller, 1983). The Aquilanian stage is characterized by the dominance of coarse-clastic rocks, paucity of marine organisms and low taxonomic diversity. Besides the South China continent, both the Shenhu and Dongsha uplifts also provided part of terrigenous materials. A depositional break occurred in the uplift areas and their vicinities.

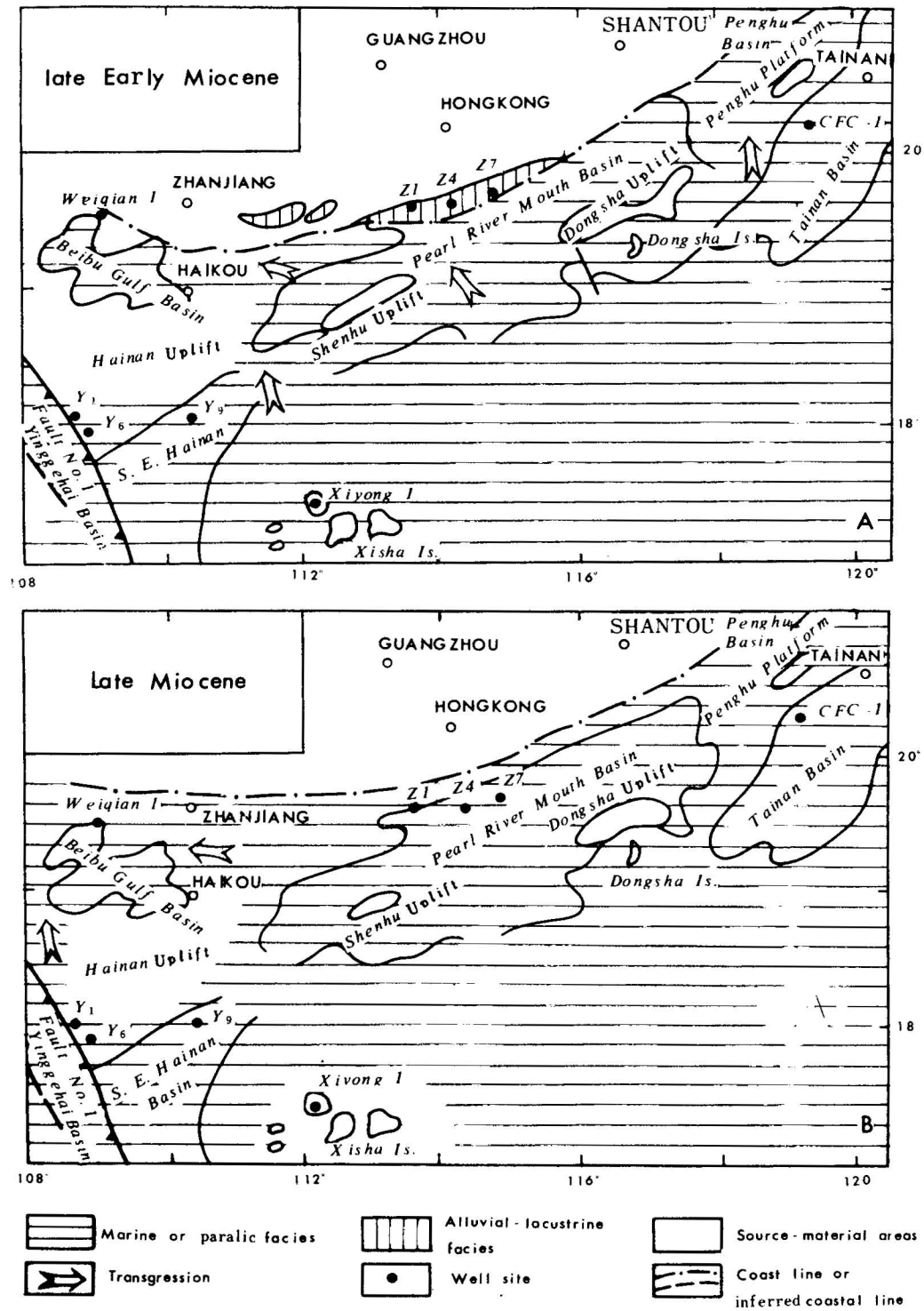


Fig. 3. Sketch map showing the early Tertiary palaeogeography of northern margin of the South China Sea.

The marine Burdigellian stage (lower Miocene) is widely distributed in the north of the South China Sea. As the early Miocene transgression expanded, sea water invaded from southeast to northwest, and part of it passed the Shehu uplift and entered the western part of the Pearl River Mouth basin, where it joined the sea water in the east (Fig. 3A). Transgression on the northern margin of the South China Sea first reached a climax in the late part of the early Miocene and continued until the early part of the middle Miocene, when there were deposited neritic sediments bearing nannofossil zones NN4–NN5 and the foraminifer assemblage of *Globorotalia jiaoweiensis- Cassigerinella chipolensis* and the mid-upper parts of the Zhuhai Formation dominated by mudstone and fine-clastic rocks and their equivalents. During this transgression, in the west of the northern margin of the South China Sea, sea water invaded from west of the Pearl River Mouth basin through south of the Leizhou Peninsula and for the first time innundated the Beibu Gulf basin, where the currently known marine lower Miocene Xiayang Formation was deposited. In the northeast of the northern margin of the South China Sea, the sea advanced northwards as far as the Penghu platform (Sun, 1982) so that the uplift state since the Eocene ended and the Peikang Formation of grey shale with sandstone was deposited. The Peikang Formation becomes gradually thick from Penghu eastwards, and contains elements of nannofossil zones NN2–NN6 (Huang, 1982). It is the main target at present for oil and gas exploration in the west coast of Taiwan.

In the middle and later parts of the middle Miocene, the crustal movement related to the global sea level drop brought about rising of the Dongsha uplift as a whole, which again became a terrigenous provenance denuded intensely. The Serravallian stage and part of the Tortonian stage in the Pearl River Mouth basin prossess distinctive indices of regressions (Duan et al., 1984). The aggredational deposits of delta-front facies developing in the Hanjiang Formation, the incomplete development or absence of nannofossil zones NN9–NN10 within a large areal extent and the absence of foraminifer zone N15 are all strong evidence of regression. On the northern slope of the Southeast Hainan basin, strata bearing nannofossil zones NN6–NN11 are probably absent over a large areal extent. It is possible that the Meishan Formation and Huangliu Formation are stratigraphic units that only represent part of the middle and upper Miocene in the region. Through studies of surface and borehole geological structures in the southern part of Taiwan province, Xu Zhaoxiang (1979) has confirmed that the middle Miocene crustal movement is closely related to the accumulation of oil and gas in the region.

On the premise that *Brrarudosphaera bigelowi,* a calcareous nannofossil, normally adapted to a shallow-water environment, H. Stradner, after studying nannofossils from the Vienna basin of Austria, found that the size of *B. Bigelowi* is associated with the salinity of sea water (Rede, 1970). The higher the salinity of sea water is, the larger its size will be, and vice versa. *B. bigelowi* is common in the middle part of the middle Miocene Hanjiang Formation in the Pearl River Mouth basin and usually 6–8 $\mu$m in size. But it gets larger west of the basin, with the largest one reaching 16$\mu$m. This suggests that the environment of high-salinity water (gulf?) far away from freshwater recharge might once have occurred west of the Pearl River Mouth basin during the middle Miocene.

The scale and extent of the transgression in the north of the South China Sea became large again during the middle part of the late Miocene. In an area between Tainan and Hengchun to the south of Taiwan, the upper Miocene sediments bearing the *Discoaster quinqueramus* zone (NN11) are widespread (Ji, 1984); in the Pearl River Mouth basin, the

open shallow sea deposits (Yuehai Formation) bearing nannofossils of zone NN11 and the foraminifer assemblage of *Ammonia altispira-Globigerina nepenthes* may be found in hole Z1 and hole Z4 in the north (Fig. 3B). Uplifts such as the Dongsha and Shenhu uplifts were then affected by transgression and started to receive deposits. During the late Miocene in the Beibu Gulf basin, Leizhou Penninsula and Hainan area, sea water bypassed the west side of the Hainan uplift and entered the Beibu Gulf basin, where it joined the sea water which came earlier from the east, and then advanced northwards until it reached north of Zhanjiang. During the Miocene transgression, sea water inundated the Xisha Islands. Studies by Wang Chongyu (1985) on Xiyong hole No. 1 suggest that the soft chalk and magnesian chalk deposits of late Miocene age contain nannofossils *Amarulithus delicatus* and *Discoaster, surculus*. Their stratigraphical horizon should not be lower than the lower boundary of zone NN11. It is inferred that they are in overlapping contact with the underlying detrital limestone–algal limestone yielding *Miogypsina* spp.

Despite some fluctuations, the late Miocene transgression continued until the early part of the late Pliocene (equivalent to zone NN16). During this period, the northern South China Sea was in an open sea environment including the neritic to bathyal environment. In the Tainan basin, the Yunshuixi bed dominated by dark-coloured mudstone and shale bears many elements of *Ceratolithus, Amourolithus* and *Discoaster*, suggesting an outer shelf (neritic) environment. In the Southeast Hainan basin, planktonic elements generally increase in the early Pliocene foraminifer assemblage, accompanied by a series of benthonic abyssal species, such as *Pullenia bulloides, Gyrodina orbicularis* and *Martinotiella communis*. The environment might belong to the outer shelf to upper continental slope environment. In the Pearl River Mouth basin or Beibu Gulf basin, both the abundance of nannofossils and the ratios of the benthonic to planktonic genera and species in the foraminifer assemblage and their quantities indicate a normal neritic to upper continental slope environment.

During the late Pliocene, regression universally occurred in the northern part of South China Sea; as a result, the Penghu, Dongsha and Shenhu uplifts again emerged from the water and became terrigenous provenances. The area of littoral sediments expanded in the Beibu Gulf basin and the north slope of the Pearl River Mouth basin. As revealed by holes Z1 to Z7, foraminifers are either absent or occur in intercalations in the shallow-water benthonic assemblage in the upper part of the Wanshan Formation, which is equivalent to the Piacenzian stage. The NN17–NN18 nannofossil zones are occasionally seen or absent. However, upper Pliocene and Quaternary marine deposits are fairly continuous in Yinggehai and the South Tainan basin. It is inferred that this is also the case in the southern part of the Pearl River Mouth basin. The late Pliocene regression continued till the early Pleistocene, then in addition to marine deposits, alternating marine and continental deposits could also occur in the near-shore areas or ancient uplift areas on the northern continental margin of the South China Sea (Qin, 1985), and even the possibility that the continental deposits exist locally cannot be entirely ruled out.

## III. A Brief Account of the Palaeoclimates

It is well-known that the characteristics of the association of planktonic organisms and their distribution pattern are closely related to the water temperature and climate. There are usually two methods for applying calcareous nannofossils in deducing the relative tempera-

ture of ancient sea water: 1) the deduction of the water temperature based on the relative dominance of the cold- and warm-water genera and species in the assemblage; 2) the deduction of the water temperature based on the proportion (usually 100–300 grains) of *Discoaster* to some *Placoliths* (e. g. *Chiasmolithus* and *Coccolithus*) in the same sample.

Except in the west coast of Taiwan and its off-shore areas, the number of the warm-water species *Sphenolithus ciperoensis* and *S. distentus* are both small in the marine upper Oligocene of the north of the South China Sea, while the relative proportion of the cool-water species *Coccolithus pelagicus* is high in each of the samples, which indicates that the water temperature was somewhat low by that time. Such a cool-water environment continued until the early part of the early Miocene.

From the Brudigalian stage of the early Miocene to the Langhian stage of the middle Miocene (22–14 Ma), the water temperature in the north of the South China Sea generally rose and the climate turned warm. The nannofossils indicating the warm-water environment such as *Sphenolithus heteromorphus, S. belemnos* and *Sphenolithus* spp., are widespread and abundant in this period. The development of carbonate rock-bioherms also suggests that the water temperature in the region was higher at that time. According to E.M. Kemp (1978) the sea water temperature generally increased by 3℃ in the Tasmania Sea in the early Miocene, which was the main transgression stage in South Australia.

From the later part of the middle Miocene to the early part of the late Miocene, the water temperature in this region was generally low and fluctuated greatly. From the Pearl River Mouth basin to the Beibu Gulf basin, the proportion of the cool-water species *C. pelagicus* in each of the samples from zones NN6–NN10 is obviously higher. Another interesting phenomenon is that the genus *Helicosphaera* indicating the warm-water environment is miniature in size (3–5$\mu$m) in this sequence of strata. It is abundant and its stratigraphical horizon is persistent. Whether the diversity of the size of those warm-water species is related to the change in water temperature remains to be studied.

From the late Miocene (zone NN11) till the late Pliocene (zone NN16), the warm-water type nannofossils were abundant, such as *Discoaster quingeramus* or its pioneer species *D. berggrenii* and others of *Discoasters, Ceratolithus, Helicosphaera* and *Scyphosphaera*. Generally this assemblage reflects a warm environment, but zones NN13 and NN14 are usually hard to distinguish in the region, so the possibility that the water became cold at 4.7–4.0 Ma can not be ruled out.

The idea put forward above is very close to the division of the middle and late Tertiary palaeoclimates in the Pearl River Mouth basin made by Lei Zuochi (1985) on the basis of an analysis of the sporopollen assemblage.

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