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# Vegetation on the Sunda Shelf, South China Sea, during the Last Glacial Maximum

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ABSTRACT

Pollen and phytoliths from sediment cores SO18300, 18302 and 18323 on the continental shelf of the southern South China Sea are analyzed, with special attention to reconstructing vegetation and climate changes on the Sunda Shelf during the Last Glacial Maximum (LGM). The LGM pollen assemblages are characterized by high percentages of pollen from the lowland rain forests and lower montane rainforests, suggesting that the exposed shelf was covered with humid vegetation. A marshy vegetation (with plants of sedges, reeds, bamboo, etc.) developed in the valley along the North Sunda River, and around the marshes were distributed palms and a variety of ferns including tree ferns (*Cyathea*). The climate during the LGM inferred from the vegetation was cooler than that at the present day, but no significant decrease in humidity was recorded, at least the change was not sufficient to prevent the growth of rainforest. Finally, the observed fluctuations in percentage of mangrove pollen are considered as a sensitive indicator of coastline migrations on the Sunda Shelf.



## 1. Introduction

The Sunda Shelf, southern South China Sea (SCS), is the largest exposed tropical continental shelf during the Last Glacial Maximum (LGM). After decades of debate, it is generally accepted that in this region temperature was substantially lower at the LGM than it is today, a conclusion from both terrestrial (Walker and Flenley, 1976; Newsome and Flenley, 1988; Stuijts et al., 1988; Hope and Tulip, 1994; Flenley, 1996, 1998) and marine studies (Van der Kaars, 1991, 1998; Thunell et al., 1992; Pflaumann and Jian, 1999; Wang, 1999; Kershaw et al., 2007). However, evidence for humidity changes at the LGM remains controversial. A dry climate during the LGM was inferred from pollen data from Misedor, Borneo (Flenley, 1985), Danau di Atas, Sumatra (Stuijts et al., 1988), Lynch's Crater, northeast Australia (Kershaw et al., 1997), and Bundung, Java (Van der Kaars, 1998), whereas that from Sirunki, Papua New Guinea (Walker and Flenley, 1976), Hordorli, Lowland, Irian Jaya (Hope and Tulip, 1994), Bayongbong, Java and Danau Di Altas, Sumatra (Stuijts et al., 1988) indicated a humid condition. In a regional study, De Deckker et al. (2002) believed that there was a significant drop in precipitation in the Warm Pool region based on sea surface temperature reconstruction and on the increase of land mass area engendered during low sea levels.

According to palynological data (Li and Sun, 1999; Sun et al., 2002), the Sunda Shelf was covered mainly by lowland rainforest during the LGM. However, the study materials were from the continental slopes (from Sonne cores 17964 and 17962, see below). Because LGM sediments can rarely be preserved on the exposed shelf, direct evidence for paleo-vegetation on the Sunda Shelf has been absent. Fortunately, a series of cores containing LGM sediments were collected from Sunda Shelf along a paleo-river valley (North Sunda River) by the German R/V Sonne cruise 115 in 1997, and a series of papers have been published on deposition sequences and sea-level changes of the shelf area (Hanebuth and Stattegger, 2003, 2004; Hanebuth et al., 2000, 2002, 2003). Now the results from pollen analyses of the cores have been enabled us, for the first time, to demonstrate the nature of the vegetation covering the exposed Sunda Shelf, which should shed light on climate change of the region during the LGM.

## 2. Environment setting

The Sunda Shelf is located in the southwest of the SCS and west part of the WPWP, occupying a large area of $1.8 \times 10^6$ km. During the LGM, when the loss of water to the ice sheets caused regression of the sea, the Sunda shelf emerged, with a very low gradient surface. The extensively exposed surface connected Sumatra, Java and Borneo to form a large landmass called "Sunda Land" at a low sea level stand, and the so called "Paleo-Sunda River" developed on the exposed Sunda Land, draining from the above mentioned mountainous islands into the SCS (Fig. 1; Tija, 1980).

Located near the Equator and within the WPWP, the Sunda Shelf area is characterized by a non-seasonal climate with an average annual temperature of about 25–30 °C in the lowlands. The annual

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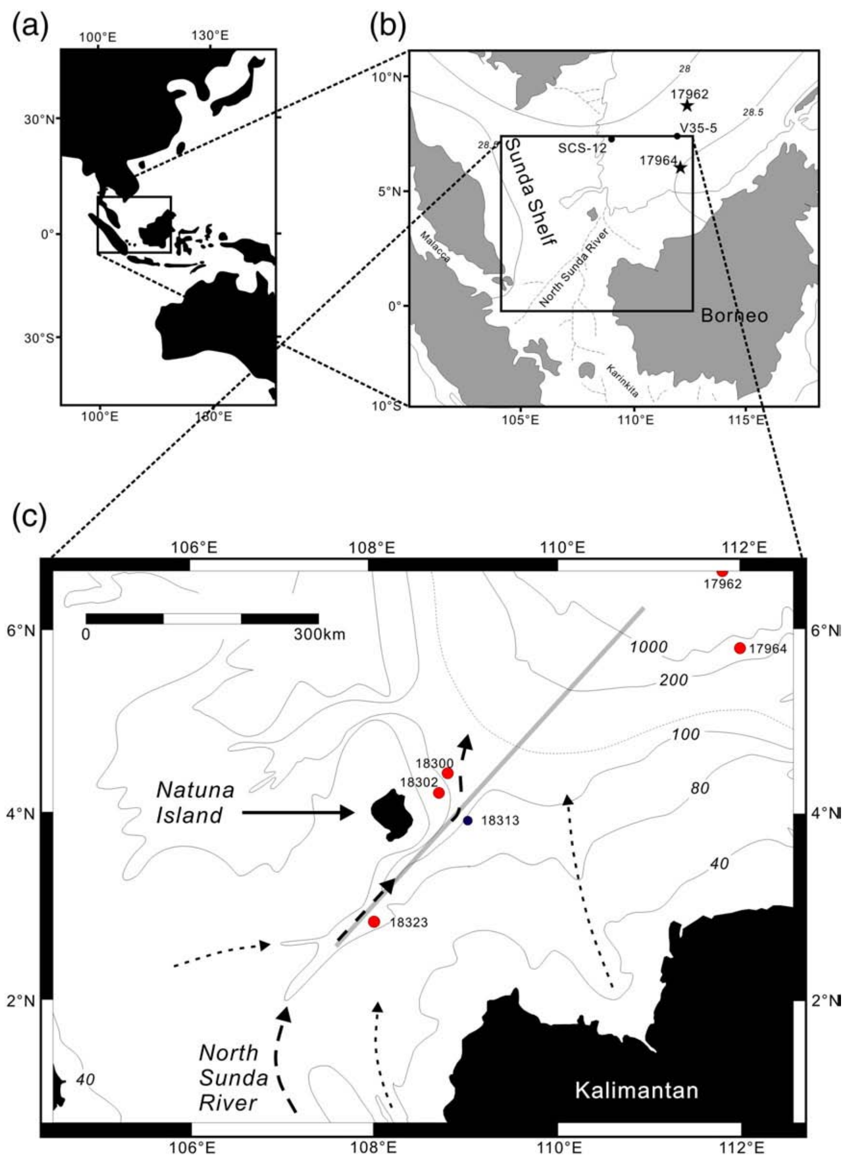


**Fig. 1.** Location of the studied area and pollen cores (based on Hanebuth and Stattegger, 2004).

precipitation is 2000–3000 mm, and monthly precipitation is no less than 100 mm and exceeds 200 mm in most parts (Heaney, 1991).

The pollen distribution pattern in the modern surface sediments from the SCS shows that the pollen and spores in the southern SCS come from the southern islands, mainly from Borneo, at the present day (Sun et al., 1999). On Borneo, a highly mountainous island, tropical rainforest is the main vegetation type, with its composition changing with altitudes. Below 1200 m a.s.l. lowland rainforest occurs, dominated by Dipterocarpaceae with many other tropical components from the Sapindaceae, Meliaceae, Moraceae Rubiaceae, Rutaceae etc. Above this zone and up to 2500 m is distributed a lower montane rainforest dominated by the Fagaceae, Lauraceae and Hamamelidaceae. At about 2900 m, an upper montane rainforest, principally taxa of *Podocarpus*, *Dacrycarpus*, *Dacrydium*, *Phyllocladus*, *Vaccinium*, *Rhododendron* and *Myrica*, extends to the timberline at ca. 3800 m. Above the timberline lies tropical alpine grassland. Mangroves (mainly *Rhizophora*, *Sonneratia*, *Avicennia*, *Luminzeta*, and *Bruguiera*) are found along the coasts and river mouths of these islands (Kitayama, 1992).

**Table 1**
Information of the studied cores.

| Core number | Latitude (N) | Longitude (E) | Water depth (m) | Recovery (cm) | Bottom age (14C yr BP) |
|---|---|---|---|---|---|
| SO 18300 | 4°21′ | 108 °39′ | 91 | 885 | 39,200 |
| SO 18302 | 4°09′ | 108 °34′ | 83 | 598 | 20,160 |
| SO 18323 | 2°47′ | 107 °53′ | 92 | 540 | 31,270 |

**Table 2**
$^{14}$C ages of the studied cores (data from Hanebuth et al., 2003 and Hanebuth and Stattegger, 2004.

| Core | Sample depth (cm) | Sampled material | AMS-14C ($^{14}$C ka BP) |
|---|---|---|---|
| 18300 | 60–62 | Bulk, organic fibres | 12440 ± 70 |
| | 206 | Bulk, organic fibres | 12650 ± 60 |
| | 400* | Root | 12580 ± 60 |
| | 590–592 | Bulk, organic fibres | 21490 ± 33 |
| | 879–881 | Bulk, organic fibres | 39210 ± 319 |
| 18302 | 85 | Wood | 11520 ± 55 |
| | 410 | Peaty | 12335 ± 60 |
| | 410* | Arcoid bivalve | 11660 ± 45 |
| | 590 | Bulk, organic fibres | 20160 ± 33 |
| 18323 | 399–401* | Rotalia | 11770 ± 60 |
| | 190–192 | Bulk, organic fibres | 14180 ± 60 |
| | 380–382 | Bulk, organic fibres | 23460 ± 160 |
| | 534–536* | Bulk, organic fibres | 22810 ± 120 |

Because of the mixing effect of younger with older material, the dating results for samples marked with * were not used in the age model).

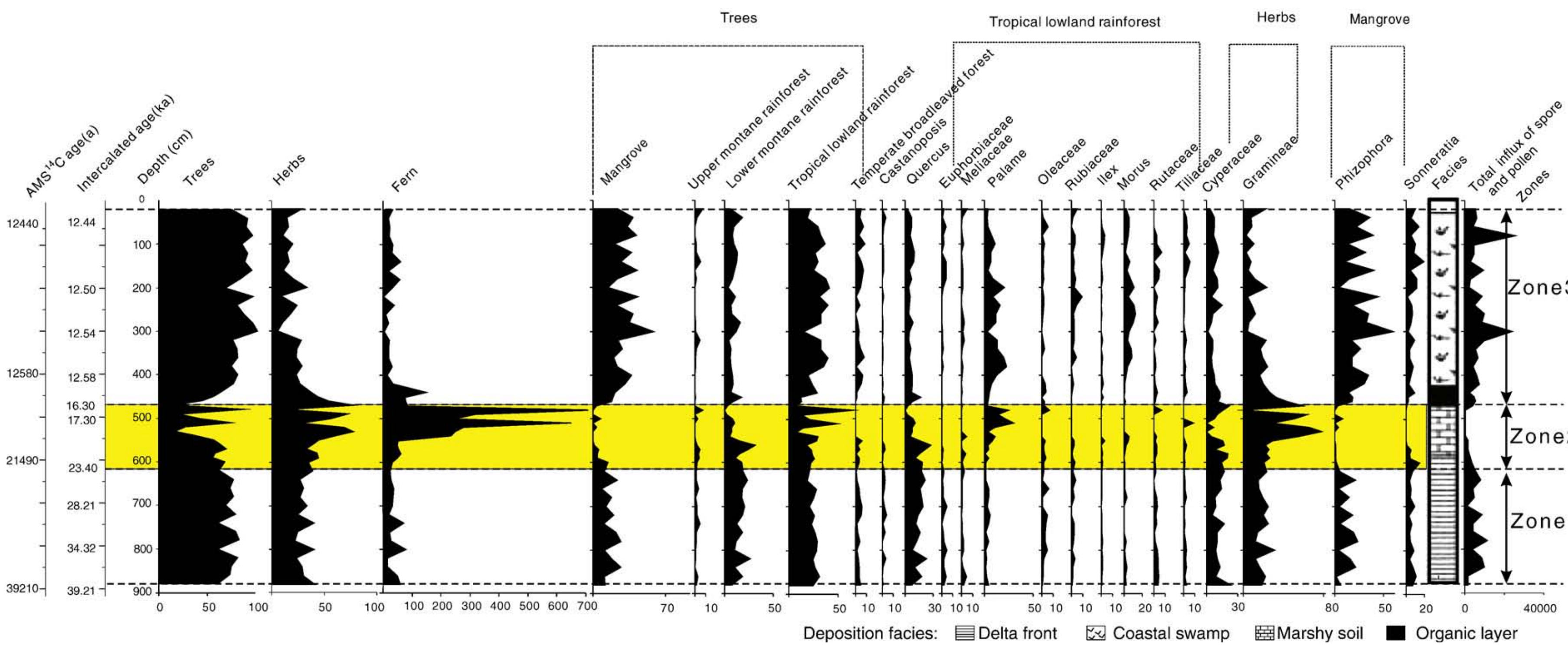


**Fig. 2.** Pollen percentage diagram of SO 18300 (shadow shows the LGM). The percentages of each group and of individual taxa were calculated on the total pollen sum of land seed plants.

## 3. Materials and methods

Three sediment cores (Table 1; Fig. 1) were collected along a transect following the paleo-valley of North Sunda River on Sunda Shelf during the R/V Sonne cruises 115 in December 1996–January 1997 (Stattegger et al., 1997). A total of 143 pollen samples were analyzed from the three cores, of which 54 were from the LGM. In addition, 60 samples were analyzed for phytoliths and 60 samples for $\delta^{13}C$ of organic carbon. All palynological samples were prepared at the State Key Laboratory of Marine Geology, Tongji University, using hydrochloric and hydrofluoric acids to remove carbonates and silicates. Further to concentrate the pollen, the materials remaining after the acid reactions were sieved through a 7 µm mesh in an ultrasonic sink. More than 200 pollen grains of land seed plants were counted for each sample (excluding fern spores and pollen of aquatics). The percentages of each group and of individual taxa were calculated on the total pollen sum of land seed plants.

Phytolith extraction followed techniques provided by Fredlund and Tieszen (1994), Pearsall (1989) and Wang et al. (2001). Organic carbon isotope was measured in the same laboratory using Flash-HT/EA-Delta$^{plus}$XP. The age model follows Hanebuth et al. (2003) which was based on uncalibrated AMS $^{14}C$ data (Table 2).

## 4. Results

More than 100 pollen types were identified in this study. According to their ecology several groups of taxa can be defined as follows:

High montane rainforest group: *Podocarpus*, *Dacrycarpus*, *Dacrydium*, *Phyllocladus* and Ericaceae;
Lower montane rainforest group: mainly taxa of *Castanopsis*, *Quercus*, Elaeocarpaceae, Myrtaceae, and Theaceae;
Tropical lowland rainforest group: Trema, Rutaceae, Sapotaceae, Araliaceae, *Ilex*, *Mallotus*/*Macaranga*, Euphorbiaceae, Palmae, *Calamus*, Meliaceae, Actinidiaceae, Dipterocarpaceae, etc. (usually including a large number of taxa, but with a few pollen grains for each taxon);
Mangroves: *Rhizophora*, *Lumnitzera*, *Avicennia*, *Barringtonia* and *Sonneratia*;
Temperate taxa: *Betula*, *Alnus*, *Carpinus*, *Juglans*, *Ulmus*, etc.;
Herb taxa: mainly Poaceae and Cyperaceae;
Ferns: *Cyathea*, *Hicriopteris*, Hymenophyllaceae, *Osmunda*, *Pteris*, *Adiantum*.

Down-core distributions of pollen are shown in Figs. 2, 4 and 5. A conspicuous feature in the stratigraphy of the studied area is the absence of Holocene deposits. The three studied cores consist of glacial deposits ranging from ca. AMS $^{14}C$ 40 ka to 11 ka. We recognized three pollen zones 1, 2, and 3(or 3/4), corresponding to Marine Isotope Stage 3 (MIS 3), the LGM and the deglaciation, respectively. Chronologically, pollen zone 2 covers a time interval from ca. AMS $^{14}C$ 23.5 ka to 16.3 ka (Figs. 2, 4, 5) which will be referred to as the LGM in the following discussion.

### 4.1. Core SO18300

The core was taken from the outer Sunda Shelf, near the paleo-river mouth (Fig. 1), at a water depth of 92 m. The 8.8 m long core covers the last glacial period from nearly 40 kyr to ~12 kyr BP.

The pollen profile is marked by a predominance of trees, low percentages of herbs and fern spores, and high proportions of mangroves through Zone 1 (MIS 3) and Zone 3 (the last deglaciation). However, Zone 2 (the LGM) (Fig. 2) is distinguished by comparatively low abundance of trees, and fairly high herb percentages, extremely high percentages of fern spores, and trace amounts or absence of mangroves.

Zone 2 covers 6.2 m~ 4.8 m in the core and is represented by marsh soil, from which a total of 13 samples have been counted. As seen from the pollen diagram (Fig. 2), tree pollen, with considerable fluctuations, accounts for about 50% of the total pollen sum on average, and is dominated by lowland rainforest with Palmae as its main component, accompanied by taxa of Ilex, Moraceae, Meliaceae and other lowland rainforest taxa. The upper montane rainforest group is insignificant in proportion, whereas the lower montane rainforest group shows its higher values in the early stage of the LGM than declines upwards. The fern group reaches its maximum amount in the LGM, being 7 times the total pollen sum and including a variety of spore types in which *Cyathea*, a tropical tree fern, is dominant.

Phytolith grains occurred in three deglaciation samples, but were absent in the LGM samples.

We analyzed organic carbon isotope in sediments between 400 cm and 590 cm at intervals of 10 cm (21.49 ~ 12.58 ka) (Fig. 3A). The results of 20 samples show that $\delta^{13}C$ values were heavier (−15‰ and 22‰) during the LGM (590 cm to 480 cm, 21.49 ka to 16.3 ka), and became lighter upwards (to ca. −25‰) from 480 cm to 400 cm (16.3 ~ 12.58 ka). As carbon isotope values in $C_4$ plants, basically including herbs and some shrubs, are heavier (−14‰ to −10‰) than $C_3$ plants (−35‰ and −22‰), to which belong most of trees (Cerling

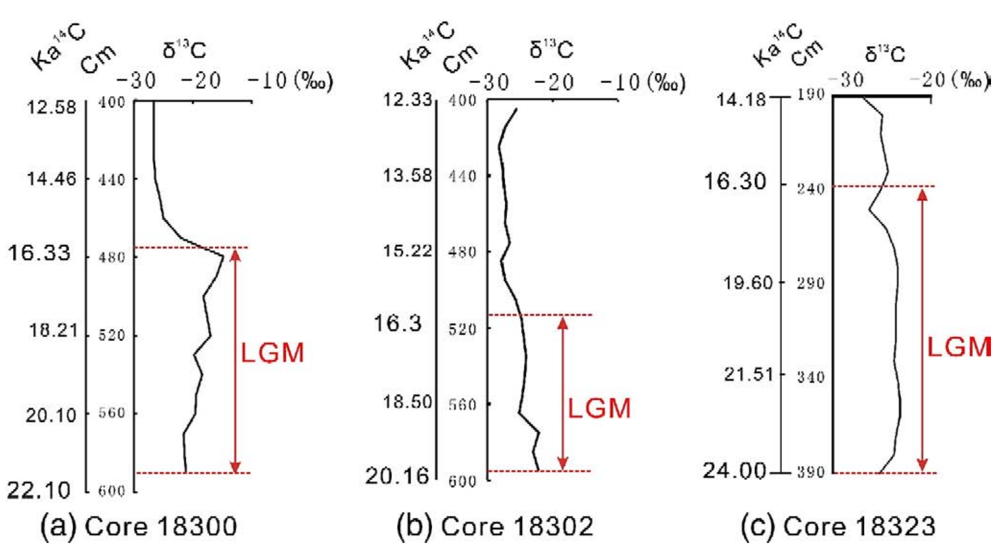


**Fig. 3.** $\delta^{13}C$ of organic carbon at the LGM from cores (a) SO18300, (b) SO18302, (c) SO 18323.

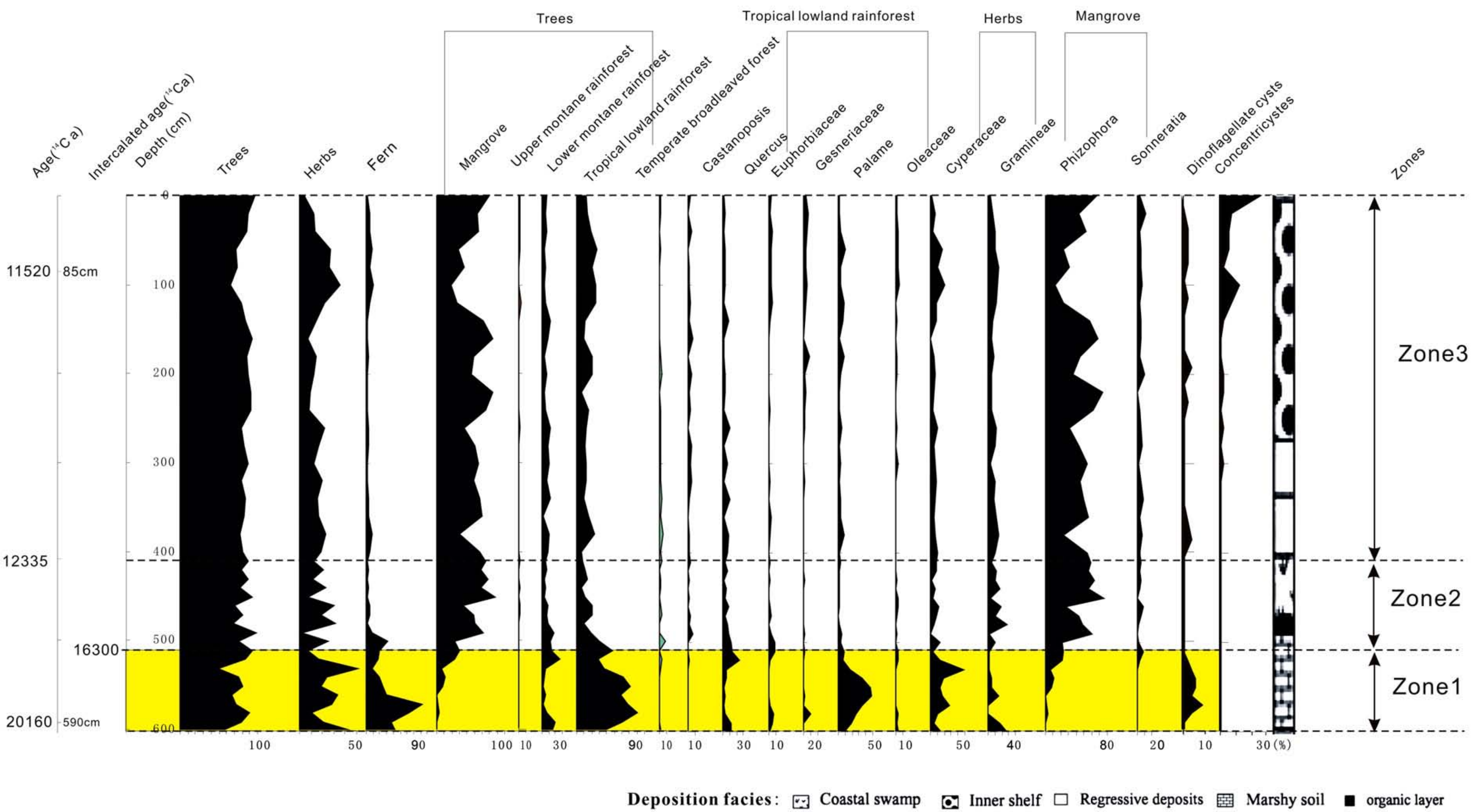


**Fig. 4.** Pollen percentage diagram of SO18302 (shadow shows the LGM). The percentages of each group and of individual taxa were calculated on the total pollen sum of land seed plants.

et al., 1989, 1993), the above results may indicate that $C_4$ plants (mainly the herb biomass) were more abundant in the Sunda River valley during LGM than in the deglaciation, supporting the results of pollen analyses (Fig. 3A).

### 4.2. Core SO 18302

The core was recovered from the inner Sunda Shelf, with a modern water depth of 83 m. The 5.98 m-long core provides records of only the LGM and deglaciation, from ca.20–11 ka. Again, the pollen profile in the deglaciation section is marked by a predominance of trees, comparatively low proportions of herbs, high percentages of mangrove pollen, but very low percentages of fern spores. The interval of 5.9–5.1 m of the core was dated to the LGM (ca.20.16 ~ 16.3 ka) and was mainly composed of marshy sediments (Fig. 4). A total of 16 pollen samples from the LGM interval were analyzed. While the main characteristics of the pollen diagram are similar to those from SO18300, the LGM pollen assemblage is more conspicuous, with comparatively higher proportions of herb pollen and very high percentages of fern spores. Mangrove pollen is rare or absent.

Tree pollen is dominant (ca. 50 ~ 80%) in Zone 1 (the LGM) though its proportion is lower than that in the upper part of Zone 2. Pollen from tropical lowland rainforests is the absolutely dominant component of the tree pollen group throughout the core, and the Palmae plays a particularly important role for the LGM. Mangrove pollen is almost absent at the bottom of the LGM section, then increases in proportion gradually from 18.1 ka to 16.3 ka, becoming fairly rich during the deglaciation. Herbs reaches 20 ~ 50% in the LGM before decreasing upward. The fern spores are abundant in the LGM in contrast to their lower values in the deglaciation. Ferns amount to 90% of the total pollen sum of land seed plants at the bottom and decline to ca. 20% at the top of the LGM section. No phytolith taxa have been found in the sediments from this core.

The $\delta^{13}C$ values of organic carbon are slightly heavier (ca. −22 ~ −25‰) in the LGM than in deglaciation (Fig. 3B), corresponding to a minor increase of herb abundance in the pollen diagram between 5.9 and 5.1 cm (Fig. 4).

### 4.3. Core SO18323

The core was collected from the inner Sunda Shelf, with a water depth 92 m at the present day. The core is 540 cm long. (Fig. 5).

The LGM deposits (Zone 2) from 3.8 m to 2.1 m (23.46–16.3 ka) are composed of marsh soil in the lower part and an organic layer with coastal swamp sediments in its upper part. 18 pollen samples were counted.

In line with the previous pollen profiles, the LGM samples are also characterized by abundant fern spores (up to 2.5 times more than the total pollen sum of land seed plants), high percentages of herb pollen (reaching 50%) and trace amount to absence of mangrove pollen. The pollen profile shows some difference between the lower and upper parts of the LGM pollen zone. The lower part (3.8 ~ 3.5 m, 23.46–22.1 ka) is marked by lower percentages of tree pollen (ca. 50%) and fern spores (150% of the total pollen sum of land seed plants), and higher percentages of herb pollen (ca. 50%). In the upper part (3.5 ~ 2.1 m, 22.1–16.3 ka) tree pollen increases to 80%, while herb pollen decreases to 20% and ferns rise continuously to 200% (Fig. 5).

Phytoliths were analyzed at 10 cm intervals in the core section between 190 and 390 cm (14.18–24 $^{14}C$ ka, the last deglaciation and the LGM) (Table 3).

From various morphological groups of phytoliths, we can recognize only a few taxa of plant, e.g. bamboo (bamboo type) and reed (fan type). Nevertheless, the different morphological types of phytoliths have been assigned to plants with certain ecological features. For example, plants producing phytoliths of stick type, needle type and saddle type are associated with dry conditions, whereas phytoliths of fan type, dumbbell type, square to rectangle type and bamboo type are related to plants usually growing in humid environments. Therefore, the abundance ratio of dry/humid types of phytoliths can be used to indicate climate conditions (Lue and Liu, 1999; Fredlund and Tieszen, 1997; GPWG, 2001).

Similarly, phytoliths can also be separated into cool and warm climate types: the former mainly including stick and point types, and the latter including fan, dumbbell, rectangle and saddle types (Fredlund and Tieszen, 1997; GPWG, 2001).

In our case, the ratios of cold to warm phytoliths in the last deglaciation samples (190 cm to 240 cm; 14.18 to16.50 $^{14}C$ ka) were lower (0.65 to 0.9, average 0.8) than those of the LGM (240 cm to 390 cm; 16.50 to 23.46 $^{14}C$ ka) (0.80 ~ 2.11, average 1.33). This may imply that the temperature was lower during the LGM than that in the early stage of the last deglaciation.

In terms of humidity, the ratio of dry to humid phytoliths ranges from 0.64 to 0.92, averaging 0.79 (Table 3) in the last deglaciation (14.18 to16.50 $^{14}C$ ka), which is significantly lower than those (0.75–2.09, averaging 1.3) in the LGM (16.50 ka to 23.46 $^{14}C$ ka). This may suggest a relatively drier climate during the LGM than that during the last deglaciation, but the significance of our phytolith results should not be overestimated because all the observations are based only on one and the same herb family Poaceae.

The organic carbon isotopes analysis shows $\delta^{13}C$ values of −27 to −24‰ during the LGM, as compared to −25 to −27‰ during the deglaciation (Fig. 3C). This subtle change is in line with the insignificant decrease of herb pollen from the LGM to the deglaciation (Fig. 5).

## 5. Discussion

In this study we focused on the climate and vegetation of the Sunda Shelf during the LGM. The percentages of fern spores were much higher during the LGM than those in the other periods in all three cores (SO 18300, 18323, 18302), whereas the percentages of herb pollen were generally higher than those in the MIS 3 and deglaciation. It is crucial to know where these pollen grains and spores came from and what kind of vegetation and environment were represented by the pollen assemblages. During the LGM the three study sites were situated in the river valley, and should have two pollen source areas. One was local, i.e. from the vegetation growing around the studied sites in the paleo-river valley, and another one was regional, i.e. from the vegetation distributed over the Sunda Land.

### 5.1. Pollen and vegetation

In the LGM pollen assemblages, the herb pollen is composed of a variety of taxa but only those of Poaceae and Cyperaceae with significant numbers are counted. We have already mentioned that pollen types of Cyperaceae are usually assigned to swamp plants. According to the phytolith analysis a large number of Poaceae usually inhabit swamps or wet places, e.g. bamboo and reed. Since herbs are usually much smaller than trees, dispersal ability of herb pollen grains is much weaker. Therefore, a large amount of herb pollen grains indicates a local vegetation.

Most ferns are distributed in humid places. Their spores are usually larger in size than pollen grains of trees and herbs, and hence are transported mainly by water. Extremely large proportions of fern spores including tree fern (mainly *Cyathea*) in the pollen assemblages imply a vegetation prevailed by ferns.

According to pollen dispersal ability, herb pollen and fern spores in the assemblages are most likely generated from the old river valley, and indicate the vegetation in the valley. In other words, the deep valley along the river was occupied by swamp grass vegetation. This is also supported by the marsh and swamp sediments deposited during the LGM in the area (Hanebuth et al., 2000). In the river valley, a large

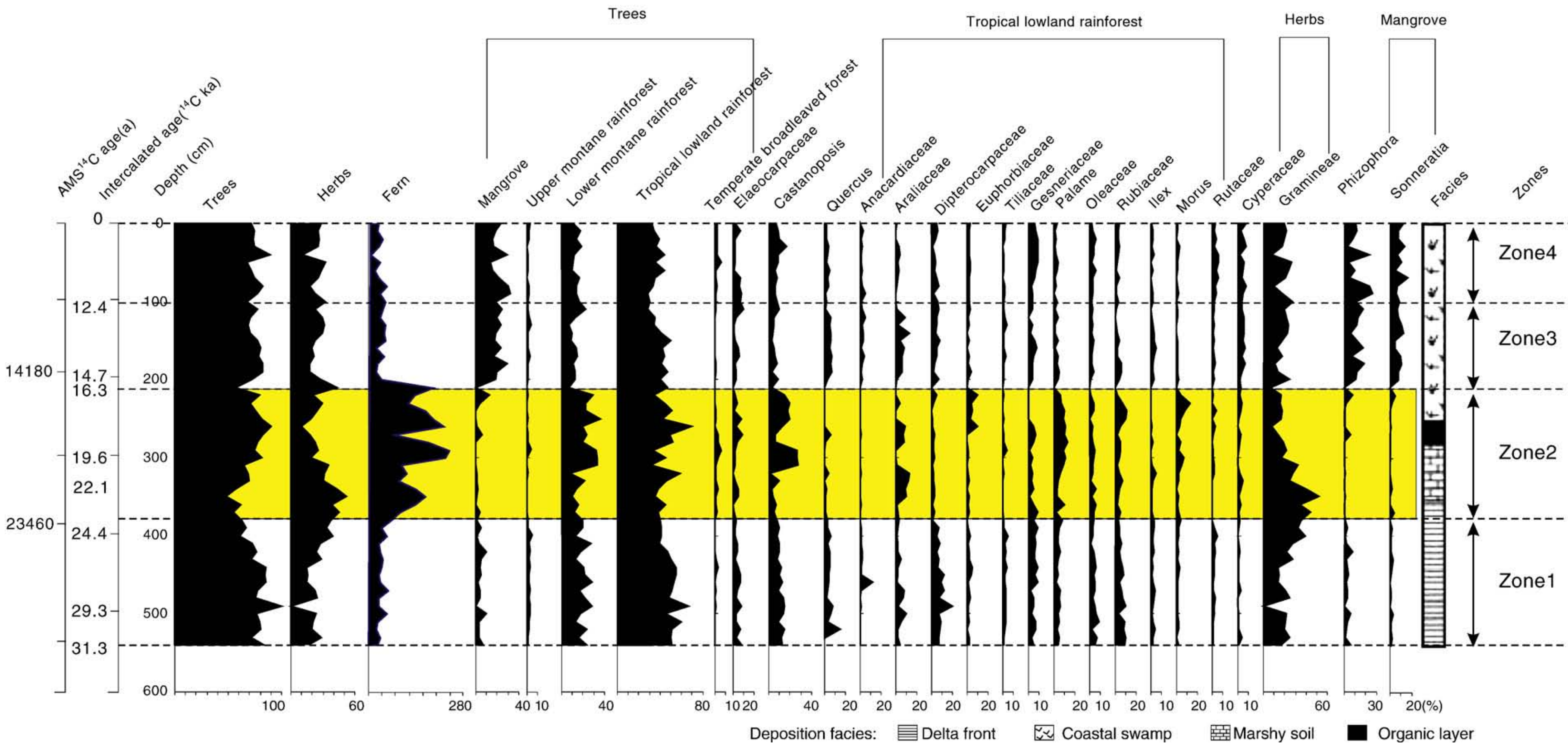


**Fig. 5.** Pollen percentage diagram of SO18323 (shadow shows the LGM). The percentages of each group and of individual taxa were calculated on the total pollen sum of land seed plants.

number and a variety of ferns, including tree ferns, and some hygrophilous trees, like palms, probably also flourished there. Likely, it was humid and warm in the river valley to maintain such vegetation.

In the pollen assemblages, tree pollen percentages usually fluctuate between 50% and 80%. Where should be the source areas of these tree pollen grains? The answer to this question may lie in the pollen results from the continental slope, such as those from cores SO 17962 and SO 17964 (see Fig. 1 for locations) analyzed several years before (Li and Sun, 1999; Sun et al., 2000, 2002) (see below).

### 5.2. Slope and shelf

In the two profiles from the slope (17962 and 17964), the LGM spans ca. 22 ka to 16 ka. Surprisingly, the pollen records of the LGM from the continental slope and from shelf localities are very different. The pollen assemblages of SO17962 (7°11' N, 112°12' E, water depth 1968 m) and SO17964 (6°9.5' N, 112°12.8' E, water depth 1556 m) at the LGM are dominated by tree pollen (ca. 80%). Herb pollen accounts only ca.20%, and fern spores make up no more than half of the total pollen sum. Lowland rainforest taxa such as *Trema*, Rutaceae, Palmae, *Calamus*, *Ilex*, *Mallotus*/*Macaranga*, Meliaceae, Dipterocarpaceae and Anacardiaceae dominate the tree group. Pollen from lower montane rainforests, mainly *Castanopsis*, *Quercus*, Elaeocarpaceae and Myrtaceae, is relatively abundant. Pollen of upper montane rainforests reached its maximum in Core 17964. Moreover, the absolute numbers of pollen grains (pollen influx) are very high, ca. 10 times more than those in the Holocene, suggesting that large amounts of pollen grains were transported onto the continental slope during the LGM. All these results are in a sharp contrast to the LGM pollen assemblages from cores on shelf as described above. Why are there such large differences between the shelf and slope pollen records of the same ages? It seems that the differences can be ascribed to the pollen source areas and the geomorphologic positions of the pollen sites.

At the LGM, the pollen source areas for the continental slope sites were much more enlarged due to the exposure of the shelf. Today and throughout the late Holocene, the southern islands were almost the only pollen source areas. By contrast, at the LGM, the exposed shelf, if covered by vegetation, would have been a more important pollen source area. A study on transport of sediments to the SCS during the MIS 3 showed that 93% to 95% of sediments were brought in by rivers, but only 2% to 5% by air (Hu, 2002). Pollen grains are just like sediment particles, and fluvial transport may be the main mechanism of pollen dispersal in the SCS. The Paleo-Sunda River, with its large catchments on Sunda Land, drained to the continental slope, near the sites of SO 17964 and SO 17962, with large amounts of sediments and pollen grains. Therefore, most tree pollen grains in the pollen assemblages should have come from the exposed Sunda Land. As a result, these sites could have received a great amount of pollen from the large area of the exposed Sunda shelf by fluvial transport. Consequently, the recovered pollen assemblages during the LGM may reflect the regional vegetation cover on shelf about 16 ka ago.

### 5.3. Vegetation and climate

From the above discussion, we can speculate that, during the LGM, lowland rain forests and lower montane rainforests covered the exposed shelf, and the upper montane rainforest periodically migrated down slopes of the southern islands. In the valley along the North Sunda River developed marshes where wetland plants grew, e.g., plants of sedges, reeds, bamboo, etc. Around these marshes grew a variety of ferns including tree ferns (*Cyathea*), and palms. The high values for fern spores might indicate a cooler climate at that period, “as ferns are often better represented in submontane than lowland forest (Anshari et al., 2004).” As to the humidity, the analyses of pollen and the phytoliths provide slightly different answers. No decrease in humidity during the LGM can be inferred from the pollen records predominated by rainforest and ferns, whereas the ratios of the dry/humid phytoliths from core 18323 indicate relatively drier conditions during the LGM than in the early stage of deglaciation and probably today (Table 3). However, as already mentioned, these results are based on only one, although important family (Poaceae) from the herb group. Since the present climate of the area is extremely humid, “there could be a decrease in the total precipitation which the area receives, without there necessarily being any recognizable effect on vegetation” (Newsome and Flenley, 1988). This observation is similar to that in west Kalimantan where rainforest still retained during the LGM, as the decline in precipitation was not sufficient to open up the forest canopy and allow grassland establishment (Anshari et al., 2004; Kershaw et al., 2007). At the same time, the extensive shelf in the southeast Asia-Sahul Shelf and northeastern Australia was covered by grassy and shrub vegetation indicative of a dry environment (Van der Kaars, 1991; Kershaw, 1986; Kershaw et al., 1993). Why such a big

**Table 3**
The LGM phytolith morphological types in Core SO18323.

| Inter-polated ages ($^{14}$C ka) | Depth (cm) | Phytolith type | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Needle type | Stick type | Saddle type | Total dry type | Fan type | Square, rectangle type | Bamboo type | Dumbbell type | Total humid type | Dry / humid | cold/ warm |
| 14.18 | 190 | 21.8% | 0.2% | 0.0% | 22.0% | 6.6% | 19.2% | 0.7% | 0.0% | 26.5% | 0.83 | 0.85 |
| 14.64 | 200 | 11.4% | 10.2% | 0.0% | 21.5% | 9.7% | 16.3% | 0.7% | 0.0% | 26.7% | 0.81 | 0.83 |
| 15.11 | 210 | 5.0% | 14.6% | 0.0% | 19.6% | 7.4% | 20.7% | 0.0% | 0.0% | 28.1% | 0.70 | 0.70 |
| 15.57 | 220 | 5.4% | 17.7% | 0.2% | 23.4% | 9.2% | 15.8% | 0.0% | 0.5% | 25.5% | 0.92 | 0.90 |
| 16.04 | 230 | 6.0% | 12.9% | 0.0% | 18.9% | 10.8% | 18.4% | 0.3% | 0.0% | 29.4% | 0.64 | 0.65 |
| 16.50 | 240 | 13.7% | 8.6% | 0.0% | 22.3% | 9.4% | 15.9% | 0.6% | 0.0% | 26.0% | 0.86 | 0.88 |
| 16.96 | 250 | 12.1% | 12.1% | 0.3% | 24.5% | 6.5% | 16.8% | 0.0% | 0.3% | 23.5% | 1.04 | 1.02 |
| 17.43 | 260 | 11.7% | 16.5% | 0.0% | 28.2% | 5.2% | 14.2% | 0.2% | 0.0% | 19.6% | 1.44 | 1.45 |
| 17.89 | 270 | 12.2% | 18.1% | 0.5% | 30.8% | 4.1% | 11.6% | 0.5% | 0.0% | 16.2% | 1.90 | 1.87 |
| 18.36 | 280 | 10.2% | 16.6% | 0.0% | 26.8% | 5.2% | 13.9% | 0.0% | 0.7% | 19.8% | 1.35 | 1.35 |
| 18.82 | 290 | 15.8% | 11.6% | 0.0% | 27.3% | 9.0% | 10.6% | 0.8% | 0.0% | 20.4% | 1.34 | 1.39 |
| 19.28 | 300 | 19.2% | 10.0% | 0.0% | 29.2% | 6.6% | 11.7% | 0.5% | 0.0% | 18.8% | 1.56 | 1.60 |
| 19.75 | 310 | 23.1% | 9.0% | 0.2% | 32.3% | 3.9% | 10.6% | 0.5% | 0.5% | 15.5% | 2.09 | 2.11 |
| 20.21 | 320 | 22.0% | 9.3% | 0.3% | 31.6% | 3.7% | 11.9% | 1.1% | 0.0% | 16.7% | 1.90 | 1.98 |
| 20.68 | 330 | 17.3% | 8.4% | 0.0% | 25.8% | 5.2% | 14.2% | 1.6% | 0.0% | 21.0% | 1.23 | 1.33 |
| 21.14 | 340 | 14.4% | 6.4% | 0.0% | 20.7% | 9.2% | 16.6% | 1.4% | 0.2% | 27.5% | 0.75 | 0.80 |
| 21.60 | 350 | 19.3% | 4.8% | 0.0% | 24.1% | 6.2% | 15.7% | 1.2% | 0.0% | 23.1% | 1.04 | 1.10 |
| 22.07 | 360 | 20.2% | 3.2% | 0.0% | 23.4% | 7.2% | 16.2% | 0.6% | 0.0% | 24.0% | 0.98 | 1.00 |
| 22.53 | 370 | 15.1% | 6.0% | 0.4% | 21.5% | 5.8% | 19.3% | 0.9% | 0.0% | 26.0% | 0.83 | 0.83 |
| 23.00 | 380 | 14.9% | 6.4% | 0.2% | 21.5% | 7.5% | 17.1% | 1.1% | 0.0% | 25.7% | 0.84 | 0.86 |
| 3.46 | 390 | 19.3% | 6.2% | 0.1% | 25.7% | 9.5% | 10.3% | 1.2% | 0.7% | 21.7% | 1.18 | 1.24 |

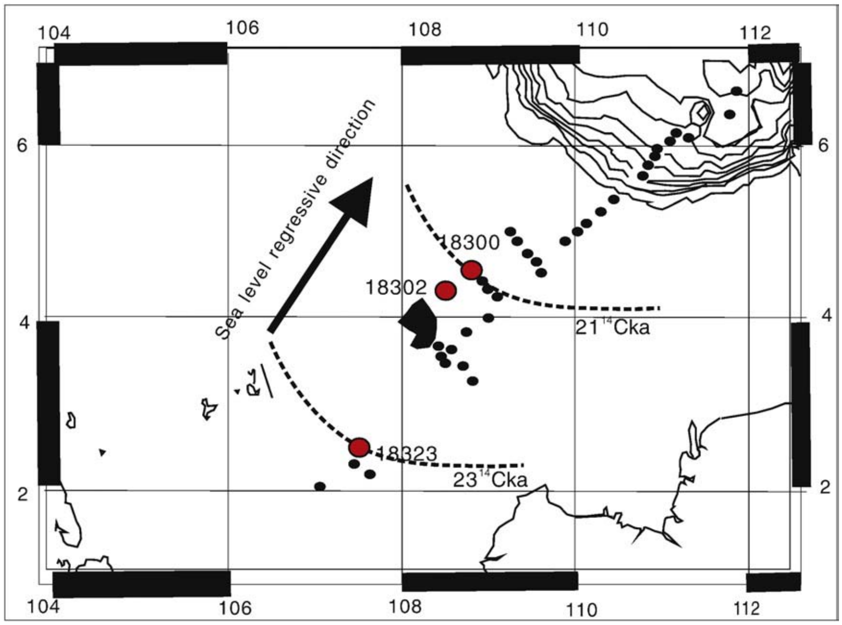


**Fig. 6.** Coastline migration indicated by mangrove pollen. Dotted lines denote paleo-coastlines, arrow shows direction of regression.

contrast in vegetation and climate between the two neighboring regions?

The Sunda and Sahul are two largest low-latitude continental shelves in the modern world, separated by the Equator and by chains of highly mountainous islands. The observed contrast between the Sunda and Sahul shelves during the LGM can be speculatively accounted for by one of two factors: either by the orographic effects of the island mountains blocking the vapor transport from the sea (Sun et al., 2000), or by the out-of-phase monsoon response to the precession forcing between the Northern (Sunda Shelf) and Southern (Sahuls Shelf) Hemispheres (Wang, 2009). Further work including climate modeling is required to find the final answer to this extremely interesting question.

### *5.4. Mangrove and coast line*

Mangroves thrive in silt-rich and brackish water environments along tropical coasts and they are usually near river estuaries, particularly along the coast of the Malaysian Peninsula and adjacent islands (Grindrod, 1988). Therefore, mangroves are a good indicator of coast lines. The sudden and significant decrease or even disappearance of mangrove pollen at the LGM in the pollen profiles should indicate the process of sea level lowering, the coast line migration, and emergence of the Sunda Shelf from the sea water. Based on the abrupt decreasing or disappearance of the mangrove pollen in these pollen profiles we can roughly identify the coast line location around or outside SO 18323, i.e. the southeastern part of the shelf, at ca.23 ka, and beyond this site the land was exposed. The coast line had migrated to SO18300 at ca. 21 ka, near the river mouth of the Paleo-Northern Sunda River, implying a complete exposure of almost the entire Sunda Shelf (Fig. 6).

## 6. Conclusions

Based on the pollen, phytolith and carbon isotope data of sedimentation cores from old Sunda Land and from the continental slope, it is found that during the LGM in the valley of the Northern Sunda River, land vegetation grew with swamp and wet land vegetation from sedges, reeds, bamboos, ferns and palms etc. At the same time the Sunda Land, exposed Sunda Shelf, was covered mainly with lowland rainforests and some lower montane rainforests. Both pollen and phytolith data imply that the LGM was cooler than present day, but remained quite humid. A great decrease of humidity was not recognized, but a slightly lower precipitation, as indicated by phytolith data, is not excluded. Since the present climate is extremely humid, a slight decrease in total precipitation during the LGM in some areas may not necessarily be recognizable at all.

Judging from the sudden fall or disappearance of mangrove pollen, the coast line migrated to near the location of core SO 18323 at ca. 23 ka, and almost the whole Sunda Shelf was exposed at around 21 ka.

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