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A First Tentative Holocene Sea-Level Curve for Singapore

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ABSTRACT

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A Holocene sea level curve for Singapore is presented. Radiocarbon dating of a variety of shell, wood, peat and coral material is utilised to derive the curve. Most of the dated material comes from a low energy, "quietwater" estuarine environment at Sungei Nipah, and the remainder from the tops of relict *Porites* coral bommies at Pulau Semakau. Determination of the curve takes into consideration the environmental factors and conditions that determined the elevation range of the material dated. The tentative results indicate that the Holocene Post-Glacial Marine Transgression reached present mean sea level around 6,500 to 7,000 years BP, rose to nearly 3m above present, and began to fall to present MSL around 3000 or less years ago. A comparison of the proposed sea-level curve with the curve for Peninsular Malaysia indicates that the highest mid-Holocene sea level may have been closer to +3m rather than +5m.

ADDITIONAL INDEX WORDS: *Sea-level change, coral bommies, marine transgression.*

INTRODUCTION

This paper presents a Holocene sea-level curve for Singapore. While there are Holocene sea-level curves for nearby peninsular Malaysia (*e.g.* GEYH *et al.*, 1979; STREIF, 1979; TJIA *et al.*, 1975, 1977, 1983; TJIA, 1992; TJIA and FUJI, 1992) and neighbouring countries in South-East Asia (*e.g.* SINSAKUL, 1992), the applicability of these to Singapore has never been tested. In addition, the data utilised to derive the regional sea-level curves comes from a wide variety of sources and materials and may suffer from surveying errors and, in particular, difficulties in determining relatively accurate maximum and minimum vertical uncertainty ranges for dated material (*cf.* PIRAZZOLI, 1991).

GEOMORPHOLOGICAL BACKGROUND AND METHODS

The dated material utilised to construct the sea-level curve comes from two areas in Singapore, Sungei Nipah and Pulau Semakau. Sungei Nipah is a small fluvial and estuarine stream located on the southwestern shore of Singapore. Virtually the entire stream now flows within a concrete channel which was emplaced in 1985. The catchment is small, and was selected for study because parts of the surrounding valley have not yet been developed, thus allowing access for a drilling rig, and because there is a greater likelihood of preservation of sedimentary sequences in such low energy environments (Figure 1).

Wave energy at the adjacent coast is low to very low, and the region is outside the storm belts and therefore unaffected by storm surges except for squalls or "Sumatras" during the southwest monsoon (WONG, 1992). Tides are semi-diurnal, and the spring tide range is 2.5m (CHOU and CHIA, 1991).

A percussion drilling rig was utilised to extract relatively undisturbed cores from two sites in the Sungei Nipah valley (Figures 1 and 2). Detailed sampling was also carried out at a large construction excavation ("Glory Development") within the valley. Several hand augered holes were also drilled at various sites within the catchment to verify the spatial and vertical extent of sedimentary units. Radiocarbon dating was carried out on a variety of materials (peat, wood, shells) extracted from the cores and the construction site.

Pulau Semakau is one of the larger southern Islands of Singapore, lying approximately 8km south of the central southwest Singapore coast (Figure 1). The island is one of the few remaining relatively unmodified coral reefs in the region. It is approximately 2 km long and varies from 20 to 200 m wide. It has a core of deeply weathered sandstone, and comprises a subaerial, low sand flat, with a fringing coral reef on the west coast and an extensive intertidal mud flat and mangrove system on the east coast. The west coast reef flat forms a gently sloping intertidal platform 400–500 m wide that culminates in a subdued reef crest and steep reef slope. Scat-

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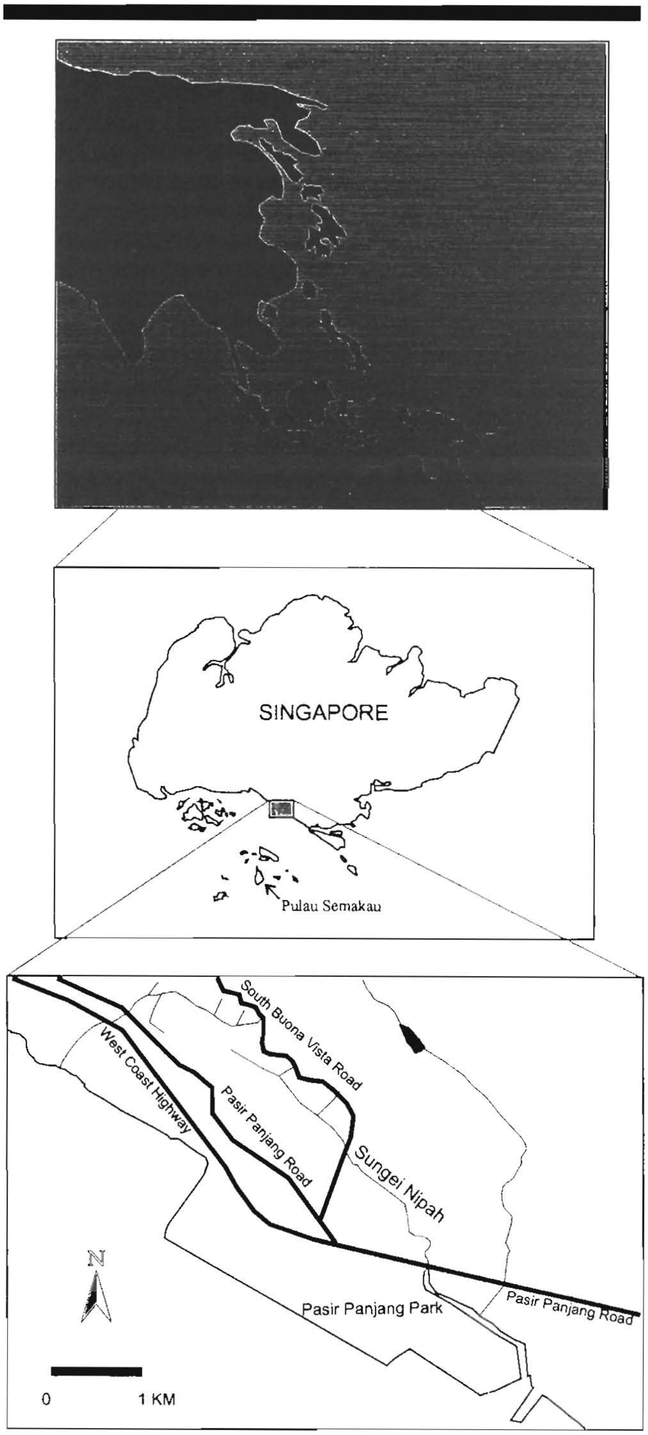

Figure 1. Location map of Singapore and southern islands, and the Sungei Nipah catchment.

tered boulder corals occur within 100–200 m of the reef crest, however, most coral growth is confined to the reef slope below the level of mean low water neap tides. This morphology is representative of Singapore patch and fringing reefs, and typical of low energy coasts of SE Asia (Type D reefs of MOHAMED and BARARUDDIN, 1991).

Along the eastern, sheltered coast of P Semakau, there is evidence of a former coral reef, now partly covered by mangroves and associated fine sediments. Scattered coral bommies of *Porites lutea* form conspicuous pinnacles that rise 1–1.6 m above the surrounding reef flat and are typically 1–1.5 m in diameter All have been eroded by karstification, resulting in the formation of a bowl-shaped depression and/or fragmentation, so that their living morphology is not immediately obvious. They are spherical in plan view and the internal structure is clearly evident and suggestive of unconstrained vertical and lateral accretion from a central core. It is probable, therefore, that they had rounded tops. Coral samples taken approximately 10 cm below the tops of these bommies were ^{14}C dated. The first, topmost 10 cm of coral was discarded to avoid contamination by modern marine organisms and remove karstified coral.

Dumpy levelling was carried out at both sites to determine elevations of the dated samples relative to present mean sea-level. In the case of S. Nipah, closed traverses were conducted, and all levels were cross-checked utilising two separate Survey Department benchmarks. Surveying errors were less than 3cm maximum. In the case of P. Semakau on which there is no SD benchmark, a series of surveys were carried out to determine mean seawater levels at various times and stages of the tide. These were correlated with SD accurate tidal elevations at nearby Pulau Sakeng. Survey errors are considered to be less than 5cm maximum.

THE SEA-LEVEL CURVE

The dates, type and depth of the various samples sent for radiocarbon dating are presented in Table 1

The proposed sea level curve for the southwestern coast of Singapore during the Holocene is shown in Figure 3. Note that an envelope curve is used to represent a range of mean sea level position related to the dates obtained. The general pattern of the sea level data is a rapid Postglacial Marine Transgression until about 6,500 years BP. The sea level then peaked at about +3m between 6,000 and 3,500 years BP and tapered to present levels thereafter.

ANALYSIS OF DATED MATERIAL AND CONSTRUCTION OF THE SEA LEVEL CURVE

There are three main factors that render the relation of the elevation of a dated deposit to a specific tidal datum difficult in this study. Firstly, the wide range of depths over which a given "quietwater facies" may accumulate, especially in subtidal muds, the most common environment of deposition in this environment. Secondly, the wide range of elevations above high water mark at which peat may accumulate, and thirdly, the uncertainty in assessing the degree to which dateable material is reworked (*cf.* THOM and ROY, 1983: 68). In the following we outline the methods utilised to assess the possible range of vertical growth or depositional positions of the dated samples.

An examination of the curve reveals that most data points (except for wood sample) have vertical uncertainty (error?) ranges defining the environmental range during deposition.

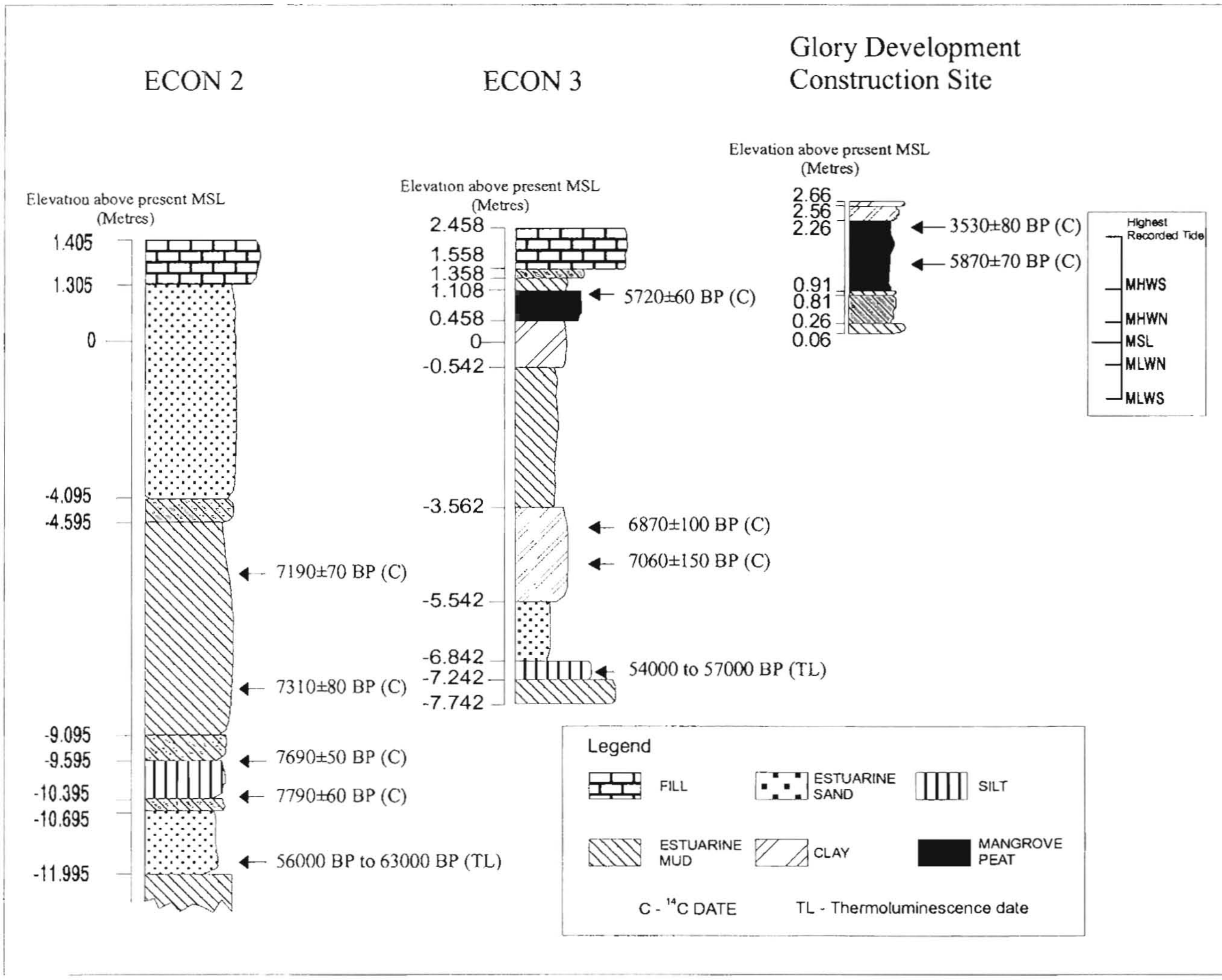

Figure 2. Sedimentology of the two drillholes and the construction site from which the ^{14}C dated samples utilised in this study have been extracted.

The ^{14}C standard deviation terms involved in dating have not been included as they are quite small (see Table 1).

PEAT SAMPLES

The "youngest" dated material are the peat samples from the "Glory Development" construction site and the Econ 3 drillhole which were found above present mean sea-level. The "Glory" site dates indicate the age of the top and the middle of the peat sequence, and the top of the peat at Econ 3. Within the "Glory" site peat, the remains of palm leaves were common and have been identified as *Nypa fruticans* (Nipah palms). *Nypa fruticans* grows extensively and best along banks of tidal rivers where the water is almost if not quite fresh at low tide (Watson, 1928: 92). According to ADIWIRYONO *et al.* (1984), in the mangrove forest of Tanjung Bungi, Nipah palms are never found below the low tide level (Adiwiryono et al., 1984: 243). Moreover, MACNAE (1968) suggested that Nipah palms grow extensively in regions flooded by the highest spring tides (MACNAE, 1968: 97).

From published surveys of mangals in which Nipah palms occur (*e.g.* WATSON, 1928; ADIWIRYONO *et al.*, 1984; MACNAE, 1968) and observations in Malaysian mangrove swamps, we believe that it is reasonable to place the vertical range of *Nypa fruticans* and the peat surface associated with it at between the highest spring tide and the low neap tide. For the construction of the curve, the Mean High Water Springs (MHWS) and the Mean Low Water Neap (MLWN), at 1.1 m above MSL and 0.5 m below MSL respectively, were used to determine the possible positions of the sea level associated with the Nipah peat deposits. Supposing that the Nipah peat was deposited at its lowest elevation limit (*i.e.* the Nipah palms were growing on the peat surface), the sea-level must be, at most, 0.5 m above the peat. Similarly, the sea level would be, at most, 1.1 m below the peat when they were deposited at MHWS. This explains the range used in Figure 3.

Table 1. *Results of radiocarbon dating.*

Lab. No.	Depth of Sample in Core Relative to MSL (metres)	Material Dated	¹⁴C Date (B.P.) (Conventional age)
		ECON 2	
BETA 78259	−5.595	Whole Oyster (*Pinctada* sp.)	7,190 ± 70
BETA 78260	−8.795	Whole Oyster (*Pinctada* sp.)	7,310 ± 80
BETA 78261	−9.595	Shell (*Anadara* sp.)	7,690 ± 50
BETA 78262	−10.395 to −10.495	Wood fragments	7,790 ± 60
		ECON 3	
BETA 78265	−3.562 to −4.062	Whole shells (*Batillaria zonalis* and *Marcia japonica*)	6,870 ± 100
BETA 78267	−4.542	Whole shells (*Batillaria zonalis* and *Marcia japonica*	7,060 ± 150
BETA 80795	+1.108	Peat	5,720 ± 60
		GLORY DEVELOPMENT CONSTRUCTION SITE	
BETA 78268	+2.16	Peat	3,530 ± 80
BETA 78269	+1.36	Peat	5,870 ± 70
		PULAU SEMAKAU	
WK 3428	+0.55	*Porites lutea* coral	6,420 ± 60
WK 3429	+0.426	*Porites lutea* coral	6,270 ± 60
WK 3430	+0.011	*Porites lutea* coral	6,490 ± 60
WK 3431	+0.246	*Porites lutea* coral	6,510 ± 60

Another indication that the peat facies were probably deposited near sea level is the existence of a piece of wood with seagrass remains on it found between the two peat samples in the sequence at the construction site. This is interpreted as a piece of driftwood sunk into a seagrass bed.

In addition, we conducted a survey of long term local residents to ascertain the pre-channelization (pre-concrete channel) environment of the stream. The oral history reconstruction indicates that the site where peat was found was inhabitated by *Rhizophora* mangroves and *Nypa fruticans* in the

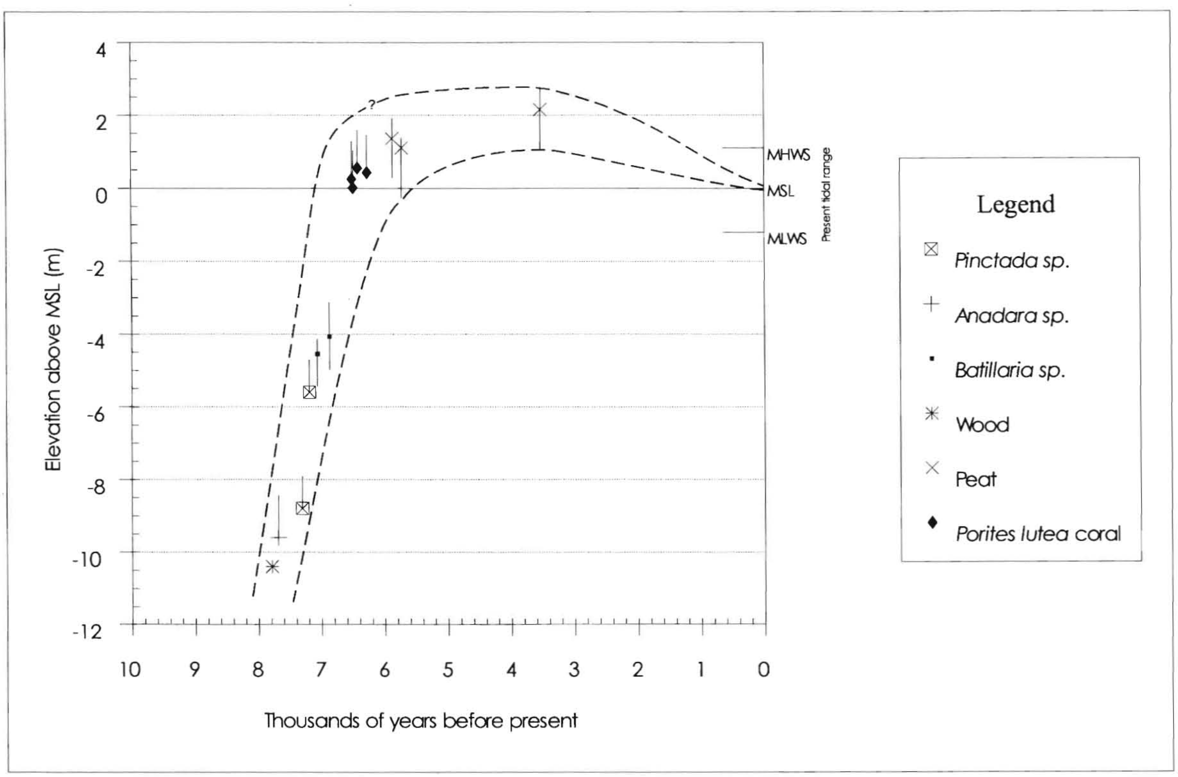

Figure 3. The tentative Holocene sea level range curve for Singapore. The vertical uncertainty ranges of the dated samples are indicated.

1930's. Cross-verification is available from Dr. D.H. Murphy (Zoology Dept., N.U.S., *personal communication*) who conducted mangrove surveys near the mouth of the estuary up to the 1980's. There is, therefore, a high possibility that there were Nipah palms and mangroves growing along the banks (where the construction site is now) during a higher mid-Holocene sea-level given that they are found at a lower sea level in the1930's. The naming of the stream as Sungei Nipah (the colloquial spelling of *Nypa*) is also instructive.

Compaction and/or elevation of the peats is possible. Many large peat swamps in the region form domal shapes (*e.g.* WHITMORE, 1990), elevated above the original formative MSL/water table levels. Equally, many peat swamps are subject to compaction (*e.g.* BLOOM, 1964). The peats examined in this study were overlaid by a maximum of around 60cm of muds. They were waterlogged and loose in section. We do not believe that there has been much compaction in these circumstances. We cannot ascertain if doming has taken place, although it is considered to be minimal given the relatively small areal extent of the original peat swamp.

CARBONATE SAMPLES

The set of next "older" dates are associated with the conical shells identified as *Batillaria zonalis* and *Marcia japonica*. A literature search only indicated that the shells commonly live on mud or soft sea beds in warm, brackish waters (LINDNER, 1979:46). In a field survey by the first author at another Singapore estuary, Sungei Api Api, *Batillaria zonalis* shells were observed to live between 40 cm above and 80 cm below MSL. Given the lack of information from the literature, the vertical limits observed in the field can at least be used to determine the minimum vertical range of this species assuming no post-death transport. Furthermore, the field survey was conducted at an estuary of similar climatic and oceanographic setting as the study area. Assuming that the shells were deposited *in situ* at their highest possible elevation limit, the sea level could be at most 40 cm below the level where the shells were deposited. Similarly, the sea level was at most 80 cm above the shells when they were deposited at their lowest elevation limit. In this study, sample number BETA 78265 was dated over a range of 3.56 to 4.06 m below MSL. However, the problem of ascertaining whether the shells were deposited *in situ* or not, adds to the list of factors hindering the accurate reconstruction of sea level in this study.

The next older set of bivalve shells dated are whole oyster shells of the *Pinctada* genus. The samples were complete shells indicating little or no post-mortem transportation (REINECK and SINGH, 1975: 136). A search of this species' environmental range in the literature only indicated that the bivalve was often found on shallow sand to rock bottom conditions (ABBOTT, 1991:92). Again, the results of a field survey conducted by the first author at Sungei Api Api, revealed that the shell was not found above MSL and it was rarely found at greater depths than 40 to 80 cm below MSL. Taking 80 cm as the lowest possible elevation range, the sea level must be around 0.8 m above the shell when it was deposited *in situ* at its approximate lowest elevation limit.

In the case of *Anadara* species, ABBOTT (1991: 89) states only that it is found in sandy shallow seas. However, LIM (1965) conducted a detailed study of the genus *Anadara* in the Malay Peninsula and adjacent islands. Of 11 species studied the maximum vertical living range extended from HWST to infratidal. If the species was *A. cuneata,* as we suspect, then it typically grows within the intertidal zone between HWST and MSL. Since the shells collected were vertically inclined in the sediments they are likely to have suffered minimal transport.

PORITES LUTEA

The uppermost *Porites* corals forming the bommies at Pulau Semakau were erect forms which had not reached maximum growth positions. They were not at all mushroom shaped, did not display any signs of medium to long term exposure or bleaching and were therefore unlike micro-atolls (*cf.* WOODROFFE and McLEAN, 1990). In all probability, they were 'catch-up' corals which did not reach a maximum vertical growth position before the mid-Holocene sea-level fell. This makes it very difficult to determine a maximum vertical upper growth range.

Porites lutea is generally found on the reef flat, including the shoreward reaches of reef flats around Singapore (CHOU and CHIA, 1991). In Singapore waters, *Porites* grows to a maximum level dictacted by the mean low water springs, and has been recorded at a maximum depth of 9 m below MSL (CHOU and WONG, 1986). However, recent surveys on coral distribution conducted by the Department of Zoology suggest that the lower limit of this species does not extend more than 6 m below the reef crest.

HIGHSMITH (1979) reported *Porites* corals growing in water depths ranging from zero to at least 30 m at Enewetak. Mean annual growth rates ranged from 3.5 to 11.8 mm year^{-1} (mean 7.6 mm year^{-1}). WOODROFFE and McLEAN (1990) state that *Porites* grow rapidly in subtidal situations and are limited in upward growth by the level of the low spring tide (MLWS). SCOFFIN *et al.* (1992) found that vertical growth, or linear extension rates of *Porites* in southern Thailand ranged from 1.5 to 3.45 cm year^{-1} for modern corals. They reported that the extension rates decreased with increasing hydraulic energy, and that these sites were inshore sheltered sites with high turbidity.

The Pulau Semakau *Porites* sites are sheltered, low energy, inshore sites. Mud flat and mangrove development probably took place after the mid-Holocene sea level began to fall, so the waters in the area may not have been particularly turbid during coral growth. The rate of mid-Holocene sea-level rise from 7,000 to 6,500 years BP (-4 m to 0 m MSL) indicated on Figure 3 is 0.8 cm year^{-1}. If we are conservative and take the lowest vertical linear growth rates of 1.5 cm year^{-1} reported by SCOFFIN *et al.* (1992) we find that the *Porites* could potentially easily have kept up with the rate of sea-level rise. If we take the mean growth rate indicated by HIGHSMITH (1979) of 0.76 cm year^{-1} coral growth would have lagged behind the rate of sea-level rise by only 0.04 cm year^{-1}. This indicates (if correct) that the corals would have been 20 cm below MLWS when the marine transgression reached present MSL. This assumes several things not least of which is that

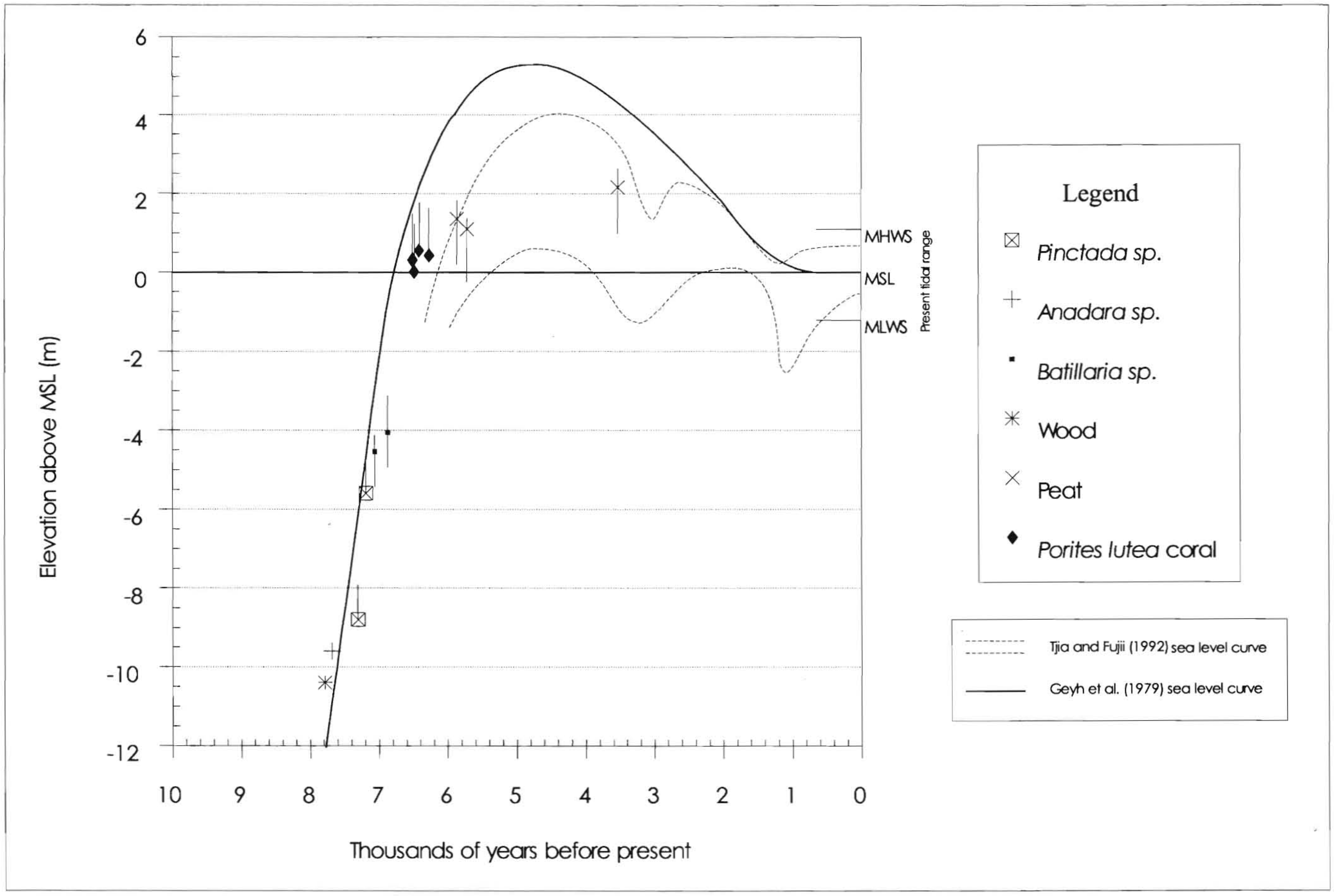

Figure 4. Comparison of the Holocene sea level data presented in this study and previous curves from Geyh *et al.* (1979) and Tjia and Fujii (1992).

the corals were at 4 m water depth when the marine transgression MSL was at 4 m.

The lowest that the MSL could have been is therefore around +1.7m, the height required to satisfy the condition that *Porites* could not grow above the MLWS level. We can add 0.2 m to this to obtain a rough indication of the position of MSL if the corals were growing at the lowest rate reported by HIGHSMITH (1989). The highest MSL above the top of the corals possible cannot be readily determined and is open to speculation.

A COMPARISON WITH EXISTING SEA-LEVEL CURVES IN THE REGION

Figure 4 illustrates the various ^{14}C dates and their ranges found in this study plotted against the GEYH *et al.* (1979) and TJIA and FUJII (1992) sea level curves for the Straits of Malacca and Peninsular Malaysia. TJIA and FUJI's (1992) curve has two sea level highs at around 4,500 and 2,500 years (*cf.* TJIA, 1992). The first high sea-level event was up to 4 metres above present according to TJIA and FUJII (1992: 40). However, their original data displays a large scatter (hence the wide range of sea level indicated) and their interpretation of the data to create their curve is open to question. The GEYH *et al.* (1979) curve indicates a maximum mid-Holocene sea level of +5 m. These dates are based on peat deposits which appear to have been compacted, the amount of compaction apparently estimated at +5.5 m. This estimate was based on the "level of a marine abrasional platform on weathered granite" (1979: 442). Since the age of abrasion is unknown, this estimation of peat compaction and their assumed maximum sea-level heights must be regarded with caution. In addition, there are likely to be regional differences in the hydro-isostatic responses of different parts of the continental shelves and straits in the region to water loading during the PMT, and direct comparison of curves between places in the region may therefore be difficult. GEYH *et al.* (1979) show a smoothly falling sea level but state that they are unable to determine whether sea level fell smoothly or in an oscillatory manner.

The data collected in this study, indicates that sea level was at most 2.5 to 3 metres above present levels, although we have a limited number of data points in the age range 5,000 to 1,000 years BP. Aerial photographic mapping and field examination of various sites does not indicate any higher sea-level related landforms above +3 m in the Sungei Nipah valley or on the adjacent coast. Earlier detailed geomorphological surveys by SWAN (1971), conducted at a time prior to large scale land development, and now near impossible to repeat due to destruction by development, indicate that presumed Holocene emerged coastal landforms indicating higher sea levels were not higher than around 3 m. Until further dates become available, we are inclined to take a conservative stance and suggest that sea level probably fell smoothly from around 5000 years BP rather than irregularly or in an oscillatory manner, as indicated by more detailed studies elsewhere (*e.g.* THOM and ROY, 1983; CHAPPELL, 1987).

CONCLUSION

This reconstruction of the sea level history for Singapore must remain tentative until further dates are available for the last 6,000 years, and for dates from which a maximum vertical uncertainty range can be determined. The basic pattern is a rapid Postglacial Marine Transgression rising to present mean sea level at 6,500 BP. Sea level then rose to around 3 m above present, tapering to present levels from around 1,000 to 2,000 years BP. Given the shallowness of the surrounding shelf in the Singapore/Malaysia/Indonesian region, the sea levels indicated are probably compatible with a hydro-isostatic deformational response to an increasing water loading as the PMT took place (*cf.* CHAPPELL *et al.,* 1982).

The need to identify facies which can be tied to modern datums and thus to reproduce an unambiguous record of sea level fluctuations is difficult. In particular, there is a lack of information in the literature regarding the environmental ranges of the various facies and samples used for dating, and there is the problem of ascertaining if the shell samples were deposited *in situ.*

In conclusion, although the data conforms in general, but only in part with earlier findings in the region by TJIA and FUJII (1992) and elsewhere (*e.g.* CHAPPELL, 1987), the sea level curve presented here must be regarded as tentative and an approximation at best.

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