### Late Cenozoic relative sea-level highstand record from Peninsular Malaysia and Malaysian Borneo: Implications for vertical crustal movements

PETER R. PARHAM

Southeast Asia Disaster Prevention Research Initiative Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor Email address: drpeterparham@gmail.com

Abstract: In order to predict the manner in which global sea-level change will impact the wide variety of coastal conditions and communities in Malaysia, this study sought to gain insight into the vertical components that determine the relationship between the coastal land areas of Malaysia and changes in sea level over time periods of 10<sup>6</sup> to 10<sup>2</sup> years. This was a regional-scale, reconnaissance-level field survey of the Malaysian coasts, coastal plains, most islands and many river systems to determine the presence, absence and spatial variability of evidence for late Pliocene-Quaternary sea level(s) higher than present. In Peninsular Malaysia, no conclusive evidence was found to indicate that RSL was ever higher than the mid-Holocene maximum during the late Cenozoic. This indicates long-term (10<sup>4</sup> to 10<sup>6</sup> yrs) subsidence for at least the coastal parts of the region. Superimposed on this long-term subsidence are eustatic rise and continental levering associated with hydro-isostatic adjustment (HIA) over time scales of 10<sup>2</sup> to 10<sup>3</sup> yrs. In areas where HIA appears to be in equilibrium (e.g. NE Peninsular Malaysia), long-term subsidence and eustatic rise are the dominant factors influencing RSL change, resulting in increased flooding and coastal erosion. These detrimental effects are commonly exacerbated by anthropogenic activities. Along much of the remainder of the Peninsular Malaysia coast, uplift associated with HIA appears to continue, counterbalancing eustatic rise and resulting in little net change in RSL. This, in tandem with abundant sediment supply, has resulted in generally prograding coasts in areas minimally influenced by anthropogenic modifications. The RSL record of Malaysian Borneo is much more complex, even in western Sarawak, which is situated on supposedly stable Sundaland. Possible strandplain deposits overlying coarse alluvium in the Kuching area could reflect last interglacial highstand deposition but more likely result from uplift or eolian reworking of alluvial deposits. This alluvium, along with similar deposits associated with the Kayan and Rajang rivers, clearly represents deposition under very different environmental conditions than present. Ongoing subsidence of the peatland-dominated coastal plain, from Kuching to Bintulu, is probably mainly due to sediment loading. North of the Lupar Line, RSL histories are mainly the product of tectonism and differential movement of the upper crust. The coast and interior from Bintulu, Sarawak to Bongawan, Sabah, has undergone Quaternary uplift, probably episodic and differential, with the most recent uplift event in the Miri area during the early mid-Holocene. Relative vertical stability is suggested for mid-Holocene to present. Geomorphic indicators and lack of emergent RSL indicators along the western Sabah coast, north of Bongawan, suggest ongoing subsidence. The RSL record from eastern Sabah is exceedingly complex with, sometimes close-spaced, areas with different histories of movement over time scales of  $10^1$  to  $10^6$  yrs.

Keywords: Malaysia, Sundaland, Borneo, Late Cenozoic, relative sea level, Quaternary, tectonics, paleo-environmental change, isostasy

### INTRODUCTION

Malaysia (Figure 1) is a predominantly coastal country with a vast array of associated infrastructure, livelihoods and ecosystems. All stand to be impacted by climate and sea-level change. Our understanding of these natural forces and the region's coastal response to past periods of climate and sea-level change is very limited. Predicting and preparing appropriate responses to future changes in climate and sea level is critical. One of the most important contributions geologists can make to Malaysia is to ascertain her status with respect to ongoing global sea-level change and make predictions of potential future sea-level change scenarios based on understanding of the past. This understanding will help enable Malaysia to anticipate and minimize the impact of future sea-level change. Much, if not most, of Malaysia's infrastructure is on the coastal plain. This coastal plain, as we know it today, did not exist 7 thousand years ago (ka) during maximum Holocene transgression (Parham *et al.*, 2014a). It was constructed subsequently.

Rising eustatic sea level is expected to result in substantial shoreline erosion, land loss, flooding and ecosystem displacement throughout many coastal areas of the world (IPCC, 2001, 2007). However, a land area's relationship with long-term sea-level changes is not solely a function of eustasy. Depending on location, several other factors contribute variably to the vertical relationship between a land area and the sea. The interplay of these forcing factors determine the relative sea-level (RSL) status of an area. These factors include tectonism, isostasy, and steric effects. Tectonism can result in uplift or subsidence of portions of the earth's crust in response to plate movements. Isostasy can produce regional uplift or subsidence in response to loading or unloading of the Earth's crust with polar ice, seawater, sediment, etc. Steric effects reflect changes in sea level resulting from changes in seawater density related to ocean temperature, salinity and atmospheric pressure (Bryan, 1996). Of these, tectonism and isostasy have the greatest potential to substantially influence the RSL record of a region. Either, or both together, can accelerate, cancel out or reverse eustatic trends. It is critical that a nation understand the RSL status of its coasts in order to develop policy addressing future sea-level change, coastal maintenance and development, and disaster response.

The late Cenozoic era has been characterized by major shifts in climate and oscillations in eustatic sea level driven largely by variations in the Earth's Milankovich orbital parameters (Haq et al., 1987; Imbrie et al., 1989; Pillans et al., 1998; Zachos et al., 2001; Siddall et al., 2007). Global sea levels during portions of the late Neogene were at least 50 m above present (Haq et al., 1987; Miller et al., 2005; Lourens et al., 2010). The frequency of eustatic sea-level oscillations increased dramatically (ca. 1 sea-level cycle/40-120 ka) during the Quaternary (Pillans et al., 1998; Zachos et al., 2001) with sea-level lowstands extending >120 m (Fleming et al., 1998) below present mean sea level (MSL) and highstands reaching possibly as much as 20 m above (Hearty et al., 1999; Olson & Hearty, 2009; van Hengstrum et al., 2009). During the last interglacial (ca. 120 ka), global sea level was at least 6.6 m higher than today with a high probability that it was between 8 and 10 m higher (Kopp et al., 2009).

The last ca. 18 ka has been characterized by eustatic sea-level rise of over 120 m, largely in response to meltwater contributions from polar ice caps as climate changed from a full glacial mode to the present interglacial stage (Fleming *et al.*, 1998). In tectonically stable regions, post-last glacial maximum (LGM) RSL records vary considerably, depending on proximity to LGM ice sheet margins, and are mainly influenced by isostatic adjustment (e.g. Clark *et al.*, 1978; Peltier *et al.*, 1978; Peltier, 2002; Potter & Lambeck, 2003) (Figure 2). In tectonically active regions, uplift can result in a falling RSL record (e.g. Chappell *et al.*, 1996) while subsidence results in increased submergence (e.g. Lambeck *et al.*, 2004).

Certain geomorphic and stratigraphic attributes serve as indicators of an area's RSL history. In areas that have been

uplifted (whether tectonic or isostatic), the geomorphology of the coastal plain consists of emergent marine terrace/scarp sets, each corresponding to different sea-level cycles that stair step down in elevation and decrease in age seaward and towards major drainages (Muhs et al., 2003) (Figure 3). Along stable coasts, this stair step geomorphology may also be present, but emergent marine terrace/scarp sets can only occur for eustatic sea-levels that were higher than present (Parham et al., 2012). Along both uplifted and stable coastal plains, emergent marine deposits associated with previous sea-level highstands are commonly exposed in stream cut banks and excavations. In areas that have experienced long-term subsidence through the late Cenozoic, deposits associated with pre-Holocene transgressions occur in the subsurface, below present sea level, as lithologicallysimilar stacked sequences that have been highly modified and truncated by subsequent transgressions (Riggs et al., 1992; Parham et al., 2007, 2012). They tend to show decreasing onlap of the continental margin with increasing age (Bhattacharya & Posamentier, 1994).

The late Cenozoic sea-level history of the Malaysia region (Figure 1) is poorly constrained. Most previous studies have focused on the sea-level record from the LGM lowstand (ca. 21 to 18 ka) until the present (e.g. Biswas, 1973; Geyh et al., 1979; Tjia, 1996; Hesp et al., 1998; Hanebuth et al., 2000, 2002, 2004, 2011; Kamaludin, 2003; Horton et al., 2005; Woodroffe & Horton, 2005; Bird et al., 2007, 2010, Tjia & Sharifah Mastura, 2013). However, the pre-LGM late Cenozoic sea-level history of this region is poorly documented. The goal of this study was to gain insight into the vertical components, uplift, subsidence or stability, that determine the relationship between the coasts of Malaysia and eustatic changes in sea level over 106 to 102 year time scales. This was a regional-scale, reconnaissance-level field survey of the Malaysian coasts, coastal plains, river systems and islands to determine the presence, absence and spatial variability of evidence for late Pliocene-Quaternary sea level(s) higher than present.

### **REGIONAL GEOLOGIC SETTING**

The Peninsular Malaysia and western Borneo portions of the study area (Figure 1) are situated within the Sundaland,



Figure 1: The study area included the coastal plains, islands and many of the river systems of Peninsular Malaysia, Sarawak, Labuan and Sabah. Highlights represent areas that were surveyed.

Bulletin of the Geological Society of Malaysia, Volume 62, December 2016



**Figure 2.** Map shows zones that have characteristic sea-level curve signatures (assuming tectonic stability) reflecting crustal responses to isostatic adjustment relative to proximity to LGM ice sheets (Clark *et al.*, 1978; Peltier *et al.*, 1978). Near-field locations (e. g. Ottawa Islands, Canada that were located beneath the LGM ice sheet) tend to show falling RSL since LGM because the rates of glacio-isostatic rebound exceed those of eustatic sea-level change. Intermediate-field locations (e. g. Georgia, USA) are dominated by flexure and relaxation of the glacio-isostatic forebulge and tend to show consistently rising RSL from LGM to present with decreased rates after ca. 5 ka in response to cessation of major meltwater inputs (Potter and Lambeck, 2003). Relative sea-level records from far-field locations (e. g. Sunda Shelf [Hanebuth *et al.*, 2011] and New Zealand) are dominated by continental levering associated with hydro-isostaty (Bradley *et al.*, 2016) because the glacio-isostatic signal is minimal at these distances from former ice sheet margins. Relative sea-level curves from far-field locations tend to peak above present mean sea level ca. 6 ka and then decrease towards present level.

a southern extension of the Eurasian continental plate (Hutchinson, 2007) (Figure 4).Very low seismicity rates suggest that Sundaland presently moves as a coherent lithospheric block (Simons *et al.*, 2007) and has generally been regarded as tectonically stable during the late Cenozoic (e.g. Ben-Avraham & Emery, 1973; Tjia, 1992,1996;

Hutchinson, 2007). This assumption of tectonic stability has been questioned by some researchers (e.g. Bird *et al.*, 2006; Hall, 2014). Northeast of the Lupar Line (Lupar River), considered the northern boundary of Sundaland on Borneo by Hutchison (2007), the geology of the remainder of Sarawak and Sabah is more complex and generally

Bulletin of the Geological Society of Malaysia, Volume 62, December 2016

PETER R. PARHAM







Figure 4: Plate tectonic setting for the Southeast Asian region showing the Sundaland extension of the Eurasian continental plate and sedimentary basins (dashed circles). Much of the study area (Figure 1) is situated within Sundaland. Portions of Sarawak and all of Sabah lie outside of Sundaland. Map from Hall & Morley (2004).

characterized by a basement of Mesozoic oceanic crust that was accreted to Sundaland during the Cretaceous, then overlain by thick Cenozoic sedimentary sequences (Hall & Morley, 2004; Hall et al., 2008). Uranium-series, electron spin resonance and paleomagnetic data from limestone notches indicate Quaternary uplift rates of ca. 20 cm/ka for portions of northeastern Sarawak (Farrant et al., 1995). Radiocarbon age data for marine terrace deposits along the northern Sarawak coast suggest uplift of ca. 20 m during the early to mid-Holocene which may be ongoing (Kessler & Jong, 2014a, b, 2015). The study region is bordered to the west, south and east by subduction and collision zones (Figure 4). To the north, Cenozoic deformation associated with the collision of India with Asia resulted in uplift of the Himalayas, major faulting in Thailand and Myanmar and undetermined influence on the tectonic evolution of Sundaland (Hall & Morley, 2004; Hall et al., 2008).

The Sunda Shelf (Figure 4) is the presently flooded portion of Sundaland. It is the second largest continental shelf in the world and has an average water depth of 70 m (Hanebuth *et al.*, 2002, 2011). Sundaland has been largely emergent or only shallowly submerged since the early Mesozoic (Hall *et al.*, 2008) even though eustatic sea levels were over 100 m above present through much of the Cretaceous and portions of the Paleocene and Eocene (Haq *et al.*, 1987; Miller *et al.*, 2005).

Sundaland sedimentary basin formation, resulting mainly from rifting and regional extension, began during the Eocene concomitant with northward movement of Australia and re-initiation of subduction along the Sunda Trench (Hall, 2009) (Figure 4). Relatively small onshore Tertiary basins of Peninsular Malaysia are restricted to the western side of the peninsula and are filled with terrestrial deposits (Raj *et al.*, 2009). Marine flooding of sedimentary basins

in, what is now, the Sunda Shelf and Straits of Malacca commenced in the late Oligocene to early Miocene (Azmi et al., 1996; Cole & Crittenden, 1997; Tan, 2009) and by the middle Miocene evidence of full marine conditions are observed in all basins (Hutchison, 2007). Subsequent oscillations in eustatic sea level resulted in periods of submergence and emergence with major unconformities associated with prolonged periods of emergence. Increasing persistence of widespread marine conditions from Miocene to present despite generally falling eustatic sea levels for the same period has been suggested as a dynamic topographic effect related to long-term subsidence (Lithgow-Bertelloni & Gurnis, 1997; Spasojevic & Gurnis, 2012) although subsidence during the Miocene had a tectonic origin (Hall, 2002; Hall & Morley, 2004). Tectonic-driven subsidence in Straits of Malacca sedimentary basins is indicated well into the Pleistocene (Koesoemadinata et al., 1995). Kudrass & Schluter (1994) suggest subsidence of the Peninsular Malaysia region based on litho- and seismostratigraphic patterns of Pleistocene sedimentary sequences in the Straits of Malacca. Bird et al. (2006) conclude that subsidence or down-warping enabled incision of the paleo-Johore River, in the Singapore area, to depths of ca. -90 m during Pleistocene sea-level lowstands.

The Pliocene to late Pleistocene sea-level record from the study area is poorly developed. There are no direct sea-level highstand data for this period (Haile, 1971, 1975; Hanebuth *et al.*, 2011). The stratigraphic record preserved offshore is relatively well developed, particularly for the late Quaternary. Unfortunately, maximum levels attained by previous transgressions of the sea can only be estimated based on offshore data. During the LGM, with sea level >120 m below present, the Sunda Shelf was emergent (e.g. Hanebuth & Statteggar, 2004) (Figure 5) with a defined drainage pattern, much of which represented down-stream extensions and confluences of present drainage systems (Molengraaff, 1921). It is presumed that drainage patterns during previous sea-level lowstands were similar and, with each succeeding sea-level cycle, river valleys backfilled and incised in response to changes in base level. Seismic data from the up to 86 m thick Pleistocene section of the Malay Basin (Figure 4) indicate fluvial styles ranging from wide braided systems to relatively narrow meander belts (Miall, 2002). Drainage systems of the emergent Sunda Shelf emptied into the lowstand South China Sea between Borneo and Indo-China to form the Molengraaff paleo-delta (Wong *et al.*, 2003) and drainage in the Straits of Malacca during the LGM was north into the ancestral Andaman Sea (Emmel & Curray, 1982).

Seismic evidence from the Molengraaff paleo-delta suggests deposition back to 570 ka with prograding wedges of deltaic sequences, each corresponding to successively younger lowstand depositional periods, and subsidence over the last 20 ka of ca. 50 m (Wong et al., 2003). Seismic, core and age data indicate that late Quaternary paleovalley deposits on the shelf are characterized by an upward succession from seaward prograding sandy clinoforms that accumulated during the general fall in sea level from 50 ka to LGM, soil formation and subaerial weathering during sea-level lowstand, rapidly backstepping peat-rich coastal deposits without stacking patterns associated with post-LGM transgression, and a thin marine-mud condensed section that marks the base of the Holocene highstand systems tract (Steinke et al., 2003; Hanebuth et al., 2002; Hanebuth & Stattegger, 2004; Hanebuth et al., 2011). An over 1 km thick Quaternary section preserved in the Baram Delta complex off the north coast of Borneo is interpreted to be the product of several glacial-interglacial sea-level cycles



Figure 5: Sea-level lowstand of >120 m below present during the last glacial maximum (LGM) resulted in subaerial exposure of the majority of the Sunda Shelf and a dramatic increase in the land area of Southeast Asia. Modified from Sathiamurthy & Voris (2006).

Bulletin of the Geological Society of Malaysia, Volume 62, December 2016

(Hiscott, 2001). Within sections from the inner continental shelf, laterite, lateritic wash and spherulitic siderite are commonly associated with the Holocene/Pleistocene contact (Biswas, 1973).

Over time, various names have been used for different late Cenozoic sedimentary units (Table 1). Deposits interpreted as Pleistocene marine occur in the subsurface nearshore and onshore Peninsular Malaysia but lack definitive age estimates and generally have not been approached from a sequence stratigraphic perspective. Shelly marine deposits (Kempadang Fm in Table 1) have been encountered below present sea level and underlying the basal Holocene contact in drill cores from the Lumut area, Perak coastal plain and northern portions of the Pahang delta (Suntharalingam, 1983; Suntharalingam & Ambak, 1986). A 10-20 m thick marine clay unit, containing fine shell fragments, occurs in the subsurface of the Singapore area and is extrapolated to represent accumulation during MIS 5 sea-level highstand (Bird et al., 2006). Thermoluminescence age analysis of quartz sand associated with mangrove deposits at ca. 11 m below present sea level at the Pantai Remis mine, Perak vielded estimates of ca. 67 ka and were correlated with the Kempadang Fm but since this age was considered questionable, the authors concluded that deposition probably occurred during MIS 5e (Kamaludin et al., 1993; Azmi & Kamaludin, 1997).

The Simpang Formation is interpreted as likely Pleistocene and considered equivalent to the Old Alluvium

and Boulder Beds (Table 1) of the Kinta Valley of Perak, Kuala Lumpur area, south Johor, and Singapore (e.g. Suntharalingum & Teoh, 1985; Yunus et al., 1991). It is broadly distributed on the Peninsular Malaysia coastal plain (Bosch, 1989) and is generally overlain or lapped onto by Holocene deposits. No evidence of marine influence has been observed in Simpang Fm sediments. In Johor and Singapore, the Simpang Fm ranges in vertical distribution from ca. -45 m to +69 m (Raj et al., 2009). Paleomagnetic analysis of the Boulder Beds and lower Old Alluvium indicates accumulation during the Matuyama Reversed Epoch (2.48 Ma to 730 ka) while the upper Old Alluvium (Transitional Unit in Table 1) accumulated under normal polarity conditions of the Brunhes Epoch (730 ka to present) (Batchelor, 1988). Teeuw et al. (1999) suggest a late Pleistocene age for the Old Alluvium on Peninsular Malaysia based on a ca. 76 ka OSL age estimate from the White Sands Complex, western Borneo which they correlate with the Old Alluvium. It seems likely that the Simpang Fm and its correlatives represent similar lithofacies and possibly depositional environments that were deposited at different times.

Evidence of higher than present pre-Holocene sea levels has mainly been reported from western Peninsular Malaysia (Figure 6). Radiocarbon age estimates for marine shells preserved at ca. +10 m elevation in a cave in the Kodiang Hills, northern Kedah ranged from ca. 27 to 21 ka (Tjia, 1996). Stacked notches occur at the same and

		Ofi	fshore Lumut-Dindings (1) (West Coast)	(2) Coastal Lowlands	(3) Kinta Valley	South China Sea <sup>(4)</sup> (East Coast)
HOLOCENE		ung Alluvium	Younger Sedimentary Cover DISCONFORMITY	Beruas Formation Gula Formation	Organic mud and peat Young Alluvium	•
PLEISTOCENE	Late	Уо	Alluvial Complex DISCONFORMITY Transitional Unit DISCONFORMITY			
	Middle	л т		Kempadang Formation Simpang Formation	Old Alluvium	
	Early	, Cover	Alluvial Plain Facies			l Pilong Formation
PLIOCENE	Late	Older Sedimentary	Piedmont Fan Facies (Boulder Beds/ GraniteWash)	<b>X X X X</b>	Boulder Beds ???	
	Early	к	Sundaland Regolith			
LATE MIOCENE		0	$\checkmark$			Y

**Table 1:** Correlation chart for variously named late Cenozoic sedimentary units of Peninsular Malaysia (from Yunus *et al.*, 1991). Sources: (1) Batchelor (1979), (2) Suntharalingam & Teoh (1985), (3) Walker (1956), (4) Du Bois (1985).



Figure 6: Map of Peninsular Malaysia showing localities where possible evidence for pre-Holocene sea-level highstands has been reported.

lower elevations in the limestone of the Kodiang Hills. Tjia (1996) suggests geoidal changes as possibly responsible for marine deposition at this high elevation at a time when global records indicate that sea-level was no higher than -60 m (Lambeck et al., 2002). In the Seberang Prai area, eastern Penang and western Kedah, terraces, interpreted as possibly of marine origin, occur up to an elevation of ca. 30 m (Courtier, 1974). Shallow marine fossils, interpreted to represent late Quaternary deposition, have been recorded at elevations up to +15 m in Sri Medan, western Johore coastal plain (Gray et al., 1978; Tjia, 1992). Little emergent pre-Holocene sea-level highstand evidence has been reported for the east coast of the peninsula. Elevated notches in metavolcanic rocks are reported from Mersing, east coast Johore (Tjia, 1992). Beach ridges occur at elevations up to 11 m along the coastal plain between Kuala Terengganu and Kuantan (Fitch, 1949, 1952; Nossin, 1965). These are likely of middle Holocene age since, along the high wave energy east coast, modern beach ridges can build to an elevation of over 3 m above high tide (Tjia, 1992).

The coastal plain of Peninsular Malaysia is dominated by Holocene age deposits (Figure 7). Most records from Peninsular Malaysia indicate that relative sea level peaked at ca. +5 m between 6 and 5 ka and has decreased to its present level since (Geyh *et al.*, 1979; Tjia, 1992, 1996; Abdullah *et al.*, 2003; Kamaludin, 2003) (Figure 2, Sunda Shelf curve). This sea-level curve pattern with a mid-Holocene highstand results mainly from continental levering associated with hydro-isostatic adjustment (HIA), is predicted by geophysical models (Clark *et al.*, 1978; Peltier *et al.*, 1978; Peltier, 2002; Bradley *et al.*, 2016) and is typical for far-field tropical regions (e.g. Potter & Lambeck, 2003; Horton *et al.*, 2005; Woodroffe & Horton, 2005). Relative sea-level curve patterns for previous interglacials were likely similar, with similar magnitude peaks or inflections corresponding with termination of major meltwater contribution (Lambeck *et al.*, 2012).

Holocene coastal deposits commonly extend well inland of the modern shoreline and generally consist of sandy paleo-beach ridges interspersed with swales and extensive wetland flats. Plant macro-fossil and pollen analyses indicate that marine influence increases down section within coastal wetland deposits (Hillen, 1986; Kamaludin, 1989, 2002; Horton *et al.*, 2005). Numerous radiocarbon (e.g. Geyh *et* 

Peter R. Parham



Figure 7: Map of Peninsular Malaysia showing th e approximate shoreline position with relative sea level ca. 1.5 m above present during Holocene maximum transgression ca. 7 ka. Maximum Holocene transgression shoreline position is basedondatafromfield surveys (this study), Parham et al. (2014a) and inferred from sediment distribution patterns portrayed on Quaternary geological (Bosch, 1989) and soil survey (Law, 1970) maps of Peninsular Malaysia.

*al.*, 1979; Tjia, 1992, 1996; Tjia & Sharifah Mastura, 2013; Parham *et al.*, 2014a) and optically stimulated luminescence (Mallinson *et al.*, 2014) age estimates for organic material and interior beach ridge sand support a Holocene age. Fossil coral evidence from the NE Peninsular Malaysia mainland indicates maximum Holocene transgression occurred ca. 7 ka (Parham *et al.*, 2014a). Upper intertidal-to-emergent corals also indicate higher mid-Holocene RSL (Tjia, 1992, 1996). On Lankawi Island, anomalously high elevations (>20 m) for Holocene sea-level indicators with radiocarbon age estimates between 9500 to 6500 ka have been interpreted to represent substantial local uplift (Zaiton *et al.*, 1999; Nakamura & Tjia, 2002).

### **METHODS**

Sites and outcrops that have previously been interpreted as Plio-Pleistocene (e.g. Old Alluvium, Simpang and Kempadang formations) or as evidence of pre-Holocene sea-level highstands(Figures 6 and 8) were visited and re-evaluated from a sequence-stratigraphic perspective. The coastal plain and islands of Peninsular Malaysia, Sarawak, Labuan and Sabah were surveyed for evidence of higher-than-present late Pliocene-Quaternary sea levels (Table 2). Evidence of former sea level position included constructional paleo shorelines and other coastal deposits, erosional scarps and wave-cut notches, encrusting marine fossils on outcrops, marine/estuarine strata exposed along stream cutbanks or in excavations, and emergent fossil corals (Figure 9). Particular emphasis was placed on the survey of river systems because it was expected that former sea-level highstand deposits, if present, would be exposed in cutbanks near the landward margin of the coastal plain where streams dissect these older sediments. Surveys were conducted via small watercraft, ground survey on foot or automobile as conditions dictated. Stream surveys were conducted during periods of relatively low water. Elevation and location were determined using real time kinematic (RTK) global positioning system (GPS), Emery Method (Emery, 1961; Krause, 2004) or Jacob's Staff (Compton, 1962). Sections were photographed, measured and described using the protocols of Compton (1962) and Folk (1974). Invertebrate macrofossils were identified using Carpenter & Niem (1998) and other appropriate references. Material considered to contain viable sea-level highstand evidence was submitted for age analysis. Radiocarbon age analysis was performed using accelerator mass spectrometry (AMS) by Beta Analytic, Inc. Results were calibrated using Calib Revision 7.0.4, the Marine13dataset (Reimer et al., 2013) and local Delta R values (Southon et al., 2002).



Figure 8: Map of Malaysian Borneo showing localities where possible evidence for pre-Holocene sea-level highstands has been reported.



Figure 9: Some indicators of former higher sea level (from Tjia, 1992, 1996).

### RESULTS AND DISCUSSION Localities previously reported as possible evidence of high pre-Holocene sea levels

Locations of sites referred to in this section are shown in Figures 6 and 8.

### Langkawi islands

Fossil oysters encrusting limestone 23 m above MSL above Teluk Cini Mati on Pulau Tanjung Dendang were reported by Zaiton *et al.* (1999). Two oyster samples were age dated at the Teledyne Brown Engineering laboratory yielding radiocarbon ages of 6970 +/-120 yr BP and 7858 +/-100 yr BP (Zaiton *et al.*, 1999). Zaiton *et al.* (1999) do not indicate whether their age estimates were calibrated. When calibrated using Calib rev 7.0.4 marine13 curve and local Delta R value, these samples produce 2-sigma

age ranges of 7788-7138 cal yr BP and 7858-7275 cal yr BP. Subsequent age analysis by this study of fossil oysters from the same site produced an age of 7229-6663 cal yr BP.

The age of the site spans probably several hundred years. The oysters are not in growth position. Rather, they have been reworked and are cemented to the walls of the overhanging limestone cliff in a mud matrix along with many other types of shells as described by Zaiton *et al.* (1999). Bivalves are mostly whole and in very good condition, not worn and rounded as they would be if this were shoreline deposits. The limestone overhanging cliff is not a wave-cut notch. It is not horizontal but rather dips northward along the base of the cliff, an artefact of the internal structure of the limestone. This site is not a direct indicator of former sea level. It is a shell midden. Early man used this natural rock shelter as a site to process seafood. Over time, the

Table	2:	List	of	primary	areas	surveyed	in	the study	
-------	----	------	----	---------	-------	----------	----	-----------	--

State/Territory	Coast/coastal plain	Islands	River systems
Kelantan	Tumpat to	NA	Sg. Kelantan
	Kuala Besut		
Terengganu	Kuala Besut to	Bara, Redang, Pinang, Limau, Paku Besar, Paku Kecil, Karrenga, Lang	Sg. Besut,
	Kuala Kemaman	Tengah, Karah, Bidong, Geluk, Tengkorak, Yu Besar, Yu Kecil, Perhentian	Sg. Terengganu,
		Besar, Perhentian Kecil, Serenggeh, Susu Dara, Dara Kecil, Teku Burung,	Sg. Dungun
		Tokong Kemudi, Rawa, Kapas, Tenggol, Nyrih, Tokong Burung	
Pahang	Cherating to Endau	Seri Buat, Sembilan, Bertan Barat, Bertan Tengah, Bertan Timor, Tasu,	Sg. Pahang,
		Tioman	Sg. Endau
Johor	Endau to Tg. Sedili;	Aceh, Harimau, Babi Besar, Mensirip, Gual, Rawa, Babi Hujung, Babi	Sg. Endau, Sg. Sembrong,
	Kota Tinggi to Muar	Tengah, Pemanggil, Tinggi, Ibol, Penyenbang, Mentinggi, Nanga Kecil,	Sg. Lenggor, Sg. Johor,
		Nanga Besar, Simbang, Apil,Sibu, Sibu Tengah, Sibu Kukus	Sg. Batu Pahat,
			Sg. Simpang Kanan,
			Sg. Bekok,
			Sg. Simpang Kiri
Melaka	Sg. Rambai to	NA	Sg. Linggi,
	Sg. Linggi		Sg. Rembau
Negeri	Sg. Linggi to	NA	Sg. Linggi,
Sembilan	Port Dickson		Sg. Rembau
Perak	Perak River to	Pangkor, Pangkor Laut, Dua, Simpan, Udang, Mentangor, Giam, Tukun	Sg. Perak
	Pantai Remis	Terindak, Pelanduk, Agas, Tukun Perak, Payong, Nipis,	
		Rumbia, Lalang, Buloh, Saga	
Penang	Mertajam to	Pinang	Sg. Muda,
_	Kuala Muda		Sg. Kulim
Kedah	Kuala Muda to	Langkawi, Langgun, Anak Tikus, Tanjung Dendang, Gemorok, Timun,	Sg. Mudah,
	Sanglang	Chorong, Dangli, Gasen, Pasir, Bumbon Besar, Kerai, Bumbon Kecil,	Sg. Kulim
		Kukus, Tanggok Besar, Tanggok Kecil, Enggong, Nyior Setali, Buyong,	
		Tiloi, Lading, Paku, Tuba, Dayang Bunting, Selang, Lintang, Ujong Buloh,	
		Balar, Gubang Laut, Batu Merah, Gubang Laut, Puchong, Ketumbu,	
		Chupak, Jerkom Besar, Singa Besar, Jong, Singa Kecil, Ular, Kentut Besar,	
		Beras Basah, Tepor, Rebak Besar, Rebak Kecil, Borau, Paya, Lembu,	
		Kacha	
Perlis	Sanglang to Kuala	NA	Sg. Perlis
0 1	Perlis		
Sarawak	Tanjung Datu to	Satang Besar,	Big. Kayan, Big. Lupar,
	Limbong	Satalig Kecil, Teleang Samnadi	Dig. Kajang, Dig. Talau,
	Trucon to Moronali	Tokong, Sampau,	Dta Limbana Dta Trucon
	Trusan to Merapok	Talang Besal,	Big. Linibalig, Big. Husan,
Lahuan	ol1	Labuan Varaman Bugukan Vagil Bugukan Bagar	Dig. Lawas
Cabab	dii Sindumin to Ditogr	Tiga Kalampunian Manukan Caya Sulua Mamlitik Sani Mantanani	NA Sa Dadaa
Saban	J shult Divor to	Dasar Mantanani Kasil Dalambangan Danggi Maliangin Mariangan	Sg. Pauas,
	Labuk Kiver to	Besar, Mantanani Kecil, Balambangan, Banggi, Maliangin, Mariangan,	Sg. Papar,
	Labed Dates to	Culican Silican Dalit Satu Dum Dur Kain Juan Silican N	Sg. Tempessuk,
		Julisan, Siligan, Kakii Salu, Bum Bun, Karindingan, Sipangau, Nusa	Sg. Labuk,
	NaiaDaKan	Solakan Sahangkat Laranan Silawa Salaman Mata Dahi Dura Dura	sg. Minadatangan
		Salakan, Sabangkai, Larapan, Shawa, Selangan, Mata Pani, Puna Puna,	
1	1	11mbun Mata, Tatagon	1

debris from these activities accumulated on the floor of the rock shelter and mixed with mud. The sea at that time (ca. 7 ka) would have been near its present level, a short walk down hill.

A similar rock shelter site, at ca. 10 m above modern high tide limit, was observed at the mouth of Gua Pinang, northern Pulau Langkawi. Age results for shells from this site (7407-6872 cal yr BP) indicate anthropogenic activity at the same time as on P. Tanjung Dendang. These sites deserve further archaeological investigation.

### Kodiang Hills, northern Kedah

At Gua Kelubi in Bukit Hantu, Tjia *et al.* (1977) dated two mollusc shells from layered marine molluscs estimated to be between 8 and 10.4 m above MSL. Radiocarbon ages were 21,070 +/-890 yr BP at 8.7 m and 26,840 +/-1540 yr BP at 10.35 m. Calibrated, these age estimates yield 2-sigma ranges of 26,696-22,696 cal yr BP and 33,633-27,648 cal yr BP, respectively.

My measurement in this cave in Bukit Hantu suggests that the shelly deposits occur between 6 and 8 m above MSL. They comprise marine molluscs, including oysters, in a mud matrix somewhat similar to the midden deposits from the Langkawi sites. The difference is that shell material is chalky, poorly preserved and recrystallization is extensive. Two oyster shells, showing minimal evidence of recrystallization, from an elevation of ca. 7 m were selected for radiocarbon age analysis. AMS results yielded calibrated age ranges >40 ka. The ages for this site remain anomalous. There are two reasonable possibilities. 1) The base of the mouth of the cave lies at ca. 3 m > MSL. This was a sea cave during the mid-Holocene when RSL was 3-4 m above present. A

wave-cut notch occurs at the cave mouth and rises gently for about 10 m toward the cave interior. This was likely a wave run-up ramp filled with sand, cobbles, shell and other washed-in debris during the mid-Holocene highstand. The cave faces NW, so that during times of high wave energy, or even tsunami, shells and other material could have been pushed up to the level of fossil shell beds. Subsequent solution of the much older limestone and recrystallization of the shell beds has resulted in older apparent ages compared to the true ages of the shells. This would explain the ca. 10,000 yr difference between the age estimates of this study and those of Tjia et al. (1977). 2) The shell deposits are of anthropogenic origin. Their appearance is very much like other midden sites. The age dates of Tjia et al. (1977) were performed using conventional techniques which are less sensitive for older samples. The age estimates for my study were determined using AMS, which is considered accurate to around 40 ka. RSL ca. 40 ka (MIS 3) could have been around 30 m below present along the NW coast of Peninsular Malaysia. Bukit Hantu would have risen from this 40 ka sea much as the Langkawi islands do today. The modern coastal plain did not exist. The cave may have been an optimal site for processing seafood. It would have been contemporary with known human occupation at Niah Cave, Sarawak where marine shell is also common in the midden. This site deserves further study.

There is no evidence that notches in the limestone of the Kodiang Hills, northern Perlis and Bukit Kepala (Gunung Keriang) that are higher than those of the mid-Holocene RSL highstand are the result of higher stands of the sea.

### Eastern Penang/southern Kedah

Courtier (1974) reported terraces at the base of a hill at Kampung Dua Kongsi between elevations between 6 and 15 m above MSL. These are terrestrial alluvial fan deposits with subtle evidence of terraces. The lowermost, and most distinct, scarp remnant possibly represents the mid-Holocene highstand shoreline. Corresponding terraces were not observed in adjacent areas. Haile (1975) arrived at similar conclusions about this site.

### Simpang Formation/Old Alluvium

These alluvial deposits are of terrestrial origin and range in age from Pliocene to late Pleistocene (Batchelor, 2015). Shelly layers (Kempadang Fm of Suntharalingam & Ambak [1986]) encountered well-below present sea level, beneath delta deposits near Kuantan, are likely of Last Interglacial (MIS5e) age and contemporary with the Lower Marine Clay of Singapore. None of these deposits have been dated. Marine and estuarine deposits encountered well below present sea level at Pantai Remis, Perak are also likely of MIS5e age although, based on radiocarbon and thermoluminescence age data, Kamaludin *et al.* (1993) suggested the possibility of a MIS3 age. Batchelor (2015) justly questioned the validity of this age data.

#### Limestone notches, Kinta Valley, Perak

Basal notches are commonplace in the limestone hills of the Kinta Valley at 20 m and more above present MSL. Raj *et al.* (2009) speculated that some, such as those that occur near the base of Gunung Rapat, could be the result of higher Pleistocene RSL. Ros Fatihah of University Malaya, who worked extensively on the Kinta Valley karst system, concludes that basal notches result from lateral dissolution of the limestone by pond water (Ros Fatihah & Komoo, 2003). Vertical series of notches represent lowering of base level and thus denudation and lowering of plain level since middle Pleistocene time (Ros Fatihah *et al.*, 2002). Based on my reconnaissance of Kinta Valley karst, I concur with the explanations of Ros Fatihah.

### Sri Medan, Johor

Gray *et al.* (1978) reported marine molluscs in black clay up to an elevation of 14.95 m "above sea level" at the Sri Medan bauxite mine. Elevation was determined using a barometric altimeter with a reported accuracy of +/- 1 m. The shelly deposits were reported to have been artificially elevated as a "bulge" at the base of tailings from the mine. The weight of the extensive tailings dump pushed up the surrounding soft sediments. Gray *et al.* (1978) stated that they planned to submit samples for radiometric age analysis. Tjia & Sharifah Mastura (2013) report that age analysis was conducted and that the ages of the samples were beyond the range of the radiocarbon method but no further details were given.

The Sri Medan mine has since been converted to a park and horticultural center. I located the old tailings pile but the land immediately below the pile is now completely vegetated. No shells could be found for re-analysis. My measurements indicate that the base of the tailings pile is no more than 7 m above MSL. The remainder of the Sri Medan area was extensively surveyed. No shelly deposits or other evidence of RSL above mid-Holocene highstand position were observed. However, shelly Holocene deposits similar to those described by Gray et al. (1978) were found on and in the Holocene coastal plain that extends up the stream systems around Sri Medan. The elevation of this plain is ca. 2 m and streams are tidally influenced. It is likely that similar Holocene marine/estuarine depositswere in place where the Sri Medan mine tailings dump was established and were indeed uplifted around the periphery of the dump as Gray et al. (1978) described.

### High paleo-beach ridges along Peninsular Malaysia east coast

Beach ridges as high as 11 m above MSL were described by Fitch (1949, 1952) and Nossin (1965) between Kuantan and Kuala Terengganu. These paleo-beach ridges are a product of high energy wave and storm conditions during the mid-Holocene RSL highstand and are constrained to that time by NE Peninsular Malaysia age data (Mallinson *et al.*, 2014; Parham *et al.*, 2014a).

### Old alluvium, Ketereh, Kelantan

Bosch (1986) recorded a plain of gravelly alluvium in the Ketereh area adjacent to the Kelantan River that he suggested may have been related to a higher Quaternary sea stand. I surveyed all of the Kelantan River system between Temangan and Pasir Mas, as well as the Ketereh area. Elevated gravelly braided river deposits are common along this section of river and are exposed in higher cut banks. They are a product of adjustment of the long profile of the river to a lower sea level when the Sunda Shelf was exposed.

# High-level terrace/Old alluvium, Kuching area, Sarawak

Lam (1997) described gravelly to cobbly alluvial terrace deposits that could potentially be related to higher Pleistocene RSL. These deposits mainly occur between Kuching and Santubong at elevations up to 14 m > MSL. Similar deposits also occur in the Bukit Kawa area east of the Sarawak River (Tan, 1981). Wilford (1955) observed that, in places, Kuching-area high-level alluvium is capped by humate sand and uppermost clean white sand and interpreted this as evidence of higher Pleistocene RSL.

I investigated these sites, and others in the Kuching area and Btg. Kayan area to the west. They are interpreted to represent fluvial braidplain deposits of the ancestral Sarawak river system graded to a lower base level. Radiocarbon age analysis of wood from these deposits yielded an age of >43,000 yr BP (Figure 10). Similar deposits along Btg. Kayan near Lundu were dated to ca. 35 ka. The overlying humate sand and clean white sand north of Kuching are similar to uplifted strandplain deposits in the Bekenu-Miri area (Kessler & Jong, 2014a). However, they differ in that there are no trace fossils to indicate a marine to marginalmarine depositional environment. In addition, they do not show the trough cross-bedding characteristic of the Bekenu-Miri humate sands. It is possible that the Kuching-area alluvium capping sands are of marginal marine origin and have been uplifted. It is also possible, and probably more likely, that they represent eolian activation and reworking of fines from underlying alluvial deposits. Humate sand and clean white sand were not observed overlying alluvium in the Btg. Kayan valley.

# High-level terrace/Old alluvium, Sibu/Rajang Delta, Sarawak

Staub & Gastaldo (2003) interpreted sediments bordering the landward fringe of the Rajang Delta, 5 to 7 m > MSL, as beach and terrace deposits associated with the MIS5e sea-level highstand. They have no direct age data to support this conclusion. One age date for a freshwater root from what they term the "white podzol"returned an age of 26,769+/-1,360 <sup>14</sup>C yr BP. Most of their conclusions about the distribution of these deposits, from Sarikei to Belingian, were based on aerial imagery interpretation.

These deposits occur most extensively in the Rantau Panjang area and along the Tanjung Manis road ca. 10



**Figure 10**: Clean white sand and humate sand (A) overlying highlevel alluvium (B) north of Kuching. Radiocarbon age analysis of wood from this deposit (B) yielded an age >43,000 yr BP.

km west of Sibu. They rise up to 15 m above high tide level, attain thicknesses up to 10 m and rest directly and unconformably on Tertiary bedrock. The contact is irregular. The upper surface is also irregular and dissected by erosion. These deposits comprise gravel to small boulder clasts, irregular sandy and muddy layers, peaty layers and abundant detrital woody plant material up to tree size. Radiocarbon analysis of part of a large log from these deposits yielded an age >43,000 yr BP. These are fluvial/alluvial deposits graded to a lower sea level and are very similar to those in the Kuching area. As a unit, they dip seaward beneath Holocene delta peatlands. There are occasional highs that emerge a few meters through the peat. These deposits extend up river to Kanowit where they occur sporadically on the tops of hills up to 19 m > MSL and overlie Tertiary bedrock. Fort Emma is situated on one of these hills.

The distribution of fluvial/alluvial deposits suggests that the paleo-trajectory of the Rajang River was to the north toward Oya and Mukah rather than to the west as it is today. The mouth of the Rajang River appears to have shifted progressively westward, during the mid- to late Holocene, in response to longshore drift from the NE. Seaward of fluvial/ alluvial deposits, paleo-beach ridges in the Rajang Delta have been radiocarbon dated to 7 ka and younger (Staub & Gastaldo, 2003). During Holocene maximum transgression (ca. 7 ka), the shoreline likely fronted the fluvial/alluvial deposits briefly but delta progradation was ongoing and rapid due to large sediment loads from the Rajang River.

In the area north of Sibu, near Btg. Lebaan, deposits that match the description of Staub & Gastaldo (2003) occur 5 to 6 m > high tide level, seaward of and overlying fluvial/ alluvial deposits. They are characterized by uppermost 20 to 40 cm of clean white sand overlying a ca. 1 m thick layer of semi-indurated humate sand, which in turn overlies leached white sandy mud. These are likely the deposits from which Wolfenden (1960) reported the presence of foraminifera. These deposits are cut by a ca. 1 m wide vertical joint filled with asphalt that strikes N 75° W. Similar jointing was observed in fluvial/alluvial deposits at Rantau Panjang where the strike is N 45° W. This jointing indicates post-depositional fracturing and possibly uplift. The sandy deposits resemble strandplain deposits seen on both the Holocene coastal plain and uplifted in the Bekenu-Miri area (Kessler & Jong, 2014a). Radiocarbon age data suggest uplift in the Bekenu-Miri area as late as ca. 8 ka or after (Kessler & Jong, 2014a). It is possible that the sandy strandplain deposits along the inner margin of the Rajang Delta were uplifted contemporaneously. Age data for paleobeach ridges in the Rajang Delta (Staub & Gastaldo, 2003) indicate relative vertical stability from ca. 7 ka onward.

### Uplifted/folded Pliocene deposits, NE Sarawak

Liechti *et al.* (1960) and Wolfenden (1960) reported uplifted and slightly folded marginal marine strata in NE Sarawak and Brunei that appear to be of Pliocene age. These have been called the Liang Formation. Exposures in Sarawak are most extensive in the Mukah-Balingian area (Fromm & Stegele, 1994) and north of Limbang (Rashid Ahmad, 2009). Along the Mukah road, sequences have been uplifted and tilted to the south so that the succession is from Miocene Balingian Fm to Pliocene Begrih Fm to Pliocene Liang Fm, in an inland direction (Fromm & Stegele, 1994). To the south, the Liang Fm abuts the Eocene Belaga Fm along the Tatau-Mersing Line (Hutchison, 2005). In the Limbang area, the Liang Fm unconformably overlies the Miocene Belait Fm and is generally horizontally bedded (Rashid Ahmad, 2009). No findings from my study dispute previous interpretations of the origin and uplift history of these deposits.

## Uplifted marine terraces between Bintulu and Miri, Sarawak

Kessler & Jong (2014a) report evidence of, and radiocarbon ages for, uplifted coastal terraces between Bekenu and Miri. With the exception of Canada Hill, which is interpreted to have a unique uplift history (Kessler & Jong, 2014b), the uppermost elevation of these terraces is ca. 23 m > MSL (Kessler & Jong, 2014a). The deposits generally comprise nearshore sand with extensive Ophiomorpha overlain by humate-rich trough cross-bedded/laminated strandplain sand that is in turn overlain by leached white sand typically < 50 cm thick. The deposits extend as far south as Similajau National Park and are extensive in the Tanjung Similajau and Kuala Nyalau areas, where they reach elevations up to +20 m (Figure 11). They extend inland around the Suai embayment, as well as north along the west coast of Brunei. Similar, but without Ophiomorpha, uplifted sands occur up the Baram River system in the Marudi area along Sg. Bakong. Ten age estimates by Kessler & Jong (2014a) range from ca. 28 to 8 ka, indicating uplift occurred post-8 ka although uplift timing may not have been uniform. Coral age data from this study from near modern sea level on the east side of Canada Hill constrain uplift timing to before ca. 6 ka.

Hunt & Premathilake (2012) obtained 17 up-section calibrated radiocarbon age estimates from a 40 m core in





Bulletin of the Geological Society of Malaysia, Volume 62, December 2016

Loagan Bunut lake, in the middle Sg. Tinjar valley of the Baram drainage system. Age estimates ranged from 11.3 to 7.03 ka. Lake level is ca. +14 m and water depth at the core site ca. 2 m. The cored section extends from ca. +12 m to -28 m. Based on pollen and micropaleontological evidence, interpreted paleoenvironments grade upward from subtidal to marginal marine/mangrove to terrestrial in the upper 2 m (Hunt & Premathilake, 2012). Hunt & Premathilake (2012) conclude that the section is 15 to 20 m higher than would be predicted if the area was tectonically stable. This is approximately the same magnitude of uplift indicated by raised strandplain deposits between Similajau and Miri (Kessler & Jong, 2014a; this study), further constraining the uplift timing to between ca. 7 and 6 ka.

### High-level alluvium, Limbang area, Sarawak

Wilford (1961) and Rashid Ahmad (2009) reported gravely to cobbly high-level terrace deposits in the Limbang area. Deposits directly overlie Tertiary bedrock. Along the eastern side of Bukit Mas, in the Sg. Pandaruan drainage system, these terrace deposits occur over 15 m > MSL. They occur in the pass between Sg. Berawan and Sg. Selangan and on the hill around Kg. Melais, north of the Limbang River. They extend up the sides of the Limbang River valley to Nanga Medamit and beyond, increasing in elevation, up the tributaries of the Limbang River system. Based on their occurrence in the Limbang area, Rashid Ahmad (2009) speculated that these terrace deposits were the result of higher late Pleistocene sea level. There is no evidence to support this conclusion. These are clearly fluvial terrace deposits. Kessler & Jong (2015) observed the same deposits in the Limbang River system as well as similar ones in the Baram and Temburong drainage systems. In addition to these, I observed these types of deposits in the Trusan, Lawas, Mengalong and Padas river systems, as well as coarse alluvial fan deposits as far north as Bongawan, Sabah. Kessler & Jong (2015) interpret these as nested fluvial deposits that, if continuous rather than episodic, suggest uplift rates of 6-7 mm/yr in this part of northern Borneo. I

concur with their interpretation. Extensive coarse alluvial fan deposits occurring in the Keningau/Tenom region of interior Sabah (Collenette, 1958) are probably also related to this uplift.

### Raised terraces on Pulau Balambangan, Sabah

Wilson (1961) and Che Aziz et al. (2008) mention Pleistocene uplift of Pulau Balambangan. The Timohing limestone occurs on the western side of the island and consists, at least partially, of both in situ fossil corals and beds of reworked fossil corals. Wilson (1961) considered this limestone to be of Pliocene age. Judging from the extensive recrystallization of the corals, this age estimate is probably fairly accurate. However, no direct age data are available. Much of the eastern and portions of the northern part of the island comprise sandy terraces elevated up to 12 m above high-tide limit. These sandy terraces are characterized by a cap of bleached white sand overlying a chocolate brown humate-rich sand layer which overlies bioturbated sandto-muddy sand which, where exposed, overlies weathered Tertiary rocks (Figure 12). These deposits strongly resemble raised strandplain deposits observed between Bintulu and Miri and are interpreted to represent uplifted strandplain sediments. The timing of uplift is yet undetermined but potentially could be as late as Holocene.

### Raised coral reef, Semporna area, Sabah

Tjia *et al.* (1972) obtained a radiocarbon age of 23,800 +/-800 yr BP for fossil coral collected at 12 m > MSL near Semporna. Calibrated using the local Delta R value of -37+/-70, the 2-sigma age range for this coral sample is 29,108-25,994 cal yr BP. The coral reef limestone that this sample came from was measured to rise to +20 m (Tjia *et al.*, 1972). Taira & Hashimoto (1971) radiocarbon dated several coral and oyster samples from the Semporna area with results ranging from 30-36 ka. Radiocarbon analysis, by this study, of an oyster shell embedded in coral reef limestone from the north end of P. Manampili (Figure 13) produced an AMS age >43,000 yr BP. The limestone on P.



Figure 12: Uplifted strandplain deposits on east central Pulau Balambangan, Sabah.

Bulletin of the Geological Society of Malaysia, Volume 62, December 2016

Manampili rises to ca. 7 m above the high tide line. Based on the range of estimates determined by different researchers, it is likely these raised coral reef limestones are not all the same age. The youngest age (29,108-25,994 cal yr BP) of Tjia *et al.* (1972) constrains the timing of uplift to after that time. Since global sea level was well below present ca. 27 ka, substantial uplift has occurred. It should be noted that recrystallization is extensive in corals from the Semporna limestone (Zainal Abidin *et al.*, 2012) which can result in inaccurate age estimates.

Uplift in the Semporna area is likely related to late Quaternary volcanism. However, the age of the younger volcanic rocks in the Semporna Peninsula area is not well established. Lim & Heng (1985) suggest ages of 27 ka or younger, which fits nicely with age data of Tjia *et al.* (1972). Based on whole-rock K-Ar analysis, Rangin *et al.* (1990) determined an age range of 3.1 - 2.8 Ma. But, these age estimates have not been considered reliable. Bellon & Rangin (1991) considered these K-Ar ages suspect concluding that some of the volcanism may be very young and that faults are still active.

Based on the findings of Taira & Hashimoto (1971) and Tjia *et al.* (1972), Tjia (2006) estimated an annual uplift rate for the Semporna area of 7 mm/yr. However, although the Semporna region has clearly been uplifted, possibly within the last ca. 20 kyr, other evidence indicates non-uniform relative vertical motion of the area, at least since the mid-Holocene.

1) Age data for raised, *in situ* fossil oysters at 1.5 m above high tide on P. Timbun Mata (Figure 13) indicate a



Figure 13: Geologic map of the Semporna Peninsula area, eastern Sabah (modified from Kirk, 1962). Approximate distribution of coral reef limestone has been expanded. Presumed Timbun Mata fault trend based on Kirk (1962) and Rangin *et al.* (1990).

Bulletin of the Geological Society of Malaysia, Volume 62, December 2016

calibrated AMS age of ca. 5.5 ka. This is largely consistent with RSL data for that time from western Sarawak and Peninsular Malaysia and suggests vertical stability at least since the mid-Holocene. This vertically stable area occurs north of a fault, interpreted by Kirk (1962) to separate P. Timbun Mata from the Semporna Peninsula (Figure 13).

2) Lack of evidence of higher Holocene RSL (e.g. intertidal fossil corals, raised fossil oysters, raised wave-cut notches above modern level, raised constructional paleo-shoreline features) around the eastern Semporna Peninsula and islands as far east as P. Bohay Dulong (Figure 13) suggests subsidence in this area. This subsidence is further suggested by living corals that have pioneered habitat to the low-tide shoreline, especially around the islands.

3) Along the southern coast of the Semporna Peninsula, ongoing subsidence is obvious in Tagasan Bay (Figure 13). Here, drowned forest extends well into the bay, indicating ongoing submergence (Figure 14).

### Peninsular Malaysia

During this study, no compelling evidence was observed on Peninsular Malaysia to indicate that RSL was ever higher than present during late Pliocene to early Holocene time. Questions remain concerning the origin of deposits at Sri Medan (Gray *et al.*, 1978) and Bukit Hantu, Kedah (Tjia *et al.*, 1977). These localities have been discussed in the previous section and plausible explanations given. All confirmed higher than present RSL evidence is of Holocene age and related to the mid-Holocene RSL highstand (Parham *et al.*, 2014b; Parham *et al.*, 2015). Index points indicate that that RSL was as much as between 4 and 5 m above present during this time (Parham *et al.*, 2014b; Parham *et al.*, 2015) with maximum levels varying slightly across the region in response to variability in HIA (Bradley *et al.*, 2016) (Figure 14) or other local factors.

The lack of evidence of pre-Holocene higher than present RSL suggests long-term subsidence, at least of coastal regions, on time scales of  $10^4$  to  $10^6$  years. The effects of HIA and continental levering are superimposed on this longterm subsidence on time scales of  $10^2$  to  $10^3$  years. If this part of Sundaland was stable, it should record evidence of



Figure 14: Drowned forest in Tagasan Bay, southern side of Semporna Peninsula, Sabah.

higher late Cenozoic eustatic sea levels. Global sea levels during parts of the late Neogene were at least 50 m above present (Haq *et al.*, 1987; Miller *et al.*, 2005; Lourens *et al.*, 2010) and during the Pleistocene interglacials possibly as much as +20 m (Hearty *et al.*, 1999; Olson & Hearty, 2009; van Hengstrum *et al.*, 2009). It is well established that eustatic sea level during the last interglacial (MIS5e, ca. 120 ka) was over 6 m above present (e.g. Kopp *et al.*, 2009; Dutton & Lambeck, 2012; Rovere *et al.*, 2016). Evidence of these global sea-level highstands does not exist on Peninsular Malaysia.

During the late Holocene, variability in HIA, sediment availability and hydrodynamics have resulted in slightly different ongoing changes in RSL and transgression/ regression along different sections of the Peninsular Malaysia coast. Isostatic equilibrium appears to have been approached or reached along the NE coast (Parham *et al.*, 2014b) resulting in rising RSL and shoreline recession in many areas (Figure 15). RSL change there is thus a function of eustatic rise and long-term subsidence. Anthropogenic activities, such as shoreline hardening, "reclamation" of coastal waters and sand mining, exacerbate shoreline recession and throw the natural sediment budget of the coast out of equilibrium (e.g. Kuala Terengganu) (Parham *et al.*,



**Figure 15:** Map of the Peninsular Malaysia area shows generalized processes along different parts of the peninsula that influence RSL and/or shoreline position where anthropogenic modifications are minimal. Most of these processes can be related to slight variability in hydro-isostatic adjustment, which influences RSL change, and sediment availability, which influences shoreline position. Contours (in meters) show predicted RSL at 6 ka based on the geophysical model of Bradley *et al.* (2016). All areas are experiencing long-term ( $10^4 - 10^6$  kyr) subsidence.

2014c). In Kelantan, erosion of the southern delta coast is mainly a result of Holocene northwestward migration of the Kelantan River mouth (Tjia, 2001) and subsequent sediment starvation of updrift coastline.

Along the SE Peninsular Malaysia coast, HIA appears to continue to the extent that uplift from continued continental levering is balanced with eustatic rise and long-term subsidence resulting in negligible RSL change (Parham *et al.*, 2014b) (Figure 15). In addition, sediment contributions from the Pahang River and erosion of soft volcaniclastic bedrock (widespread south of Endau) has resulted in prograding coasts in many areas. Late Holocene subsidence, due to sediment loading, is suggested for the northern Pahang/ Kuantan delta area by sea-level index points (SLIPs) that are lower (Kamaludin, 2002, 2003) than contemporary SLIPs from headland-dominated parts of the peninsula.

RSL conditions along the west coast of the peninsula

appear to be generally stable (Figure 15). RSL, in most areas, is thus a function of HIA, eustatic rise, and longterm subsidence. Relatively low wave energy and abundant sediment supply has resulted in prograding coastlines in many areas (e.g. Tjia, 2001, 2004). Localized erosion is mainly attributable to anthropogenic activities. Late Holocene subsidence, due to sediment loading, is suggested for the lower Perak River delta by SLIPs from offshore islands being ca. 1 m lower than contemporary SLIPs from headland-dominated parts of the peninsula.

### **Malaysian Borneo**

The Quaternary RSL record from Borneo is much more complex than that of Peninsular Malaysia. West of the Lupar Line (Figure 16), the RSL record is, predictably, similar to that of Peninsular Malaysia. Northeast of the Lupar Line, in the remainder of Sarawak, Brunei, Labuan and Sabah,



Figure 16: Simplified geological map of Borneo showing major lineaments that have been active during the Cenozoic (modified from Hall *et al.*, 2008). Tenom thrust fault trend based on Cullen (2010). Timbun Mata fault based on Kirk (1962)and Rangin *et al.* (1990).

Bulletin of the Geological Society of Malaysia, Volume 62, December 2016

the RSL record appears to be mainly controlled by the relative movement of the upper crust. As recent as early mid-Holocene, there has been uplift between Similajau and the Baram drainage basin and late Quaternary uplift as far north as Bongawan, Sabah. This area of uplift is generally bounded by the Tinjau Line and the Tenom Fault (Figure 16). Minor associated early mid-Holocene uplift may have occurred in the Rajang Delta as suggested by jointed strandplain-like deposits 5 to 6 m above the modern high tide limit. However, these slightly higher than Holocene RSL maximum strandplain-like deposits could also be accounted for by continental levering associated with HIA as predicted by the geophysical model of Bradley *et al.* (2016). This model predicts between 6 and 7 m isostatic uplift for the landward fringe of the Rajang Delta (Figure 17).

Wilson (1964) interpreted elevated sandy deposits on the SE part of Labuan, Klias Peninsula, and along the Brunei Bay coast between Sipitang and Weston as raised beaches. On Labuan, he identified a ca. 25 m platform and ca. 10 m platform and on Klias Peninsula, an upper platform and a lower (2-5 m) platform. The lower platform is clearly of Holocene origin. Holocene age data from Labuan suggest a similar RSL history to that of Peninsular Malaysia (Parham et al., 2014b, 2015), implying relative tectonic stability since ca. 7 ka. Age data from basal deposits of the 10 m platform (Wilson, 1964) indicate a ca. 42 ka age, implying uplift between then and early mid-Holocene, similar in timing to Similajau-Baram uplift. On the Klias Peninsula, sandy deposits occur unconformably overlying Tertiary bedrock between +15 and +25 m on both sides of the NE-SW trending ridge that forms the western side of the peninsula. The sands are highly bioturbated with evidence of Ophiomorpha (Figure 18) suggesting a marine or marginal marine origin. Uplift timing is likely the same as for Labuan. Ongoing activity in the Klias Peninsula area is further indicated by mud volcanoes along a NE-SW trend (McManus & Tate, 1986). Sandy deposits similar to those on Klias Peninsula occur near Kg. Klias, north of Beaufort, where they overlie gravel alluvium and deformed Tertiary bedrock. Flat, sandy-topped hills (ca. +30 m) between Sipitang and Mesopol (Wilson, 1964) and along the west coast of Brunei (Liechti et al., 1960) are likely uplifted strandplain deposits similar to those documented between Miri and Similajau (Kessler & Jong, 2014a; this study) and may result from the same uplift.

Figure 19 shows generalized processes that influence the coastal geometry of Malaysian Borneo and have been ongoing, at least, since the mid-Holocene. Decreasing elevation of SLIPs (*in situ* fossil corals and oysters) in western Sarawak between Tg. Datu and P. Satang suggests increasing subsidence eastward. This implied subsidence is likely due to sediment loading from the multitude of rivers that empty into the Lupar embayment. Although subsidence due to sediment loading is suggested, large sediment contributions from rivers as far NE as Bintulu result in generally prograding coasts. Localized erosion is occurring along portions of the Santubong embayment coast.



Figure 17: Google Earth image of the Borneo island area shows contours (m) of predicted RSL at 6 ka based on the geophysical model of Bradley *et al.* (2016).



Figure 18: Uplifted (ca. 10 - 12 m > MHT) sandy deposits on the west side of Klias Peninsula, near Kg. Menampang, are bioturbated with possible *Ophiomorpha*.

The region between Bintulu and Bongawan (Figure 19) has experienced episodic Quaternary uplift as recently as early mid-Holocene and has been discussed above. However, rocky headland parts of this coast are currently eroding and receding.

Based on lack of emergent Holocene RSL highstand SLIPs and geomorphic evidence, the western Sabah coast between Bongawan and Simpang Mengayau appears to be subsiding. Holocene SLIPs in the form of *in situ* fossil coral and rock-clinging oysters were observed on the P. Tiga islands (N of Kuala Penyu) with ages and elevations comparable to contemporary Peninsular Malaysia SLIPs (Parham *et al.*, 2015). Extensive survey of the remainder of the Sabah west coast and islands revealed no such evidence even though areas such as the limestone of the Mantanani



Figure 19: Map of Borneo Island shows generalized mid-Holocene to present processes influencing the Malaysian Borneo coast.

islands are favourable to the preservation of raised fossil coral and oysters.

In western Sabah, north of Bongawan, there is a notable difference in the character of rivers where they enter the coastal plain. In relatively many areas (e.g. Kayan, Sarawak, and Rajang river systems, Figure 20), extensive and coarse braidplain alluvium occurs >10 m above modern fluvial deposits. This suggests different late Pleistocene flow regimes, grading to a lower base level and a shoreline position well seaward of present. In uplifted areas, elevated coarse fluvial deposits are nested in series along valley sides, each corresponding to a period of uplift and incised by modern streams (Kessler & Jong, 2015) (Figures 20 and 21). Such deposits do not occur along the west coast of Sabah north of Bongawan.

Wilson (1961) cites evidence of eastward tilting, possibly into recent times, on P. Balambangan, P. Banggi and the Benkoka Peninsula. Ages for intertidal in situ fossil corals from the north and west coasts of P. Banggi indicate a similar Holocene RSL history to that of Peninsular Malaysia and thus relative stability since ca. 7 ka. No emergent paleo-sea level indicators were observed along the south or east coasts of P. Banggi or around smaller islands in that vicinity, suggesting that this area is indeed subsiding as Wilson (1961) speculated. Relatively recent mud volcanism east of P. Banggi is further evidence of the activity of this area. Large reworked coral blocks (>2 m diameter) are common on intertidal-to-emergent coral rubble platforms adjacent subtidal living coral reef along the north coast of P. Banggi (Figure 22). Their occurrence indicates that this coast is periodically exposed to high wave-energy events or tsunami. Similar large coral blocks were observed around some of the Terengganu islands.

Lee (1970) reported up to 8 m thick gravelly-to-pebbly high-level alluvium, in the airport area NW of Sandakan, with distinct terraces at ca. 25 m, 15 m and 5 m above present MSL. The deposits consist of rounded vein quartz, rounded quartzitic sandstone, plant material rich muddy layers, and carbonized wood to tree trunk size (Lee, 1970). Pebbles are progressively smaller on lower terraces. These deposits (Figure 21) extend northward, discontinuously, along the eastern side of the Sandakan Peninsula. Similar high-level alluvial deposits occur in the Kinabatangan valley, near Bukit Garam (Figure 21), and in the Labuk valley, near Telupit. Lack of serpentinite clasts (common in Labuk valley alluvium) in the Sandakan Peninsula alluvium suggests a provenance elsewhere, likely to the SSW. The high-level fluvial deposits on Sandakan Peninsula are clearly uplifted. Mud volcanism on islands north of the peninsula (McManus & Tate, 1986) attests to the ongoing activity of the area.

Late Holocene and ongoing subsidence in the Semporna Peninsula area occurs south of the Timbun Mata Fault (Figures 13 and 16) while P. Timbun Mata, north of the fault, has remained relatively stable since the mid-Holocene. See discussion in previous section.

### CONCLUSIONS

In Peninsular Malaysia, no conclusive evidence was found to indicate that RSL was ever higher than mid-Holocene maximum during the late Cenozoic, suggesting long-term ( $10^4$  to  $10^6$  yrs) subsidence for the region. Over time scales of 10<sup>2</sup> to 10<sup>3</sup> yrs, eustatic rise and HIA are superimposed upon this long-term subsidence. In areas where HIA appears to be in equilibrium, long-term subsidence and eustatic rise are the dominant factors influencing RSL change, resulting in increased flooding and coastal erosion. These are commonly made worse by anthropogenic activities including attempts to prevent erosion. Along much of the remainder of the Peninsular Malaysia coast, continued uplift associated with HIA counterbalances eustatic rise resulting in little net change in RSL. This, in tandem with abundant sediment supply, has resulted in generally prograding coasts in areas minimally influenced by anthropogenic modifications.

The RSL record of Malaysian Borneo is very complex. Even in western Sarawak, the Quaternary RSL record is somewhat different than that of Peninsular Malaysia. Possible strandplain deposits overlying coarse alluvium in the Kuching area could reflect last interglacial highstand deposition but more likely result from uplift or eolian reworking of alluvial deposits. This alluvium, along with similar deposits associated with the Kayan and Rajang rivers, clearly represents deposition under different environmental conditions than modern. Ongoing subsidence of the peatlanddominated coastal plain, from Kuching to Bintulu, is probably mainly due to sediment loading from the numerous rivers watering the region. North of the Lupar Line, RSL histories are mainly the product of tectonism and differential movement of the upper crust. The coast and interior from Bintulu, Sarawak to Bongawan, Sabah, has undergone episodic Quaternary uplift, with the most recent uplift event

Peter R. Parham



**Figure 20:** Examples of elevated coarse fluvial deposits associated with relatively stable and uplifted drainage systems in Malaysian Borneo.

in the Miri area during the early mid-Holocene. For this same coastal area, relative vertical stability is suggested from mid-Holocene to present. Geomorphic indicators and lack of emergent RSL indicators along the western Sabah coast, north of Bongawan, suggest ongoing subsidence. The RSL record from eastern Sabah is exceedingly complex with, sometimes close-spaced, areas with different histories of vertical movement over time scales of 10<sup>1</sup> to 10<sup>6</sup> yrs. Ongoing subsidence along the southern Semporna Peninsula is indicated by drowned forests.

### ACKNOWLEDGEMENTS

I would like to thank Rokiah Suriadi, Noraisyah Sapon, Noor Azariyah Mohtar, Mary Ann Parham and Joseph Bidai for their assistance in portions of this research. I would also like to thank all of the boatmen and other local people from various parts of Malaysia that made much of the field research for this project possible. This research was partially funded by Malaysia Ministry of Science and Innovation (MOSTI) ScienceFund project number 04-01-12-SF0163.



**Figure 21:** Uplifted coarse fluvial deposits along Sg. Kinabatangan and on the Sandakan Peninsula.



Figure 22: Large reworked coral block along the north coast of Pulau Banggi, Sabah.

### REFERENCES

- Abdullah, S., Kamaludin, B. H. & Tjia, H. D., 2003. The Holocene optimum in Malaysia. Minerals and Geoscience Department Malaysia Technical Papers, 2, 37-67.
- Azmi, M. Y., Awalludin, H., Bahari, M. N. & Morley, R. J., 1996. Integrated biostratigraphic zonation for the Malay Basin. Bulletin of the Geological Society of Malaysia, 39, 157-184.
- Azmi, M. Y. & Kamaludin, H., 1997. Palynology of late Quaternary coastal sediments, Perak, Malaysia. Catena, 30, 391-406.
- Batchelor, B. C., 1979. Geological characteristics of certain coastal and offshore placers as essential guides for tin exploration in Sundaland, SoutheastAsia. Bulletin of the Geological Society of Malaysia, 11, 283-313.
- Batchelor, D. A. F., 1988. Dating of Malaysian fluvial tin placers. Journal of Southeast Asian Earth Sciences, 2, 3-14.
- Batchelor, D.A.F., 2015. Clarification of stratigraphic correlation and dating of Late Cainozoic alluvial units in Peninsular Malaysia. Bulletin of the Geological Society of Malaysia, 61, 75-84.
- Bellon, H. & Rangin, C., 1991. Geochemistry and isotopic dating of the Cenozoic volcanic arc sequences around the Celebes and SuluSeas. In: Silver, E.A., Rangin, C., von Breymann, M.T. (Eds.), Proceedings of the Ocean Drilling Program Scientific Results, 124, 321–338.
- Ben-Avraham, Z. & Emery, K. O., 1973. Structural framework of Sunda Shelf. AAPG Bulletin, 57, 2323-2366.
- Bhattacharya, J. P. & Posamentier, H. W., 1994. Sequence stratigraphy and allostratigraphic applications in the Alberta foreland basin.
  In: Mossop, G. D. & Stetsen, I. (Eds.), Geological atlas of the Western Canada Sedimentary Basin. Canadian Society of Petroleum Geologists and Alberta Research Council, 407-412.
- Bird, M.I., Pang, W.C. & Lambeck, K., 2006. The age and origin of

the Straits of Singapore. Palaeogeography, Palaeoclimatology, Palaeoecology, 241, 531–538.

- Bird, M.I., Fifield, L.K., Teh, T.S., Chang, C.H., Shirlaw, N. & Lambeck, K., 2007. An inflection in the rate of early mid-Holocene eustatic sea-level change: a new sea-level curve from Singapore. Estuarine, Coastal and Shelf Science, 71, 523–536.
- Bird, M.I., Austin, W.E.N., Wurster, C.M., Fifield, L.K., Mojtahid, M. & Sargeant, C., 2010. Punctuated eustatic sea-level rise in the early mid-Holocene. Geology, 38, 803–806.
- Biswas, B., 1973. Quaternary changes in sea-level in the South China Sea. Geological Society of Malaysia, Bulletin 6, 229–256.
- Bosch, J. H. A., 1989. Quaternary geologic map of Peninsular Malaysia. Geological Survey of Malaysia Publication.
- Bradley, S.L., Milne, G.A., Horton, B.P. & Zong, Y., 2016. Modelling sea level data from China and Malay-Thailand to estimate Holocene ice-volume equivalent sea level change. Quaternary Science Reviews, 137, 54-68.
- Bryan, K., 1996. The steric component of sea level change associated with enhanced greenhouse warming: a model study. Climate Dynamics, 12, 545–555.
- Carpenter, K. E. & Niem, V. H. (Eds.), 1998. The living marine resources of the Western Pacific Volume 1: seaweeds, corals, bivalves and gastropods. Food and Agriculture Organization of the United Nations, Rome. 686 p.
- Cole, J. M. & Crittenden, S., 1997. Early Tertiary basin formation and the development of lacustrine and quasi lacustrine/marine source rocks on the Sunda Shelf of SE Asia. Geological Society, London, Special Publications, 126, 147-183.
- Collenette, P., 1958. The geology and mineral resources of the Jesselton-Kinabalu area, North Borneo. Geological Survey Department, British Territories in Borneo, Memoir 6. 194 p.
- Chappell, J., Omura, A., Esat, T., McCulloch, M., Pandolfi, J., Ota, Y. & Pillans, B., 1996. Reconciliation of late Quaternary sea levels derived from coral terraces at Huon Peninsula with deep sea oxygen isotope records. Earth and Planetary Science Letters, 141, 227-236.
- Che Aziz, A., Kamal, R.M. & Ibrahim, K., 2008. Geoheritage of Pulau Balambangan, Kudat, Sabah. Geological Survey of Malaysia Bulletin, 54, 91-95.
- Clark, J. A., Farrell, W. E. & Peltier, W. R., 1978. Global changes in post-glacial sea level: a numerical calculation. Quaternary Research, 9, 265-287.
- Compton, R. R., 1962. Manual of field geology. John Wiley and Sons, Inc., New York. 388 p.
- Courtier, D. B., 1974. The geology and mineral resources in the neighborhood of the Kulim area, Kedah. Geological Survey of Malaysia Map Bulletin, 3. 50 p.
- Cullen, A.B., 2010. Transverse segmentation of the Baram-Balabec Basin, NW Borneo: refining the model of Borneo's tectonic evolution. Petroleum Geoscience, 16, 3-29.

Bulletin of the Geological Society of Malaysia, Volume 62, December 2016

- Du Bois, E. P., 1985. Review of principal hydrocarbon-bearing basins around the South China Sea. Bulletin of the Geological Society of Malaysia, 18, 167-209.
- Dutton, A. & Lambeck, K., 2012. Ice volume and sea level during the last interglacial. Science, 337, 216-219.
- Emery, K.O., 1961. A simple method of measuring beach profiles. Limnology and Oceanography, 6, 90-93.
- Emmel, F. J. & Curray, J. R., 1982. A submerged late Pleistocene delta and other features related to sea level changes in the Malacca Strait. Geology, 47, 197-212, 215-216.
- Farrant, A. R., Smart, P. L., Whitaker, F. F. & Tarling, D. H., 1995. Long-term Quaternary uplift rates inferred from limestone caves in Sarawak, Malaysia. Geology, 23, 357-360.
- Fitch, F. H., 1949. Evidence for recent emergence of the land in East Pahang. Journal Malayan Branch Royal Asiatic Society, 22, 115-122.
- Fitch, F. H., 1952. The geology and mineral resources of the neighborhood of Kuantan, Pahang. Geological Survey Department Federation of Malaya Memoir 6. 144 p.
- Fleming, K., Zwartz, D., Yokoyama, Y., Lambeck, K. & Chappell, J., 1998. Refining the eustatic sea-level curve since the Last Glacial *Maximum using* far- and intermediate-field sites. Earth and Planetary Science Letters, 163, 327–342.
- Folk, R. L., 1974. Petrology of Sedimentary Rocks. Hemphill Publishing Co., Austin, TX. 182 p.
- Fromm, R. & Stengele, F., 1994. Geology and coal potential of the Mukah-Balingian region, central Sarawak (NW Borneo). Report, Department of Mineralogy, University of Karlsruhe, Germany. 59 p.
- Geyh, M.A., Kudrass, H.R. & Streif, H., 1979. Sea-level changes during the late Pleistocene and Holocene in the Strait of Malacca. Nature, 278, 441–443.
- Gray, L.M., Basir Jasin, & Tjia, H.D., 1978. Fossils at Sri Medan, Johor. Warta Geologi, 4, 81-84.
- Haile, N.S., 1971. Quaternary shorelines in West Malaysia and adjacent parts of the Sunda Shelf. Quaternaria, 15, 333-343.
- Haile, N.S., 1975. Postulated Late Cainozoic high sea levels in the Malay Peninsula. Journal of the Malaysian Branch of the Royal Asiatic Society, 48, 78-88.
- Hall, R., 2002. Cenozoic geological and plate tectonic evolution of SE Asia and the SW Pacific: computer-based reconstructions, model and animations. Journal of Asian Earth Sciences, 20, 353-431.
- Hall, R. & Morley, C. K., 2004. Sundaland Basins. In: Clift, P. D., Wang, P., Kuhnt, W., Hall, R. & Tada, R. (Eds.), Continent-ocean interactions within the East Asian marginal seas. Geophysical Monograph Series, 149, 55-85.
- Hall, R., van Hattam, M. W. A. & Spakman, W., 2008. Impact of India-Asia collision on SE Asia: the record in Borneo. Tectonophysics, 451, 366-389.
- Hall, R., 2009. Hydrocarbon basins in SE Asia: understanding why they are there. Petroleum Geoscience, 15, 131-146.
- Hall, R., 2014. The origin of Sundaland. Proceedings of Sundaland Resources 2014 MGEI Annual Convention, Palembang, South Sumatra, Indonesia, 1-25.
- Hanebuth, T. J. J., Stattegger, K. & Grootes, P. M., 2000. Rapid flooding of the Sunda Shelf: a late-glacial sea-level record. Science, 288, 1033-1035.
- Hanebuth, T. J. J., Stattegger, K. & Saito, Y., 2002. The stratigraphic architecture of the central Sunda Shelf (SE Asia) recorded by shallow-seismic surveying. Geo-Marine Letters, 22, 86-94.
- Hanebuth, T. J. J. & Stattegger, K., 2004. Depositional sequences on a late Pleistocene–Holocene tropical siliciclastic shelf (Sunda

Shelf, southeast Asia). Journal of Asian Earth Sciences, 23, 113-126.

- Hanebuth, T. J. J., Voris, H. K., Yokoyama, Y., Saito, Y. & Okuno, J., 2011. Formation and fate of sedimentary depocentres on Southeast Asia's Sunda Shelf over the past sea-level cycle and biogeographic implications. Earth Science Reviews, 104, 92-110.
- Haq, B. U., Hardenbol, J. & Vail, P. R., 1987. Chronology of fluctuating sea levels since the Triassic. Science, 235, 1156-1167.
- Hearty, P. J., Kendler, P., Cheng, H. & Edwards, R. L., 1999. A+20 m middle Pleistocene sea-level highstand (Bermuda and the Bahamas) due to partial collapse of Antarctic ice. Geology, 27, 375-378.
- Hesp, P.A., Hung, C.C., Hilton, M., Ming, C.L. & Turner, I.M., 1998. A first tentative Holocene sea-level curve for Singapore. Journal of Coastal Research, 14, 308–314.
- Hillen, R., 1986. Palynology as a tool in delineating tropical lowland depositional environments of late Quaternary age. Bulletin of the Geological Society of Malaysia, 19, 495-504.
- Hiscott, R. N., 2001. Depositional sequences controlled by high rates of sediment supply, sea-level variations and growth faulting: the Quaternary Baram Delta of northwestern Borneo. Marine Geology, 175, 67-102.
- Horton, B.P., Gibbard, P.L., Milne, G.M., Morley, R.J., Purintavaragul, C. & Stargardt, J.M., 2005. Holocene sea levels and palaeoenvironments, Malay-Thai Peninsula, southeast Asia. The Holocene, 15, 1199-1213.
- Hunt, C.O. & Premathilake, R., 2012. Early Holocene vegetation, human activity and climate from Sarawak, Malaysian Borneo. Quaternary International, 249, 105-119.
- Hutchison, C.S., 2005. Geology of North-West Borneo: Sarawak, Brunei and Sabah. Elsevier, 421 p.
- Hutchison, C. S., 2007. Geological evolution of South-EastAsia (2<sup>nd</sup> Ed.). Geological Society of Malaysia, Kuala Lumpur. 433 p.
- Imbrie, J., MacIntyre, A. & Mix, A.C., 1989. Oceanic response to orbital forcing in the late Quaternary: observational and experimental strategies. In: Berger, A., Schneider, S.H. & Duplessy, J.C. (Eds.), Climate and Geosciences, a challenge for science and society in the 21<sup>st</sup>Century. D. Reidel Publishing Company, Boulder, CO, 121-164.
- Intergovernmental Panel on Climate Change (IPCC), 2001. Climate Change 2001: The Scientific Basis: Cambridge University Press, Cambridge, UK. 881 p.
- Intergovernmental Panel on Climate Change (IPCC), 2007. Climate Change 2007: The Physical Science Basis: Cambridge University Press, Cambridge, UK. 989 p.
- Kamaludin, B. H., 1989. Significance of palynology in late Quaternary sediments in Peninsular Malaysia. Bulletin of the Geological Society of Malaysia, 24, 57-66.
- Kamaludin, B. H., Nakamura, T., Price, D. M., Woodroffe, C. D. & Fugii, S., 1993. Radiocarbon and thermoluminescence dating of the Old Alluvium from a coastal site in Perak, Malaysia. Sedimentary Geology, 83, 199-210.
- Kamaludin, B. H., 2002. Holocene sea level changes in Peninsular Malaysia. Bulletin of the Geological Society of Malaysia, 45, 301-307.
- Kamaludin, B. H., 2003. Mid-Holocene to recent sea level changes in Peninsular Malaysia: a tectonic implication. Bulletin of the Geological Society of Malaysia, 46, 313-318.
- Kessler, F.L. & Jong, J., 2014a. Habitat and C-14 ages of lignitic terrace deposits along the northern Sarawak coastline. Bulletin of the Geological Society of Malaysia, 60, 27-34.

- Kessler, F.L. & Jong, J., 2014b. The origin of Canada Hill a result of strike-slip deformation and hydraulically powered uplift at the Pleistocene/Holocene border? Bulletin of the Geological Society of Malaysia, 60, 35-44.
- Kessler, F.L. & Jong, J., 2015. Incision of rivers in Pleistocene gravel and conglomeratic terraces: further circumstantial evidence for the uplift of Borneo during the Neogene and Quaternary. Bulletin of the Geological Society of Malaysia, 61, 49-57.
- Kirk, H.J.C., 1962. The geology and mineral resources of the Semporna Peninsula, North Borneo. Geological Survey Department, British Territories in Borneo Memoir 14. 178 p.
- Koesoemadinata, R. P., Samuel, L. & Tachjudin, M. I., 1995. Subsidence curves and modeling of some Indonesian Tertiary basins. Bulletin of the Geological Society of Malaysia, 37, 205-230.
- Kopp, R.E., Simons, F.J., Mitrovica, J.X., Maloof, A.C. & Oppenheimer, M., 2009. Probabilistic assessment of sea level during the last interglacial stage. Nature, 462, 863-868.
- Krause, G., 2004. The "Emery-Method" revisited-performance of an inexpensive method of measuring beach profiles and modifications. Journal of Coastal Research, 20, 340-346.
- Kudrass, H. R. & Schluter, H. U., 1994. Development of cassiteritebearing sediments and their relation to late Pleistocene sealevel changes in the Straits of Malacca. Marine Geology, 120, 175-202.
- Lam, S.K., 1997. Quaternary geology of the Kuching area, Sarawak, Malaysia. Geological Survey Department Malaysia Map Report 9. 84 p.
- Lambeck, K., Yokoyama, Y. & Purcell, T., 2002. Into and out of the Last Glacial Maximum: sea-level change during Oxygen Isotope Stages 3 and 2. Quaternary Science Reviews, 21, 343-360.
- Lambeck, K., Antonioli, F., Purcella, A. & Silenzi, S., 2004. Sealevel change along the Italian coast for the past 10,000 yr. Quaternary Science Reviews, 23, 1567–1598.
- Lambeck, K., Purcell, A. & Dutton, A., 2012. The anatomy of interglacial sea levels: the relationship between sea levels and ice volume during the Last Interglacial. Earth and Planetary Science Letters, 315-316, 4-11.
- Law, W. M., 1970. Generalized soil map Peninsular Malaysia. Soil Survey Division, Ministry of Agriculture and Fisheries, Malaysia.
- Lee, D.T.C., 1970. Sandakan Peninsula, eastern Sabah, East Malaysia. Geological Survey, East Malaysia, Report 6. 75 p.
- Liechti, P., Roe, F.W. & Haile, N.S., 1960. The geology of Sarawak, Brunei and western part of North Borneo. Geological Survey Department British Territories in Borneo Bulletin, 3. 325 p.
- Lim, P.S. & Heng, Y.E., 1985. Geological map of Sabah 1:500,000. Geological Survey of Malaysia.
- Lithgow-Bertelloni, C. & Gurnis, M., 1997. Cenozoic subsidence and uplift of continents from time-varying dynamic topography. Geology, 25, 735-738.
- Lourens, L. J., Becker, J., Bintanja, R., Hilgen, F. J., Tuenter, E., van de Wal, R. S. W. & Ziegler, M., 2010. Linear and non-linear response of late Neogene glacial cycles to obliquity forcing and implications for the Milankovitch theory. Quaternary Science Reviews, 29, 352–365.
- Mallinson, D.J., Culver, S.J., Corbett, D.R., Parham, P.R., Shazili, N.A.M. & Rosnan, Y., 2014. Holocene coastal response to monsoons and relative sea-level changes in north-east Peninsular Malaysia. Journal of Asian Earth Science, 91, 194-205.
- McManus, J. & Tate, R.B., 1986. Mud volcanoes and the origin of

certain chaotic deposits in Sabah, East Malaysia. Bulletin of the Geological Society of Malaysia, 19, 193-205.

- Miall, A. D., 2002. Architecture and sequence stratigraphy of Pleistocene fluvial systems in the Malay Basin, based on seismic time-slice analysis. AAPG Bulletin, 86, 1201-1216.
- Miller, K. G., Kominz, M. A., Browning, J. V., Wright, J. D., Mountain, G. S., Katz, M. E., Sugarman, P. J., Cramer, B. S., Christie-Blick, N. & Pekar, S. F., 2005. The Phanerozoic record of global sea-level change. Science, 310, 1293-1298.
- Molengraaff, G. A. F., 1921. Modern deep-sea research in the East Indian Archipelago. The Geographical Journal, 57, 95-121.
- Muhs, D. R., Wehmiller, J. F., Simmons, K. R. & York, L. L., 2003. Quaternary sea-level history of the United States. Developments in Quaternary Science, 1, 147-183.
- Nakamura, T. & Tjia, H. K., 2002. Holocene seas at Pulau Pinang and Pulau Langkawi: new dates. Sains Malaysiana, 31, 23-31.
- Nossin, J. J., 1965. Analysis of younger beach ridge deposits in Eastern Malaya. Zeitschrift fur Geomorphologie, 9, 186-208.
- Olson, S.L. & Hearty, P.J., 2009. A sustained +21 m sea-level highstand during MIS 11 (400 ka): direct fossil and sedimentary evidence from Bermuda. Quaternary Science Reviews, 28, 271-285.
- Parham, P. R., Riggs, S. R., Culver, S. J., Mallinson, D. J. & Wehmiller, J. F., 2007. Quaternary depositional patterns and sea-level fluctuations, northeastern North Carolina. Quaternary Research, 67, 83-99.
- Parham, P. R., Riggs, S. R., Culver, S. J., Mallinson, D. J., Rink, W. J. & Burdette, K. E., 2012. Quaternary coastal lithofacies, sequence development and stratigraphy in a passive margin setting, North Carolina and Virginia, USA. Sedimentology, 60, 503-547.
- Parham, P. R., Saito, Y., Noraisyah, S., Rokiah, S. & Noor Azariyah, M., 2014a. Evidence for ca. 7 ka maximum Holocene transgression on the Peninsular Malaysia east coast. Journal of Quaternary Science, 29, 414-422.
- Parham, P.R., Noraisyah, S., Rokiah, S. & Noor Azariyah, M., 2014b. Holocene relative sea-level highstand patterns, Peninsular Malaysia east coast. Abstracts with Programs, Geological Society of America Annual Meeting. Vancouver, BC, Canada.
- Parham, P.R., Noraisyah, S. & Rokiah, S., 2014c. A tale of two transgressions: comparison of mid-Holocene and modern, anthropogenic-influenced conditions along the NE Peninsular Malaysia coast. 13<sup>th</sup> Regional Congress on the Geology, Mineral and Energy Resources of Southeast Asia (GEOSEA XIII), Yangon, Myanmar.
- Parham, P.R., Noraisyah, S., Rokiah, S. & Noor Azariyah, M., 2015. Holocene relative sea-level highstand record from farfield Peninsular Malaysia. XIX INQUA Congress. Nagoya, Japan.
- Peltier, W. R., Farrell, W. E. & Clark, J. A., 1978. Glacial isostasy and relative sea level: a global finite element model. Tectonophysics, 50, 81-110.
- Peltier, W. R., 2002. On eustatic sea level history: last Glacial Maximum to Holocene. Quaternary Science Reviews, 21, 377-396.
- Pillans, B., Chappell, J. & Naish, T. R., 1998. A review of the Milankovitch climatic beat: template for Plio–Pleistocene sea-level changes and sequence stratigraphy. Sedimentary Geology, 122, 5–21.
- Potter, E. K. & Lambeck, K., 2003. Reconciliation of sea-level observations in the Western North Atlantic during the last glacial cycle. Earth and Planetary Science Letters, 217, 171-181.
- Raj, J. K., Tan, D. N. K. & Abdullah, W. H., 2009. Cenozoic

stratigraphy. In: Hutchison, C. S. & Tan, D. N. K. (Eds.), Geology of Peninsular Malaysia. Geological Society of Malaysia, Kuala Lumpur, 133-173.

- Rangin, C., Bellon, H., Benard, F., Letouzey, J., Müller, C. & Tahir, S., 1990. Neogene arc–continent collision in Sabah, N. Borneo (Malaysia). Tectonophysics, 183, 305–319.
- Rashid Ahmad, A., 2009. Quaternary geology of the Limbang area, Sarawak, Malaysia. Minerals and Geoscience Department Malaysia Map Report 20. 113 p.
- Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Ramsey, C.B., Buck, C.E., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Haflidason, H., Hajdas, I., Hatté, C., Heaton, T.J., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, C.S.M. & Plicht, J.V.D., 2013. IntCal13 and MARINE13 radiocarbon age calibrationcurves 0-50000 years calBP. Radiocarbon, 55, 1869–1887.
- Riggs, S. R., York, L. L., Wehmiller, J. F. & Snyder, S. W., 1992. Depositional patterns resulting from high-frequency Quaternary sea-level fluctuations in northeastern North Carolina. In: Fletcher, C.H. & Wehmiller, J.F.(Eds), Quaternary Coasts of the United States: Marine and Lacustrine Systems. SEPM (Society for SedimentaryGeology) Special Publication, 48, 141–153.
- Ros Fatihah, M. & Komoo, I., 2003. The Kinta Valley karst landscape – a national heritage to be preserved. Bulletin of the Geological Society of Malaysia, 46, 447-453.
- Ros Fatihah, M., Yoshidi, D., Tani, A. & Smart, P.L., 2002. Implications of electron spin resonance and U-series dating techniques in the Kinta and Lenggong valleys, west Malaysia. Advances and ESR Applications, 118, 19-26.
- Rovere, A., Raymo, M.E., Vacchi, M., Lorsheid, T., Stocchi, P., Gomez-Pujol, L., Harris, D.L., Casella, E., O'Leary, M.J. & Hearty, P.J., 2016. The analysis of Last Interglacial (MIS5e) relative sea-level indicators: reconstructing sea level in a warmer world. Earth Science Reviews, 159, 404-427.
- Sathiamurthy, E. & Voris, H. K., 2006. Maps of Holocene sealevel transgression and submerged lakes on the Sunda Shelf. The Natural History Journal of Chulalongkorn University, Supplement 2, 1-43.
- Siddall M., Chappell J. & Potter E.K., 2007. Eustatic sea level during past interglacials. In: Sirocko, F., Litt, T., Claussen, M. & Sanchez-Goni, M. F. (Eds.), The climate of past interglacials, Elsevier, Amsterdam, 75-92.
- Simons, W. J. F., Socquet, A., Vigny, C., Ambrosius, B. A. C., Haji Abu, S., Chaiwat Promthong, Subarya, C., Sarsito, D. A., Matheussen, S., Morgan, P. & Spakman, W., 2007. A decade of GPS in Southeast Asia: ResolvingSundaland motion and boundaries. Journal of Geophysical Research, 112.
- Southon, J., Kashgarian, M., Fontugne, M., Metivier, B. & Yim, W. W-S., 2002. Marine reservoir corrections for the Indian Ocean and Southeast Asia. Radiocarbon, 44, 167-180.
- Spasojevic, S. & Gurnis, M., 2012. Sea level and vertical motion of continents from dynamic earth models since the Late Cretaceous. AAPG Bulletin, 96, 2037-2064.
- Staub, J.R. & Gastaldo, R.A., 2003. Late Quaternary sedimentation and peat development in the Rajang River delta, Sarawak, East Malaysia. In: Hasan Sidi, F., Nummedal, D., Imbert, P., Darman, H. & Posamentier, H.W. (Eds.), Tropical deltas of Southeast Asia – sedimentology, stratigraphy, and petroleum geology. SEPM Special Publication, 76, 71-87.
- Steinke, S., Kienast, M. & Hanebuth, T., 2003. On the significance of sea-level variations and shelf paleo-morphology in governing

sedimentation in the southern South China Sea during last deglaciation. Marine Geology, 201, 179-206.

- Suntharalingam, T., 1983. Cenozoic stratigraphy of Peninsular Malaysia. Proceeding of the Workshop on Stratigraphic Correlation of Thailand and Malaysia, 1, 49-158.
- Suntharalingam, T. & Teoh, L. H., 1985. Quaternary geology of the coastal plain of Taiping, Perak. Geological Survey of Malaysia Quaternary Geology Bulletin 1. 64 p.
- Suntharalingam, T. & Ambak, G., 1986. Quaternary stratigraphy and prospects for placer tin deposits in the Kuantan area, Pahang. Bulletin of the Geological Society of Malaysia, 20, 791-801.
- Taira, K. & Hashimoto, W., 1971.<sup>14</sup>C-age calculated for raised coral reeflimestone near Semporna, Sabah, North Borneo, Malaysia. Geology and Paleontology of Southeast Asia, 9, 161-164.
- Tan, D.N.K., 1981. The geology of the Kuching area, west Sarawak, Malaysia. Geological Survey of Malaysia report 16. 161 p.
- Tan, D. N. K., 2009. Malay and Penyu Basins. In: Hutchison, C. S. & Tan, D. N. K. (Eds.), Geology of Peninsular Malaysia. Geological Society of Malaysia, Kuala Lumpur, 175-196.
- Teeuw, R. M., Rhodes, E. J. & Perkins, N. K., 1999. Dating of Quaternary sediments from western Borneo using optically stimulated luminescence. Singapore Journal of Tropical Geography, 20, 181-192.
- Tjia, H. D., 1992. Holocene sea-level changes in the Malay-Thai Peninsula, a tectonically stable environment. Bulletin of the Geological Society of Malaysia, 31, 157-176.
- Tjia, H.D., 1996. Sea-level changes in the tectonically stable Malay-Thai Peninsula. Quaternary International, 31, 95-101.
- Tjia, H.D., 2001. The rate of geological processes: natural modifications and destruction of the environment. Universiti Kebangsaan Malaysia, Lestari lecture 30.
- Tjia, H.D., 2004. Accelerated shoreline growth and landscape development in Sungai Muda coastal plain. Warisan Geologi 6, LESTARI, Universiti Kebangsaan Malaysia, p. 195-206.
- Tjia, H.D., 2006. Geological evidence for Quaternary land bridges in insular Southeast Asia. In: Simunjuntak, T. (Ed.), Archeology: Indonesian Perspective: R.P. Soejono's Festschift. Indonesian Institute of Sciences, 71-78.
- Tjia, H.D., Fujii, S., Kigoshi, K., Sugimura, A. & Zakaria, T., 1972. Radiocarbon dates of elevated shorelines, Indonesia and Malaysia. Par. 1. Quaternary Research, 2, 487-495.
- Tjia, H.D., Fujii, S. & Kigoshi, K., 1977. Changes of sea level in the southeastern South China Sea area during Quaternary times. United Nations, ESCAP-CCOPTechnical Publication, 5, 11-36.
- Tjia, H.D. & Sharifah Mastura, S.A., 2013. Sea level changes in Peninsular Malaysia: a geological perspective. Penerbit Universiti Kebangsaan Malaysia, Bangi. 150 p.
- van Hengstrum, P.J., Scott, D.B. & Javaux, E.J., 2009. Foraminifera in elevated Bermudian caves provide evidence for +21 m eustatic sea level during Marine Isotope Stage 11. Quaternary Science Reviews, 28, 1850-1860.
- Walker, D., 1956. Studies on the Quaternary of the Malay Peninsula and the relative levels of land and sea. Federal Museum Journal I and II, 19-34.
- Walker, M., 2005. Quaternary dating methods. John Wiley and Sons, Ltd., Chichester, England. 286 p.
- Wigley, T.M.L. & Raper, S.C.B., 1987. Thermal expansion fsea water associated with global warming, Nature, 397, 293–300.
- Wilford, G.E., 1955. The geology and mineral resources of the Kuching-Lundu area, west Sarawak. Geological Survey Department, British Territories in Borneo, Memoir 3. 254 p.
- Wilford, G.E., 1961. The geology and mineral resources of Brunei and adjacent parts of Sarawak with description of Seria and Miri

oil fields. Geological Survey Department, British Territories in Borneo, Memoir 10. 319 p.

Asia – Sedimentology, Stratigraphy and Petroleum Geology. SEPM Special Publication, 76, 200-234.

- Wilson, R.A.M., 1961. The geology and mineral resources of Banggi Island and Sugut River area, North Borneo. Geological Survey Department, British Territories in Borneo, Memoir 15, 143 p.
- Wilson, R.A.M., 1964. The geology and mineral resources of Labuan and Padas Valley area, Sabah, Malaysia. Geological Survey Borneo Region, Malaysia, Memoir 17. 150 p.
- Wolfenden, E.B., 1960. The geology and mineral resources of the lower Rajang Valley and adjoining areas, Sarawak. Geological Survey Department, British Territories in Borneo, Memoir 11, 167 p.
- Wong, H. K., Ludmann, T., Haft, C., Paulsen, A-M., Hubscher, C. & Geng, J., 2003. Quaternary sedimentation in the Molengraaff paleo-delta, northern Sunda Shelf (southern South China Sea). In: Sidi, F. H., Nummedal, D., Imbert, P., Darman, H. & Posamentier, H. W. (Eds.), Tropical Deltas of Southeast

- Woodroffe, S. A. & Horton, B. P., 2005. Holocene sea-level changes in the Indo-Pacific. Journal of Asian Earth Sciences, 25, 29-43.
- Yunus, A. R., Loh, C. H. & Kamaludin, H., 1991. Quaternary stratigraphy of Peninsular Malaysia. Quaternary Stratigraphy of Asia and the Pacific IGCP, 296, 30-36.
- Zachos, J., Pagani, M., Sloan, L., Thomas, E. & Billups, K., 2001. Trends, Rhythms, and aberrations in global climate 65 Ma to present. Science, 292, 686-693.
- Zainal Abidin, N.S., Pierson, B.J. & Ani Aiza, A., 2012. A microscopic analysis of recent lithified limestones from present-day platforms, east of Sabah, Malaysia. Malaysian Journal of Microscopy, 8, 11-16.
- Zaiton, H., Basir, J. & Kamal, R. M., 1999. A new evidence of a higher Quaternary sea level in Lankawi Islands. Bulletin of the Geological Society of Malaysia, 43, 503-511.

Manuscript received 25 October 2016 Revised manuscript received 20 November 2016 Manuscript accepted 26 November 2016