Quaternary palaeoenvironments of the Kallang River Basin, Singapore

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**NANYANG
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UNIVERSITY**

SINGAPORE

**QUATERNARY PALAEOENVIRONMENTS OF THE
KALLANG RIVER BASIN, SINGAPORE**

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KALLANG RIVER BASIN, SINGAPORE**

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A thesis submitted to the Nanyang Technological University in partial fulfillment
of the requirement for the degree of
Doctor of Philosophy

2019

Candidate Statement of Originality

I hereby certify that the work embodied in this thesis is the result of original research, is free of plagiarised materials, and has not been submitted for a higher degree to any other University or Institution. I confirm that the investigations were conducted in accord with the ethics policies and integrity standards of Nanyang Technological University and that the research data are presented honestly and without prejudice.

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In preparation for Journal of Quaternary Science***

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***Paper 2, A revised and extended Holocene sea level curve for the far-field region of Singapore
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Chapter 3 uses material from Chua, S., Switzer, A., Chiam, K., 2016. Quaternary Stratigraphy of the Kallang River Basin, Singapore. Underground Singapore, 261-270.

The contributions of the co-authors are as follows:

- Assoc Prof Adam Switzer provided the initial project direction and edited the manuscript drafts.
- I prepared the manuscript drafts. The manuscript was revised by Assoc Prof Adam Switzer.
- I collated and analyzed all the borehole logs, interpreted all data and constructed the geological model.
- Mr Kiefer Chiam provided the borehole data and geotechnical advice.

3 June 2019

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Summary

The Quaternary period represents the last ~2.6 Ma a period when global climate was marked by a series of more than 50 glacial–interglacial climate cycles. Palaeoenvironmental records from this period enable us to reconstruct past sea level change, climate change, and associated environmental response, which can be used to better predict and prepare for future environmental change. Unfortunately, there remains a paucity of such records in the Sunda shelf region where at least 450 million people face environmental risks associated with future climate change.

The Quaternary stratigraphy of the inner Sunda shelf and much of the coastal areas in Southeast Asia is poorly understood. Developing a detailed framework for the Quaternary evolution of geological terranes is important as many coastal megacities are built on such coastal-marine sequences formed predominantly by palaeoenvironmental change over the last 2.6 million years. A detailed record will also shed light on sea level, climate and coastal change during the Quaternary, of which we know little compared to other parts of the world.

Singapore lies near the core of Sundaland which was largely exposed during the penultimate and last glacial maximums. It is considered to exhibit relative tectonic stability, and the meso-tidal conditions coupled with relatively low-energy wave and wind regime result in reliable, relatively undisturbed sedimentary archives recording palaeoenvironmental change.

In my thesis, I report on the Quaternary stratigraphy, sea level, and coastal change, of the Kallang River Basin (KRB) based on high-resolution sedimentological and geochemical analysis of a ~38.5 m sediment core (~50m below mean sea level) sediment core (MSBH01B), constrained by 23 ¹⁴C AMS dates, and augmented by an extensive collection of borehole data within the KRB. The dataset allows an improved understanding of the stratigraphy of this

critical area which contain Singapore's downtown area, National Stadium and numerous commercial, retail and residential buildings.

First, I created fence diagrams comprising 14 cross-sections spanning the KRB as well as the first 3D geological model with chronology constrained by radiocarbon and OSL ages. My new geological model reveals a more complex geology than currently known, as well as late Quaternary morphological and hydrological changes in the basin, with strong implications for geotechnical and engineering work in the area.

Second, I produced 4 new sea level index points (SLIPs) obtained from basal peats from MSBH01B, recalibrated existing SLIPs, and used a Bayesian modelling approach to produce an extended, statistically-robust sea level history for Singapore. This new record reveals a period of rapid sea level rise (>15 mm/yr) from 9.5 ka BP before a slowdown at ~ 9 ka BP, and a 2nd slowdown between 8 ka and 6 ka BP at ~ 4 mm/yr. The revised sea level record shows a minor inflection at ~ 7.5 ka BP and no unequivocal evidence for notable meltwater pulses observed at 8.2 ka and 7.5 ka elsewhere.

Third, I analysed sediment core MSBH01B using sedimentological and geochemical techniques at high-resolution (cm-scale) to produce a coastal evolution model for Singapore during the early-mid Holocene (~ 9.5 ka - 7.3 ka BP). A mangrove coast existed from ~ 9.5 ka – 9.2 ka BP becoming locally extinct within 300 years as estuarine conditions set in from ~ 9.2 ka – 8.8 ka BP. Prodelta muds were deposited from ~ 8.8 ka to 8.25 ka BP coincident with an increase in subtidal calcareous fauna, succeeded by delta front sediments deposited from ~ 8.25 ka - 7.8 ka BP. A period between 8.5 ka and 8 ka BP with markedly higher precipitation and weathering rates coupled with a dip associated with monsoon weakening is a possible

local expression of the 8.2 ka climate event. Finally, seaward progradation of coarse, shelly deltaic sediment occurred from 7.8 ka - 7.3 ka BP, coeval with global delta initiation.

This thesis improves our understanding of Singapore's late Quaternary stratigraphy through a high-resolution geological model of the Kallang River Basin. The thesis also contributes new knowledge about early-mid Holocene sea level and Holocene environmental change in Singapore and the region.

Chapter 1

Introduction

The Quaternary period refers to the last 2.6 million years in Earth's history and it is characterised and dominated by glacial-interglacial cycles (e.g. Lisiecki and Raymo, 2005; Pillans and Gibbard, 2012; Elias, 2013; Lowe et al., 2013) which are controlled predominantly by orbital and solar insolation cycles (e.g. Milankovitch, 1930; Berger, 1988; Paillard, 2015). The Quaternary comprises the Pleistocene (2.6 Ma to ~11.5 ka BP) and Holocene (11.5 ka BP to present) epochs, with the last 800 ka marked by regular cycles glacial (ice ages) and interglacial (warm periods) at frequencies of approximately 100,000 years (e.g. Shackleton, 2000; Wunsch, 2004; Grant et al., 2014). The glacial cycles also strongly influenced sea level changes up to 140m in amplitude (e.g. Lambeck et al., 2002; Siddall et al., 2003; Clark et al., 2009; Dutton et al., 2015) which greatly altered the geomorphology and depositional patterns at the coastal zone (e.g. Stanley and Warne, 1994; Blum and Törnqvist, 2000; Plater and Kirby, 2011). The Holocene follows the Pleistocene and has recently been ratified and subdivided into the Greenlandian Stage/Age (11.7 ka to 8.2 ka), the Northgrippian Stage/Age (8.2 to 4.2 ka BP) and the Meghalayan Stage/Age (4.2 ka BP to present)(Walker et al., 2018).

Understanding palaeoenvironmental change of the Quaternary is key to predicting and preparing for future environmental change in the context of a

changing climate (e.g. Siddall et al., 2009; Bowen, 2010; Candy et al., 2014). For example, the past, particularly the early phase of an interglacial period, provides invaluable information of how coastal areas respond to sea level, hydrological and climatic shifts (Nicholls and Cazenave, 2010; Woodroffe and Murray-Wallace, 2012). Information on such changes commonly remain archived in the local stratigraphic / sedimentary sequences of coastal deposits and allow inferences on the hydrological interface between ice sheets and oceans (Lambeck and Chappell, 2001; Levac et al., 2015; Pico et al., 2016) and are critical for modelling future sea level dynamics (e.g. Kopp et al., 2017; Horton et al., 2018). Unfortunately, there is still a lack of adequate understanding of Quaternary palaeoenvironments in many parts of the world and particularly in the tropics which includes the now submerged Sundaland region which is particularly poorly studied.

1.1. Study Area

1.1.1. Singapore climate

Singapore lies off the southern tip of the Malaysian Peninsula between the latitude and longitude of 1°09'N and 1°29'N and 103°38'E and 104°06'E respectively. Singapore's climate is tropical given its near-equator location and dominated by the northeast monsoon which is accompanied by frequent rain from December to January, as well as the slightly drier southwest monsoon usually manifested as early-morning storms associated with Sumatran squalls from May to September (Field et al., 2018). The mean annual temperature generally ranges from 31 – 33 °C during the day and 23 - 25 °C at night, with little

monthly variability, accompanied by a mean annual precipitation of about 2200 mm (Meteorological Service Singapore, 2017). The hot and wet climate has a significant impact on the hydrology of Singapore (e.g. rivers, tributaries, estuaries etc.), and also exacerbates normal erosion and weathering processes. These processes greatly alters the surface geology and hydromorphology of the island (Rahardjo et al., 2004; Agus et al., 2005) which have implications for coastal sedimentation regimes.

1.1.2. The Sunda Shelf

The Sunda shelf is the largest continental shelf area in the world (Tjia, 1980; Hanebuth et al., 2009), and was largely exposed during the Last Glacial Maximum (LGM) ~20,000 years BP where sea levels were approximately 120 m below those of today (Hanebuth et al., 2000; Hanebuth et al., 2009). Singapore is situated near the centre of Sundaland, away from tectonic plate boundaries and is generally considered to be relatively tectonically stable (Tjia, 1996; Hanebuth et al., 2000), though a more recent paper suggests downwarping of up to 0.19 mm/yr (Bird et al., 2006). The topography of Singapore is relatively flat (maximum elevation of 163 m) and its coastal areas have a gentle gradient which mean small changes in sea level could potentially lead to relatively large lateral and vertical modifications to the nearshore zone (Tam et al., 2018). Singapore as a modern high-urbanised city-state thus faces environmental pressures especially to its highly vulnerable coastal ecosystems (Hilton and Manning, 1995; Lai et al., 2015)

The Quaternary geology of Singapore mainly comprise sedimentary units deposited by fluvial and nearshore processes (PWD, 1976; DSTA, 2009). The extent and thickness of these units are spatially variable, and temporally controlled by environmental forcing from sea level, climate and hydrological changes.

The Quaternary sediments of Singapore effectively comprise of the units referred to as the Old Alluvium and the more recent Kallang Group, deposited during the penultimate and current interglacial periods. Given the topography of the island, it is clear that rising sea level would inundate coastal areas, fringing mangrove coastlines and tidal estuaries (Wong, 1992; Bird et al., 2007). The major distributary, the Singapore River Basin (demarcated in Fig. 1.1), remains the most extensive Kallang Group deposits where its name was derived.

Figure 1.1. Geology map of Singapore with orange and yellow regions representing Quaternary deposit outcrops. The Kallang River Basin is demarcated at the southeast portion of Singapore. From Mote et al., (2009) modified from Pitts (1984).

1.2. Introduction to the Quaternary Geology of Singapore

Here, I review and present the current understanding of Singapore's Quaternary geology. There is currently a national-level committee overseeing the renaming and reclassification exercise of the geology of Singapore and the newly proposed nomenclature is presented as part of this thesis in Chapter 3.

Much of the current understanding of Singapore's Quaternary geology (Fig. 1.1) was first gleaned from studies in the early-mid 20th Century. The earliest comprehensive field survey was by Scrivenor (1924) who mapped three rock units which he termed Granite, Shale and Sandstone (sedimentary group). He also mapped High Level Alluvium together with Recent Alluvium as the last unit, and stated that they are located generally in central and eastern tip of Singapore, west dipping into southern tip and southeast to east respectively. This was the first notable mention of the Quaternary alluvial deposits for Singapore. Later, Alexander (1950) renamed the High Level Alluvium 'Older Alluvium' based on observations of its base being below modern sea level and its field age being older than that the recent alluvial deposits overlying it. A later study by Burton (1964) concluded that the Older Alluvium was formed during the pre-glacial of the First Interglacial (Gunz-Mindel or Aftonian) during the mid-Pleistocene up to possibly late Pliocene, and was later renamed 'Old Alluvium' (PWD, 1976; Gupta et al., 1987) and very recently, the 'Bedok Formation' (Kendall et al., 2018).

The Plio-Pleistocene Old Alluvium is overlain by the Kallang Formation, named after the Kallang River Basin where it is extensively found. This formation mainly comprises late Pleistocene and Holocene deposits of marine and estuarine origins and covers approximately a quarter of the island (Pitts, 1992). Much of the coastal plains, tidal and inter-tidal zones and incised river valleys (from the previous interglacial) are covered by these deposits up to 5 m above present sea level (Pitts, 1984; Tan et al., 2003; Bird et al., 2007).

The next sections review our current understanding of Singapore's geology based on the existing nomenclature (DSTA, 2009).

1.2.1. Old Alluvium (OA)

The Old Alluvium (OA) is considered a highly-variable sedimentary layer of fluvial origin inferred to be primarily channel fill (Stauffer, 1973) that is associated with the palaeo-Johore River trending in a southeasterly direction (CCOP, 1980). Field observations of OA reveal coarse sandy sediments, often structureless, accompanied by discontinuous beds and prevalence of scour marks, suggesting that OA was laid down by a braided river system (Gupta et al., 1987). The OA has been observed to be variably cemented and shows evidence of exposure to deep weathering processes, particularly in the uppermost layers (Chiam et al., 2003).

1.2.1.1. Distribution and thickness of the OA

The OA is predominantly found to outcrop in the north and northeast of the Kallang River Basin sitting unconformably between the Central and Changi granite. Similar sediments covering an area of about 12 km² exist in Sungei Buloh Besar (or 'Big' Buloh river) in the northwest of Singapore where it sits juxtaposed against the Jurong Formation. The OA is mainly found in the eastern part of Singapore existing as a prevalent, uninterrupted sheet either exposed (Bedok and Changi) or buried underneath the younger deposits of the Kallang Group. (Fig. 1.1).

Previous studies estimate that OA thickness ranges from at least 50 m (CCOP, 1980) to at least 100 m (Gupta et al., 1987). Many boreholes have not been able to reach the granitic basement. Further, from the nearest granitic outcrop, the undulating basement granite was reached at a depth of 53 m (PWD, 1976), while another deeper borehole failed to reach the basement even at a depth of 122 m. Although it is difficult to ascertain the thickness of the sediments, the deepest recorded borehole found that the OA extended to a depth of 149 m and laid directly on quartz sandstone (Sajahat Formation). Nearby OA hills at the height of 35 – 45 m located close to the borehole gives a potential aggregate thickness of 195 m. However, the quartzites, sandstones and argillites of this deposit resemble weathered OA and identification and confirmation of the basal transition remain subjective (DSTA, 2009).

1.2.1.2 Sediment characteristics of the OA

The particles size distribution in OA can serve to classify the types of beds observed, namely pebbles, coarse sand with fine pebbles, medium to coarse sand, and finally clay and silt. The OA sands are mainly quartzo-feldspathic and are found to be semi-indurated (Gupta et al., 1987). These four classes of sediments concomitantly carry unique sedimentary structures and hence quintessential morphological features (see Fig. 1.2 below). The interface between layers is also marked by cross-bedding, scour marks, gravel stringers and silt and clay lenses interdigitated chaotically within the OA. Another method of segregation and classification was attempted by Burton (1964) who classified OA into three zones – the uppermost weathered zone, followed by the mottled zone then the basal unweathered zone. The sediments in the topmost zone is almost completely weathered and stained by iron oxide, giving it its reddish or brownish-yellow hue. The deep chemical weathering destroyed almost all ferro-magnesian minerals and the feldspars have been kaolinised, up to depths of approximately 8 m (Gupta et al., 1987). This weathered zone transits abruptly into the mottled zone which is characterised by white or cream-coloured fresh arterial variegated by red, pink, brown, purple patches which is associated to a fluctuating water table. In some case the mottled zone can be up to 5 m in thickness (Sharma et al., 1999). This zone grades down to an unweathered zone, albeit occasionally interrupted by thin clay and silt beds at various depths (Chiam et al., 2003). It is imperative to note that the simple model of succession here is highly variable both vertically and laterally, and as

seen in Fig 1.2, consists of a myriad of subunits depicting fluvial associations (Gupta et al., 1987).

The above categorization of zones is important as they reveal crucial information about the sedimentological and environmental processes and conditions involved, e.g. energy of the river system, exposure of OA to weathering processes, rate of deposition, extent and time of inundation etc. From the data obtained, one can surmise that OA was heavily weathered and oxidised due to the hot and humid climate, and that the depositional environment was a high energy one due to the prevalence of sand and pebbles. The angular shape of the clasts also indicates a short transportation and burial process, where the source would be unweathered rocks which were eroded further upriver (Chiam et al., 2003).

Figure 1.2. Schematic illustration of the bedded layers within the Old Alluvium. From Gupta et al. (1987).

1.2.1.3 Age of the OA

As a result of its sedimentological formation, the absolute age of OA has been difficult if not impossible to determine due to the dearth of wood, fossils, pollen

or other dateable materials, even in the thicker silt or clay beds (Gupta et al., 1987). Earlier estimates put the age at Plio-Pleistocene (Burton, 1964; Pitts, 1984), and indirect comparisons of evidence from the region (Stauffer, 1973) also implied a late Pliocene to Pleistocene age for OA. A recent geological age of the OA is also suggested by the presence of fresh alkali feldspar crystals among the clay minerals which likely indicates it is not very old (Gupta et al., 1987; Chiam et al., 2003). Of greater certainty is that its formation precedes the Holocene due to the overlying younger Holocene alluvium (PWD, 1976; DSTA, 2009).

1.2.2. Tekong Formation (TF)

The Tekong Formation consists of littoral sediments forming wide terraces standing between 3.6 and 5.5 m above sea-level, with an average elevation of 4 m, on Pulau Tekong and its sister island, Pulau Tekong Kechil (or 'small' P. Tekong) hence its name. Borehole observations describe the Tekong Formation as unconsolidated and loose, fine-grained, light brown sand with peat, wood fragments and the occasional quartz pebbles and fragmented shells (PWD, 1976; DSTA, 2009), although Pitts (1984) included even the pre-reclamation coastal peats and estuarine muds.

1.2.2.1 Distribution and thickness of the TF

Similar subsurface sediments have been found within a similar elevation range on P. Ubin and Changi. Terrace remnants along the northeast and southwest coasts of Singapore, and terrace deposits in the tidal boundaries of Sungei

Serangoon, Lower Seletar Reservoir, Kranji Reservoir, Sungei Pandan, have all been correlated with the Tekong Formation (DSTA, 2009). Such sediment composition is indicative of highwater coastal deposition; similar characteristics displayed in contemporary sand banks south of P. Tekong, adding weight to the suggestion that the Tekong formation represents beach and offshore sandbank deposits formed during higher sea level.

1.2.2.2. Age of the TF

Without confirmation by dating techniques, the age of the TF can only be inferred. It is postulated that the TF was deposited from ~7 ka BP to present during the mid-Holocene highstand (Bird et al., 2007; Bird et al., 2010). During the initial stages of the highstand, the exposed shoreline was subjected to severe erosion, leading to the development of sandsheets intercalated with muddy sediments in the uppermost intertidal zone (Bird et al., 2003).

1.2.3. Kallang Group - Marine Member (MM)

Covering about a quarter of Singapore, the Marine Member (MM) of the Kallang Group constitutes the largest volume of late Quaternary sediments and is found sitting unconformably atop older lithologies on the coastal fringes and river basins. Essentially, this formation is kaolinite-rich marine clay with moderate amounts of montmorillonite and illite (Sharma et al., 1999). The marine member contains two recognised divisions in boreholes, namely the Upper Marine Member/Clay (UMC) and the Lower Marine Member/Clay (LMC),

separated by a thin veneer of weathered marine clay, postulated to be the desiccated crust of the LMC when it was exposed to terrestrial weathering.

1.2.3.1 Distribution and thickness of the MM

No surface outcrops exist, but marine clay can be found within 1 m of the land surface in the Kallang River Basin. The highest recorded occurrence of the UMC is 1.8 m above sea-level (PWD, 1976; DSTA, 2009) in the vicinity of the Rochor/Beach Road area, and it likely accumulated above modern MSL during and after the mid-Holocene marine highstand of approximately +2.5 m around 6000 years ago (Bird et al., 2003). The UMC is widely distributed beneath the Central Business District and the western parts of the Island (e.g. Jurong), often infilling incised palaeochannels cut in LMC or Old Alluvium during the last glaciation (PWD, 1976; DSTA, 2009).

The UMC and LMC are widespread throughout the coastal areas of the island, as well as underlying much of Singapore's Central Business District, Jurong, and southern and eastern offshore islands. On mainland Singapore, undifferentiated marine clay sediments have been found in many inland parts of the island. The maximum recorded thickness to date is approximately 35 m located near Rochor Canal Road, in the south of Singapore, although thicknesses over 55 m have been reported on the offshore island of Pulau Tekong (Tan et al., 2003). Extensive tunnelling activities to build the train system (Mass Rapid Transit) in Singapore has revealed deep deposits in the Kallang Basin (Krishnan et al., 1999), although the depth is highly variable due to the prevalent paleochannels

that commonly trend southeast from the central granitic bedrock (Mote et al., 2009).

The thickness of the UMC formation is variable - from 10 m – 15 m near estuaries, to greater than 40 m especially near the current seaward extent of the Singapore River basin. Likewise, the underlying LMC appear to range from at least 50 m below sea-level to the highest reported occurrence of –4 m in Bedok (Pitts, 1983), an exceptional claim which is unverifiable. The top of the ‘stiff clay’ and LMC deposits are usually located -8 to -9 m deep with the stiff clay commonly forming a sub-horizontal layer situated about -15 m relative to MSL (Bird et al., 2006). In the downtown area, the stiff clay has been observed even deeper, almost 28 m below MSL (PWD, 1976; DSTA, 2009). Offshore, the depth of the LMC and stiff clay unit, if present, can reach up to 30 m below sea level (e.g. Pulau Tekong) (Tan et al., 2003). Davies and Walsh (1983) note that where there is variation in the thickness of the LMC, the depth to the ‘stiff clay’ increases as depth of the LMC increases, presumably due to consolidation/compaction of LMC over time.

Boreholes and cores at other coastal regions show a shallower sequence of the marine member. At the southwestern tip of Singapore where several coastal estuaries were dammed to produce reservoirs, a borehole (BH1A9) showed that LMC (7 m) was much thicker than UMC (2 m), at depths of -18 m. It is notable that no Old Alluvium was encountered with depth, instead here the UMC sits unconformably atop Jurong Formation. In the north where Singapore is

separated from Malaysia via a narrow and shallow strait, the marine clay layer is even thinner. In sharp contrast to the thick depositional bands of Holocene sediments in the southern part of Singapore, the northern coast facing the Straits of Johore contain a thinner and shorter parasequence of marine and more recent mangrove transgressive sediments. A series of cores obtained proximal to Sungei Buloh, a wetland reserve on the northwest coast of Singapore, managed to penetrate through to the heavily-weathered Old Alluvium basement (Bird et al., 2003). One of the cores was obtained below MSL encountered OA at -3.3 m CD (Chart Datum). That same core revealed a well-weathered basal alluvium overlain by clay with increasing amounts of organic matter, presumably mangrove sediments. Here there is an absence of the UMC and oft-concomitant desiccated LMC transitional facies and the marine clay is quickly overlain by a transgressive mangrove sequence followed by a regressive one deposited as the sea retreated after the mid-Holocene highstand. This suggests that unlike the southern coast, mangrove colonies in the north are able to accrete faster than the SLR (rate of approximately 5 mm/year), effectively 'keeping up' with the rising seas (Bird et al., 2004). Finally, in the eastern portion of Singapore, the Changi East Reclamation Project, completed in March 2005, was aimed at increasing total land area in order to expand the capacity of Changi International Airport. The extensive data obtained showed that the marine member was up to 40 m thick and comprises two distinct layers with an intervening desiccated zone (Bo et al., 2003). In summary, the marine member is deposited mainly in the east and southeast parts of the island and provide a sedimentary record of the inundation of these coasts and palaeovalleys, with

thinner deposits in the south-western coastline (e.g. Jurong Lake area) and much thinner units in the northern coasts.

1.2.3.2 Sediment characteristics of the MM

The marine member generally possesses more than 50 % clay content, a relatively constant silt/clay ratio with depth but high and variable organic matter content (Pitts, 1983), as well as highly variable water content relative to depth (Bird et al., 2003). Considered Singapore's earliest Quaternary marine sediments, the LMC is described as homogenous green-grey to dark-blue kaolinite-rich, silty clay, intercalated with occasional macroscopic shell fragments and organic detritus such as peat (Pitts, 1984). The UMC is similar in terms of its geotechnical and mineralogical characteristics to the LMC and often directly overlies the stiff clay unit, where the two clay units are differentiated. It was also observed in lab tests as being highly consolidated, with an overconsolidation ratio (OCR) as high as 8, postulated to be due to factors such as desiccation and aging (Chu et al., 2002).

Although the UMC and LMC are usually differentiated in the field through the presence of the 'stiff' clay interface, Tan et al (2003) observed that another distinguishing factor is that the kaolinite in the LMC has a compact structure which contrasts with the well-flocculated structure clay mineral in the UMC. DSTA (2009) also reports the boundary between LMC and UMC to comprise of stiff reddish brown silty clay and occasionally even as a bed of loose sand, reflecting perhaps the depositional environment at that time. A more detailed

mineralogical examination of the marine member was done by Bo et al. (2003) who described the UMC comprising kaolinite and smectite with small amounts of mica and chloride, while the LMC consists of quartz, kaolinite and smectite with small amounts of mica, chloride, albite, orthoclase, pyrite and halite, suggesting deeper weathering processes. Expectedly, the desiccated zone of stiff clay was classified as an overconsolidated layer of LMC given its similar mineralogy.

1.2.3.3 Age of the MM

Initially, the depositional timeframe of the LMC was hypothesised to be between 12,000 and 18,000 years ago at the end of the Pleistocene epoch. Subsequently, this was inferred to be due to the Small Ice Age which occurred during the Younger Dryas (Gupta et al., 1980). It was suggested that the top part of the LMC was exposed to terrestrial weathering processes. The inundation which ensued due to global sea level rise in the mid Holocene then deposited the UMC upon the weathered intermediate layer, creating the observed stratification (Pitts, 1992). The chronologies were subsequently revised by Bird *et al.* (2003, 2007) who posited that LMC was deposited even earlier during Marine Isotope Stage 5e (~125 ka BP), along with eroded sediments from the unlithified Old Alluvium (Bird et al., 2006). Due to the initial exposure during the sea level regression, terrestrial weathering processes produced the mottled 'stiff' clay that serves as the transitional facie between LMC and UMC. This 'stiff' clay is commonly overlain by peats and sand layers of variable thickness before overlain subsequently by the UMC. At on-shore locations, the UMC grades

upwards into peaty and sandy members of the Kallang Formation, especially around bedrock highs (Bird et al., 2003).

1.2.4. Kallang Group - Alluvial member (AM)

The alluvial member is interpreted as valley fill deposited by fluvial processes, and have been observed interdigitating with other members of the Kallang formation (Bird et al., 2003). The deposits vary widely from pebble beds through sand, muddy sand, to clay and peat (DSTA, 2009; PWD, 1976).

1.2.4.1 Distribution and thickness of the AM

The alluvial member is widely distributed as valley fills throughout Singapore (especially in minor river mouths located along the coastline, and as a thin veneer on the Kallang and Jurong River basin floors). Similar sediments interdigitate with the other members of the Kallang Group and in some instances can underlie the Singapore Clay Formation (Bird et al., 2003). The AM typically exists as thin sequences several metres thick and can be found up to 50 m below MSL underlying the LMC (DSTA, 2009).

1.2.4.2 Age of the AM

Initial estimates put AM at Holocene age (PWD, 1976), but Chang (1995) obtained thermoluminescence dates ranging from 60,000 to >137,000 yr BP for alluvial sand and clayey sand underlying the Singapore Clay Formation at Sungei Nipah in Pasir Panjang. Adding credibility to the claim, a date of 23,000 yr BP was obtained for peaty clay at the base of a 1 m sequence of mostly Holocene

peaty sediments from a freshwater swamp in Central north Singapore (Taylor et al., 2001).

1.2.5. Kallang Group - Littoral member (LM)

Although similar lithologically to the Tekong Formation, the littoral member is distinguished from the TF based on age and depth, where deposition is associated not with highstand elevations but sea level change in between these sea level maximums. The sediments range from pebbly sand to clean sand to shelly sand, sometimes containing up to 60 % calcareous material (Swan, 1971). In cases where beachrock has formed (e.g. Pulau Tekukor), the matrix is either iron-cemented or formed as a lithic conglomerate (DSTA, 2009). At offshore locations such as Pulau Sekudu and Beting Brunok littoral deposits are also formed primarily from lateritic nodules eroded from the underlying weathered granite bedrock.

1.2.5.1 Distribution and thickness of the LM

LM exists in the form of beach deposits, proximal offshore deposits, tidal sandbanks and buried beach terraces. It is found along the southern and eastern coasts of Singapore and on the offshore islands of Pulau Tekong, Pulau Ubin and Pulau Seletar. Beachrock on Pulau Tekukor and St. John's Island is also assimilated into this member. The deposits have been observed in boreholes to a depth of approximately -10 m, but usually not more than 5 m deep, and up to 2.8 m above sea-level on beach ridges and terraces on mainland Singapore and offshore islands (PWD, 1976; DSTA, 2009).

1.2.5.2 Age of the LM

No dating has been attempted for this member (Bird et al., 2003) but PWD (1976) suggests a mid-Holocene to present-day age for these deposits, while the revised geological study by DSTA (2009) further linked the depositional age as early as late Pleistocene given its occurrence below the UMC.

1.2.6. Kallang Group - Transitional member (TM)

The Transitional Member is archetypical mangrove and estuarine sediment characterized by unconsolidated black, greyish to blue-grey mud, muddy sand or sand with high organic content, even grading into pure peat, suggesting a strong association with mangrove deposits deposited in a low-energy environment (Bird et al., 2003; DSTA, 2009).

1.2.6.1 Distribution and thickness of the TM

The Transitional Member is found in the river mouths and tidal swamps around the perimeter of Singapore, especially at the western end (DSTA, 2009), where it is located up to a few metres above sea level. In terms of field relations, it is typically found overlying the UMC and TF in pre-reclamation soils (Bird et al., 2003). A 0.5 m mangrove peat unit was observed in a recovered sediment core from Bras Basah Road at a depth of 4 m below sea level (Bird et al., 2007).

1.2.6.2 Age of the TM

Dating of this member has been non-conclusive, with PWD (1976) and DSTA (2009) proposing a recent to present-day age as it has been mapped and

observed in contemporary times, as supported by a ~1200 cal yr BP age from a core in Geylang (Bird et al., 2010). However, field observations by Pitts (1983) revealed this member intercalating with and/or underlying the Singapore Clay Formation which suggests a much broader age range. Further, radiocarbon dates of 3,500 - 5,900 yr BP for TM (peat) located 1.2 to 2.0 m above modern sea-level in Pasir Panjang confirms that it was deposited at least mid-Holocene (Chang, 1995).

1.2.7. Kallang Group - Reef Member (RM)

The Reef Member is predominantly composed of coral reef platforms and calcareous detritus. These reefs units are exposed during low-tide as fringing islandic platforms, as disconnected shoals associated with former islands (DSTA, 2009), or underlie parts of present-day islands (e.g. Pulau Ubin).

1.2.7.1 Distribution and thickness of the RM

RM has been observed on the southern, western and southwestern side of Singapore and southwestern group of offshore Islands. Its location within the Quaternary strata is intercalated with the Tekong and Raffles Formation of the Kallang Group (DSTA, 2009). No RM have been observed within the Kallang River Basin.

1.2.7.2 Age of the RM

Dates of 6,300 - 6,500 yr BP have been obtained from relict raised corals (0 - 0.5 m above modern MSL), suggesting that these corals grew during the mid-Holocene sea-level highstand (Hesp et al., 1998).

1.2.8. Depositional history of the Quaternary deposits

The lowermost unit the Old Alluvium (OA) was inferred to be braided river fluvial deposits deposited during the Plio-Pleistocene epochs (possibly 0.2 – 5 million years ago) where sea levels were much lower than present (Gupta et al., 1987). The overlying Lower Marine Clay (LMC) was postulated to be subsequently deposited over the Old Alluvium as early as ~140,000 years ago following the end of the penultimate glacial period (Bird et al., 2003). During MIS stage 5e sea level likely reached levels higher than today from 125,000 - 115,000 years ago (e.g. Hearty et al., 2007; Rovere et al., 2016) which deposited the Littoral Member, largely coarse sediments intercalated with mud in the highest intertidal zone during periods of HAT (highest tides). Persistent sea level rise resulted may have also resulted in the deposition of mangrove peat (Transitional Member) over the interdigitated sand and mud layer as mangrove colonisation occurred, or in the form of alluvial deposits in fluvial or estuarine environments, before being succeeded by LMC upon more permanent marine inundation. However, the transitional nearshore facies are not recorded in existing borehole data.

Sea level began fluctuating between –20 and –70 m approximately 115,000 and 85,000 years ago (e.g. Lambeck and Chappell, 2001), with the LMC in Singapore possibly deposited periodically in deeper parts of the downtown area (Bird et al., 2003; Bird et al., 2007). During the Last Glacial Maximum, sea levels in the Sunda region regressed to a low of ~130 m below current MSL (Hanebuth et al., 2000) which resulted in the LMC being exposed to terrestrial pedogenic processes producing the surficial ‘stiff’ mottled clay differentiating it from the UMC. It is noteworthy that in some boreholes this differentiation is not observed, possibly due to little to no subaerial exposure during sea level lows, or substantial erosion of the uppermost portion. Post-LGM sea level rise during the early Holocene about 11,000 years ago (~20 – 25 m below MSL) was postulated to have breached the eastern and western sills of the Singapore palaeostraits (Bird et al., 2006), resulting in rapid inundation of mainland Singapore where UMC was deposited. This led to rapid deposition of marine/hemipelagic sediments, followed by an overlay and accumulation of transgressive mangrove peat (Transitional Member) juxtaposed laterally with fluvial deposits (Alluvial Member). Highstand conditions presumably led to mangrove peat deposition in more inland regions of Singapore, while subsequent sea-level retreat resulted in prograding accumulation of littoral/alluvial units till modern sea levels were reached. Figure 1.3 shows the proposed profile of the stratigraphy in the Kallang Group based upon a sedimentology model for Singapore by Bird et al. (2003).

Figure 1.3. A schematic illustration of the stratigraphic relationships between the Kallang Group and Tekong Formation of Singapore. Adpated from Bird et al., (2003).

1.3. Aim of Study

The Quaternary geology of Singapore, particularly in the Kallang River basin, potentially contains good archives for understanding palaeoenvironmental and sea level change from the late Pleistocene to present. The multitude of boreholes available due to the rapid development in the area provide good high-resolution data for an improved understanding of the stratigraphy, sea level dynamics and palaeoenvironmental change of Singapore and the region during the late Quaternary phase. The borehole information also served to highlight key locations for obtaining scientific continuous sediment cores for the purpose of palaeoenvironmental reconstructions.

The work of this thesis aims to answer the following scientific questions:

1. How and where were different sedimentary facies deposited from the late Quaternary to present in the Kallang River Basin, and how is the facies distribution superimposed against a backdrop of sea level change of up to 130 m amplitude?
2. How does our current understanding of Singapore's Quaternary stratigraphy compare with hitherto unsynthesised borehole data?
3. What are the ages for the different late Quaternary sedimentary facies?
4. Was sea level during the early Holocene stepped or continuous?
5. How did the Kallang river basin evolve during the early Holocene?
6. Are there clear palaeoclimatic or palaeohydrological shifts that can be observed in the sediments (e.g. mid-Holocene Climate Maximum)?

1.4. Structure of Thesis

Chapter 2 provides a literature review that examines Quaternary sea level, stratigraphic and palaeoenvironmental records at various scales with a focus of setting the context for the Kallang River Basin studies. I review hitherto studies done from the larger global context, followed by Asian records, then studies done in the Sunda region and ultimately Singapore.

In Chapter 3 I aim to review the current understanding of the Quaternary stratigraphy of Singapore comparing with borehole data found within the Kallang River Basin where extensive Quaternary units were deposited. I construct the first geological model for the Kallang River Basin and use it to

better understand geomorphological changes over broader spatial and temporal scales. The new model will inform local geotechnical and engineering agencies and provide guidance on viable sites for future sediment core recovery, which would provide sample ages to build a chronology for the various Quaternary units.

In Chapter 4 I produce a recalibrated and extended sea-level record for Singapore through obtaining new sea-level index points (SLIPs) from this study and augmenting that with existing SLIPs (i.e. Bird et al., 2007; Bird et al., 2010). I use new standardized protocols (Hijma et al., 2015), introduce new age-dates from our core, and Bayesian statistical methods (Cahill et al., 2015) to produce a new sea-level record for Singapore.

Chapter 5 aims to study the palaeoenvironmental change of the Kallang River Basin through high-resolution subsampling of sediment core material at cm-scale using a suite of sedimentological (e.g. grain-size analysis, loss-on-ignition) and geochemical (e.g. X-ray fluorescence scanning) approaches. I then reconstruct palaeoenvironmental change for Singapore constrained in time by >20 radiocarbon dates.

Chapter 6 is a synthesis where I highlight key results from Chapters 3 to 5, and highlight some of the limitations and challenges which I hope can be resolved and/or improved upon in future studies.

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Chapter 2

A review of the Late Quaternary stratigraphy, sea level and palaeoenvironments of the Sunda Shelf, Southeast Asia.

This chapter looks at the environmental change (e.g. climate, sea level change) occurring during the Quaternary (i.e. last ~2.6 million years). I review Quaternary climate and sea level change starting with selected global records before narrowing down to Asian records and finally to records from within Sundaland and Singapore, where available. The primary emphasis will be put on Holocene records as this is synchronous with the sediment core obtained as part of this dissertation. I focus mainly on the late Quaternary, in particular the last two glacial/interglacial cycles (i.e. from MIS 5e to the Holocene) where I will review in detail the surficial Quaternary stratigraphy of the Sunda Shelf.

2.1. Introduction – The Quaternary

The Quaternary period represents the last ~2.6 Ma of geological time, a period when global climate was marked by a series of >50 glacial–interglacial climate cycles (Elias, 2013; Lowe et al., 2013). The Quaternary is divided into the Pleistocene epoch (2.6 Ma to ~11.5 ka BP) that saw longer glaciations (ice ages), separated by warm intervals (interglacial periods) of shorter durations, and finally the Holocene epoch which is the current interglacial period that began

about ~11.5 ka BP (Pillans and Gibbard, 2012; Elias, 2013). The base of the Quaternary Epoch is defined by the GSSP (Global Stratotype Section and Point) for the Gelasian Stage at Monte San Nicola section in Sicily, Italy (Gibbard et al., 2010; Pillans and Gibbard, 2012). This base is coincident with Marine Isotope Stage (MIS) 103 with a basal age of 2.59 Ma (Murray-Wallace and Woodroffe, 2014). The base of the Holocene Epoch is also defined in the NGRIP ice core from the central Greenland ice sheet at a depth of 1492.45 m, with an age, based on multi-parameter annual layer counting, of 11,700 years b2k (before AD 2000), with a maximum counting error of 99 years (Walker et al., 2009). More recently, a formal ratification was done further subdividing the Holocene into 3 stages with the introduction of two new GSSPs (Walker et al., 2018). The first new GSSP is defined by a base dated at 8236 years b2k from the NGRIP 1 Greenland ice core at the depth of 1228.67 m that displays a clear signal of climatic cooling. The period from 11.7 ka to 8.2 ka BP is thus demarcated and termed the Greenlandian Stage/Age. The second new GSSP is defined from speleothem KM-A obtained from Mawmluh Cave in the northeastern Indian State of Meghalaya. A marked shift to heavier isotopic values was observed at 4250 years b2k, which effectively delineated the period from 8.2 to 4.2 ka BP as the Northgrippian Stage/Age, and the Meghalayan Stage/Age from 4.2 ka BP to present.

2.2. Records of Quaternary climate change

Quaternary climate was strongly influenced by Milankovitch cycles which are orbital and solar insolation cycles named after Serbian geophysicist Milutin Milankovitch (Milankovitch, 1930). Reviews by Berger (1988) and Paillard (2015) provide a reasonable context and note that the last 800 ka was characterized by more regular glacial-interglacial 100 ka cycles, instead of the predominantly ~40 ka oscillations that marked the early Pleistocene, with the transition (mid-Pleistocene climate transition or MPT) discovered in the mid-1970s (Shackleton, 1976). The glacial-interglacial cycles occur on approximately 100-ka time scales (Shackleton, 2000; Wunsch, 2004) with superimposed 23-ka and 41-ka cycles (e.g. Imbrie et al., 1984; Imbrie et al., 1992; Raymo et al., 2006) discovered primarily from oxygen isotope records in deep-sea sediment cores. Earlier pioneering work in the 1970s (e.g. Broecker and Donk, 1970; Hays et al., 1976) revealed the timing and repetition of these cycles with their sawtoothed pattern by analysing O^{18}/O^{16} curves from deep-sea benthic foraminifera found in sediment cores. Subsequent landmark studies produced the first algorithm-aligned 5.3-Ma stack ('LR04' stack) of benthic $\delta^{18}O$ records from 57 globally distributed sites (Lisiecki and Raymo, 2005; Raymo et al., 2006) (Fig. 2.1).

Figure 2.1. A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}\text{O}$ records spanning the last 5.3 Ma. Adapted from Lisiecki and Raymo (2005).

2.2.1. Global records of Quaternary climate change

The initial high resolution ice-core chronologies from the Russian Vostok station in East Antarctica spanned the last 420 ka (Petit et al., 1999), with noticeable differences between deep-sea and ice oxygen isotope records which were subsequently calibrated by incorporating the influence of the Dole effect (Jouzel et al., 2002). More recent Vostok records up to 400 ka reveal carbon dioxide concentrations comparable to pre-industrial conditions at 278 ppm (Raynaud et al., 2005). Further, longer Antarctic records from Vostok and Dome C (EPICA project) up to 3200 m deep stretched the record to MIS 20 (800 ka BP) suggests a general increasing CO_2 trend by ~ 25 ppm from 800 to 400 ka BP (Lüthi et al., 2008). Elsewhere, two ice-cores obtained from central Greenland (Greenland

Ice-core Project or GRIP) suggest the presence of abrupt climatic shifts over the past 250 ka (Dansgaard et al., 1993). A later project (North Greenland Ice Core Project or NGRIP) which commenced in 1996 obtained another ice-core that extended back to 123 ka BP which revealed a hitherto unrecognized abrupt warm period at ~115 ka BP (North Greenland Ice Core Project et al., 2004).

Studies incorporating other types of records such as coral proxies, notably from Barbados and the raised terraces of the Huon Peninsula, obtained good chronologies using ^{14}C and $^{230}\text{Th}/^{234}\text{U}$ techniques which show the same 100 ka cycles in the oxygen isotopic record (e.g. Chappell and Shackleton, 1986; Fairbanks, 1989; Bard et al., 1990). In one example coral records from Huon Peninsula (core V19-30) extend to the past 340 ka and demonstrated a strong relationship between deep water temperatures in the abyssal zone and ice age climate (Chappell and Shackleton, 1986). These records agree with the 100-ka glacial cycles revealed in other proxy records, and suggest early strongly-coupled responses between surface, deep ocean and atmospheric CO_2 and lagged ice sheet growth in glacial cycles. Agreement was also obtained from atmospheric $\delta^{18}\text{O}$ signals from analysis of air bubbles trapped in ice-core records (e.g. Shackleton, 2000; Jouzel et al., 2002), a finding that partially addresses the issue of contamination in the benthic foraminiferal records by deep-water temperature variability.

Marine Isotope stage (MIS) 5e, commonly considered the start of the 'Last Interglacial' or LIG, was dated to begin at approximately 130 ka BP and lasted

till approximately 116 ka BP, based on correlation to uranium–thorium dates of raised coral reefs in Barbados (Bard et al., 1990). Support for the timing also came from Cutler et al. (2003) who provided augmented dates from the Huon Peninsula, Papua New Guinea and provided an age constraint of 113.1 ± 0.7 ka as the end of MIS 5e. MIS 5e was likely characterized by a warmer climate and higher sea levels than modern conditions as suggested by numerous studies worldwide (e.g. Hearty et al., 2007; Rovere et al., 2016; Hoffman et al., 2017). In one example detailed proxy records from the Vostok ice core showed that temperature reached modern levels by 132 ka BP and rose for another two millennia (Kukla et al., 2002). Elsewhere, evidence from planktic foraminiferal assemblages from sediment cores recovered from the Norwegian Sea suggest an early warm phase resulting in deglaciation of the Saalian ice sheets from 135 ka – 124.5 ka BP, followed by a cooling phase till 118.5 ka BP (Bauch and Erlenkeuser, 2008). Oxygen isotopic records from a deep ice core obtained in the 1990s from central Greenland (NGRIP) suggest that climate was largely stable from MIS 5e through the LIG, with temperatures up to 5 °C warmer than modern conditions (North Greenland Ice Core Project et al., 2004), before cooling down rapidly entering the Last Glacial Maximum.

2.2.2. Asian records of Quaternary climate change

In Asia, long oxygen isotope records have been obtained from Chinese stalagmites which include the 640 ka record from Sanbao Cave in central China (Cheng et al., 2016). Their record shows millennial-scale monsoonal rainfall reduction, or dry phases, associated with each glacial termination. Another

oxygen isotope record spanning ~75 ka to 11 ka BP was obtained from 5 stalagmites from Hulu Cave east of Nanjing (Wang et al., 2001) with good agreement with Greenland ice core records. The cave records show millennial-scale variability matching solar insolation records, with a generally warm and dry period from 75 ka – 60 ka BP, followed by an abrupt shift to wetter conditions during Heinrich Event 6 (~60 ka BP), a slow decrease from warm/wet to warm/dry conditions from 60 ka to 30 ka BP, followed by an accelerated arid phase from 30 ka to ~16 ka BP. Monsoon strength is inferred to be weakest at ~16 ka BP by the cave records before increasing into the early Holocene producing possibly coincident with warmer and wetter conditions. Such millennial-scale variability was also observed from stable isotope records of foraminifera recovered at ODP Site 1144 in the northern part of the South China Sea, where a dominant cyclicity of ~1.4 ka from 800 ka – 1060 ka BP was detected in association with East Asian monsoon changes (Jin and Jian, 2013). Similar trends with slight temporal offsets were obtained from a ~70 ka $^{87}\text{Sr}/^{86}\text{Sr}$ record recovered from lake deposits obtained from Huguangyan Maar in southern China which reflect wet and dry periods during the LIG (Zaarur et al., 2018). The results generally show a drier period from 70 ka to 40 ka BP before rising up to peak moisture conditions from 30 ka to 20 ka BP and decreasing from 20 ka BP to the mid Holocene.

Elsewhere in Asia, two stalagmites from Kiriana cave, central Honshu, Japan provide an oxygen isotope record reaching back 83 ka (Mori et al., 2018). Key findings include a postulated +9 °C warming between the LGM and mid-

Holocene, a general drying trend between 40 ka and 22 ka BP, and -3°C cooling at Heinrich events. Climate evidence from deep-sea cores in the South China Sea and waters east and south of Sundaland led De Deckker et al. (2002) to correlate the increase in sea surface salinity in the Indo-Pacific Warm Pool (IPWP) with significant reduction in precipitation and thus drier conditions during the LGM. Numerous studies in Sulawesi on changes to the IPWP from the last Interglacial also showed similar climatic trends (e.g. Russell et al., 2014; Costa et al., 2015; Wicaksono et al., 2015). However, sediment cores taken off the continental shelf of the southern South China Sea provided pollen and phytolith evidence suggesting a colder but not significantly dryer climate during the LGM (Wang et al., 2009). Indeed, a record showing a wetter period from 15 ka to 7 ka BP was obtained from sediment samples recovered from a deep-sea core (2064 m water depth) from the Andaman Sea and four Marthaban shelf sediments off Myanmar river mouths and the Arakan coast (Miriayala et al., 2017). Analysis using chemical weathering proxies such as chemical index of alteration (CIA), elemental Al/K, Rb/Sr and $^{87}\text{Sr}/^{86}\text{Sr}$ isotope ratios of the detrital sediments strongly suggest that ~15 ka - 7 ka BP is a period of increased monsoon and concomitant runoff strongly associated with intensified chemical weathering.

2.2.3. Records of Quaternary climate change from the Sunda Shelf

A pollen record recovered from a marine core (BAR94-42) off the coast of southwest Sumatra was used to reconstruct the palaeoclimate over the last 83 ka (van der Kaars et al., 2010). The results suggest a humid regional climate with shorter, drier seasons during MIS 5a, supported by a dominance of rainforest and herbaceous swamp species pollen. A shift to drier conditions occurred from MIS 4 to MIS 1 where the coolest and driest phase was identified from ~52 ka to 43 ka BP with a coincident increase in montane trees. Conditions stayed cool but wetter after 43 ka BP with increased monsoon strength where rainforests became dominant over southwest Sumatra. There is good agreement with another vegetation record obtained from the Kelabit Highlands of Sarawak, Borneo, spanning 50 ka to 12.7 ka BP (Jones et al., 2014). They too observe higher occurrence of upper-montane taxa pollen from ~47.7 ka to 30 ka BP indicative of cooler conditions, accompanied by possibly extreme aridity periods between 30.2 ka and 12.7 ka BP suggested by thick charcoal bands. Other studies have also suggested relatively colder and more arid conditions from 30 ka to 11.9 ka BP (Cook and Jones, 2012b; Niedermeyer et al., 2014; Russell et al., 2014) in Sundaland. Dryer and cooler conditions from the LGM to the Holocene were postulated to have produced a savannah corridor as land bridges connected much of insular Southeast Asia during periods of lowered sea levels (Bird et al., 2005). However, a more recent study using floristic cluster analysis from tree inventories in Sumatra, Borneo and Peninsular Malaysia provided no support for the savannah corridor hypothesis which suggest that drier conditions may not have been long-lived (Slik et al., 2011). A review of pollen

records from mainland Southeast Asia was done by Chabangborn et al. (2018) to reconstruct temperature-rainfall patterns from 18.5 ka to 11.5 ka BP. Their results suggest generally warming patterns during this period coeval with shifts in mean Intertropical Convergence Zone (ITCZ) positions leading to spatially variable precipitation patterns due to changes in monsoonal strength. Rapid sea level rise gradually led to connections with oceanic water, in particular the Indo-Pacific Warm Pool, which were likely to have contributed to warming and wetter conditions in inner Sundaland during the first half of the Holocene (Niedermeyer et al., 2014). The extent and distribution of vegetation in Sundaland changed since the LGM in response to sea level rise, where coastal swamps and evergreen experienced substantial expansion from 11 ka to 9 ka BP, reaching current positions at ~8 ka BP (Cannon et al., 2009).

Some studies suggest that the postulated arid post-LGM period were not expressed in vegetation change in all parts of Sundaland. For example, Hu et al. (2003) studied the molecular distribution and stable carbon-isotopic composition ($\delta^{13}\text{C}$) of *n*-alkane from a southern SCS sediment core which showed no significant vegetation change in Sundaland from LGM to the early Holocene. The isotopic composition for the entire core ranges from -27.1‰ to -33.9‰ for $\text{C}_{27}\text{--}\text{C}_{33}$ *n*-alkanes indicating mainly C_3 higher plant inputs consistently from 19.6 ka to 1.4 ka BP.

2.3. Records of Holocene climate change

The Holocene epoch, in particular the early Holocene (11.65 ka to 7 ka BP) (Smith et al., 2011) was marked by abrupt shifts in climate at millennial timescales (e.g. Mayewski et al., 2004; Törnqvist and Hijma, 2012; Goslin et al., 2018) potentially due to catastrophic deglaciation events (Carlson et al., 2008; Ullman et al., 2016). Together such changes lead to significant global environmental change along coastal zones across the earth (Törnqvist and Hijma, 2012; Plag and Jules-Plag, 2013; Pedoja et al., 2014). Findings from Holocene climate change records are highly critical to understanding future ice-sea-climate interactions (e.g. Woodroffe and Murray-Wallace, 2012; Stokes et al., 2015; Hu and Bates, 2018).

To test the relationships between solar insolation patterns and global climate/monsoon patterns during the Holocene, Kutzbach (1981) conducted a sensitivity experiment by running general circulation models using solar radiation values for 9000 yrs BP. His results show that global average solar radiation for July during this early Holocene timeframe was 7 % higher than modern conditions, while his model further agrees with palaeoclimate evidence showing stronger monsoons between 10 ka and 5 ka BP. This phase has been termed the “Holocene Thermal Maximum” and characterised by relatively warmer conditions with spatially-variable time lags across the global (Renssen et al., 2012; Marcott et al., 2013).

2.3.1. Global records of Holocene climate change

Steinhilber et al. (2012) combined different ^{10}Be ice core records from Greenland [GRIP - Yiou et al. (1997)] and Antarctica [EPICA - (Muscheler et al., 2004; Ruth et al., 2007)], in particular a new high-resolution ^{10}Be record from Dronning Maud Land, with the global ^{14}C tree ring record (Reimer et al., 2009) to derive a new synthesized total solar irradiance record. This new record suggests stronger cosmic ray intensity from 9 ka to 7 ka BP relative to the rest of the Holocene. This stronger solar insolation directly resulted in a warmer global climate during the early Holocene. A set of Monte-Carlo derived stacked records from 73 globally distributed temperature palaeorecords show warmest temperatures during the early Holocene (10 ka to 5 ka BP) followed by $\sim 0.7^\circ\text{C}$ cooling through the middle to late Holocene (<5000 years ago) (Marcott et al., 2013). Insolation changes directly led to the southward shift through the Holocene of the Atlantic ITCZ, supported by titanium and iron concentration data from sediment records from the Cariaco Basin at offshore Venezuela obtained at ODP site 1002 (Haug et al., 2001).

The most significant climate event during the Holocene is the so-called '8.2 ka event' which may have only lasted for a period as short as ~ 150 years (Alley et al., 1997; Mayewski et al., 2004; Cronin et al., 2007; Kobashi et al., 2007; Oster et al., 2017). Excellent globally-synthesized reviews have been done to show a widespread albeit spatially-variable climate anomaly in the Northern hemisphere, parts of Middle East and Central Asia, and as far as the low latitudes (Morrill and Jacobsen, 2005; Rohling and Pälike, 2005). A more precise

chronology from Greenland ice core records show the 8.2 ka event started at 8175 ± 30 cal BP and reached maximum cooling of 3.3 ± 1.1 °C in central Greenland in less than 20 years where cold temperatures were sustained for a further 60 years (Kobashi et al., 2007). A multi-stage 8.2 ka event was proposed earlier by Ellison et al. (2006), who detected cooling events at 8490 and 8290 yr BP based on a deep-sea sediment core from the southern limb of the Gardar Drift in the subpolar North Atlantic. Using a different line of evidence from XRF-scanning of sinkhole sediments from northern Cuba, Peros et al. (2017) further showed three peak climate cooling conditions at 8150, 8200, and 8250 cal yr BP.

Alley and Ágústsdóttir (2005) proposed that the abrupt 8.2 ka climate event generally introduced colder and dryer conditions to the northern hemisphere which possibly affected negatively Neolithic farmers in South-East Europe (Weninger et al., 2006). Interestingly, a speleothem record from White Moon Cave, central California, suggests that this event was instead characterized by wetter conditions instead due to increased storminess in the region (Oster et al., 2017).

2.3.2. Asian records of Holocene climate change

The Asian Monsoon intensification during the early Holocene is thought to be a result of heightened orbitally-induced summer insolation influencing Intertropical Convergence Zone (ITCZ) positions which has a profound effect on low-latitude precipitation (Mohtadi et al., 2016). Such shifts in ITCZ position have been shown to affect precipitation and overall hydroclimatic conditions

especially in the interior of the Maritime Continent which is situated and influenced significantly by the Indo-Pacific Warm Pool (Niedermeyer et al., 2014).

The oxygen isotope record from the Dongge caves, China, reveals strong anti-correlation between $\delta^{18}\text{O}$ values and Asian summer monsoon strength, and an overall strong Asian monsoon interval between 9 ka and 7 ka BP followed by general weakening over the rest of the Holocene (Wang et al., 2005). The extended and higher-resolution record from the same cave by Dykoski et al. (2005) showed similar patterns, albeit a longer period of heightened monsoon strength from the start of the Holocene at ~ 11.5 ka – 5.5 ka BP and punctuated by abrupt shifts to weaker monsoons centred at 11225 ± 97 yr BP, 10880 ± 117 yr BP, 9165 ± 75 yr BP, and a double event centered at 8260 ± 64 yr BP and 8080 ± 74 yr BP which agrees with the Hulu cave data. Solar forcings appear to be the dominant mechanism, juxtaposed against punctuations possibly correlated with Lake Agassiz outburst events between 9 ka and 8 ka BP. Monsoon proxy records (*G. bulloides* $\delta^{18}\text{O}$ data) from sediment cores obtained from the continental margin of Oman, Arabian Sea, also provided evidence showing intervals of weaker Asian southwest monsoon coincident with cold periods in the North Atlantic coeval with possible meltwater discharge events (Gupta et al., 2003).

Superimposed within this timeframe is the '8.2 ka climate event' (e.g. Alley et al., 1997; Alley and Ágústssdóttir, 2005; Matero et al., 2017; Oster et al., 2017), but there are few climate records attributed to this cooling event in Asia. In

temperate South Korea an abrupt shift to higher aridity around 8.2 ka BP was recorded in the Bigeum Island pollen records and implied by a decline in *Alnus firma* which colonizes water-logged soils (Park et al., 2018). Some Asian records support the ‘multi-stage hypothesis’, with speleothems from China and Oman showing evidence of double-plunging patterns at 8212 and 8086 yr BP (Cheng et al., 2009). Nonetheless, there is little evidence of disruption to farming communities in Southwest Asia (Flohr et al., 2016) which suggest at best a lower magnitude climate event in this region.

2.3.3. Records of Holocene climate change from the Sunda Shelf

Sundaland is largely tropical, delineated by boundary latitudes of approximately 9° N and S, where low-latitude Holocene climate is strongly influenced by solar insolation intensities (e.g. Kutzbach, 1981; Wang et al., 2005; Cook and Jones, 2012b) and precipitation by the strengths of summer and winter monsoons (e.g. An, 2000; Goodbred Jr and Kuehl, 2000; Wang et al., 2005; Colin et al., 2010; Wang et al., 2012a; Li and Xu, 2016; Rao et al., 2016). Several high-resolution speleothem records have been instrumental to our understanding of monsoon patterns and trends during the Holocene within the Sunda Shelf, in particular the Australian-Indonesian Summer Monsoon (AISM) and the East Asian Summer Monsoon (EASM) (Partin et al., 2007; Griffiths et al., 2013; Wurtzel et al., 2018). Three well-dated stalagmite $\delta^{18}\text{O}$ records spanning the last 27,000 years were obtained from Gunung Buda National Park in northwestern Malaysian Borneo (Partin et al., 2007). The oxygen isotopic data showed that western tropical Pacific atmospheric circulation and hydrology trended towards drier conditions

(maximum stalagmite $\delta^{18}\text{O}$ values) at 16.3 ± 0.3 ka BP, before decreasing steadily from ~ 16 ka BP and reaching minima values of between ~ -8 to -10 ‰ at ~ 5 ka BP. These records indicate a wetter early to mid-Holocene, strongly suggesting that the ITCZ mean position migrated southwards during the Holocene in response to precessional forcing, crossing the equatorial west Pacific approximately 5000 years ago.

A series of papers based on precisely-dated stalagmite oxygen isotope record from Liang Luar Cave, Flores showed monsoon intensification from 11 ka to 7 ka BP. This rapid change in precipitation patterns is expressed as $\delta^{18}\text{O}$ depletion from ~ -4 ‰ to -6 ‰, which was adjusted subsequently by correcting for Indo-Pacific warm pool SST and global ice volume to show a ~ 1 ‰ decrease in $\delta^{18}\text{O}$ from the early to mid-Holocene indicative of monsoonal rainfall change (Griffiths et al., 2009). Further work incorporating Mg/Ca, Sr/Ca and $\delta^{13}\text{C}$ data on stalagmite LR06-B1 display an overall reduction in monsoon precipitation, specifically the Australian–Indonesian Summer Monsoon (AISM), during the early Holocene (relative to modern levels) before rapidly intensifying from 10 ka BP to the mid-Holocene (Griffiths et al., 2010). The strong coherence between trace element and oxygen isotope data also validates the signal authenticity of the $\delta^{18}\text{O}$ record in response to the hydrology above the cave system. Griffiths et al. (2013) then used a robust “ramp-fitting” method to detect time-series inflections in the Liang Luar records and confirmed statistically the rapid wetting trend beginning at ~ 9.5 ka BP.

More recently Wurtzel et al. (2018) recovered aragonite–calcite speleothem from Tangga Cave, central West Sumatra where the $\delta^{18}\text{O}$ measurements and chronology covered the last 16 ka. This high-resolution palaeo-archive records eastern Indian Ocean hydroclimate variability where rainfall source and intensity is strongly linked with southeasterly trades that form during boreal summer monsoons. The $\delta^{18}\text{O}$ record shows a significantly drier period between 13 ka and 11.5 ka BP with $\delta^{18}\text{O}$ enrichment by 1.5 ‰ before rapid depletion from ~ -5 ‰ to ~ -8 ‰ between 11.5 ka and 8.5 ka BP representing rapid shifts to wetter regimes during the early Holocene. However, it should be noted that the maxima observed in the Tangga records lags the more isotopically-depleted Gunung Buda record by at least 3000 years. These cave records show strong agreement with 17 other separate palaeorecords (published lacustrine or wetland sedimentary sequences) located across continental Southeast Asia which were compiled and analysed to infer a strong Asian Monsoon commencing from the early Holocene and reaching peak warm/wet climatic conditions between 7.3 ka and 6.5 ka BP (Cook and Jones, 2012a).

A relatively wetter phase between 8 ka to 6.5 ka BP in Northwest Sumatra was also detected from stable hydrogen (δD) and stable carbon ($\delta^{13}\text{C}$) isotopic composition of terrestrial plant waxes (Niedermeyer et al., 2014). The authors specifically targeted the $n\text{-C}_{30}$ and $n\text{-C}_{32}$ alkanoic acids which allowed for inference of hydrological and vegetation changes on land during the Holocene. The increase in monsoon-induced precipitation led to increased chemical weathering of terrigenous material. Increased proportions of kaolinite as well

as higher smectite/(illite + chlorite) ratio of sediments from core CG2 recovered from the continental slope at the southern South China Sea suggest high monsoon strength from the Younger Dryas to ~9 ka BP which tapered from the mid-Holocene to present (Huang et al., 2016).

2.3.4. Records of Quaternary/Holocene climate change from Singapore

A key palaeoclimate study done in Singapore was a pollen study from sediments from the peat-forming freshwater Nee Soon swamp by Taylor et al., (2001). Their work suggests colder but possibly humid and not drier conditions during the LGM as indicated by the occurrence of certain montane pollen types in the sediment record. Their findings concur with other nearby pollen records suggesting relatively consistent humid vegetation growth (i.e. lowland rainforests) from the LGM to the present (Hu et al., 2003; Wang et al., 2009; Raes et al., 2014).

2.4. Records of Quaternary sea level change

Like climate, knowledge of past sea levels during interglacial warm periods can provide valuable analogs for adapting to climate driven changes in current and future sea level (e.g. Bowen, 2010; Rohling et al., 2010; Roberts et al., 2012; Woodroffe and Murray-Wallace, 2012; Dutton et al., 2015). Sea level chronologies spanning the last 500 ka have shed light on the variability of relative sea level change during the mid-late Pleistocene (Rohling et al., 2009; Grant et al., 2014).

2.4.1. Global records of Quaternary sea level change

Notable stages during the Quaternary include MIS 11 which is an extraordinarily long interglacial lasting ~30 ka some 400 ka ago (Murray-Wallace and Woodroffe, 2014) with purported sea level highstands above modern MSL of 6 – 13 m in the Bahamas and Bermuda, up to 13 m in South Africa (Roberts et al., 2012; Dutton et al., 2015) and even up to 21 m in Bermuda (Olson and Hearty, 2009; van Hengstum et al., 2009), possibly achieved at the second MIS-11 solar insolation maximum centred at ~401 ka BP (Rohling et al., 2010). Candy et al. (2014) further argued that MIS 11 is the best analog for Holocene climate change due to similarities in insolation patterns, as well as orbital climate forcing and sea level histories (Rohling et al., 2010). However, data on MIS 11 remains sparse and the best preserved evidence for past interglacial highstands likely remains with the penultimate one termed MIS 5e due to the relatively recent timeframe and sea level rising above current levels (e.g. Hearty et al., 2007; Blanchon et al., 2009; Pan et al., 2018).

Sea levels during MIS 5e are posited to have risen from up to -130 m relative to modern MSL during the previous glacial maxima (MIS 6) at 140 ka BP (Lambeck and Chappell, 2001) continuing to rise to between 2 m and 9 m above modern sea levels during the peak MIS 5e where Greenland and Antarctica ice sheets were smaller than today (Dutton and Lambeck, 2012; Dutton et al., 2015). This general summary is supported by recent MIS 5e highstand records based on sea-level indicators from eleven tectonically-stable Mediterranean sites that provide evidence of sea levels of 2 – 10 m above modern levels during MIS 5e,

and even suggest a two-step highstand during this time period (Stocchi et al., 2018). However, evidence for ice-sheet regrowth driving such fluctuations during MIS 5e was not readily found (Barlow et al., 2018).

Optically-Stimulated Luminescence (OSL) dates of shoreline deposits from South Africa also provide new elevation constraints for MIS 5e highstand values for that part of the world. In a recent study at the *Swartvlei* and *Groot Brak* estuaries in southern South Africa, Carr et al. (2017) identified beach berm/swash facies and inferred a maximum sea-level of ~ 7.8 m above MSL between OSL-dated ages of 125 ± 7 ka and 122 ± 7 ka. OSL ages from 10 samples collected from calcified shallow marine (palaeobeach) and aeolian (palaeodune) facies along the southern Cape coast form a single cluster of ages ranging between 135 ± 8 ka and 111 ± 8 ka BP, and a dominant MIS 5e highstand height of 6.3 m above MSL at ~ 120 ka BP (Cawthra et al., 2018). Dendy et al. (2017) cautions however that errors of ~ 2 m and ~ 5 m for far-field and fore-bulge sites respectively potentially exist in MIS 5e and LIG highstand predictions.

Post MIS 5e sea levels receded in a series of stepwise stages as the earth began entering into the glacial phase (Fig. 2.2). In one notable example elevated coral reef terraces in the northeast Gulf of Aqaba, north of the Red Sea, provided an age constraint of 104 ± 6 ka BP for sea level returning to peak stage 5 levels during MIS 5c (Bar et al., 2018). Their findings are supported by U-Th dating of speleothems indicating RSL above modern sea level for both MIS 5c and 5a at Bermuda (Wainer et al., 2017). ^{230}Th and ^{231}Pa dating techniques used on corals

from the Huon Peninsula, Papua New Guinea and Barbados showed sea levels dropping from ~ -10 to -57 m during the MIS 5c-5b transition between ~ 100 ka BP and 92.6 ± 0.5 ka. Sea level rose by >40 m to ~ -10 m from MIS 5b – 5a within 10,000 years, which lasted till 76.2 ± 0.4 ka BP at the depth of -24 m (Cutler et al., 2003). Independent records from the Red Sea (*G. ruber* $\delta^{18}\text{O}$ record) from core KL11 also show good centennial-scale agreement with these fossil-coral records from 70 ka – 25 ka BP (Siddall et al., 2003). More recent GIA simulations using a compiled global data support the two highstand depth values, concluding that global mean sea level peaked at averaged values of -8.5 ± 4.6 m during MIS 5a and -9.4 ± 5.3 m during MIS 5c (Creveling et al., 2017).

Figure 2.2. Sea-level record spanning the last 140 ka showing great variability from MIS 5e to the Holocene. Adapted from Lambeck and Chappell (2001).

Discrete coral terraces from the Huon Peninsula provided support for repeated sea-level highstand episodes associated with North Atlantic climate reversals (Heinrich events) during MIS 3 where sea levels oscillated between -60 and -90

m from 60 ka BP to 30 ka BP (Yokoyama et al., 2001b; Chappell, 2002), a much broader range compared with results from redated corals from Huon Peninsula, Papua New Guinea and Barbados giving a depth range of -74 m to -85 m between 36.8 ka and 60.6 ka BP (Cutler et al., 2003). Ice volumes approached constant maximum values from ~30 ka to ~19 ka BP, where eustatic sea levels receded to -107 m at 23.7 ± 0.1 ka BP early in MIS 2 (Cutler et al., 2003) with a possible rapid fall of ~50 m in <1000 years, (Hanebuth et al., 2009) postulated to be at ~25 ka BP (Lambeck and Chappell, 2001). Recent studies have suggested a possible two-step sea level plunge, up to 20 m between 21.9 ka and 20.5 ka BP before rising by 3.5 mm/yr for ~4000 years into the LGM based on shelf-edge fossil coral and coralline algae deposits at the Great Barrier Reef (Yokoyama et al., 2018), and finally to the lowest depths of around -120 m during the LGM (Peltier, 2002).

Numerous studies modelling ice sheet and sea level interaction for the North American/Greenland (e.g. Huybrechts, 2002; Carlson et al., 2008; Mitrovica et al., 2018) and Antarctic Ice sheets (e.g. Weaver et al., 2003; Mackintosh et al., 2014; Hodgson et al., 2016) over the recent decades have improved our understanding of post-LGM sea level change (Clark and Mix, 2002; Lambeck et al., 2014). These models have been supported by results of cosmogenic-nuclide exposure (e.g. ^{10}Be) and radiocarbon ages from locations such as Mac. Robertson Land, East Antarctica (Mackintosh et al., 2011), Quebec and Labrador (Ullman et al., 2016), and the Mediterranean (Zecchin et al., 2015). Global sea levels rose from maximum depths of between 120 m and 135 m (Hanebuth et

al., 2000; Clark and Mix, 2002; Peltier and Fairbanks, 2006) from as early as 21 ka BP (Peltier, 2002; Lambeck et al., 2014), with LGM termination by 19 ka BP (Yokoyama et al., 2000) and the main deglaciation phase occurred from ~16.5 ka to ~8.2 ka BP (Lambeck et al., 2014).

Initial post-LGM sea level rise may be as rapid as 15 m in 500 years commencing at 19.5 ka BP based on synthesized observational global data from locations such as Bonaparte Gulf and Huon Peninsula (Lambeck et al., 2002). This is supported by evidence from the Kilkeel Steps channel located in the Irish Sea basin indicating the termination of the LGM and a meltwater pulse of at least 10 m named the 19-ka MWP (Clark et al., 2004). Data from Bonaparte Gulf, Australia (Yokoyama et al., 2001a) shows similar SLR of magnitude around 10 m starting at around 19.6 ka – 18.8 ka BP lasting for ~500 - 800 years. This rapid SLR phase was followed by relatively slow 3.3 mm/year SLR from ~19 ka – 16 ka BP and subsequently more rapid and sustained rise occurred from about 16 ka – 12.5 ka BP at an average rate of about 16.7 mm/year (Lambeck et al., 2002). Ooid formation from the southern Great Barrier Reef provided further age-depth constraints of 16.8 ka BP at 100 m below MSL (Yokoyama et al., 2006).

It has been proposed for some time that post-LGM sea level record is characterized by stepwise patterns of increase, based initially on drowned corals in Barbados (Fairbanks, 1989), Tahiti (Bard et al., 1996) and Papua New Guinea (Chappell and Polach, 1991; Edwards et al., 1993), Caribbean-Atlantic area (Blanchon and Shaw, 1995) and radiocarbon dating from coastal and marine sediments obtained from the central Great Barrier Reef shelf in Australia

(Larcombe et al., 1995). These relatively short periods of accelerated sea level rise have been termed Meltwater pulse or MWP, of which up to 4 have been posited spanning ~15 ka to 7 ka BP (Liu et al., 2004).

Meltwater pulse 1A occurred approximately 14,600 years ago (e.g. Peltier and Fairbanks, 2006; Deschamps et al., 2012; Liu et al., 2015), although Blanchon and Shaw (1995) termed it Catastrophic Rise Event 1 (CRE1) when they noted that CRE1 represented a 13.5 m rise at ~14.2 ka BP. Newer data from offshore corals from Tahiti constrained MWP-1A as a 12 – 22 m global mean sea level rise occurring from 14.65 ka to 14.31 ka BP lasting 340 years (Deschamps et al., 2012). Recently, GIA-model simulations by Liu et al. (2015) who combined and reinterpreted sea level data from Barbados, Sunda Shelf and Tahiti calculated a more conservative magnitude of MWP 1A of between 8.6 m and 14.6 m. The impact of such a meltwater pulse possibly led to the Bølling-Allerød Warm Interval, due perhaps to strengthening of the North Atlantic Deep Water warming the North Atlantic region (Weaver et al., 2003).

Though no confirmed source for MWP-1A has been found the mechanism responsible could be reduced Southern Ocean overturning immediately after Heinrich Event 1, when accelerated ice-sheet retreat was triggered by warmer subsurface water in Antarctica (Golledge et al., 2014). Another possible cause was identified as ice saddle collapse occurring at the North American ice sheets (Gregoire et al., 2012; Ivanovic et al., 2017). The Antarctic source was also supported by evidence of the onset of West Antarctic Ice Sheet deglaciation

from 15 ka to 14 ka BP, which Clark et al. (2009) asserted as the primary meltwater source for MWP-1A. The debate is still ongoing and the actual source remains equivocal (Weaver et al., 2003; Peltier, 2005; Liu et al., 2015).

A period of increasing global sea level continues into and characterizes the early Holocene period which occurred between 11.65 ka and 7 ka BP (Smith et al., 2011; Törnqvist and Hijma, 2012) and its terminus is broadly coincident with the final deglaciation phases of global ice sheets from between 7.5 ka and 6.7 ka BP (e.g. Carlson et al., 2008; Lambeck et al., 2014; Ullman et al., 2016; Hillenbrand et al., 2017). Superimposed within this timeframe is MWP-1B which was first reported as a rapid rise sea level of up to 28 m in Barbados centred upon 10,800 yr BP based on relict *Acropora palmata* (Fairbanks, 1989). Later, Blanchon and Shaw (1995) obtained age-depth data based on elevations and ages of drowned *A. palmata* from the Caribbean-Atlantic region and inferred that the dataset showed a catastrophic 7.5 ± 2.5 m rise at 11.5 ± 0.1 ka BP which they termed Catastrophic Rise Event 2 (CRE 2). However, Bard et al. (2010) dated three new cores at the onshore barrier reef and failed to reveal significant discontinuities in sea level rise during the MWP-1B timeframe. MWP-1B, like its predecessor remains poorly constrained particularly in the far field.

Multiple sea-level indicator types from the Caribbean showed highest rates of RSL change during the early Holocene coeval with the proposed MWP-1c, with a maximum rise rate of 10.9 ± 0.6 m/ka in Suriname and Guyana and minimal rate of 7.4 ± 0.7 m/ka in south Florida from 12 ka to 8 ka BP (Khan et al., 2017).

Another study also showed that sediment records and geophysical surveys provide evidence of a ~14 m rapid sea level rise between 9.5 ka and 7.5 ka BP at Chesapeake Bay (Cronin et al., 2007). Nearfield data from Prydz Bay, East Antarctica showed rapid sea level rise with rates of between 12 mm/yr and 48 mm/yr from 9678 to 9411 cal yr BP in the Vestfold Hills followed by a deceleration to 8.8 mm/yr from 8882 to 8563 cal yr BP from records in the Larsemann Hills (Hodgson et al., 2016).

In the early-mid Holocene, the 8.2 ka climate anomaly has been attributed to the retreat of the Laurentide Ice sheet, where an ice dam separating freshwater from proglacial lakes Agassiz and Ojibway from the Labrador Sea and the North Atlantic catastrophically collapsed resulting in the weakening or even complete shutdown of the Atlantic Meridional Overturning Circulation (AMOC) (Barber et al., 1999; Teller et al., 2002; Alley and Ágústssdóttir, 2005; Gregoire et al., 2012). The freshwater discharge was modelled to contribute approximately 5 Sv rate of discharge (Teller et al., 2002; Clarke et al., 2004) although the sea-level signature of the outburst would be spatially variable dependent on source proximity (Kendall et al., 2008). More recent modelling work however showed that the lake outburst alone produced inadequate climate forcing, and counter-proposed the mechanism as meltwater release due to the collapse of the ice-sheet saddle between the Keewatin and Labrador domes (Matero et al., 2017), or accelerated meltwater from the collapsing ice saddle that linked domes over Hudson Bay (Matero et al., 2017). Evidence for the 8.2 ka pulse and related modelling work have been done for proximal (e.g. Törnqvist et al., 2004; Cronin

et al., 2007; Hillaire-Marcel et al., 2007; Kendall et al., 2008) and distal regions (e.g. Hori and Saito, 2007; Liu et al., 2007; Tamura et al., 2009; Nguyen et al., 2010; Tjallingii et al., 2014), although the magnitude and timings of the sea level jump are not well resolved (Clarke et al., 2004; Cronin et al., 2007; Hijma and Cohen, 2010; Gregoire et al., 2012).

More recent findings point to multiple pulses of freshwater discharge from as early as 8760 - 8640, 8595 – 8465 and 8323 - 8218 cal yr BP, based on estuarine and salt-marsh records from Cree Estuary, Southwest Scotland (Lawrence et al., 2016). This is not inconceivable given that multiple potential sources and occurrences of freshwater discharge have been proposed. A ~1.2 m sea level pulse dated to between ~8.86 ka and 8.25 ka BP was observed based on basal peat sea level data from the Mississippi delta; the large age-range stem from sample dating offsets between two sediment cores (Törnqvist et al., 2004). Li et al. (2012) too collected cores from the Bayou Sale area in the Mississippi Delta and identified a eustatic sea level jump of similar magnitude ($1.2 \pm 0.2\text{m}$) but between 8310 and 8180 cal yr BP, a temporal offset of up to 500 years. Further afield, a larger local magnitude of $2.11 \pm 0.89\text{ m}$ sea level jump at $8450 \pm 44\text{ cal yr BP}$ was detected from peat samples from within the Rhine-Meuse delta in western Netherlands (Hijma and Cohen, 2010).

The final and possibly last early Holocene meltwater pulse recorded likely occurred at ~7.5 ka BP and was first posited and observed in sites such as the Caribbean-Atlantic region from drowned *A. Palmata* reef records (Blanchon and

Shaw, 1995). This same pulse, possibly up to 6 m in magnitude, was also detected in relic *A. Palmata* from the eastern shelf of Grand Cayman based on reef accretion cessation constrained by U-Th dating at ~7.6 ka BP at a depth of ~19 m (Blanchon et al., 2002). Elsewhere, a rapid localized jump of ~4.5 m was also observed at ~7.6 ka BP based on sediment cores recording lacustrine-marine transitions in basins along the southeastern Swedish coastline facing the Baltic Sea (Yu et al., 2007).

2.4.2. Asian records of Quaternary sea level change

Many Asian records contain relatively shorter chronologies but higher-resolution analysis of Quaternary sea level change. In east Asia, MWP 1B was a ~20 m rapid sea level rise timed between 11.6 ka and 11.2 ka BP based on gravity core sediment data from the subaqueous Yellow River delta sequence between the Bohai and North Yellow Seas (Liu et al., 2004). In later work a sediment core obtained off the Yangtze River estuary provided indirect evidence for MWP 1B in the region by analyzing the changes in foraminiferal and ostracod assemblages between two distinct lithofacies suggesting a rapid rise in sea level between 11.5 ka and 11.2 ka BP (Liu et al., 2010).

Meltwater pulse 1c (MWP-1c) was first reported in Asia as a period of rapid SLR of ~15 - 30 m from 9.5 ka – 9 ka BP based on data from the Yellow River delta, Eastern China (Liu et al., 2004). This early Holocene sea level pulse was also observed from sediments in the Pearl River Delta (PRD) on the Southern Chinese coast, where sea level rose from -30 m MSL at ~10 ka BP to -10 m to -15 m MSL

by ~8.5 ka BP (Zong et al., 2012). Zong and colleagues (2012) suggest that at the PRD relative sea level rose at a rate of 16.4 ± 6.1 mm/yr at ~10.5 ka BP to a maximum SLR rate of 33.0 ± 7.1 mm/yr at ~9.5 ka BP before decelerating to 8.8 ± 1.9 mm/yr at ~8.5 ka BP (Xiong et al., 2018). Elsewhere in Asia, sea level data from four sediment cores obtained from the west coast of South Korea show evidence of RSL rising rapidly from -28 m to -8 m MSL between 9.8 ka and 8.4 ka BP at a rate of ~14 mm/yr before slowing down (Song et al., 2018). Surprisingly, sediment cores from the southern Yangtze delta plain, China provide evidence of a ~2 m rapid rise in RSL at ~8.6 ka BP (Wang et al., 2012b) instead of sea level deceleration during that time period as reported in the other studies.

A ~7.5 ka meltwater pulse was only observed in Korea for the region of Asia, where sediment cores from river mouths on the west coast of South Korea likewise suggest an 'inflection' centred at ~7.8 ka BP followed subsequently by rapid SLR till mid-Holocene highstand levels (Song et al., 2018). This final Holocene pulse is however not detected elsewhere, for example in the Philippines where ^{230}Th -dated coral ages from Paraoir, western Luzon showed consistent gradual sea level rise between 10.3 ka and 7.2 ka BP from depths of 29 m to 8 m, instead of any evidence of sea level pulses either associated to the 8.2 ka or 7.5 ka events (Siringan et al., 2016). In contrast, other records strongly suggest that the rate of sea level rise instead decelerated between 8 ka and 7 ka BP. Sediment cores recovered from the Pearl River deltaic (PRD) basin a gradual and slightly decelerating rate of sea level rise from 8 ka to 7 ka BP (Zong

et al., 2012), with agreement provided by a more recent study based on seven new cores from the PRD showed sea level change rate decelerating gradually from 8.8 ± 1.9 mm/yr at ~ 8.5 ka BP to 1.7 ± 1.3 mm/yr around 7.5 ka BP (Xiong et al., 2018). Recently, new sedimentary records from Yaojiang Valley in the southern Hangzhou Bay in China also showed a reversed sea level trend from 8.5 ka to 7.5 ka BP as RSL dropped from -10 m to -6 m (Liu et al., 2018).

2.4.3. Records of Quaternary sea level change from the Sunda Shelf

A landmark study on post-glacial sea level rise from the Sunda shelf was published in the year 2000 with a record spanning 21 ka to 14 ka BP produced from more than 50 sediment cores collected off the Vietnam coast (Hanebuth et al., 2000). This marine sediment data was recovered from cruise 115 of R/V Sonne (Stattegger et al., 1997) and showed post-LGM (from 19.0 ka to 14.6 ka BP) sea level rise from -114 m to -96 m, followed by a 16 m rapid SLR between 14.6 and 14.3 ka BP (MWP-1A) where sea level rose from -96 m to -80 m at an accelerated rate of 5.33 m per 100 years. Between 14.3 ka and 13.1 ka BP, sea level rose more gradually from -80 m to -64 m at a rate of 1.33 m per 100 years, followed by sea level rise up to 11 ka BP at an average rise of 8 m in 700 years. A subsequent paper revisiting the Sunda shelf sea level data (Hanebuth et al., 2009) revised the LGM sea level minima for the Sunda shelf based on comparisons with data from Bonaparte Gulf (Yokoyama et al., 2000) to -123 ± 2 m relative to MSL. Subsequent sea level rise commenced as early as 19.6 ka BP, followed by a postulated rapid ~ 10 m rise till 18.8 ka BP (Hanebuth et al., 2009).

Sediment cores from various locations within the Malay-Thai Peninsula also show RSL rising rapidly from a minimum of -22 m from 9.7 ka to 9.25 ka BP, gradually increasing without internal fluctuations to ~-10 m at 8.5 ka BP (Horton et al., 2005). To date there is no strong evidence for MWP-1c from the equatorial Sunda Shelf. Other sedimentary records in the region indirectly infer the existence of sea level pulses through sediment offsets or sharp decreases in sedimentation rate. Sedimentary evidence obtained from the Song Hong (Vietnam), Changjiang (China) and Kiso (Japan) delta systems suggest rapid sea level rise from ~9 ka – 8.5 ka BP inferred from a concomitant sharp decrease in sedimentation rate (Hori and Saito, 2007).

In areas distal from the Hudson Bay region, an approximate 5 m abrupt sea level rise was detected at 8.5 ka – 8.4 ka BP through sediment cores from the Cambodian lowlands near the Mekong River (Tamura et al., 2009) which they suggested could be associated with the 8.2 ka event meltwater pulse. Age–depth data from coastal deposits from the Southern Vietnam shelf show a vertical offset in the RSL records which suggest rapid sea level rise from depths of ~-28 m to -10 m between 9.0 ka and 8.2 ka BP (Tjallingii et al., 2014).

There were several studies on Holocene sea level change done in the Malay Peninsular region (e.g. Biswas, 1976; Geyh et al., 1979; Tjia, 1996; Hesp et al., 1998; Hassan, 2002), with some disparity between datasets of different vintages and an apparent absence of high-resolution record for the early Holocene. The earliest sea level study by Biswas (1976) produced a coarse sea level plot by

determining Quaternary high and lowstands using benthic planktonic foraminifera from cores taken off the east of Peninsular Malaysia and the northern Sabah coast. The Biswas (1976) study applied the basic premise that there is a depth-temperature (thermocline) relationship between foraminiferal abundance and water depth, and produced a sea level curve using contemporary conditions at set depths to establish a modern analog. He proposed the presence of 3 highstand occurrences (T1-3) at ~280 ka BP, 100 ka BP, and mid-Holocene, and 2 lowstands (R1-2) centred at ~180 ka BP and 11 ka BP. However, the chronology was only constrained by a single age of 13021 ± 288 cal yr BP, whereas other maxima and minima were probably inferred from known sea level curves of the time. Although there is clear discrepancy between his work and our current understanding of Quaternary sea level dynamics, an approximate age-marker (~13 ka BP) for the post-LGM marine transgression for the outer Straits of Malacca off the western Malay Peninsula was proposed and likely remains valid.

Geyh et al. (1979) obtained 33 ^{14}C -dated fossil mangrove deposits in the Straits of Malacca, and showed that relative sea level was at least 40 m below modern MSL between 36,000 and 10,000 BP. Holocene sea level then rose from -13 m to 5 m (one mid-Holocene highstand) above present MSL between ~8900 and ~4500 cal yr BP. The few and variable age/depth points for the early Holocene were inconclusive with large differences in depth as well as age reversals. In the mid-1990s Tjia (1996) compiled a database from a variety of published and unpublished index points for the Malay-Thai Peninsula. Using biogenic and

geomorphological indicators, his sea-level curve implies two Holocene highstands at 5000 and 2800 ^{14}C yr BP for Peninsular Malaysia (Tija, 1996). In contrast his sea-level reconstruction for Thailand indicates potentially three mid-late Holocene highstands at 6000, 4000 and 2700 ^{14}C yr BP respectively (Tija, 1996). Unfortunately, I am unable to access the original data for the purpose of ^{14}C age calibration. Hassan (2002) obtained sediment cores from both the east (Kelang) and west (Kuantan) coast of Peninsular Malaysia, and produced 7 index points between 4500 – 6400 cal yr BP at elevations of ~1.2 m – 3.4 m above MSL. Interestingly, coeval sample elevations obtained from west coast are on the order of ~3 times higher than the east coast. Further north, Horton et al. (2005) used regional index data from the Great Songkhla Lakes and other parts of the Malay-Thai Peninsula, which revealed an upward trend of Holocene relative sea level from a minimum of -22 m at 9700 - 9250 cal yr BP to a mid-Holocene highstand of 5 m at 4850 - 4450 cal yr BP. Data density was centred between 8000 and 6000 cal yr BP, with few data points for the early Holocene.

2.4.4. Records of Quaternary sea level change from Singapore

In Singapore the study by Hesp et al. (1998) showed a rapid transgressive sequence from 8567 ± 157 cal yr BP and a marine highstand of approximately 2.5 m above MSL dated at 3811 ± 100 cal yr BP. Unfortunately, the abovementioned studies considered but did not incorporate sediment compaction into their results.

The most comprehensive sea level study for Singapore to date was produced by Bird et al. (2007) which involved more than 50 sea level index points (SLIPs) with incorporated data from Hesp et al. (1998), in producing a sea level record spanning ~8.9 ka to near present. A revised curve was provided by subsequently dating 15 shell and mangrove wood samples from the 30 m deep Geylang core (Bird et al., 2010), and redating 15 of the previous 50 from Bird et al. (2007). The sea level record by Bird et al. (2010) suggest that Holocene marine clays at the Geylang palaeovalley began accumulating at –15 m (MSL) at approximately 8900 cal BP and initially accumulated very rapidly at 8.8 mm/yr until 7900 cal BP (–7.77 m MSL). Sea level rise then slowed to 2.6 mm/year until 6710 cal BP (–4.69 m MSL), ultimately indicating an inflection in the local sea level rise centred upon ~7600 cal BP. The data imply that Holocene sea level rise ended with a mid-Holocene marine highstand of approximately 2.5 m above MSL through the period of ~6000 - 3000 years BP before regressing to modern sea levels.

2.5. Quaternary Stratigraphy of the Sunda Shelf

Such dramatic sea level changes of up to 130 m during the Quaternary likely had profound impacts upon the broad, relative low relief Sunda shelf (Tjia, 1980; Darmadi et al., 2007; Hanebuth et al., 2011) (Fig. 2.3). The Sunda Shelf is a wide, tropical siliciclastic continental shelf with high sediment supply where the late Quaternary stratigraphy is strongly influenced by sea level fluctuations and fluvial-deltaic processes and biodiversity response (e.g. mangroves), which are reflected in the history of coastline migration and partially driven changes in the

availability of accumulation space (Tjia, 1980; Hanebuth et al., 2002; Hanebuth et al., 2011). The continental core of Sundaland (i.e. Sumatra, Java, Borneo, Malay-Thai Peninsula and parts of Indochina) was assembled during the Triassic Indosinian orogeny, and formed an exposed landmass during Pleistocene glacial sea level lowstands (Hall and Morley, 2004).

Figure 2.3. Palaeo-coastlines reconstruction, based on modern bathymetric depth contours, showing extent of land exposure and marine influence at LGM and just after MWP-1B (marine inundation of palaeo-rivers). Adapted from Sathiamurthy and Voris (2006).

The boundary of ice-age Sundaland is approximated by the 120 m isobath (Voris, 2000; Sathiamurthy and Voris, 2006) (Fig. 2.4), and bounded at the south and west by the Indian Ocean and small island chains in Indonesia. Eastward, Sundaland is separated biogeographically from the region of Wallacea by deep-water channels (Wicaksono et al., 2017). It is however difficult to delineate Sundaland's northern boundary, with studies proposing the modern Thailand–Malaysian border at 9°N as the most appropriate boundary latitude (e.g. Bird et al., 2005). The width of the Sunda shelf reaches up to 800 km with an average modern water depth of 70 m (Tjia, 1980; Hanebuth et al., 2002). The Molengraaff River system developed in this tropical lowland (Molengraat, 1921; Pelejero et al., 1999). This river system comprised of several major palaeo-rivers, i.e. the South Sunda, North Sunda and Siam, and Malacca Rivers (Fig. 2.4) which drain from inner Sundaland to waters north of Bali, south of South China Sea and east Indian Ocean respectively (Bird et al., 2005).

Figure 2.4. Exposure experienced by Sundaland during the Last Glacial Maximum depicted in light grey, with modern land distribution in darker grey. The dashed line represents the northern boundary of Sundaland defined by 9°N latitude. Numbers 1-4 denote the mouths of the major Molengraaff Rivers as follows: 1—South Sunda River; 2—North Sunda River; 3—Siam River; 4—Malacca River. The letters L mark the locations of possible lakes. Adapted from Bird et al. (2005).

The core of Sundaland is much more tectonically stable than the outer shelf regions. The outermost shelf depressions experienced tectonic subsidence rate of up to 27 cm/ka during the later Pleistocene, which increased significantly to 2.5 m/ka during postglacial times, with differential displacements in localized areas due to tectonic activity (Wong et al., 2003). Numerous deep sedimentary basins were produced during the Cenozoic deformation of Sundaland alongside elevated highlands (Fig. 2.5), which were subsequently filled by locally derived sediment (Hall and Morley, 2004).

Figure. 2.5. Principal geographical, geological and tectonic features of Sundaland (Shaded in beige) and the surrounding region bounded by the 200m isobath. The other bathymetric contours are at 2000, 4000 and 6000 m. Adapted from Hall and Morley (2004).

2.5.1. Outer Shelf Stratigraphy

This section reviews post-MIS 5e to present stratigraphic evolution for the Sunda shelf where the timing and nature is still poorly constrained. The locations of the study sites are outlined here in Fig. 2.6 below.

Figure 2.6. Locations of Quaternary Stratigraphy studies in Sundaland (demarcated approximately by black dashed line representing ~120m isobath).

Earlier work done on the outer rim of the Sunda shelf was focused on regional tectonics and for petroleum exploration purposes. On the western margin of Sundaland Samuel et al. (1997) reviewed hitherto studies and observed occurrences of late Quaternary uplifted coral reef terraces sometimes overlain by alluvium (Gupta et al., 1987; Harbury and Kallagher, 1991) in islands along the Sumatran Forearc (i.e. Nias, Banyak Islands etc). Reflection seismic data collected from the nearby Sunda Straits grabens reveal largely parallel uppermost pelagic sediments of Pleistocene age (Lelgemann et al., 2000; Susilohadi et al., 2009), where further east at the Lombok Forearc Basin such graben deposits have been interpreted as turbidite and pelagic clay alternations (van der Werff et al., 1994). Quaternary topsets are observed in Central Luconia, Sarawak Basin, offshore NW Borneo characterized by wedge-shape geometry,

expanding rapidly basinward and pinching out landward (Koša, 2015). These strata are predominantly aggradational, oversteepened and dipping in response to continuous tectonic tilting.

2.5.2. Middle and Inner Shelf Stratigraphy

In the 1990s and 2000s a series of landmark studies based on seismic data and sediment cores taken during research cruise SO-115 of R/V Sonne (Stattegger et al., 1997) were instrumental to improving our understanding of outer-middle shelf Quaternary stratigraphy for Sundaland. The main transect was oriented northeast-southwest, extending 600 km from the upper continental slope to the middle shelf in the area of the former North Sunda River (Hanebuth et al., 2000) (Fig. 2.7). Seven seismic facies (potentially reaching back to 570 ka BP) were distinguished in the Molengraaff paleo-delta underlying the postglacial unit which were interpreted as shelf-margin lowstand wedges related to submarine delta progradation deposited during periods of sea-level highstand or forced regressions (Wong et al., 2003).

Figure. 2.7. (a) Regional location map (b) solid line: SO-115 transect on the Sunda Shelf (c) locations of sediment cores (black circles) with core numbers shown. A-V, NS-V, PKV, PL-V indicate the positions of the Anambas, North Sunda, Kapuas and Lupar rivers paleo-valleys. From Hanebuth and Stattegger (2004).

Some work focused on shallow seismic profiles, augmented by sediment core data, along the main 4000 profile-transect (Hanebuth et al., 2002) revealed a diverse array of seismic facies of which seven types were identified (Facies A to G) corresponding to 9 seismic units or boundaries that they correlate with relative sea level change (Fig. 2.8). Central to their chronological inference is the identification of three major boundaries potentially correlated with the past three sea-level lowstands which provides an approximate time interval of the past 280 ka (Hanebuth et al., 2002). Facies A is a thick, continuous and stratified regressive layer inferred to be deposited during lowered sea level stages of MIS 9 – 7. Channel deposits infilling local incisions (Facies F and G) sit atop Facies A which are interpreted as transgressive or ravinement fills during MIS 6/5 terminations. Regressive depression fills (Facies E) are subsequently deposited during lowered sea level at MIS 4, followed by differentiated irregular depression fills (Facies C) comprising nearshore material deposited during MIS 3 which is intermingled with extended and chaotic deposits of terrestrial to estuarine origins, separated by a sequence boundary interpreted as palaeosol forming at MIS 2 between 23 ka and 21 ka BP. Deglacial transgressive deposits in the form of local channel fills (Facies F and G) were deposited between 16 ka and 14 ka BP, followed by thin sheets of marine mud stratigraphically associated with Holocene sea level rise and highstand conditions.

Figure. 2.8. Shallow-seismic Parasound profiles across the Sunda Shelf demonstrating the complexities and facies associations between seismic facies A-G. Interpreted seismic/sedimentary stratigraphic units are shown as numbers. Adapted from Hanebuth et al. (2002).

Later studies incorporating seabed sediment cores provided higher-resolution chronological constraints allowed the authors to elucidate more on the post-MIS 5e (last 50,000 years) stratigraphic evolution of the Sunda shelf (Hanebuth, 2003; Hanebuth et al., 2003; Hanebuth and Stattegger, 2004). Hanebuth et al. (2003) distinguished between three types of regressive deposits deposited during the last fifty thousand years based on shallow seismic investigations (Fig. 2.9). The lowermost comprise of thick lens-shaped prograding clinoform sediment 'bodies' extending from 20 - 30 km wide filling gentle depressions in the central part of the Sunda shelf. These deposits form discrete patches which are likely a function of the combined effects of the low morphological gradient and minor sea-level fluctuations during MIS 3. The second type is thin horizontally-stratified deposits situated as lateral continuations between the lens-shaped 'bodies'. Finally, a thick progradation sediment wedge was identified on the outer shelf and shelf margin which gradually thickens basinward. Sediments cores from this transect terminated at the upper parts of the regressive sequence, and six types of sedimentary facies were identified containing regressive-transgressive chaotic successions of terrestrial (floodplain), nearshore (mangrove, beach and tidal flat) and shallow-marine sediment (shelf, lagoon, delta front) facies spanning the last 50 ka. Generally, delta front and lagoonal bay facies were deposited between 40 ka and 50 ka BP during sea level lowering (latter MIS 3). A low stand hiatus ensued until ~27 ka BP before deposition of an organic rich nearshore facies from 27 ka – 21 ka BP grades to a mangrove/marsh facies. Finally, tidal flat and delta front facies were dated at ~17 ka BP.

Figure 2.9. Shallow-seismic records and interpretation of (A) Profile from the innermost part and (B) Profile from the middle part of SO-115 transect. Late Pleistocene land surface shown as bottom strong seismic reflector. The regressive units are represented by grey/dashed and white/hatched regions and subdivided into upper and lower parts. Subsequent transgressive deposits are shown as middle grey area. Thin Holocene blanket is shown as dark grey unit. Adapted from Hanebuth et al. (2003).

While this record is clearly the most comprehensive seismic and sediment record in the region Hanebuth et al. (2003) conceded however that the ages can have large uncertainties and insufficient age determination due to ages reaching the upper limits of AMS radiocarbon dating.

Steinke et al. (2003) selected several of these same cores and concentrated on the sedimentation regime over the last 20,000 years with chronology constrained by a total of 33 oxygen isotope analogue dates and ^{14}C AMS dates from planktonic foraminifera. Their higher-resolution study showed high accumulations of fine-grained siliciclastic material mixed with terrestrial organics on the slope and shelf margin, and wave and current reworking at the outer shelf from 20 ka to 16.5 ka BP. Thick delta front sediments accumulated at the North Sunda River mouth as it retreated from 16.5 ka – 14.5 ka BP, and reduced sediment supply to the shelf margin and continental slope. Rapid sea level rise was postulated between 15 ka and 14 ka BP for the Sunda region (Hanebuth et al., 2000), but no distinct changes were reflected in the sedimentation patterns. The post-14 ka system is characterized by a reduction in terrigenous supply to the shelf slope likely due to flooding of the North Sunda river plains as sea levels reached modern elevations. The subsequent transgressive deposits and marine muds were closely associated with the rapidly migrating paleo-shoreline during this phase of sea level rise and complete transition into modern hydrographical conditions.

In a 2004 follow-up study 80 new AMS- ^{14}C dates were obtained from new gravity cores taken from the same palaeovalley at 70 m – 130 m modern water depth provided a better understanding of the inundation stages of the central Sunda Shelf (Hanebuth and Stattegger, 2004) (Fig. 2.10). Here, an overconsolidated, distinct soil unit characterized by orange mottling over pale grey clay, was identified as Pleistocene palaeosol. Relative to this unit, 4

stratigraphic units associated with sea level change from MIS 3 to present were inferred. The basement regressive unit deposited from 50 ka to 30 ka BP is composed of basinward clinoforms which gradually thicken shelfward cut by truncations which were eventually infilled by deposits during marine transgression. An extensive soil horizon has formed at the top of this unit probably related to aerial exposure during the LGM, overlain by a succession of transgressive terrestrial, tidal and marine deposits which generally thins with decreasing modern water depth. Rapid retrograde migration of the facies association occurred between 19 ka and 13 ka BP corresponding to rapid SLR, translating to mangrove and mudflat deposits dominating in mid-valley as deltaic conditions transit progressively to estuarine ones after 13 ka BP, while delta front facies are observed distally (Hanebuth and Stattegger, 2004).

Figure 2.10. Stages of inundation of the central Sunda Shelf. Selected time-sliced stages at (a) Clinoform progradation and isolated sediment bodies (30 ka BP) (b) Widespread exposure and sediment bypass and deposition in the shoreline area (21 ka BP) (c) Deltaic to estuarine conditions (15 ka BP) (d) Accelerated sea-level rise led to rapid river mouth retreat and drowning of valley (14 ka BP) (e) Complete submergence of the area (13 ka BP). Adapted from Hanebuth and Stattegger (2004).

A review of Post-MIS 5 stratigraphy along the Sunda transect shows a spatially diverse and variable distribution of lithofacies (Hanebuth et al., 2011). Transgressive units with channel cut-and-fill structures were deposited during the penultimate transgression between ~127 ka and 124 ka BP followed closely

by coastal facies during MIS 5e highstand conditions until ~118 ka BP. A regressive system comprising terrestrial, coastal and shallow-marine sediments was deposited across the shelf-ramp, with thickness of up to 30 m from ~115 ka – 80 ka BP. Distal from shelf core, open-marine hemipelagic and occasional turbidite and slide deposits to the order of tens of meters were deposited concurrently. Late regression and lowstand shallow-marine sediments were deposited between ~90 ka and 20 ka BP to form massive progradation wedges up to 80 m thick at the shelf edge, with sporadic lens-like structures up to 10m thick during periods of forced regression. Coarse-grained channel fill up to tens of meters thick were likely deposited during glacial periods of exposure on the inner shelf (21 ka - 19 ka BP), while sand barrier and tidal flat facies were located at the border between the central and outer shelf. Grey stiff clays marked by orange oxidized flames interpreted as palaeosols often form thin several metre thick facies successions that record terrestrial exposure of estuarine and shallow marine deposits. Much of the Sunda shelf was drowned during rapid SLR from 18 ka – 12 ka BP. Thin sequences of marine carbonate muds were deposited from 13 ka BP and provide a sedimentary record of the shelf flooding, overlain in coastal areas by beach sands, swamp, lagoonal and shallow-marine muds further inland during highstand conditions in the mid-Holocene (Hanebuth et al., 2011).

Elsewhere in the Sunda shelf, a synthesis study used existing data (i.e. logs, boreholes, open pits and groundwater well samples) to review the Quaternary stratigraphy of the Lower Central Plain or Chao Phraya Plain, in the upper Gulf

of Thailand by Sinsakul, (2000) described a Plio-Pleistocene fault-bounded basin that contains Quaternary sediment postulated to reach a thickness of almost 2000 m, where only the upper 300 m is known. The upper 600 m comprise Pleistocene-Holocene unconsolidated sediments that are subdivided into eight aquifers to form intercalated layers (up to 100 m thick) of coarse-grained poorly sorted sand and gravel with clay lenses, interpreted mostly as fluvial or deltaic deposits, all which underlie marine clays (Bangkok Clay) that are up to -30 m followed by surficial intertidal and floodplain sediments from mid-Holocene age (Sinsakul, 2000). The uppermost sediments show sequential succession firstly of tan sand and gray clay inferred as Late Pleistocene shallow marine and fluvial sediments (Unit I). This is overlain by a bauxite granules and pebbles in a sandy matrix interpreted as basal lag sediments (Unit IIa), and then by dark gray clay and silty clay which are ^{14}C AMS dated Holocene deltaic and shallow marine sediments (Unit IIb). A schematic showing the Quaternary stratigraphy of the Lower Central Plain is shown in Fig. 2.11. Subunits representing prodelta and seafloor, delta front, upper tidal flat and floodplain sediments were observed in Unit IIb. All these units formed from between 8 ka and 7 ka BP to present (Tanabe et al., 2003).

Figure 2.11. A schematic representation of the Quaternary stratigraphy of the Lower Central Plain, Chao Phraya Delta, Thailand. Adapted from Sinsakul (2000).

Other studies of the inner shelf stratigraphy on the margins of the Sunda Shelf fill spatial gaps, but unfortunately most lack detailed chronological controls (Hiscott, 2001; Darmadi et al., 2007; Alqahtani et al., 2015). In one example ~1500 km lines of seismic surveys were done on the Baram delta at the western shelf and slope of Brunei were augmented by 15 geotechnical drillholes for ground-truthing (Hiscott, 2001). Seismic profiles and drillholes up to 50 m deep display at least 5 main seismic facies showing basal infill deposits of the palaeo-Baram valley consisting of silty clay, interbedded with sand veneers and shell and wood fragments. Atop this unit sits a younger facies of silty to medium-grained sand, wood and shell interpreted as channel-fill deposits during channel

migration, with evidence of lateral accretion bedding. The slightly dipping, laminated silty clays of Facies 3 is interpreted as prodelta muds, overlain by largely parallel Facies 1 and 2 which are soft clay with scatter shell fragments and silty clay respectively, both interpreted as prodelta mud supplied by the prograding Baram Delta. Though the age of the sequence remains uncertain the outer shelf profiles likely record a depositional sequence comprising repeated reflector/fluvial channel stacks encompassing 7 glacial-interglacial cycles.

In another study Darmadi et al. (2007) studied the dominantly fluvial successions of Belida Field in West Natuna basin, offshore Indonesia using ~680 km² seismic survey. Penetration of the seismic likely reached ~225 m below the modern sea floor and this thick progradational sequence set (called the upper Muda Formation) generally coarsens upward from marine shelf to deltaic and finally fluvial deposits based on seismic analysis which identified 5 sequences up to tens of metres thick and concomitant boundaries marked by erosion and gully formation.

A more recent large-scale (11,500 km²) shallow three-dimensional seismic survey (Fig. 2.12) was performed over a Late Pleistocene incised valley situated within the 'Malay Basin' approximately 200 km east of Peninsula Malaysia (Alqahtani et al., 2015). Analysis of the seismic data and sediment core data reveal three main seismic units in the deeply incised valley systems up to 80 m deep and 18 km wide. The study identified a basal unit (labelled by them as U6) as non-marine floodplain deposits composed of stiff greenish grey silty clay with traces of organic material. Unit 7 comprise a suite of seismic facies and

associated lithologies with lenticular to sinusoidal structures. This unit is generally poorly-sorted and chaotic and interpreted as valley fill for the Chao Phraya-Johore River. Unit 8 is loosely made up of 3 gradation sub-units. The lower portion is composed of very soft, water rich clay, overlain by stiff, shell-rich clay and subsequently succeeded by intercalated coarse-grained unconsolidated sands and very soft clays with wood fragments which is capped ultimately by marine clays.

Figure. 2.12. (A) Interpreted regional seismic section through the 3D seismic dataset (B). Schematic cross-section showing the seismic units (1 to 8), bounding surfaces (Horizons A to H), and major incised valleys, channels and features in various colours. Adapted from Alqahtani et al. (2015).

A critical outcome of these stratigraphic studies is the possible correlation of regressive, transgressive and stable phase facies at the middle and outer shelf to onshore Malaysian stratigraphy encompassing the transitional, alluvial and

young sedimentary units (Hanebuth, 2003), which correspond to the 'stiff clay' palaeosol, transgressive marine muds and younger estuarine, fluvial deposits in Singapore (PWD, 1976; DSTA, 2009)

2.5.3. The Mekong system of northern Sundaland: A case study

There are more than 20 studies on the late Quaternary evolution of the Mekong River in Southern Vietnam, albeit mostly focusing on delta initiation during the early Holocene (e.g. Lap Nguyen et al., 2000; Ta et al., 2002; Tamura et al., 2009; Nguyen et al., 2010; Hanebuth et al., 2012). These studies nonetheless provide a comprehensive understanding of the processes leading to the stratigraphic succession of the South East Vietnam shelf (Schimanski and Stattegger, 2005; Dung et al., 2013; Tjallingii et al., 2014). In one example, Dung et al. (2013) obtained 2D seismic reflection data from various cruises along the Vietnam Shelf as part of the Vietnam–German cooperation project from 1999 – 2008 at water depths of up to 200 m. They identified five seismic units and three major bounding surfaces spanning the last 26 ka. Sediment cores obtained independently along the different transects provided further chronological constraints (Schimanski and Stattegger, 2005; Tjallingii et al., 2010) (Fig. 2.13). The bottommost facies (U1) consists of progradational oblique wedge-shaped clinoforms deposited at ~24.3 ka BP associated with final stages of the LGM stillstand. U1 was observed at the outer shelf with thicknesses of up to 50 m. U2 overlies it and is composed of incised channel fill of 0 – 30 m thickness and interpreted as lowstand to transgressive fluvial deposits, and U2 is in turn overlain by an extensive shallow-marine unit (U3) up to 15 m thick spanning the

entire shelf. U2 and U3 were deposited between 13.3 ka and 9 ka BP and represent the transition from fluvial to marine conditions (Tjallingii et al., 2010; Tjallingii et al., 2014). Thin fully marine deposits (U4) up to 1 m thick were deposited from 8 ka - 0.3 ka BP at the mid and outer shelf areas while delta deposits (U5) analogous to modern Mekong subaqueous sediments up to 25 m thick were deposited from 0.05 ka to 3.12 ka BP at the inner shelf (Dung et al., 2013).

Figure 2.13. Map of the study area off the present day Mekong Delta, Vietnam. Core locations are shown as red stars, seismic lines as thin grey line, and Parasound tracks as thin grey dashed line). (a) The cores analysed in this study (stars) were obtained from the main incised valley recognized on the seismic profiles (thick black dashed lines). (b) Close up of the seismic profiles of Fig. 2a. Adapted from Tjallingii et al. (2010).

A thick sequence of Late Pleistocene lateritic soil deposits, potentially pedogenically-altered upon subaerial exposure during the LGM, is a common feature of the inner Sunda shelf stratigraphy, and provides a good boundary for

inferring depositional ages of the overlying sediments (Schimanski and Stattegger, 2005; Hanebuth et al., 2012; Dung et al., 2013; Tjallingii et al., 2014). Hanebuth et al. (2012) recovered a collection of sediment cores along a transect corresponding to the main Mekong tributary which terminate in a late Pleistocene palaeosol, characterized by orange-flamed, light grey clayey soil. Three main types of shallow marine deposits were identified in upward stratigraphic order: (1) Dark greenish brown organic-rich homogenous clay with few shell fragments (Bay deposits); (2) Dark gray clay intruded frequently sand lenses, mollusc shells and mica sheets (Prodelta deposits); (3) Coarsening-upward, intercalated reddish gray to dark gray clay with fine sand layers (Delta front deposits) (Hanebuth et al., 2012). Similar post-LGM deposits were identified in delta evolution and sea level history studies done on the Mekong delta (e.g. Lap Nguyen et al., 2000; Ta et al., 2002; Tamura et al., 2009; Nguyen et al., 2010; Tjallingii et al., 2010).

2.5.4. Synthesis of the Quaternary Stratigraphy of the Sunda Shelf

In summary, the stratigraphic studies done within the Sunda region show that the Quaternary Stratigraphy of the Sunda shelf is characterized by a series of regressive units deposited during lowstand conditions in previous glacial periods, which typically contain incised channels and associated fluvial/floodplain deposits. The outer shelf stratigraphy near the southern edge of the proto South China Sea is marked by recurring sequences of regressive-transgressive chaotic successions of terrestrial (floodplain), nearshore (mangrove, beach and tidal flat) and shallow-marine sediment (shelf, lagoon,

delta front). In middle and inner-shelf locations, an expansive lateritic stiff palaeosol of late Pleistocene age is identified marking potentially the last regressive-transgressive boundary (i.e. LGM) where the entire shelf was subaerially exposed. However, certain areas proximal to modern deltas with high riverine sedimentation rate would only experience fluvial sedimentation and are marked by channel migration fill and/or floodplain deposits. Post-LGM sea level rise resulted in vertically and laterally-ordered deposition of nearshore and marine sediments and the coincident infilling of palaeochannels, with wedge-shaped fans observed further offshore due to sediment bypassing.

Sea levels during the early-mid Holocene were near modern levels which led to deposition of prodelta and delta front sediment near modern shorelines associated with worldwide delta initiation (Stanley and Warne, 1994; Hori and Saito, 2007; Gao and Collins, 2014). Major river deltas experienced early growth between 8 ka and 6 ka BP due to RSL slowdown or even stillstands, including the Mekong (Tamura et al., 2009; Nguyen et al., 2010; Hanebuth et al., 2012), the Pearl River (Zong et al., 2009; Zong et al., 2012), and the Yangtze (Hori and Saito, 2007; Wang et al., 2012b) river deltas. Sea level in Singapore was also postulated to have decelerated during this period with an inflection between 7.8 and 7.4 ka BP (Bird et al., 2010), which could conceivably have provided stable nearshore conditions for deltaic sediment accretion and seaward progradation.

2.6. Synthesis of the literature review

Much of the understanding of climate change and associated sea level change during the Quaternary was derived from global and polar records comprising mainly ice cores and deep-sea sediment cores (e.g. Petit et al., 1999; Shackleton, 2000; Jouzel et al., 2002; Shakun et al., 2015), providing an insight into orbital-scale cyclicities and sub-orbital variability at glacial time-scales (e.g. Rohling et al., 2009; Grant et al., 2014). High-resolution sea level records, especially from MIS 5e to present, were obtained from various proxies such as raised terraces and biological indicators, coral reef records, sediment proxies etc from various locations worldwide (Hearty et al., 2007; Rovere et al., 2016). However, there remains a paucity of Quaternary palaeoclimate and sea level records in the Sunda shelf region, and in particular Singapore, where palaeoenvironmental records are rare and do not extend past the LGM.

Little is known about the palaeoclimate of Singapore and surrounding region, where the longest record is ~83 ka from Sumatra. The pollen record from Singapore is the only known palaeoclimate record (Taylor et al., 2001), but other studies suggest that vegetation change may not track true climate change well during the late Quaternary (e.g. Wurster et al., 2010; Wicaksono et al., 2015) highlighting the need for the further examination of other climate proxy records.

Though high-resolution Holocene sea level records have been obtained from Singapore and Malaysia (e.g. Geyh et al., 1979; Tjia, 1996; Bird et al., 2007; Bird

et al., 2010), they do not extend to the early Holocene or earlier and are unable to observe possible sea level signatures from past meltwater pulses.

Lastly, the Quaternary Stratigraphy of Singapore has been studied from a geotechnical/ geoengineering perspective at relatively low spatial resolution (PWD, 1976; DSTA, 2009), augmented by much earlier geological studies which lack tight chronological controls (e.g. Scrivenor, 1924; Pitts, 1984). The Quaternary deposits of Singapore require further work as we do not fully understand the true underground conditions and complexities, nor do we fully know the facies associations and age constraints of these Quaternary deposits.

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Chapter 3

A revised Quaternary Stratigraphy of the Kallang River Basin, Singapore

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Abstract

The Quaternary stratigraphy of many inner shelf and coastal areas in Southeast Asia is poorly understood. Developing a detailed framework for the Quaternary evolution of geological terranes is important as many coastal cities are built on such coastal-marine sequences. This study reviews the current understanding of Quaternary deposits in the Kallang River Basin, Singapore by selecting 161 boreholes from ~4000 borehole logs to create 14 cross-sections and 3D geological model. I augmented the dataset with a ~38.5 m sediment core obtained from Marina South (1.2726°N, 103.8653°E) and compare it to a previous record from Geylang (1.3137°N; 103.8917°E) to provide age constraints and an important new stratigraphic reference. Our new geological model reveals a more complex geology than currently presented. The sequence comprises interdigitating sequences of mangrove peat, coastal sands and fluvio-alluvial units deposited during marine transgressive and regressive phases. Our model is constrained by radiocarbon and Optically-Stimulated Luminescence (OSL) dating and also identifies various palaeo-features that record the geomorphic and sedimentary evolution of the basin and offer serious engineering challenges to the ongoing development of the city. The Bedok Formation (formerly Old Alluvium) is the lowermost Quaternary unit and is interpreted as fluvial deposits of Plio-Pleistocene age. The Bedok Formation is unconformably overlain by fine to coarse grained littoral/tidal sands (Tekong/Jalan Besar Formation) inferred to have been deposited during MIS 5e (~125 ka BP). The coastal sands are overlain by the Tanjung Rhu member (Lower Marine Clay), a slightly silty marine clay that was deposited during a high stand

of sea level during MIS 5e. Subsequent subaerial exposure during the last interglacial is recorded as a 'stiff clay' layer that varies in thickness from 0.9 - 13.6 m. The stiff clay is overlain by Holocene transgressive sands (Jalan Besar Formation) and nearshore peats (Kranji Formation) that were deposited around 9.5 ka BP. This unit is overlain by the Upper Marine clay (Rochor member) which is composed of grey-blue clayey silt up to 16.7 m thick and has a basal age of ~9.2 ka BP. The marine muds are partially overlain by a sequence of regressive inland peats that were deposited ~1.2 ka BP as sea levels receded from marine highstand levels around ~2 ka - 4 ka BP. This re-interpretation of the Quaternary stratigraphy provides important constraints on the sea-level history of the region, the geomorphological evolution of Singapore southern coastal area and inner Sunda from MIS5e to present. The work also provides a geological framework for geotechnical engineering that underscores the complexity of Quaternary geology in the region and the complexities of work in such subsurface terrane.

3.1. Introduction

Sea level fluctuations of up to 120 m below modern Mean Sea Level (MSL) during the present and last interglacials have been well studied (Lambeck and Chappell, 2001; e.g. Hanebuth et al., 2009; Grant et al., 2014), and continue to generate great interest with implications for future sea level rise (SLR) projections (e.g. Church et al., 2013; Horton et al., 2014) and concomitant effects on the coastal zone (e.g. Nicholls and Cazenave, 2010; Pachauri et al., 2014).

Central to this concern is a clear need for developing a detailed understanding of how sea level dynamics will affect the coastal zone, as nearshore and coastal sedimentation is influenced greatly by tidal range, sediment supply and bio-morphology (e.g. Mogensen and Rogers, 2018; Trenhaile, 2018). This is especially critical to low lying coastal countries and islands in Southeast Asia where megacity development continues on late Quaternary deposits (Sengupta et al., 2018).

The Kallang Basin is located in the southern part of Singapore and drains the central catchment of Singapore (Figure 3.1). Singapore is an island state that lies in the central part of the Sunda Shelf at the core of the geographical area of Sundaland. The knowledge of late Quaternary deposits within the inner shelf region of Sundaland remains limited (Hanebuth et al., 2011).

Hitherto, there is only a limited understanding of inner shelf and coastal sedimentary units and their stratigraphic associations particularly for the period 8 ka – 10 ka BP (Figure 3.2b).

Figure 3.1. Composite figure providing geographical context. A) Regional map of Southeast Asia with red square showing location of Singapore. Light brown regions demarcate the extent of Sundaland based on modern bathymetric data (produced by Ocean Data View). B) Outline map of Singapore depicting the approximate catchment extent of the Kallang River Basin. C) Satellite image of Singapore (Google Earth Pro) with overlay mapping thickness of marine clay in the KRB. Red Squares denote coring locations and red star denotes location of the Geylang Core (Bird et al., 2010). Dashed line is estimated separation between original and reclaimed coastline.

3.1.1. Geography of Singapore

Located between latitude 1°09'N and 1°29'N and longitude 103°38'E and 104°06'E, Singapore lies off the southern tip of the Malaysian Peninsula (Figure 3.1). Being located near the equator, the climate of Singapore is tropical, and precipitation is controlled by the northeast monsoon (Nov to Mar); first intermonsoon period (April/May); southwest monsoon (Jun to Sep); and the second intermonsoon period (Oct/Nov). The mean annual temperature is 26.9 °C with little monthly variability, accompanied by a mean annual precipitation of about 2200 mm (Meteorological Service Singapore, 2017) . The hot and wet climate makes a significant impact to the hydrology of Singapore (e.g. rivers, tributaries, estuaries etc.), and also exacerbates normal erosion and weathering processes, which all contribute to enhanced weathering and erosion on the island (Rahardjo et al., 2004; Agus et al., 2005). Recent research revealed that the onset of the Holocene marked a climatic shift in the Sunda region towards warmer, wetter conditions as opposed to cold and arid conditions from ca. 30 ka to 11.9 ka BP (Cook and Jones, 2012).

Singapore is of moderately low relief and with minimal topography, with > 60% of land surface below 30 m relative to Mean Sea Level (MSL) underpinning its inherent vulnerability to sea level rise (SLR). Coastal waters are generally shallow (< 30 m deep), although depths of up to 200 m have been observed along the Straits of Singapore (Bird et al., 2006). A short wave fetch, compounded by the fact that directions of strongest winds rarely coincide with maximum fetch, produce low energy wave conditions where breaker height is

often < 20 cm (Chia et al., 1988). The coastline of pre-development Singapore was dominantly characterised by dense mangrove forests (Corlett, 1992; Ng et al., 1999). Mangrove species have been observed to inhabit from just below mean tide levels (e.g. *Avicennia*, *Sonneratia spp*) to the highest tides (e.g. *Ceriops*, *Xylocarpus spp*) and accumulate highly organic peaty sediments within this tidal range (Ng et al., 1999; Chua, 2003; Bird et al., 2004a).

The shallow offshore regions of contemporary Singapore likely received full subaerial exposure during the current and penultimate Glacial Maximums when sea levels reached around 120 m below current levels (Fig. 3.2a). The surficial sediments of Singapore are postulated to be of Quaternary age (DSTA, 2009), and present an opportunity to better understand sedimentary succession in inner shelf conditions contemporaneous to past interglacial maximum highstand elevations. The original length of Singapore's coastline is about 131.5 km, which increased by 106 km during the early 1970s through foreshore reclamation (Chia et al., 1988). Such rapid urbanisation in recent decades provide an unexpected source of engineering data to study Singapore's subsurface conditions (e.g. DSTA, 2009; Bo et al., 2011).

Figure 3.2a Sea level record spanning the last 140 ka. Adapted from Lambeck and Chappell (2001)

Figure 3.2b. Age range of proximal sea level studies with solid lines representing higher and dashed lines showing lower datapoint density. The grey rectangle shows a data gap for the region between 9 ka and 11 ka BP.

3.1.2. Geology of Singapore

Much of the current understanding of Singapore's Quaternary geology was gleaned from studies in the early 20th Century (e.g. Scrivenor, 1924; Alexander, 1950) and more recent engineering-driven research (PWD, 1976; DSTA, 2009). The pre-Quaternary sediments and basement lithologies generally comprise late Palaeozoic and Mesozoic sedimentary rocks and intrusive igneous units, which are overlain by weathered shales and sandstones of the Jurong Formation which is possibly of late Triassic to late Jurassic age (DSTA, 2009; Oliver and Prave, 2013). The newest report by Kendall et al. (2018), using Uranium-Thorium age-dates, reclassified the Jurong Formation into the Jurong and Sentosa Groups with depositional ages spanning the Middle-Upper Triassic. Additional Formations, namely the Kusu, Bukit Batok and Fort Canning Formations, expanded the sedimentary stratigraphy from Lower Cretaceous at ~145 Ma to the Neogene at depths in the order of 200 m, postulated to be the contact with the overlying Bedok Formation (Old Alluvium).

The lower most Quaternary unit of the Singapore geology is comprised of dense, highly consolidated and variable but unlithified fluvial sands and clays of Plio-Pleistocene 'Bedok Formation' (Gupta et al., 1987), which is overlain by transitional and transgressive sequence of sand units that grade to a marine clay unit. The Lower Marine Clay (Tanjung Rhu Member) is inferred to have been deposited during MIS (Marine Isotope Stage) 5e (Bird et al., 2003). The TRM clay is capped by a highly weathered and compacted 'stiff clay layer' derived from weathering and desiccation of the 'TRM. The TRM unit was likely formed during

the Last Interglacial Period and is overlain by intercalated Holocene sediments comprising beach (Tekong Formation or Littoral Member), mangrove (Kranji Formation or Transitional Member), tidal or fluvial (Jalan Besar Formation or Alluvial Member) units and during more sustained marine sedimentation recorded by the Rochor Member or Upper Marine Clay.

The study area (See Fig. 3.3), namely the Kallang River Basin, contains the most extensive late Quaternary deposits in Singapore (PWD, 1976; DSTA, 2009).

Figure 3.3. Map showing the basic geological units of Singapore based on revised nomenclature by the British Geological Survey (Kendall et al., 2018). The Kallang Formation (in yellow and irregularly shaped) represents the extent of Quaternary deposits. From Mote et al., (2009) after Pitts, (1984)

A very recent comprehensive study of Singapore's geology was published in July 2018 (Kendall et al., 2018) where previous lithological units were reviewed, and in some cases recategorised and renamed. Table 3.1 provides the comparison between old and new nomenclature for the surficial Kallang Group. These new terms will be used henceforth in this paper.

Table 3.1. Comparison between previous and new lithostratigraphic framework for Pleistocene-present units. Equivalent units are colour-coded for easy reference.

Previous nomenclature (PWD, 1976; DSTA, 2009)			New nomenclature (Kendall et al., 2018)		
Group	Formation	Member	Group	Formation	Member
None	Kallang Formation	Reef Member	Kallang Group	Semakau Formation	
		Transitional Member		Kranji Formation	
		Littoral Member		Tekong Formation	
		Alluvial Member		Jalan Besar Formation	
	Singapore Clay Formation	Upper Marine Clay member		Marina South Formation	Rochor Member
		Lower Marine Clay member			Tanjong Rhu Member
	Old Alluvium			Bedok Formation	

This chapter reviews and refines the current understanding of Singapore's Quaternary geology using high-resolution borehole data collected from the study area. The distribution, stratigraphy and lithology of the two major formations that constitute the Quaternary deposits of Singapore are first described before a new 3-Dimensional geological model of the Kallang River

Basin is presented, which represents the most extensive and continuous sequence of late Pleistocene to Holocene deposits. Finally, the sequence stratigraphy of the Quaternary geology is developed and related to local and regional sea-level changes.

3.2. Methods and Geological model development

3.2.1. Borehole Data

Approximately 4000 borehole logs (BHs) in the Kallang River Basin were obtained from the Building and Construction Authority (BCA) of Singapore, the central depository for all soil investigation reports mandated for any development of permanent structures or infrastructure within Singapore. 161 high-quality BHs were selected to create the geologic model of this area using Subsurfaceviewer® (developed by INSIGHT, Geologische Softwaresysteme GmbH), a newer version of GSI3D which was first designed in collaboration with the British Geological Survey (BGS). These BHs were selected based on various criteria such as the termination depth, where only boreholes deeper than 20 m were utilized, where possible. The borehole logs also differed significantly in the quality of soil description and amount of detail, and only well-logged, comprehensive boreholes were used. In some cases I had to calibrate for descriptions of sediment texture, colour and strength as sediment logs across projects contained ambiguous terminology (e.g. stiff vs dense vs hard) which were reinterpreted in order to correlate across boreholes. I have also incorporated borehole data from two high-resolution sediment longcores obtained from Marina South (MS-BH01B:1.27266°N, 103.8653°E) (this study)

and Geylang (Geylang Core:1.313713°N; 103.891772°E) (Bird et al., 2007; Bird et al., 2010) to provide age constraints and stratigraphic reference.

3.2.2. Development of the geological model

All selected borehole data points for each cross-section were reinterpreted and their reliability reassessed by comparison with proximal BH data to validate accuracy and ensure consistency of borehole logging methods. The oldest map of colonial Singapore drawn in 1840 was also consulted to identify palaeofeatures and to improve our understanding of past morphology and hydrology of the Kallang River Basin. As the littoral member and the alluvial members are often described and labelled in soil investigation reports in very similar terms (i.e. F1 and F2 – fluvial clay and fluvial sand respectively), they are presented collectively as the Jalan Besar Formation (JBF). Based on the available information and given the borehole logs I would commonly use geotechnical classifications as the basis for ascribing lithological identifications.

Boreholes were carefully selected to produce 14 transects spanning the river basin (Fig. 3.4). Transects 1 – 1' to 7 – 7' are generally perpendicular to the coast, progressively moving eastward. Transects A - A' to G – G' are generally parallel to the coast and extends from the landward boundary of the river basin to its coastal fringe. After setting a high-resolution DSM (Digital Surface Model) to constrain the vertical land surface limit, and populating the cross-sections with borehole data, the shape and extent of each geological unit are assigned to

create cross-sections based on knowledge of stratigraphic association, morphology and river basin hydrology.

Next, I define the lateral and vertical distribution of each individual layer in order to calculate a three-dimensional model from the two-dimensional distribution of geological layers in the cross-sections. A Delaunay triangulation is used to compute these surfaces using all points defined in the cross-sections and along the distribution boundaries of the layers to create a TIN (Triangulated Irregular Network) layer. The triangulation is automatically limited to the lateral extension of the respective layer and the digital terrain model, which are then further refined and smoothed to generate the optimum mesh. The top surfaces of the layers are determined by cutting out the superimposed bottom surfaces of layers and putting them together to form a singular TIN layer.

The tops and base of each sedimentary unit was also calculated so as to isolate each facies in order to gain an understanding of variability in their individual thickness and extent. I provide a description of each lithofacies based on borehole information and referenced with sedimentological information garnered from long cores MSBH01B and the Geylang Core reported in Bird et al. (2010). No evidence of reef material, or Semakau Formation, was found in the borehole collection. It is also noted that it remains difficult to discriminate between the alluvial and littoral units (i.e. Tekong and Jalan Besar Formation) based on borehole log descriptions and I combine their extant and distribution in this study.

3.2.3. Sediment analysis of sediment core MSBH01B

We obtained a continuous ~38.5m (up to 50 m below MSL) core MS-BH01B at Marina South (1.27266°N, 103.8653°E). I subsampled at 1-cm resolution, removing all suitable material for ^{14}C AMS and OSL dating, before analyzing for bulk density, grain-size distribution and organic and inorganic matter content. An aluminum U-channel is used to obtain accurate and consistent sediment volumes for bulk density values. I determined the organic and carbonate content using Heiri et al. (2001)'s method for loss-on-ignition (LOI) where heating the sample to different temperatures (i.e. 105°C, 550°C and 950°C) indicates the weight percent of water content, organic content and carbonate content, respectively. Grain-size distribution of sediment samples is ascertained by an initial two-stage pretreatment of approximately 10g of sample with 10 v/v% hydrochloric acid (HCl) and 15 v/v% hydrogen peroxide (H_2O_2) to remove carbonate, organic matter and disassociate clays. Subsequently, I performed the analysis using the Malvern Mastersizer 2000 where samples were first sonicated for 60 seconds and three replicates averaged (Blott et al., 2004; Ryżak and Bieganski, 2011). Any samples where the relative standard deviation of the mean grain size values exceeded 5% were re-analysed.

Figure 3.4. Map of the Kallang River Basin showing Kallang Formation units in yellow, surrounded by Bedok Formation outcrops in orange, and lithified sediments of the Jurong Formation in light and darker blue. Green dots denote available BH data points and blue dots denote selected BH data points used in transects. The location of sediment cores MSBH01B and Geylang Core (Bird et al., 2010) are

3.2.4. Age Constraints

3.2.4.1. Radiocarbon Dating

Elemental atoms may have unstable isotopic forms with different atomic weights which experience loss of radioactive particles by spontaneous emission. These radioactive isotopes have a characteristic half-life which can be used to estimate the passage of time for a given sample (e.g. Radiocarbon dating) (Libby and Johnson, 1955; Libby, 1961). Carbon occurs in the form of two stable isotopes (^{12}C and ^{13}C) and one radioactive isotope (^{14}C , radiocarbon), which occurs in minute amounts. Radiocarbon originates in the upper atmosphere when neutrons bombard nitrogen-14 and form carbon-14 + hydrogen ($^{14}\text{N} + n \Rightarrow ^{14}\text{C} + ^1\text{H}$). The radioactive atoms combine with oxygen to produce radioactive carbon dioxide, which is distributed by atmospheric turbulence and is then incorporated into the hydrosphere and biosphere (Hajdas, 2014; Törnqvist et al., 2015). Living organisms take up radiocarbon through metabolic processes or photosynthesis, and maintains a radiocarbon equilibrium with the atmosphere (Berger et al., 1964; Bird, 2013). When organisms die and no longer metabolize new carbon, the finite amount of radioactive carbon in their tissues begins to diminish without replacement. Radiocarbon has a half-life close to 5730 years, which means that half the radioactive atoms disintegrate in that span, each producing a nitrogen atom and a beta particle ($^{14}\text{C} \Rightarrow ^{14}\text{N} + \beta$). (Walker and Walker, 2005; Hua, 2009).

^{14}C concentration in the atmosphere has not always been constant over time, and calibration curves (IntCal and MarineCal) (Hughen et al., 2004; Reimer et

al., 2009; Reimer et al., 2013a; Reimer et al., 2013b) derived from tree rings, foraminifera, corals, speleothems have been constructed and revised over time to calibrate and convert radiocarbon into sidereal ages. These ages are referenced to 1950, a convention established by international agreement to calibrate all laboratory results to a single reference year (before present”), and approximate the time before nuclear weapons changed the atmosphere’s composition (“before physics”).

3.2.3.2 Radiocarbon dating from marine and coastal environments

^{14}C dating has been extensively used to obtain age-dates up to 45,000 years ago (Walker and Walker, 2005), a period which experienced great climate and sea level variability (e.g. LGM, meltwater pulses, Younger Dryas). Dating of samples from marine and coastal regions have been instrumental in understanding global palaeoenvironmental dynamics with strong chronological controls. In particular, radiocarbon dating of sediment cores have yielded age-depth data constraining the post-LGM ice sheet extent and sea level rise since 19 ka BP (e.g. Clark and Mix, 2002; Clark et al., 2009; Smith et al., 2011). Global deglacial sea level change was spatially and temporarily variable, and relative sea level curves for both ‘nearfield’ and ‘far field’ sites, so named relative to distance from the polar ice caps, were generally established through radiocarbon dating (e.g. Yokoyama et al., 2000). Notable examples include dating of coral samples from Barbados (Fairbanks, 1989), Huon Peninsula (Chappell and Polach, 1991), Tahiti (Bard et al., 1996) which provide earliest evidence suggesting the existence of sudden surges in sea level rise or ‘meltwater pulses’.

Radiocarbon dating was also crucial in reconstructing palaeoenvironmental change in coastal areas, particularly in major river deltas and coastal cities with large population densities (Stanley, 2001). Sediment cores are often collected along transect lines which generally tracks sea level change in nearshore zones and ^{14}C dates, combined with stratigraphic and sedimentological information provide a mechanism for understanding coastal evolution. Key examples include studies on the fluvial evolution of the Nile Delta (Pennington et al., 2017), growth of the Mekong Delta (Hanebuth et al., 2012) and influence of sea level rise and monsoonal discharge affecting the evolution of the Pearl River Delta (Zong et al., 2009). Of great importance in view of future sea level rise (Pachauri et al., 2014) is building up comprehensive and robust post-LGM sea level databases (e.g. Engelhart et al., 2015; Baranskaya et al., 2018; García-Artola et al., 2018), where the chronology is mostly constrained by radiocarbon ages, which help improve current sea level and climate models and projections.

3.2.3.3 Challenges

Lowe and Walker (2000) presented challenges pertaining to radiocarbon dating and the pressing need for improving dating precision especially for the “last glacial-interglacial transition” (LGIT) which spans from ~ 14.0 to 9.0 ^{14}C ka BP. They observed that climatic events and boundaries associated with this critical timeframe (i.e. “Bølling”, “Allerød”, and “Younger Dryas”) occur in the order of hundreds of years and such temporal resolution may be unattainable with ^{14}C dating precision. Key problems frequently encountered include low organic C content of samples and low sample sizes.

Good sample selection is also critical factor contributing to the accuracy of dating a given sediment strata. Reworking or remobilisation of samples, possibly due to gravity, water or organisms (bioturbation) can significantly alter the elevation of contemporaneous samples. This is particularly important in coastal systems where organisms such as mud lobsters and other burrowing creatures can bring younger carbon downward providing an erroneous age-depth data point. On the other hand, older carbon can be remobilised by fluvial processes or precipitation and deposited on younger sediments.

Another significant concern is the discrepancy in radiocarbon ages of terrestrial as opposed to marine/aquatic samples due to the 'reservoir effect' (e.g. Reimer and Reimer, 2001; Hua et al., 2015). The ^{14}C content in the deep ocean is much lower than the atmosphere where the residence time of carbon in the former can be up to 800 years (Broecker, 2000). The ^{14}C content in these deep ocean waters is depleted due to radioactive decay of carbon that is not in equilibrium with the atmosphere. The ^{14}C concentration of the atmosphere and terrestrial living organisms are in equilibrium as they take up available radiocarbon through the food chain and other metabolic processes that is in equilibrium with the atmosphere (Hua, 2009).

Organisms living in surface oceans (e.g. corals, shells etc) obtain carbon from both atmospheric and deep ocean sources and hence their ^{14}C concentrations may be intermediate between the two carbon reservoirs which often make them older than contemporaneous terrestrial samples but to a variable degree

[the age offset is known as the marine reservoir age (R)] (Stuiver et al., 1986). Palaeoclimate studies rely heavily on reliable chronological information, underpinned by accurate dating of marine samples, such as corals, molluscs and foraminifers, and correlating them with terrestrial and ice-core records. Establishing reliable ΔR at high-resolution spatial and temporal scales are critical to achieving these ongoing scientific goals (Hua et al., 2015). To this end I observe a paucity of ΔR values in the central Sunda region, with only 2 rather disparate values obtained from pre-bomb bivalve shells attributed to Singapore (Southon et al., 2002).

3.2.4.4. Optically Stimulated Luminescence (OSL) technique

This method of determining when sediments were last exposed to sunlight was first proposed in a seminal paper published in 1985 (Huntley et al., 1985). OSL is based on the principle that natural environmental radiation causes charge (electrons and holes) to be trapped within the crystal lattice of minerals, in particular quartz. Electron traps are assumed to be emptied by exposure to sunlight (or 'bleached') and effectively reset at deposition and subsequent burial. Over time the latent luminescent signal will be built up due to exposure to surrounding naturally occurring radioisotopes (e.g. U, K, Th) and cosmic rays. These electrons can be excited again by an appropriate and laboratory-controlled light source to estimate the radiation accumulated radiation dose after burial and derive an age estimate (Walker and Walker, 2005; Rhodes, 2011).

To calculate and derive an optically stimulated luminescence (OSL) age, I need to determine the palaeodose (amount of absorbed dose since the sample burial) and the dose rate (estimated radiation flux for the sedimentary bodies), where the palaeodose (expressed in Grays) is divided by the annual dose rate (Grays/yr) (Aitken, 1998).

There have been numerous methods of determining radiation dose (D_e), with the more established ones being the single-aliquot regenerative-dose (SAR), the multiple-aliquot regenerative dose, additive-dose and single-grain protocols (Lian and Roberts, 2006).

The recent widespread adoption of the single-aliquot regenerative-dose (SAR) protocol has arguably improved D_e accuracy and precision by up to 10 times compared to multiple-aliquot protocols (Wallinga et al., 2000; Hilgers et al., 2001; Murray and Wintle, 2003; Duller, 2004; Wintle and Murray, 2006). A review by Jacobs (2008) showed that between 2000 and 2008, 70 out of the 80 studies using OSL on coastal and marine sediments used the SAR protocol.

The importance of OSL dating is underpinned by its ability to date material as far back as 200 ka BP (Rhodes, 2011), supported by test studies such as those conducted on Danish Eemian coastal marine deposits (Murray and Funder, 2003). This fills a critical dating gap beyond the scope of radiocarbon dating (<45,000 yrs) where obtaining suitable material for U-series dating techniques can be problematic.

3.2.4.5. OSL dating of marine and coastal sands

Jacobs (2008) counted 196 peer-reviewed publications between 1978 and 2008 utilising some form of luminescence dating of sediments in coastal and marine settings. Of this collection of studies, 69 used OSL and 26 used a combination of thermoluminescence (TL) and rest solely TL.

Studies have found that dose rate is not constant, and can fluctuate over time due to variable uptake of radiation from radioisotopes in the geochemically active sediments which can result in significant OSL age underestimation (Li et al., 2008). Partial bleaching prior to deposition is also likely in fluvial and waterlain environments, caused by attenuation of light through water, exacerbated by turbidity and water movement. Furthermore, an influx of non-bleached sediment through erosion can lead to result scatter (Rittenour, 2008). Ideally, OSL works best on dry, fully bleached, quartz or feldspar-rich samples under stable environmental conditions. For marine and coastal settings, this would often translate to OSL-dating of beach terraces and ridges (e.g. Choi et al., 2003; Tamura et al., 2018).

Recent developments of more robust statistical models helped ameliorate the accuracy of OSL results for dating coastal and marine sediments. Several studies looking at the evolution of the Yangtze River used OSL dating successfully to construct chronological frameworks to understand its evolution. Nian et al. (2018) used eight OSL samples and fourteen ^{14}C samples to construct a chronological framework for the Yangtze Delta and corrected her burial age

using the Minimum age model (MAM) effectively in identifying incomplete bleaching for medium- or coarse-grained quartz. Wang et al. (2018b) traced the evolution of Liangzhu culture proximal to the south Yangtze coastal plain by AMS ^{14}C dating of peat and macrofossils and OSL dating of a sand ridge just below the peats. The chronological framework helped to better constrain the timings associated with Liangzhu cultural decline, marine flooding and past human responses to extreme events. Lastly, OSL was even used effectively alongside other techniques to date young delta sediments (<200 years) in the Yangtze River (Wang et al., 2018a). They compared OSL with ^{210}Pb , ^{137}Cs , $^{239} + ^{240}\text{Pu}$ geochronology, microplastics content and found the former to be a reliable dating tool even for such recent sediments.

Elsewhere, , Tsakalos et al. (2018) constructed a chronological framework for the Sperchios delta plain, Greece, using the SAR protocol and statistical modelling using the Minimum Age Model from deltaic deposits obtained by sediment cores. OSL dating was also done on sediments from the *Skagen Odde* spit system, to construct a Holocene sea level curve for the northern Denmark coast (Clemmensen et al., 2018).

3.2.5. Methodology used here

A critical yet commonly neglected component of obtaining credible age-depth data points is establishing the accurate identification of sedimentary facies, i.e. whether the lithofacies where the radiocarbon sample was obtained from belongs to said stratigraphic unit. Here, I aim to ascertain that the samples were

taken from intertidal mangrove peats through palynological techniques, and from marine muds through identification of marine benthic foraminifera.

3.2.5.1 Microfossil Analysis (Foraminifera)

Foraminifera are single-celled micro-organisms with hard shells or ‘tests’ that are sometimes calcareous and are widely used as sea level indicators (e.g. Horton, 2007; Kemp et al., 2015; Dai et al., 2018). Foraminifera species are sensitive to environmental factors such as water depth and salinity conditions (Edwards and Wright, 2015) and hence species assemblages can be used to identify coastal features (Liu et al., 2010; Wang et al., 2014; Kemp and Telford, 2015).

Samples of $\sim 0.5 \text{ cm}^3$ were randomly collected from each core segment logged visually as Upper Marine Clay (Rochor Member). All samples are washed through 61 μm and 500 μm sieves and decanted. All residuals are placed for oven-drying at $\sim 50^\circ\text{C}$ before inspection under binocular microscopes. All foraminifera were dry-picked using a fine-tipped brush and set on collection plates for abundance and species count. Some of the species identified are *Asterorotalia trispinosa*, *Cibicidoides pachyderma*, *cibicidoides wuellerstorfi*, *Ammonia* spp., and also from the genus *Elphidium*. *A. trispinosa* is commonly found in low salinity environments in marginal marine, deltaic settings (see image in Fig. 3.4).

3.2.5.2 Microfossil Analysis (Palynology)

Five samples were taken from the peaty unit (Kranji Formation) which is believed to be Holocene mangrove peat, albeit hitherto never verified. Pollen analysis was performed in order to ascertain whether the peat is from mangrove or freshwater marsh, which is critical to our stratigraphic framework. The sample was pretreated by first adding Sodium pyrophosphate ($\text{Na}_4\text{P}_2\text{O}_7$) which removes clay by acting as a deflocculent. Subsequent centrifuging will enable us to remove clay particles which remain in suspension. The samples were then washed with Potassium hydroxide (KOH) to remove 'humic acids' by bringing them into solution. Samples are macro and fine-sieved and washed with HCl to remove carbonates. Acetolysis was performed to remove polysaccharides and helps increase the contrast of features on pollen grains. Mineral fragments were then removed from organic particles through heavy liquid separation using Sodium polytungstate, $\text{Na}_6(\text{H}_2\text{W}_{12}\text{O}_{40})$, at a density of 2.0. Finally, samples were mounted on slides using glycerol before identifying pollen grains under a microscope.

3.2.5.3 Age-date sample selection for AMS ^{14}C dating

After verifying that the Rochor member and Kranji Formation are marine muds and mangrove peat respectively, dateable material (i.e. shell, charcoal, wood) were selected to constrain the chronology of sediment core MSBH01B and provide age-correlations for identified geological units. In total, 23 radiocarbon samples were cleaned with deionised (DI) water and sonicated in a water bath at least 3 times to remove sediment and other impurities, before being oven-

dried at 60 °C and stored in centrifuge tubes. Selection was based on condition of material and preservation position within the stratigraphy (e.g. situated in undisturbed as opposed to bioturbated unit). Articulated bivalves (observed through CT-scanning) were preferentially selected over gastropods. All samples were sent to Rafter Radiocarbon Laboratory, GNS Science in New Zealand for AMS radiocarbon dating. ^{14}C calibration was done using IntCal13 (Reimer et al., 2013a).

From the total radiocarbon samples 3 were basal/contact samples used to constrain the ages of the Kranji Formation (transgressive) and Rochor Member in the Kallang River Basin, and only these samples will be discussed further (Fig. 3.5).

Figure 3.5. Compound figure with A) linescan image of core segment P2 with blue-grey marine muds. The red circle shows the location of ^{14}C sample. Scanning Electron Microscope (SEM) image of benthic foraminifera validates identification of unit as marine clay (Rochor Member). B) linescan image of core segment OD3 with brown marine muds at the top, a highly-organic peaty unit followed by pre-transgressive palaeosol at the bottom. Radiocarbon samples are obtained from top and bottom contacts (red circles) and samples for pollen analysis shown as yellow circles. Pollen from common mangrove species were found abundantly in all five samples and sample photographs are shown on the right.

3.2.5.4 Method used for OSL-dating

3 samples were taken from basal sandy sediments overlying the Bedok Formation (BF). These core segments remained in their stainless steel core barrels with wax endcaps throughout the coring and storage process ensuring no exposure to light. They were cut laterally and sealed in black opaque plastic wrapping before being sent to the Sheffield Luminescence Dating Facility, University of Sheffield for Optically-Stimulated Luminescence (OSL) dating.

Inductively coupled plasma mass spectrometry (ICP-MS) was performed at SGS laboratories Ontario Canada to determine elemental concentrations of naturally occurring potassium (K), thorium (Th), and uranium (U). An estimation of 10 ± 5 % moisture was used to account for dose attenuation over time. Samples were prepared under subdued red lighting and material for dating taken from prepared quartz isolated to a size range of 125 - 250 μm . The samples underwent measurement using a Risø DA-20 luminescence reader with radiation doses administered using a calibrated ^{90}Sr beta source. Grains were mounted as a monolayer on 9.6 mm diameter stainless steel disks using silcospray. Stimulation was with blue/green LEDs and luminescence detection was through a Hoya U-340 filter. Samples were analysed using the single aliquot regenerative (SAR) approach (Murray and Wintle, 2003). Preheat temperatures of 160 °C for 10 seconds was applied to prior to each OSL measurement to remove unstable signal generated by laboratory irradiation. Data values from individual aliquots were only accepted if they exhibited an OSL signal measurable above background, good growth with dose, recycling values within

$\pm 10\%$ of unity, and the error on the test dose used within the SAR protocol was less than 20 %.

3.3. Results

3.3.1. Geological Modelling of the Kallang River Basin

Figure 3.6. shows the fence diagram constructed by combining all cross-sections created based on the 14 transects which cover the entire Kallang River Basin. Infilled palaeovalleys during phases of high sea level can be observed as U-shaped channels infilled with grey clays; these transects potentially providing a coarse model to improve current knowledge of Singapore's palaeochannels (Mote et al., 2009).

I also produce the first 3-Dimensional geological model of the Kallang River Basin (Fig. 3.7). The model shows at least 10 geological units postulated to span the late Pleistocene until present. Unfortunately the uppermost units have been removed and replaced by modern fill material. The extent and distribution of each unit is shown in the model, together with a brief description of their lithology and superimposed with coeval sea level change which greatly influenced the sedimentary evolution of the KRB.

The Quaternary geology of Singapore in the KRB is more complex than previously thought and described in the official stratigraphic framework. Most notably, there are at least 3 occurrences of Jalan Besar Formation, stratigraphically located immediately above the Bedok Formation, and

intercalated with pockets of Kranji Formation below and above the Rochor Member. Although they are lithologically similar, they vary substantially spatially and temporally, potentially up to the order of 10^5 years. I thus propose naming them JBF (I), JBF (II) and JBF (III) from deepest unit upward, and KF(I) and (II) representing lower and upper peaty units respectively.

I also observe the spatial distribution of the stiff-clay unit and see strong association with the Tanjung Rhu Member, supporting the hitherto-held assumption that it is desiccated and oxidized TRM. As its physical and chemical properties are markedly different from TRM, an argument can be made to assign it as a unique member within the current framework.

Figure 3.6. Fence diagram of Kallang River Basin created by combining all 14 transects. Extensive marine muds can be observed as infilled palaeovalley deposits which can potentially help in palaeochannel mapping. Complex coastal sequences can also be seen at the landward extent of the basin.

Figure 3.7. 3-dimensional model (exploded) showing the Quaternary geological units found in the Kallang River Basin. The 3D model is set at 15x vertical exaggeration.

3.3.2. Chronology (^{14}C dating)

Table 3.2. Summary of radiocarbon dates from lithofacie contacts.

Sample ID	Depth (m MSL)	Material	Lab code (NZA-)	Lab ID	^{14}C age (CRA)	CRA err	Calib age -Intcal13	err	- (1 σ)	+ (1 σ)
57_P2_20-22	9.517	Wood	63750	41068/8	6278	29	7199	23	7222	7176
113_OD3_9-10	18.76	Charcoal	64445	41111/5	8278	37	9282	41	9322	9241
126_OD3_72-74	19.39	Wood	63749	41068/16	8421	35	9458	26	9484	9432

The chronology of sediment core MSBH01B extends from ~7.2 ka to 9.2 ka BP for topmost Rochor Member, and Kranji Formation which was deposited from ~9.2 ka – 9.5 ka BP. The underlying pre-transgressive land surface, interpreted to be desiccated, subaerially exposed Tanjung Rhu Member, predates ~9.5 ka BP, marking the boundary of influence from post-LGM sea level rise for Singapore. I postulate this boundary represents a marked unconformity, given the absence of regressive materials overlaying the marine muds.

3.3.3. Chronology (OSL dating)

Table 3.3. Summary of single grain palaeodose data and ages for basal samples from contact between Bedok Formation and Jalan Besar Formation in MSBH01B.

Lab Code	Field Ref.	Depth (m)	<i>De</i> (Gy)	Over dispersion (%)	Dose rate ($\mu\text{Gy/a-1}$)	Age (ka)
Shfd17115	MS 01B TW10	45.1	125.1 ± 3.96	18	3346 ± 134	37.4 ± 1.9
Shfd17116	MS 01B P35	45.4	107.5 ± 2.23	11	2180 ± 95	49.3 ± 2.4
Shfd17117	MS 01B TW11	45.7	103.7 ± 4.30	29	2393 ± 120	43.3 ± 2.8

Generally the samples possessed good luminescence characteristics with a rapid decay of OSL with stimulation. *De* distributions of all samples when measured are broadly normally distributed (especially after outliers are removed) with modest levels of *De* replicate scatter. Our tests show no indication that either partial bleaching or post-depositional disturbance has influenced the samples and as such further measurements at the single grain level would have no clear benefit age calculation. *De* values for age calculation purposes have been extracted using the Central Age or Common Age Models (CAM or COM). Ages are quoted in years from the present day (2018) and are presented with one sigma confidence intervals which incorporate systematic uncertainties with the dosimetry data, uncertainties with the palaeomoisture content and errors associated with the *De* determination. The final OSL age estimates are shown in Table 3.3 with ages ranging from 37.4 ± 1.9 to 49.3 ± 2.4 ka.

3.3.4. Pre-Quaternary geology of the Kallang River Basin

3.3.4.1. Bedok Formation

A thick sequence of Bedok Formation (BF) (shown in Fig. 3.7 as an orange unit) underlies the more recent surficial late Pleistocene deposits of the Kallang Group.

Field observations reveal that the BF is composed of chaotically-bedded clay-sized up to coarse sand and pebbly sediments, accompanied by discontinuous sandy beds and prevalence of scour marks, suggesting that BF was deposits from a braided river system (Gupta et al., 1987). A report by CCOP (1980) suggested that the river system trending southeast from the Johor River. A synthesis of previous studies indicates that BF was heavily weathered and oxidised due to the hot and humid climate, and that the depositional environment was a high energy one as suggested by the prevalence of sand and pebbles. The angular shape of the clasts also indicates a short transportation and burial process, where the source would be unweathered rocks which were eroded further upriver (Burton, 1964; Gupta et al., 1987; Kamaludin et al., 1993; Chiam et al., 2003). The modelled surface for BF is also undulating with channel-like sub-linear indentations on the topmost mesh which supports the postulation that it is deposited as fluvial deposits. However the model lacks the necessary resolution to confirm this given the limited number of data tiepoints which I use for interpolating unit elevations.

Distribution of the Bedok Formation

BF is found spanning the entire extent of the Kallang River Basin, and geologically occupies the north-eastern to far-eastern portions of Singapore, in line with the hypothesis of a palaeo-fluvial system trending northwest-southeast (Gupta et al., 1987). Thickness is variable, with thicker sequences generally to the eastern regions of the model. The depth to the base of BF are highly variable with fields studies indicating a depth range of 6 m to more than 63 m with thicknesses of at least 50 m (CCOP, 1980) to up to at least 100 m in thickness, while the maximum thickness recorded in our model is 32.8 m. However, I point out that termination depths for all BH data in our model did not reach the contact between BF and underlying units.

Age of the Bedok Formation

The absolute age of BF has been difficult if not impossible to determine due to the dearth of wood, fossils, pollen or other dateable materials, even in the thicker silt or clay beds (Gupta et al., 1987). Earlier estimates put the age at Plio-Pleistocene (Burton, 1964; Pitts, 1984), and indirect comparison of evidence from the region (Stauffer, 1973) also established a late Pliocene to Pleistocene age for the BF. The age of the BF is further constrained by the presence of fresh alkali feldspar crystals among the clay minerals which implies minimal weathering possibly indicating it is not very old (Gupta et al., 1987; Chiam et al., 2003).

Our OSL samples obtained proximal to the BF - JBF contact range from 37.4 ± 1.9 to 49.3 ± 2.4 ka, and thus I can determine that deposition of the youngest BF deposits predates ~50 ka BP. Younger than expected dates were also previously obtained through thermoluminescence dating of Bedok Formation from coastal sands in Perak which produced ages from 28,000 to 67,000 yr BP (Kamaludin et al., 1993)

3.3.5. Late Quaternary Stratigraphy

The Kallang Group, named after the Kallang River Basin where it is extensively distributed, comprises sedimentary succession postulated to be late Pleistocene and Holocene deposits of marine, estuarine and fluvial origins (e.g. PWD, 1976; Bird et al., 2003; DSTA, 2009). The Kallang Group covers approximately a quarter of the island (Pitts, 1992). Much of the coastal plains, tidal and inter-tidal zones and incised river valleys (from the previous interglacial) are covered predominantly by these deposits which infilled palaeochannels up to central Singapore and above present sea level (Pitts, 1984; Tan et al., 2003). Where relevant I will augment descriptions of geological units here with sedimentological data from longcore MSBH01B (this study) and the Geylang Core (Bird et al., 2010)

3.3.5.1. Lower most, presumably Pleistocene Units deposited during the Last Interglacial

3.3.5.1.1. Jalan Besar Formation (I)

Jalan Besar Formation (I) is predominantly composed of loose, unlithified greenish-grey to light brown sediments of variable grain-size from coarse sand to silty clay. Studies elsewhere note that these deposits vary widely from pebble beds through sand, muddy sand, to clay and peat (DSTA, 2009; PWD, 1976). Some boreholes record JBF as being oxidized with reddish and brownish hues. JBF is considered as transitional facies which were temporarily near to or within the intertidal zone during the marine transgression and regression phases and identified in the stratigraphy within the Kallang Formation (Bird et al., 2003; Bird et al., 2007).

Before the availability of this high-resolution model, JBF was initially perceived to have been deposited largely by fluvial processes during the Holocene (PWD, 1976). However, Chang (1995) believed it to predate even the TRM when he obtained thermoluminescence dates ranging from 60,000 to >137,000 years for clayey alluvial sands underlying the Marine Member at Sungei Nipah in Pasir Panjang. Adding credibility to the claim, a date of 23,000 BP was obtained for peaty clay at the base of a 1 m sequence of mostly Holocene peaty sediments from a freshwater swamp in Central north Singapore (Taylor et al., 2001). Our results indicate at least 3 genetically-analogous units of JBF within the late Quaternary stratigraphy – the earliest unit inferred to be coeval with the MIS-5e marine transgression [JBF(I)], the second associated with the post-LGM

marine transgression [JBF(II)], and the final more surficial sequence deposited during the post Holocene highstand regression [JBF(III)] and renamed them accordingly.

Distribution and thickness of the JBF (I)

JBF(I) is found extending from the western to eastern boundaries of the KRB, but covers about 70% of inland regions. Based on the model, the thickness of the unit range from 2 m to almost 10 m, and can be found between the depths of between ~25 – 40 m below MSL. Elsewhere, the JBF(I) is widely distributed as valley fill throughout Singapore and as a thin expansive veneer, potentially beach and tidal banks, on the Kallang River basin floors during the MIS 5 marine transgression phases. Similar sediments interdigitate with the other members of the Kallang Group, its composition varying widely from pebble beds through sand, muddy sand, to clay and peat (DSTA, 2009; PWD, 1976).

Age of the Jalan Besar Formation (I)

Optically Stimulated Luminescence (OSL) dating of basal JBF (I) just atop the BF (45 m below MSL) gave an age of 37.4 ± 1.9 ka. Lab reports conclude that *De* (palaeodose) data is normally distributed with relatively low dispersion strongly suggesting no post-depositional disturbance or incomplete bleaching. However, I postulate that the OSL age is an underestimation affected by higher than expected moisture content (e.g. Hilgers et al., 2001) and overestimated postulated dose rates in water-lain samples (Galbraith and Roberts, 2012).

3.3.5.1.2 Kranji formation

Peaty units associated with a mangrove coastline, or Kranji Formation (KF), were only found in small isolated patches or even singular boreholes beneath the Tanjong Rhu Member (TRM) and were not considered in this model. I recognize that this unit can be elusive in soil investigations due to its thinness and likely exacerbated by substantial autocompaction (e.g. Allen, 2000; Bird et al., 2004b; Törnqvist et al., 2008; Horton and Shennan, 2009; Brain et al., 2012) . Nonetheless, the absence of more extensive peaty KF in the model suggests either a markedly faster relative rise in sea-level during MIS-5e which did not allow for mangrove colonization, or unfavourable coastal morphology where relatively higher wave energy and/or associated surface and subsurface processes prevented mangroves from keeping pace with the rising seas (Woodroffe et al., 2016).

3.3.5.1.3 Tanjong Rhu Member (TRM)

In past studies, the TRM is described as homogenous green–grey to dark-blue silty clay, intercalated with occasional macroscopic shell fragments and organic detritus such as peat (Pitts, 1984). TRM is typically kaolinite-rich with moderate amounts of montmorillonite and illite. (Sharma et al., 1999). Another study (Tan et al., 2003) showed that the TRM consists of quartz, kaolinite and smectite with small amounts of mica, chlorite, albite, orthoclase, pyrite and halite, suggesting deeper weathering processes. TRM in longcore MSBH01B shows a largely homogenous, light bluish grey silt (GLEY 2 6/10G) dominated by poorly sorted fine silt. Particle size proportion is generally in the range of ~30% clay, ~70% silt

and <0.5% sand. Dry bulk density is generally within the range of 1.0 – 1.5 g/cm³, accompanied by 4 – 8 % organic matter and 0.5 – 3 % inorganic carbon. I observe occasional indistinct light and dark banding at cm-scale, and very little to absent shells or organic macrofossils.

Distribution and thickness of the Tanjong Rhu Member (TRM)

In our model, a thick bed of TRM sits atop the early transgressive alluvial and peaty units, in some places the TRM is up to 20 m thick in palaeochannels, albeit pinching out as it extends landward to thicknesses of < 5 m. The TRM is found extensively within the Kallang River Basin based on the model, reaching the boundaries of the catchment basin. Notably, the TRM is thicker proximal to the current Singapore River mouth, with three prongs extending roughly northwest, north and northeast, which generally corresponds to palaeochannel infilling patterns.

The TRM is widespread throughout the coastal areas of the island, as well as underlying much of Singapore's Central Business District, Jurong, Changi, and southern and eastern offshore islands (PWD, 1976; DSTA, 2009; Bo et al., 2011). The thickness of this marine clay formation is variable - from 10 m to 15 m near estuaries, to greater than 40 m especially near the current Singapore River basin. Vertically, the TRM appears to range from at least 50 m below sea-level to the highest reported occurrence of –4 m in Bedok (Pitts, 1983), an exceptional claim which is unverifiable (Bird et al., 2003). I wish to point out however that there are regions where the two marine members are

undifferentiated (i.e. no intervening unit between the two marine members). The maximum recorded thickness to date is approximately 35 m located at the proximity of Rochor Canal Road, although thicknesses over 55 m have been reported on the offshore island of Pulau Tekong (Tan et al., 2003).

Age of the Tanjong Rhu Member

Initially, the depositional timeframe of the TRM was hypothesised to be between 12,000 and 18,000 years ago at the end of the Pleistocene epoch (Pitts, 1983). The geologic chronologies were further revised and refined by Bird *et al.* (2003, 2010) who posited that the TRM was deposited even earlier during the last interglacial ~125, 000 years ago (Bird et al., 2006).

Based on the OSL-based chronology, the initial deposition of the TRM would postdate the underlying strata dated at ~37 ka (youngest burial age). However I acknowledge the OSL date as an underestimation of true burial age due potentially to incomplete bleaching, and postulate that the TRM was likely deposited during more permanent marine inundation during MIS5e dated at ~120 ka.

3.3.5.1.4 Dessicated Tanjung Rhu Member ('stiff clay' layer)

The marine member (TRM and Rochor Member) are frequently separated by a thin veneer of weathered marine clay, postulated to be the desiccated crust of the TRM when it was exposed to terrestrial weathering (Bird et al., 2003). This boundary unit comprises stiff reddish brown silty clay and occasionally beds of

loose sand (DSTA, 2009). Bo et al. (2003) examined the TRM and found it comprises kaolinite and smectite with small amounts of mica and chlorite, while the 'stiff clay' layer consists similar mineralogy with additional components of albite, orthoclase, pyrite and halite, suggesting deeper weathering processes. Geotechnical lab tests show this layer as being highly consolidated, with an overconsolidation ratio (OCR) as high as 8, postulated to be due to desiccation and aging (Chu et al., 2002). Visual logging of this unit in our sediment core (MSBH01B) shows a pale very light grey-blue (GLEY 1 8/N) highly-oxidised unit with numerous red and orange sub-horizontal streaks and bands. The dense stiff clay unit characterised by high dry bulk density (Average = 1.41 g/cm^3) and low organic matter (Average = 4.92 %) and inorganic carbon (Average = 3.38 %) content. Bird et al, (2010) noted that the 'stiff clay' in the more inland Geylang Core (Figure 3.4) is composed of weathered light grey clay (5G 8/1) with prominent vertically aligned red and brown mottles. Roots are common to – 16.5 m but absent below this level. The degree of weathering and mottling decreases gradually to 18.05 m below MSL.

Thickness and Distribution of 'stiff clay' layer

The distribution of this 'stiff clay' corresponds largely to the geographical extent of the TRM, where the thickness shows great variability from 1 m to 13.5 m. Depths are variable as well, ranging from 9.7 m to a maximum depth of 25 m below MSL. In other parts of Singapore, the 'stiff clay' and LMC deposits are usually located -8 to -9 m deep with the stiff clay commonly forming a sub-horizontal layer situated about -15 m relative to MSL (Bird et al., 2006). In the

downtown area, the stiff clay has been observed even deeper, almost 28 m below MSL (PWD, 1976; DSTA, 2009). Offshore, the depth of the TRM and stiff clay unit, if present, can reach up to 30 m below sea level (e.g. Pulau Tekong) (Tan et al., 2003). Davies and Walsh (1983) note that where there is variation in the thickness of the TRM, the depth to the 'stiff clay' increases as depth of the TRM increases, presumably due to consolidation/compaction of TRM over time.

Age of the 'stiff clay' layer

Depositional age would be the same as the TRM which I postulate to be of MIS5e age (125 ka BP). However the formation of this unit was dependent on post-depositional aerial exposure and pedogenic weathering processes which would take place during the last interglacial during periods of lower sea level (between ~125 ka and ~9.5 ka BP). The uppermost palaeosol was formed before ~9.5 ka BP based on a basal wood sample from the overlying Kranji Formation.

3.3.5.2. Holocene Units

3.3.5.2.1. Jalan Besar Formation (II)

JBF(II) has similar lithology to JBF(I), and is characterised by firm and stiff brown to light grey sand to silty clay with occasional occurrences of coarse gravel and organic matter. There is little to negligible thickness of JBF(II) in both MSBH01B where the underlying 'stiff clay' progressively grades into Kranji Formation (peaty unit). Likewise this unit is absent in the Geylang Core (Bird et al., 2010), where a sharp division exists at -15 m between the RM and the underlying 'stiff clay'.

Distribution and thickness of JBF(II)

The occurrence of JBF(II) is only recorded in boreholes and is restricted to discrete regions further inland and the pockets of JBF(II) generally align themselves to the palaeochannels infilled previously by the TRM, with thicker units in the north and north east of the Kallang River Basin. The thickness of JBF(II) is generally low, from minimum thickness of ~2 m to a maximum thickness of almost 10 m. Currently the JBF(II) unit is found at depths from ~15 m to 29 m below MSL.

Age of the JBF(II)

I am unable to accurately ascribe an age for this unit given its absence in both sediment cores. Nonetheless I can infer stratigraphically that the unit is enveloped between the 'stiff clay' layer and Kranji Formation, where deposition occurred soon after the Holocene marine transgression reached the Marina South palaeocoastline. This would infer an age slightly earlier than ~9.5 ka BP.

3.3.5.2.2. Kranji Formation (I)

Kranji Formation (I) is observed in MSBH01B as organic-rich dark brown peaty (mangrove) medium-fine silt (Average: Clay = 27.6 %, Silt = 69.91 % and Sand = 2.47 %) with abundant macrofossils and fibrous material. Inorganic carbon is consistently low at about ~4 % while organic matter content is relatively high at an average value of ~12 % with maximum values of 25.66 % and low average bulk density of ~1 g/cm³.

This unit has been described in BH logs as very soft highly-organic, often highly-humified dark brown to black unit with undecomposed plant material and occasional pockets of sandy silt. It is usually associated with mangrove peat deposits (DSTA, 2009), although it has not been verified until the pollen analysis was done in this study.

Distribution and Thickness of KF(I)

KF(I) is found in only 17 boreholes in the model and thus only observed in small (<1 km) localized patches nearer to the seaward boundary of the Kallang River Basin. These isolated patches appear to conform to possible estuarine locations where the Kallang River tributaries flow out into open waters. This unit only has an average thickness of ~1 m and could be potentially missed out in borehole logs during soil investigations. The thickness of KF(I) in MSBH01B is only ~0.8 m, albeit the original thickness could be up to 200 % greater due to autocompaction by overburden stress (Bird et al., 2004b). Depths of KF(I) were up to 19.4 m below MSL in MSBH01B, and up to a maximum depth of ~31 m below MSL based on the geological model.

Age of KF (I)

PWD (1976) and DSTA (2009) both proposed a present-day age as it has been mapped and observed in modern times. However, field observations by Pitts (1983) revealed this member intercalating with and/or underlying the marine members which suggests a much broader age range. A date of 23,000 BP was obtained for peaty clay at the base of a 1 m sequence of mostly Holocene peaty

sediments from a freshwater swamp in Central north Singapore (Taylor et al., 2001). Sediment core MSBH01B reveals that KF(I) was deposited between ~9.5 ka to ~9.2 ka BP at the Marina South site based on top and basal radiocarbon dates (Table 3.1).

3.3.5.2.3 The Rochor Member (RM)

More permanent marine inundation laid down the Rochor Member (RM) a unit dominated by largely homogenous, non-laminated marine clay ranging from greenish grey (10GY 4/1) to grey (5G 5/1) with occasional shells and organic streaks. Organic matter and Inorganic carbon percentages show little variability with values at ~6.8 % and 2.5 % respectively.

The RM is logged in the Geylang Core as a homogeneous sequence of clays ranging from greenish grey (10GY 4/1) to grey (5G 5/1), with diffuse laminations 1 - 2 mm thick throughout. Bivalves, gastropods and oysters (whole and fragmented) as well as macroscopic organic material are common towards the top of the sequence but become less common downcore.

The RM shares many similar geochemical and sedimentological characteristics with TRM - kaolinite and smectite with small amounts of mica and chloride (Tan et al., 2003), albeit with a greater amount of organic matter (Pitts, 1983) and less consolidation and a more flocculated clay structure (Tan et al., 2003).

Distribution and thickness of RM

Deposition of the RM is extensive, covering the entire expanse of the Kallang River Basin from the granitic outcrop in central Singapore west of the basin, to the northern and eastern Bedok Formation foothills. It is also less undulating than the earlier sequence of marine clays, the Tanjong Rhu Member. Elsewhere, the RM is widely distributed beneath the Central Business District and the western parts of the Island (e.g. Jurong), often infilling incised palaeochannels cut in TRM or BF during the last glaciation (PWD, 1976; DSTA, 2009). The unit occurs to depths of up to 30 m below MSL, with thicknesses of more than 20 m towards the seaward margin, and occasionally in deeper infilled palaeochannels.

Thickness of RM in the model is up to ~20 m, although the true thickness cannot be verified due to truncation by modern fill material. An earlier report put the highest recorded occurrence of the UMC at 1.8 m above sea-level (PWD, 1976) in the vicinity of the Rochor/Beach Road area. Depth of RM observed in MSBH01B is ~18.6m while maximum depth observed in the model is up to 23 m below MSL.

Age of the Rochor member

The RM has been postulated to be deposited ~11,000 – 10,000 years ago and continued until sea level receded from Holocene highstand levels at around 2 - 4 ka BP (Tjia, 1996; Bird et al., 2003).

RM was deposited at the Marina South site, at a depth of ~18.7 m, from 9.2 ka to 7.2 ka BP at a depth of ~9.2 m. However, this sequence is truncated due to modern land reclamation which resulted in the dredging and removal of the topmost substrate. Further inland, RM began depositing at the Geylang site from ~8.5 ka BP to 1.2 ka BP.

3.3.5.2.4 Kranji Formation (II)

KF(II) is lithologically similar to KF(I), composed of highly organic, abundant large organic fragments, but with higher percentage of sand, expressing itself as occasional clean sand beds up to 5 cm thick. KF is characterized by unconsolidated black to blue-grey mud, muddy sand or sand with high organic content, even grading into pure peat, suggesting a strong association with mangrove deposits deposited in a low-energy environment (DSTA, 2009). This unit is absent in longcore MSBH01B.

Distribution and Thickness of KF(II)

KF(II) is found interdigitating with JBF (III), and is concentrated as isolated patches near the northern landward edge of the KRB, with a relatively broad expanse located proximal to Kolam Ayer. A thick sequence of organic-rich KF was deposited in localised pockets, mostly in the inland region of the basin probably indicating locations of low-energy, high biomass depositional environments.

It is difficult to ascertain the thickness of this unit as all occurrences of KF(II) have their uppermost portions truncated by modern fill. It is generally thin unit of ~3 – 4 m on average, with a rare 8 – 9 m thick sequence located proximal to the northern landward boundary of the Kallang River Basin. KF(II) is typically found above the depth of 7 m below MSL.

Age of KF(II)

A basal radiocarbon age of 1200 ± 150 cal BP at a depth of 1.35 m below MSL was obtained from a 1 m sequence of KF(II) from the Geylang core (Bird et al., 2010). Three radiocarbon dates were obtained from KF(II) units at the Sungei Nipah Valley in Pasir Panjang, with near-basal ages of 5720 ± 60 BP and 5870 ± 70 BP and a upper-unit age of 3530 ± 80 BP, at elevations of 1.11 m, 1.36 m and 2.16 m relative to MSL, respectively, suggesting it was deposited as early as the mid-Holocene (Chang, 1995; Hesp et al., 1998). The age of this unit is thus elevation- and location-dependent, with KF(II) at higher, more landward regions accumulating from ~6000 years to low-lying areas proximal to the coast from ~1200 years ago. This unit continues to be deposited on modern muddy coasts where fragmented mangrove forests exist today (e.g. Sungei Buloh) (Bird et al., 2004a).

3.3.5.2.5 Jalan Besar Road Formation (III)

JBF(III) is described as loose to medium-dense white to yellow silty clay to coarse sand with traces of gravel and pebbles, with some occurrences of red and brown mottling. It is sometimes found intercalated with peaty more organic-rich

sediments, especially in more inland areas in the KRB, and is associated with fluvial deposits and valley fill (PWD, 1976; DSTA, 2009).

Distribution and thickness of JBF(III)

JBF (III) is observed in our model as a thin veneer deposited in the central region of the KRB, and subsequently overlain, with a top boundary unconformity due to modern excavations and subsequent laying of modern landfill material. Thicknesses of this unit is generally between 0.5 m to 8 m although true thickness cannot be verified as the uppermost portions have been excavated and subsequently replaced by modern landfill material. It also interdigitated with KF (II) in the northern regions of the KRB.

Age of JBF(III)

JBF(III) was postulated to be deposited across the central part of the basin as sea levels receded from highstand levels during the mid to late-Holocene (approximately 4000 - 2000 yr BP) (e.g. Tjia, 1996; Hesp et al., 1998; Bird et al., 2007).

Figure 3.8. Cross-section view of Transect G-G' showing the variability and complexity of the Quaternary geology in the Kallang River Basin. Age constraints for unit contacts are given. The cross-section is set at 25x vertical exaggeration. * - recurrence of JBF within the stratigraphy but not differentiated in terms of nomenclature.

Figure 3.9. Cross-section view of Transect E-E' showing the variability and complexity of the Quaternary geology in the Kallang River Basin. Age constraints for unit contacts are given. The cross-section is set at 25x vertical exaggeration. * - recurrence of JBF within the stratigraphy but not differentiated in terms of nomenclature.

Table 3.4. Facies table representing all late Pleistocene and Holocene units

Sedimentary Unit	Sediment Type	Depth (m)	Depositional Environment	Postulated Age
Jalan Besar Formation [JBF (III)]	Loose to dense light grey, sometime reddish, silt to coarse sand with occasional traces of organic matter.	0-10	Fluvial channels, tidal channels, sand bars	2,000 yr BP to present
Kranji Formation(KF)	Loose to very loose dark brown to black peaty clay with fresh to partially decayed wood pieces.	5-10	Estuarine, backswamp, inland marsh.	2,000 yr BP to present
Jalan Besar Formation [JBF(III)]	Firm and stiff whitish to light grey silt to coarse sand with occasional gravel. Occasional red/yellow mottling.	10-20	Beach sands, tidal channels, deltaic sediments (marine regression)	6,000 - 4,000 yr BP
Rochor Member (RF)	Very soft bluish to greenish grey clayey silt with shell fragments. Occasionally stained with streaks of organic matter.	10-25	Nearshore shallow marine environment	10,000 yr BP
Kranji Formation [KF (II)]	Loose to very loose dark brown to black peaty clay with partially decayed wood pieces. Occasionally poorly sorted with fine to coarse sand.	15-20	Fringing mangrove coastal areas, riverine banks.	9,500 – 9000 yr BP
Jalan Besar Formation [JBF (II)]	Firm, medium dense brown, red to light grey silty fine to subrounded coarse sand.	20-25	Beach sands, tidal channels, deltaic sediments (marine transgression)	10,000 yr BP

'Stiff clay' layer [desiccated TRM]	Stiff, dense light grey clay with mottled red and brown streaks with occasional fine sand lenses and organic matter; Interpreted as subaerially exposed and subsequently desiccated Tanjong Rhu Formation.	20-30	Former land surface or palaeosol; marine clay exposed to erosional and weathering processes.	10,000 - 125,000 yr BP
Tanjong Rhu Formation (TRM)	Soft blue grey to dark grey clay with shells fragments with occasional occurrences of peat	25-35	Nearshore shallow marine environment	125,000 yr BP
Kranji Formation [KF (I)]	Soft to medium stiff light grey to dark brown peaty clay with decomposed wood and vegetation fragments. Highly hu	35-40	Mangrove coast, riverine banks Note : rarely observed in BH logs	125,000 yr BP
Jalan Besar Formation [JBF (I)]	Loose to medium dense light grey clayey sand to silty-sand with occurrences of fine-grained gravel.	30-40	Beach sands, tidal channels, deltaic sediments (marine transgression)	125,000 yr BP
Bedok Formation (BF)	Hard and dense green-grey silty clay, often with red and yellowish mottles) to gravelly subangular coarse sand; poorly sorted and high downcore variability,	>40	Braided river channel deposits (Gupta et al., 1987)	>125,000 yr BP

3.4. Discussion

3.4.1. Pleistocene Evolution of the Kallang River Basin

The Bedok Formation was proposed as fluvial deposits deposited during the Early-Late Pleistocene (possibly 2 – 7 million years ago) where sea levels were much lower than present (Gupta et al., 1987). The BF was also deeply incised during past sea level lowstands throughout the Plio-Pleistocene timeframe, which is the primary driver of its undulating morphology. The Tanjong Rhu Formation (TRM) is a marine sequence that was subsequently deposited over the Bedok Formation possibly as far as ~125,000 years ago following the end of the penultimate glacial period when sea levels rose sufficiently to penetrate deep into the Sunda Shelf during MIS 5e. Initially, sea-level remained constant at levels similar to today from 125,000 - 115,000 years ago (Grant et al., 2014) which resulted in a thick sequence of TRM covering the sea-floor. Sea level began oscillating between –20 and –70 m approximately 115,000 and 85,000 years ago (Cutler et al., 2003), with the TRM in Singapore possibly deposited periodically in deeper parts of the downtown area (Bird et al., 2003). In this transgressive phase variable units of peaty (estuarine) or fluvial/alluvial material were also deposited forming, often infilling valleys incised into the weathered BF before marine regression set in and continued till approximately 20,000 yr BP.

I believe that regressive facies were deposited during the sea level fall, but erosional processes removed all top-lying units, leaving only a 'stiff clay' interface, characterised typically by dispersed reddish or yellowish oxidised

ferruginous patches, typically 3 m to 5 m thick delineating the boundary between MIS 5e and MIS 2. Due to the initial exposure during the sea level regression, terrestrial pedogenic processes produced the mottled desiccated clay that is essentially overconsolidated weathered TRM (Chu et al., 2002). This postulation is supported by mineralogical similarities between the TRM and the stiff clay (Tan et al., 2003), where in the late Pleistocene would have developed as palaeosol given the long-term terrestrial exposure.

Channel fill sediment sequences (Fig. 3.10) implies that the major tributaries of the Kallang River, existed as two separate and distinct channels during the late Pleistocene. The cross-section of Transect E-E' (Fig. 3.10) displays the evolution of the Kallang River from two separate river systems during the Pleistocene to one during the Holocene. The presence of the two v-shaped depressions containing TRM showed two deeply-incised palaeovalleys during the previous glacial and subsequently infilled during the post-LGM SLR. A significant amount of unconsolidated sands and silt were likely eroded from the catchment during the late Pleistocene, as suggested by the presence of the thick contiguous sequence of alluvial/littoral material laterally deposited eastward across the flood plain. The absence of the 'stiff' clay layer located above the middle of the channel suggests that subaerial exposure of TRM may have been absent, possibly indicative of a smaller palaeochannel occupying that region.

The palaeohydrology of the Kallang River Basin, in particular more inland areas, is also more complex than earlier postulated (Mote et al., 2009). Figure 3.10

shows three palaeochannels infilled with TRM which constrains the post-MIS 5e age. The combined three channel system was subsequently overlain by Holocene sequence dominated by upper marine clays of variable thickness. Thick sequences of tidal or fluvial sands laying unconformably above the incised BF (pre-transgression land surface), could be due the availability of more erodible material as well as foreshore accumulation of beach deposits (Bird et al., 2007).

3.4.2. Holocene Evolution of the Kallang River Basin

Post-glacial sea level rise during the early Holocene reached the Kallang Basin about 10,000 years ago (25 m below MSL) and was postulated to have breached the eastern and western sills of the Singapore palaeostraits (Bird et al., 2006). This resulted in the deposition of mangrove peats (Kranji Formation) on coastal mudflats in several areas, or on littoral coasts where rapid inundation of

mainland Singapore deposited the Jalan Besar Formation during periods of HAT (highest astronomical tides) which effectively eliminated terrestrial vegetation closest to the strandline. A wood fragment found at the depth of ~19.4 m in Marina South (MSBH01B) stratigraphically located immediately above the desiccated TRM was radiometrically dated at 9458 ± 26 cal BP and is hitherto the deepest and oldest date obtained for the early Holocene marine transgression. A sea level rise hiatus or a period of significantly slowed sea level rise is inferred by the deposition of mangrove peat (Kranji Formation) over the interdigitated sand and mud layer as mangrove colonisation occurred. The KF is archetypical mangrove and estuarine sediment, largely comprising unconsolidated greyish to black mud, muddy sand, or organically rich sand, indicative of a low-energy depositional environment. Moving upward sequence of the thick unit of RM implies that the palaeovalleys and low-relief coastlines were subsequently infilled and overlain as sea levels continued to rise.

The Last Glacial Maximum was characterized by sea level variability that saw sea level drop to up to 120 m below contemporary MSL, and resulted in deep channels incised into the TRM or in most cases the stiff clay unit. Subsequently, the post-LGM marine transgression, estimated at approximately 9,500 years BP, deposited a thick sequence of alluvial and marine sediments (JBF) in the eastern and northern regions of the Kallang River Basin.

During the Last Glacial Maximum (LGM) approximately 20,000 years ago, sea levels in the Sunda region regressed to a low of up to 120 m below current MSL

(Hanebuth et al., 2009; Grant et al., 2014) before rising with several periods of accelerated sea level rise possibly punctuated by 'meltwater pulses' (Hanebuth et al., 2000; Bard et al., 2010) and hiatuses (Bird et al., 2010).

The incised multi-channel river system of the Kallang River Basin during the late Pleistocene was replaced by a larger and broader fluvio-deltaic system during the Holocene, as suggested by the isolated depressions of TRM overlain by widespread RM which extended across each cross-section transect (Fig. 3.11). The rate of the initial marine transgression was presumably high which likely flooded the coast and contributed to changes to channel width and channel patterns often associated with rapid base-level increase and a decrease in accommodation space (e.g. Blum and Törnqvist, 2000; Dalrymple, 2006). It must be noted that transect E-E' extends into more inland sectors of the island in the mid-eastward regions which may account for the absence of large river channels or river mouths which typically accumulate more sediments. The presence of a small isolated bed of organic rich peaty silty-clay labelled as KF in the middle of the transect B-B' (Fig. 3.11) suggests a palaeo-backswamp which existed during the late Pleistocene but the mangroves or marshes were possibly drowned and overlapped by transgressive marine deposits resulting in the deposition and accumulation of this organic-rich, peaty unit.

During the Holocene, the more complex multi-channel system shown in Transect B-B' (Fig. 3.11) evolved into a low-energy backswamp indicated by shallower incision, greater channel width-depth ratios and presence of a relatively thick unit of peat in the proximal northern region of the KRB. This inland backswamp covers an area about $\sim 2.5 \text{ km}^2$ is expressed as 4 discrete patches of KF(II) in the model. Its position in the stratigraphy suggest deposition during the post mid-Holocene regression, where the relatively slower rate of sea level fall allowed colonization by mangroves and other nearshore flora.

3.4.3. Stratigraphic Evolution of the Kallang River Basin

Transect 3-3' (Fig. 3.12) shows a thick (up to 25 m) sequence of Tanjong Rhu Formation which thins as the sea bottom shallows up to the pre-reclamation natural coastline. In places the late Pleistocene inland marine clays have been eroded during the subsequent marine regression, and replaced by thick deposits of alluvial or littoral units, or became weathered and desiccated upon subaerial exposure to form the 'stiff clay' unit at depths of -20 m to -30 m below MSL. The post-LGM marine transgression deposited the upper marine clay which infilled further inland than during the previous interglacial. Mangroves and marshes managed to colonize the intermediate zone approximately 3 km inland, depositing organic-rich units or in some case peat. Branching tributaries (palaeochannels) of the Kallang River further inland were infilled with both marine clay sequences and were overlain with thick deposits of peat up to the

highest water mark indicative of the mid-Holocene marine highstand (e.g. Hassan, 2002; Woodroffe and Horton, 2005; Bradley et al., 2016). A regressive succession of alluvial and peaty units in more landward areas extending seaward is indicative of coastal advance to contemporary sea levels. The absence of more marine clay sequences is notable, as it strongly suggests that previous sea level maximums did not inundate the interior Sunda shelf as extensively as the previous two (Grant et al., 2014).

The depositional evolution of the KRB and associated sea level history is generally congruent with nearby and local studies (Geyh et al., 1979; Tjia, 1996; Hesp et al., 1998), although the known chronology from these studies only extends to the early-mid Holocene. The high-resolution study by Bird et al. (2010) demonstrated that RM at the Geylang palaeovalley began accumulating at -15 m at approximately 8900 cal BP, and he inferred that it initially accumulated very rapidly at 0.88 cm/yr until 7900 cal BP (-7.77 m), but slowed to 0.26 cm/year until 6710 cal BP (at -4.69 m) (Bird et al., 2010). However, locations at current nearshore zones would yield earlier dates for the early Holocene marine transgression, which ended with the mid-Holocene marine highstand of approximately 2.5 m above MSL through the period of ~6000 - 3000 years BP before regressing to modern sea levels, typically depositing peat-rich transitional facies or sandy alluvial facies in estuarine or riverine areas respectively as the sea retreats. Geyh et al. (1979) obtained 33 ¹⁴C-dated fossil mangrove deposits in the Straits of Malacca and Indonesia, and showed that Holocene sea level rose from -13 m to 5m above present between 8000 and

4000 ^{14}C yr BP. Unfortunately, the resolution of the data was not high enough to show whether the late-Holocene drop in sea level was a steady or oscillatory process. Tjia (1996) compiled a data base for a variety of published and unpublished index points for the Malay-Thai Peninsula. The sea-level curve for the Malay Peninsula implies two Holocene highstands at 5000 and 2800 ^{14}C yr BP, whereas his sea-level reconstruction for Thailand indicates potentially three mid-late Holocene highstands at 6000, 4000 and 2700 ^{14}C yr BP respectively. Such fluctuations were also shown by coral microatoll studies Belitung Island, Indonesia, where coral SLIPs show centennial scale fluctuations of up to 0.6 m between 6850 and 6500 cal yr BP, with a peak elevation of 1.2 m at ~6.6 ka BP (Meltzner et al., 2017). The study by Hesp et al. (1998) using only samples from Singapore showed a rapid transgressive sequence from 8000 yr BP and a marine-highstand of approximately 2.5 m above MSL plateauing between 6000 and 3500 yr BP. Horton et al. (2005) used regional index data from the Malay-Thai Peninsula which revealed an upward trend of Holocene relative sea level from a minimum of -22 m at 9700 - 9250 cal yr BP to a mid-Holocene highstand of 5 m at 4850 - 4450 cal yr BP.

3.5. Conclusion

The Quaternary geology of Singapore provide extensive geological archives for understanding sea level fluctuations and facies changes from the late Pleistocene to present in the inner Sunda shelf. The multitude of boreholes due to the rapid development in the area provide good high-resolution data for understanding the stratigraphy and hence gives greater insight into the

interplay between sea level dynamics, sedimentation and coastal evolution during the late Quaternary. Essentially, the Kallang River basin transitions from a series of low-lying micro-deltas in the Pleistocene to a single channel fluvio-delatic system during the Holocene. The pre-Holocene sequence had three to four main rivers draining from the granitic headlands (southeast trending) as well as the Bedok Formation hills in the eastern regions of Singapore (Mote et al., 2009). The underlying Bedok Formation was deeply incised during lower sea levels as indicated by deep fluvial channels up to 50 m below MSL. During the last interglacial, the rising sea level deposited intercalated sequences of tidal sands, estuarine muds and in some areas peaty clays prior to more permanent marine inundation depositing marine clay (TRM). Subsequent rapid sea level fall (MIS 5d – MIS 2) resulted in significant erosion of the exposed surface, and in localized subaerial weathering and desiccation of the TRM, in tandem with the evolution of a complex palaeohydrological pattern. Post-LGM marine transgression repeated the depositional behaviour during MIS 5, albeit with RM displaying less thickness variability, as well as tendency to more peaty deposits in more inland areas following the mid-Holocene highstand. Going forward, acquiring and integrating more borehole data into this first geological model for the Kallang River Basin, as well as obtaining more quality sediment boreholes for analysis, will provide better constraints on the sea level chronology and sedimentation regime of central Sunda.

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Chapter 4

A revised and extended Holocene sea level record for the far-field region of Singapore

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Abstract

The early Holocene (11.6 – 7.0 ka BP) was a period of dramatic environmental change coincident with rapid relative sea-level (RSL) rise that provides a valuable analogue for the future. However, this critical time period remains inadequately studied, especially in far-field regions that experience mainly hydro-isostasy but minimal land level change due to glacio-isostatic adjustment. Singapore lies near the tectonically-stable core of Sundaland, and here I obtained new sea level index points (SLIPs) from a ~40 m sediment core in Marina South, Singapore, that augment and extend existing records. I dated wood and charcoal samples from basal mangrove peat to produce 4 new SLIPs spanning ~9.5 – 9.2 ka BP, which provide the earliest record of post-LGM marine transgression in the region. Additionally, I reexamined existing SLIPs and used a Bayesian modelling approach to produce a revised Holocene sea-level record for Singapore.

The new record reveals a period of rapid sea level rise from ~9.5 ka BP (up to 16 mm/yr) before a significant inflection at ~9 ka BP where the rate of sea level change rate decreased to ~4 mm/yr by ~8 ka BP. Sea levels continued to rise at a relatively consistent rate of ~4 mm/yr between 8 ka and 6 ka BP, and modern sea levels were reached at ~6.9 ka BP. The revised record shows a minor inflection at ~7.5 ka BP, although at a much lower magnitude (~0.5 mm/yr) than previously proposed. Notably, I find no unequivocal evidence for meltwater pulses observed elsewhere at 8.2 ka and 7.5 ka, although the sea level record based only on compaction-free SLIPs hint of a ~2 m, ~100-year sea level jump at

~8.4 ka BP. Our results provide new constraints with possible implications for post-LGM human dispersal patterns from continental Asia to Australasia, as well as provide new early Holocene data for constraining glacio-isostatic adjustment (GIA) models and projections of future sea level for Singapore and the region.

4.1. Introduction

The early Holocene period provides a potential analogue for understanding future sea level change (Woodroffe and Murray-Wallace, 2012) given the potential for similar rates of sea level rise in the near future (Fleming et al., 1998; Törnqvist and Hijma, 2012). However, we still do not fully understand this critical time period due perhaps to the paucity of suitable palaeo-records, especially in far-field regions which experience minimal glacio-isostatic adjustment (Milne and Mitrovica, 2008). Increasing the number of high-quality early Holocene far-field records will improve understanding of eustatic sea level (Peltier, 2002; Horton et al., 2005; Stanford et al., 2011), and in turn ocean-ice interactions associated with melting of the Laurentide (Carlson et al., 2008), Cordilleran (e.g. Gregoire et al., 2012) and Antarctic Ice Sheets (e.g. Anderson et al., 2002; DeConto and Pollard, 2016; Kopp et al., 2017).

The early Holocene is marked by sea level rise of up to 60 m in magnitude occurring between 11,650 and 7000 cal year BP (Smith et al., 2011; Törnqvist and Hijma, 2012). This period is characterised by an uneven and possibly “stepped” rise in global sea level (e.g. Hori and Saito, 2007). The magnitude and timing of such sea level jumps were not uniform globally (e.g. Fleming et al., 1998; Lambeck and Chappell, 2001; Milne and Mitrovica, 2008; Törnqvist and Hijma, 2012). Further, global mean sea level is also affected by spatial variability caused by weight redistribution of the earth’s crust, as well as gravitational changes due to fluctuations in ice and water mass and volumes (Peltier, 1999; Mitrovica, 2001; Lambeck et al., 2014; Mitrovica et al., 2018). Regions closer to

the poles (or near-field areas) are delineated geographically as margins of large ice sheets at their maximum extent, where glacio-isostatic influence (i.e. crustal loading/unloading determined by ice mass) is dominant in determining relative sea levels. The reverse is true for far-field regions where hydro-isostatic contributions are more dominant (Fleming et al., 1998; Hanebuth et al., 2011).

Singapore is considered a 'far-field' location, away from major glaciation centres, where the influence from GIA process is relatively small in comparison to near-field locations, which makes it an ideal study area for palaeo-sea level change (e.g. Bradley et al., 2016). Coastal sedimentary systems are sensitive to sea level change (e.g. Zong et al., 2012; Fanget et al., 2014; Gao and Collins, 2014) and fluvio-deltaic sequences are commonly used to infer sea level as their flooding by sea level rise is recorded in the sedimentary sequence (Blum and Törnqvist, 2000; Hori and Saito, 2007; Nguyen et al., 2010; Wang et al., 2012) and thus provide good palaeo sea level archives (Törnqvist et al., 2004; Gao and Collins, 2014).

Prominent phases of accelerated sea level rise, termed Meltwater Pulses (MWP), were posited for the early Holocene (e.g. Bard et al., 2010; Lawrence et al., 2016), but they are hardly unequivocal. Small pulse-like intervals at ~8.5 ka BP (Hori and Saito, 2007; Liu et al., 2007; Tamura et al., 2009; Nguyen et al., 2010), potentially associated with the 8.2 ka climate event (e.g. Alley et al., 1997; Alley and Ágústsson, 2005), and at ~7.5 ka (Blanchon and Shaw, 1995; Yu et al., 2007; Bird et al., 2010) were observed. The 8.2 ka MWP is attributed

to the catastrophic collapse of the remnant Laurentide ice dam in Hudson Bay between ~8600 and 8400 yr ago (Clarke et al., 2004; Cronin et al., 2007; Hijma and Cohen, 2010), resulting in freshwater discharge from proglacial lakes Agassiz and Ojibway into the Labrador Sea ('8.2 ka event') (Alley et al., 1997; Barber et al., 1999; Törnqvist et al., 2004). To date, the sea level rise signature remains elusive especially in low latitude archives (Kendall et al., 2008; Hijma and Cohen, 2010) in capturing this ~150-year climate event (Alley et al., 1997; Mayewski et al., 2004; Cronin et al., 2007; Kobashi et al., 2007; Oster et al., 2017).

Recent sea-level studies in Singapore and the inland Sunda region lack adequate data from the early Holocene (i.e. 9000 - 11,000 yr BP) (Fig. 4.1), which is a critical timeframe for modelling future sea level projections (e.g. Törnqvist and Hijma, 2012; Woodroffe and Murray-Wallace, 2012). I thus hope to answer the following questions in this study:

1. When was the earliest evidence of post-LGM marine transgression in Singapore?
2. What were the rates of Holocene sea level change and how do they compare with other estimates from the region?
3. What is the true magnitude and timing of the 'inflection' detected by Bird et al (2007, 2010) based on the updated protocols and additional SLIPs?

Here I aim to produce new early Holocene sea-level index points (SLIPs) from a ~40 m continuous sediment core (MBH01B) obtained from the southern tip of mainland Singapore. In addition, I re-evaluate existing sea-level data from Singapore using standardized protocol (e.g., Hijma et al., 2015) on the production of SLIPs. I use Bayesian modeling to produce a revised sea-level history for Singapore and quantify magnitudes and rates of RSL change.

4.2. Previous sea-level studies in Singapore and Malaysia

There are few studies on early Holocene sea level in Singapore and Peninsular Malaysia (e.g. Biswas, 1976; Geyh et al., 1979; Tjia, 1996; Hesp et al., 1998; Hassan, 2002; Bird et al., 2007; Bird et al., 2010), with some disparity between datasets of different vintages and no high-resolution record for the early Holocene. The earliest sea level study by Biswas (1976) produced a coarse sea level plot by determining Quaternary high and lowstands using benthic planktonic foraminifera from cores taken off the east of Peninsular Malaysia and the northern Sabah coast. The Biswas (1976) study applied the basic premise that there is a depth-temperature (thermocline) relationship between foraminiferal abundance and water depth, and produced their record using contemporary conditions at set depths to establish a modern analog. He proposed the presence of 3 highstand occurrences (T1 - 3) at ~ 280 ka BP, 100 ka BP, and mid-Holocene, and 2 lowstands (R1 - 2) centred at ~180 ka BP and 11 ka BP. However, the chronology was only constrained by a single age of 13021 ± 288 cal yr BP, whereas other maxima and minima were probably inferred from known sea level records of the time. Although there's clear discrepancy

between his work and our current understanding of Quaternary sea level dynamics, an approximate age-marker (~13 ka BP) for the post-LGM marine transgression for the outer Straits of Malacca off the western Malay Peninsula was proposed and remains valid.

Geyh et al. (1979) obtained 33 ^{14}C -dated fossil mangrove deposits in the Straits of Malacca, and showed that relative sea level was at least 40 m below modern MSL between 36,000 and 10,000 BP. Holocene sea level then rose from -13 m to 5 m (one mid-Holocene highstand) above present Mean Sea Level (MSL) between ~8900 and ~4500 cal yr BP. The few and variable age/depth points for the early Holocene were inconclusive with large differences in depth as well as age reversals. In the mid-1990s Tjia (1996) compiled a database from a variety of published and unpublished index points for the Malay-Thai Peninsula. Using biogenic and geomorphological indicators, his sea-level record implies two Holocene highstands at 5000 and 2800 ^{14}C yr BP for Peninsular Malaysia (Tjia, 1996). In contrast his sea-level reconstruction for Thailand indicates potentially three mid-late Holocene highstands at 6000, 4000 and 2700 ^{14}C yr BP respectively (Tjia, 1996). Unfortunately I am unable to access the original data for the purpose of ^{14}C age calibration.

In Singapore the study by Hesp et al. (1998) showed a rapid transgressive sequence from 8567 ± 157 cal yr BP and a marine-highstand of approximately 2.5 m above MSL dated at 3811 ± 100 cal yr BP. Unfortunately, the

abovementioned studies considered but did not incorporate sediment compaction into their results.

An early 2000s study by Hassan (2002) obtained sediment cores from both the east (Kelang) and west (Kuantan) coast of Peninsular Malaysia, and produced 7 index points between 4500 – 6400 cal yr BP at elevations of ~1.2 – 3.4 m above MSL. Interestingly, coeval sample elevations obtained from west coast are on the order of ~3 times higher than the east coast. Further north, Horton et al. (2005) used regional index data from the Great Songkhla Lakes and other parts of the Malay-Thai Peninsula, which revealed an upward trend of Holocene relative sea level from a minimum of -22 m at 9700 - 9250 cal yr BP to a mid-Holocene highstand of 5 m at 4850 - 4450 cal yr BP. Data density was centred between 8000 and 6000 cal yr BP, with few data points for the early Holocene.

Although the region's sea-level history shows general consistency, the studies above reveal a number of discrepancies in the magnitude of the transgression and regression phases. This led Horton et al. (2005) to conclude that sea level histories for Sundaland must be considered separately due to the spatial variation across the region, and suggest it would more favourable to pursue localized, high-resolution sea-level records.

The most comprehensive sea level study for Singapore to date was produced by Bird et al. (2007). This study produced 50 sea level index points (SLIPs) and incorporated data from new samples and from Hesp et al. (1998), to produce a

sea level record spanning ~8.9 ka to near present. A later study by Bird et al., (2010) used the protocols established (Table 4.1) as well as redating 15 of the previous 50 samples from Bird et al. (2007). Bird et al. (2010) further augmented the expanded dataset with additional geochemical proxy data and 15 new shell and mangrove wood samples from the 30 m deep Geylang core (Bird et al., 2010). These studies used samples obtained from 9 locations in Singapore including 5 locations within the Kallang River Basin and 2 from the mangrove-dominated northwest coastline at Sungei Buloh and Lim Chu Kang.

Table 4.1. Indicative meanings defined by Bird et al (2007)

Tidal datum	Reference water level (m)	Uncertainty + (m)	Uncertainty – (m)	Explanation / Stratigraphic association with indicative meaning
HAT	-2.25	0.6	0.05	Horizon I (basal) Description: Initial sediments associated with earliest Holocene marine transgression; described as organic poor sands containing occasional and isolated fragments of woody debris, thin intercalated clay beds, or white stiff clayey sands. Indicative meaning: Basal Samples from this Horizon are assumed to have been deposited upon, or soon after, the arrival of HAT.
HAT to MHWS	-1.7	0.6	0.6	Horizon I (within Horizon) Indicative meaning: Samples deposited within Horizon I are assumed to have been deposited between HAT and MHWS and the uncertainty calculated as difference in elevation between these two tidal ranges.
MHWS (to MSL)	-1.15	0.63	0.05	Horizon II (basal) Description: Reduced, organic-rich sediments associated with the establishment of mangroves; described as sandy to clay-rich peat with organic material and plant macrofossil. Indicative meaning: Samples obtained at the base of this Horizon are assumed to have been deposited upon, or soon after, the arrival of MHWS at the location, and MSL is calculated on this basis, with the elevation uncertainty quoted as half the elevation difference between MHWS and MSL.
MHWS to MSL	-0.58	0.63	0.63	Horizon II (within Horizon) Indicative meaning: Samples deposited within Horizon II are assumed to have been deposited approximately at MSL with the uncertainty in elevation quoted as half the difference in elevation between MSL and MHWS above and

				<p>between MSL and mean low water (MLW) below.</p> <p>Note : Mangroves in the modern environment in Singapore extend from approximately MHWS to MSL (Bird et al., 2004a)</p>
MSL	0	0.63	0.63	<p>Horizon III (basal)</p> <p>Description: Marine muds associated with more permanent marine inundation, described as shallow marine shelly clays.</p> <p>Indicative meaning: Samples obtained at the base of this Horizon are assumed to have been deposited upon, or soon after, the arrival of MSL at the location, and the uncertainty associated with the elevation of MSL at the time of deposition calculated on the assumption that the samples were deposited between MSL and MLW.</p>
MSL or below	0	0.8	0.05	<p>Horizon III (within Horizon)</p> <p>Indicative meaning Samples obtained from within the shallow marine muds can only be said to have been deposited below MSL.</p>
MLW or above	0.8	0.4	0.4	<p>Horizon IV (top)</p> <p>Description: Samples are coral and other biogenic indicators found near or above current sea levels. Here it includes radiocarbon dates on large (>1 m diameter) coral heads presented by (Hesp et al., 1998) from Singapore and a single coral collected for this study in nearby Johor.</p> <p>Indicative meaning: I assume that the large coral heads dated for this study grew at mean low water (MLW) or below, with the uncertainty on this constraint on minimum MSL provided by the difference between MLWN and mean low water spring (MLWS) tides.</p> <p>Note : Small coral heads currently grow up to about mean low water neap (MWLN) tide levels on reef flats around Singapore (Hilton and Loke Ming, 1999).</p>

The sea level record by Bird et al. (2010) was constructed as a generalised trend through data within the 2σ uncertainty of 88% of dates. The results suggest that Holocene marine clays at the Geylang palaeovalley began accumulating at -15 m (MSL) at approximately 8900 cal BP and initially accumulated very rapidly at 0.88 cm/yr until 7900 cal BP (-7.77 m MSL). Sea level rise then slowed to 0.26 cm/year until 6710 cal BP (-4.69 m MSL) (Bird et al., 2010), ultimately indicating an inflection in the relative sea level rise centred upon 7600 cal yr BP. The data imply that Holocene sea level rise ended with a mid-Holocene marine highstand of approximately 2.5 m above MSL through the period of ~ 6000 - 3000 years BP before regressing to modern sea levels.

The dataset in Bird et al. (2007) was broken into sets of samples within selected depth ranges to isolate sections of the record before, during and after the apparent inflection to test its validity. OxCal was used to calculate the probability density distributions for these populations, which statistically supported that SLR rate slowed or even stopped during the period centred upon 7.5 ka BP.

Figure. 4.1. Data range of sea level index points from recent studies in the region. Bold lines represent higher data density and dashed lines represent more dispersed datapoints. Grey rectangle shows poorly-studied time period between 11 ka and 9 ka BP.

4.3. Study area

Singapore is a small island state situated near the centre of the Sundaland (Fig. 4.2). This continental shelf was largely exposed when sea levels were ~ 120 m below MSL (Siddall et al., 2003; Hanebuth et al., 2009) during the Last Glacial Maximum (LGM) approximately 20,000 years ago.

Figure 4.2. Location of Singapore (In red rectangle) in relation to Sundaland (demarcated by -120 m isobath as brown region) which was fully exposed during the Last Glacial Maximum.

Distal from major plate convergence/subduction zones, Singapore has been considered tectonically stable (Tjia, 1996), though recent evidence suggests a low down-warping rate of a rate of 0.06 to 0.19 mm/year since the beginning of the Last Interglacial (Bird et al., 2006).

Singapore can be considered meso-tidal, with a tidal range of 2.4 m during spring tides and 1 m during neap tides (Fig. 4.3) (Horton et al., 2005; Alqahtani et al., 2015). These tide levels are measured to a fixed Chart Datum (CD), established in 1986 to be 1.637 m below the Precise Levelling Datum (PLD) or Mean Sea Level (MSL).

MTL is defined and calculated here as the average of mean high water (MHW) and mean low water (MLW) in both spring and neap conditions (Woodworth, 2016), and ascertained to be 1.6 m above CD. Seasonal variability is observed in local water levels, with lower than the yearly average water levels in April to September due to prevailing southwest winds, and higher levels in November and January related to the northeast monsoon (Tkalich et al., 2013).

Figure. 4.3. Tide levels for Singapore. Adapted from Wong (1992) and Singapore Tide Tables maintained by the Maritime and Port Authority of Singapore (MPA).

4.4. Method

Broadly, I will recalibrate and standardize all SLIPs from Bird et al. (2007, 2010) and this study from core MSBH01B using HOLSEA protocols as stipulated in Hijma et al. (2015) as well as in various other database papers (Engelhart et al., 2015; Baranskaya et al., 2018; García-Artola et al., 2018). The indicative meanings of each SLIP will be revised to incorporate as comprehensively as possible associated uncertainties and errors. All radiocarbon dates will also be recalibrated using the latest radiocarbon record (i.e. IntCal 13) (Reimer et al., 2013). Finally all elevation points were decompacted using the method proposed by Bird et al. (2004).

4.4.1. Collection and analysis of new early Holocene sediments

The rapid urbanisation of Singapore has indirectly benefitted this study, providing a tremendous amount of borehole data to better understand the geology of Singapore (Chua et al., 2016). Analysis of Rochor Member (Holocene marine clay) thickness and its distribution directed us to viable coring locations as shown in Fig. 4.4. Intensive land reclamation projects on the coastlines of Singapore in recent decades (Bird et al., 2004a) also meant that once shallow marine environments can now be accessed and cored by terrestrial boring methods. The Marina South area is a newly-reclaimed area and geological modelling of the area revealed a possible low-energy broad foreshore with a gentle gradient (see Chapter 3).

Figure 4.4. Composite map showing location of study area (Kallang River Basin) and core locations. Inset map of Singapore shows extensive late Quaternary deposits at the south of Singapore (yellow regions). Main map shows location of Bird et al's (2007, 2010) (red star) Geylang core and MSBH01B (red square) from this study.

Sediment cores from Bird et al., (2007, 2010) were obtained either manually (Livingstone piston corer), or by commercial hydraulic piston coring. For excavations at construction sites, samples were obtained by pushing PVC tubes horizontally into pit/trench faces. He also added selected sea level index points from cores obtained from Pasir Panjang and coral from P. Semakau (Hesp et al., 1998).

Depending on location and excavation type, all elevations were determined by referencing to national benchmarks surveyed and maintained by the Singapore Land Authority (SLA), or in rare cases by differential GPS to a horizontal accuracy of ± 0.5 m. Elevations are reported relative to the land survey datum (mean sea level = 0 m) defined by the SLA, which is 1.652 m above the Chart Datum used by the Admiralty on navigation charts for Singapore. Elevation corrections for autocompaction was done based on the methodology of Bird et al. (2004b) which entails comparing the dry bulk density of compacted and modern samples along with the organic content and grain-size distribution, with error given by the difference between the measured elevation and the maximum calculated correction.

I obtained a continuous ~38.5 m long core (up to ~50 m below MSL) (MS-BH01B) from 1.27266° N, 103.8653°E at Marina South (Fig. 4.4) on 11 March 2016 using a rotary drilling machine coupled with a condition-appropriate combination of hydraulic piston and Selby thin-walled coring methods. Elevation was obtained

through GPS (Global Positioning System) by a registered surveyor and calibrated with reference to nearby national Precise Levelling Benchmarks maintained by the Singapore Land Authority (SLA).

The core is subsampled at 1-cm resolution where an aluminium U-channel is used to obtain accurate and consistent sediment volumes for bulk density values. Particle-size analysis (PSA) of the sediment samples is ascertained by an initial two-stage pretreatment of approximately 10 g of sample with 10 v/v% hydrochloric acid (HCl) and 15 v/v% hydrogen peroxide (H₂O₂) to remove carbonate, organic matter and disassociate clays. Subsequently, I performed PSA using the Malvern Mastersizer 2000 where samples were first sonicated for 60 seconds and three replicates averaged (Blott et al., 2004; Ryżak and Bieganski, 2011). Organic and carbonate measurements were done using Heiri et al. (2001)'s method for loss-on-ignition (LOI). This involves heating the sample to different temperatures (i.e. 105 °C, 550 °C and 950 °C) which gives the weight percentage of water content, organic matter content and carbonate content, respectively.

Total organic carbon (TOC) results were obtained at 2-cm resolution. These sediment samples were milled and acidified (HCl conc. 5%) before centrifuging (at least 4 washes) and dried at 60 °C. ~15 mg of sample was weighed and placed in tin capsules before loading onto an autosampling plate. Carbon abundances were determined using an elemental analyzer (ECS 4010 CHNSO Analyzer; Costech Analytical Technologies INC, Valencia, CA, USA) fitted with a Costech

Zero Blank Autosampler coupled via a ConFloIV to a Thermo Scientific Delta VPLUS using Continuous-Flow Isotope Ratio Mass Spectrometry (EA-IRMS) at the Advanced Analytical Centre housed in James Cook University, Cairns, Australia.

Five samples were taken from the peaty unit (Unit IV) believed to be Holocene mangrove peat. The sample was pretreated by first adding Sodium pyrophosphate ($\text{Na}_4\text{P}_2\text{O}_7$) which removes clay by acting as a deflocculent. Subsequent centrifuging removes clay particles which remain in suspension. The samples were then washed with Potassium hydroxide (KOH) to remove 'humic acids' by bringing them into solution. Samples are macro and fine-sieved and washed with HCl to remove carbonates. Acetolysis was performed to remove polysaccharides and helps increase the contrast of features on pollen grains. Mineral fragments were then removed from organic particles through heavy liquid separation using Sodium polytungstate, $\text{Na}_6(\text{H}_2\text{W}_{12}\text{O}_{40})$, at a density of 2.0. Finally, samples were mounted on slides using glycerol before identifying pollen grains under a microscope.

4.4.2 Radiocarbon dating of Holocene sediments

A chronological framework was developed using 23 radiocarbon samples that were selected based on amount of material and preservation position within the stratigraphy (e.g. situated in undisturbed as opposed to bioturbated unit). Articulated bivalves (observed through CT-scanning) were also preferentially selected over gastropods. Each sample was cleaned with DI water and sonicated

at least 3 times to remove sediment and other impurities. All samples were sent to Rafter Radiocarbon Laboratory, GNS Science in New Zealand for AMS ^{14}C dating. I only considered the lowest 4 samples for the sea level record as they are samples from basal mangrove peat which provide good intertidal boundaries to constrain elevation. All samples were calibrated using IntCal13 (Reimer et al., 2013) using the online version of Calib 7.10 (Stuiver, et al., 2018).

Great care was taken to identify dateable radiocarbon samples to produce credible SLIPs. I selected four basal peat samples atop an uncompressible pre-transgression layer at the depth of ~19.4 m below MSL. Four macrofossil wood/charcoal samples were dated to obtain 4 age-dates to produce SLIPs (Table 4.3). The samples are obtained from strata without evidence of bioturbation or reworking, and are wood and charcoal samples which resolves potential reservoir effect problems

4.4.3. Producing sea-level index points (SLIPs)

Past relative sea-levels can be reconstructed from various environmental and biological indicators, or sea-level proxies, such as coral reefs, salt marsh fauna and flora, mangroves etc (e.g. Gehrels and Anderson Jr, 2014; Kemp et al., 2015; Hibbert et al., 2016; Khan et al., 2017; Johnson et al., 2018). The relationship of these proxies to the relative sea level is defined by its “indicative meaning”, which comprise of two components – the indicative range which is the vertical range of the proxy’s relationship with tide levels (set at 2σ range), and the reference water level or central tendency of the indicative range (e.g.

Baranskaya et al., 2018; García-Artola et al., 2018; Horton et al., 2018; Johnson et al., 2018).

The former refers to the relationship the coastal sample has with the local environment in which it accumulated to a contemporaneous reference tide level with an associated error range (van de Plassche, 1986; Horton et al., 2000). The latter is a water level in which the sample assemblage is assigned (e.g. at MTL). Such palaeotidal associations will enable us to produce a sea level index point (SLIP) and associated errors, basically a discrete reconstruction of RSL in space and time (Van De Plassche et al., 2014), to reconstruct past sea levels plotted against time and depth (Horton et al., 2000; Edwards and Horton, 2006).

I reviewed all SLIPs previously obtained in Singapore, incorporating the 4 new index points from this study and recalibrated them following the methodology of International Geoscience Programme (IGCP) projects 61, 200, 495 and 588 (e.g. Preuss, 1979; Gehrels and Long, 2007; Horton and Shennan, 2009; Switzer et al., 2012; Van De Plassche et al., 2014; Hijma et al., 2015).

The relative sea level for each dated proxy can be estimated using this following equation (Shennan and Horton, 2002):

$$RSL_p = E_p - RWL_p \quad (1)$$

where E_p refers to the elevation of indicator, and RWL_p refers to the reference water level of proxy p. Both are expressed relative to the same datum (MTL).

I selected only plant macrofossil dates and omitted coral samples from Bird et al. (2007) and Bird et al. (2010) to eliminate potential error caused by reservoir effects (Southon et al., 2002). The indicative meanings defined by Bird et al. (2007) are also recalibrated to encompass the possible depositional range of each proxy and all associated uncertainties (i.e. intertidal mangrove peats have an indicative meaning of MTL – HAT).

I left out coral data from Hesp et al. (1998) where GPS techniques were not as sophisticated and surveys were instead done to determine sea level based on correlating tide timings. Removing carbonate samples also eliminates error associated with reservoir effects for Singapore waters which I know little about due to a paucity of ΔR values (Southon et al., 2002).

Table 4.2. Definition of the indicative meanings used to develop the Singapore database. HAT: highest astronomical tide. MTL: mean tide level. MLWN: mean low water neap.

Sample Type	Evidence	Reference water level	Indicative range
Mangrove environment (intertidal)	Mangrove pollen	MTL-HAT	MTL-HAT/2
Marine Limiting	Plant macrofossils within sub-laminated marine muds	MLWN or below	Below MTL
	Shells in marine muds		
	In-situ corals		

4.4.4. Accounting for Compaction

Holocene sediments can undergo significant post-depositional compression, which affects the vertical accuracy of sea level reconstructions (e.g. Gehrels, 1999; Massey et al., 2006; Horton and Shennan, 2009). This process, known as autocompaction, is further exacerbated in the case of fine-grained and/or organic-rich sediments (e.g. Törnqvist et al., 2008), where highly organic peats can experience up to 90 % in volume reduction (Brain, 2015). This problem can be circumvented through judicious selection of samples from basal sediments, which are considered relatively compaction-free, especially when sitting atop an incompressible palaeostrata. In instances where SLIPs are obtained from a relatively thick peat unit, several geotechnical methods are currently available to quantify and ultimately decompact sediments (e.g. Pizzuto and Schwendt, 1997; Paul and Barras, 1998; Bird et al., 2004b; Massey et al., 2006).

I used the decompaction model of Bird et al. (2004) in this study because it was developed and calibrated for sediments from Singapore that share similar sedimentological properties to the newly collected core. In short, this method computes compaction rates by comparison of the dry bulk density, total organic content (TOC) and grain-size parameters of a compacted sample with the uncompacted dry bulk density of modern sediment samples with the same TOC and grain-size characteristics.

The equation used is displayed below:

$$\ln(\text{DBD}) = 0.316 + \{[(0.0032 \times (F < 63 \mu\text{m})) \times \ln(F < 63 \mu\text{m})] + [(0.0665 \times (\text{TOC})) \times 0.5 \times \ln(\text{TOC})]\} \quad (2)$$

where DBD is the initial uncompacted dry bulk density of the intertidal sediment unit, $F < 63 \mu\text{m}$ is the summated silt and clay percentage of the sample, and TOC is the total organic content of the sample expressed as a percentage of the sample. The correlation between DBD and $F < 63 \mu\text{m}$, TOC is high ($r^2=0.94$) between the DBD of modern intertidal sediments and the sediment properties of compacted sediments (Bird et al., 2004b).

I obtained precise measurements of $F < 63 \mu\text{m}$ and TOC at 2-cm resolution to decompact every concomitant 2cm of sediment for calculation of decompaction values. To correct for autocompaction, I calculate the original pre-compacted DBD of that sample and all underlying samples, where I can easily derive the volume (or length as I have a fixed base) as I have measured its mass. Thus I summate all the underlying original length and add to the basal depth to determine the pre-compaction elevation of a given sample.

4.5. Results

4.5.1. Stratigraphy and sedimentology of core MSBH01B

The top ~12 m of sediment was identified as modern fill material and removed, while samples from 7.52 m below MSL were retained. Recovery of sediment was at least 90 % with little slump loss or compaction. I determined that the topmost 11.9 m of sediment, which represents the depth of ~7.5 m to 19.4 m below MSL, are Holocene deposits as they sit atop a thick unit of 'stiff clay', interpreted as sub-aerially exposed, desiccated MIS 5 marine clay (Bird et al., 2007; DSTA, 2009). All depths recorded in this study will henceforth be relative to MSL, unless otherwise stated.

The sedimentology of the Holocene sediments is fairly uncomplicated, with three distinct units (Units I, III, IV), a gradational transitional unit (Unit II), and the pre-Holocene land surface (Unit V) (Fig. 4.5). Unit I (-7.52 m to -11.176 m) comprises poorly-sorted, chaotic very coarse silt-medium silt with frequent shell and coral fragments. Visual logging reveal unbioturbated sediments without visible evidence of reworking or remobilisation of material.

Figure 4.5. Sedimentological log of Holocene portion of core MSBH01B

Unit I is underlain by a transitional bedding unit, Unit II (-11.18 m to -12.53 m) that consists of poorly-sorted medium-fine silt with less common occurrence of shell fragments and near absence of coral fragments. Underlying Unit II is Unit III (-12.53 m to -18.73 m), a largely homogenous, non-laminated marine clay ranging from greenish grey (10GY 4/1) to grey (5G 5/1) with occasional shells and organic streaks. Unit IV (-18.73 m to -19.39 m) is an organic-rich dark brown peaty (mangrove) facies dominated by medium-fine silt facies with macrofossils (wood, bark and root pieces) found abundantly throughout the unit. Unit V (below -19.39 m) is a highly-oxidised, weathered, dense stiff clay unit and is interpreted as palaeosol formed after Last Interglacial marine clays were subaerially exposed. It is characterised by high dry bulk density, and low organic and inorganic carbon content, with values decreasing downcore. This paper focuses on early Holocene sea level and hence Unit V (MIS 5 desiccated marine clay) will not be discussed further.

4.5.2. Radiocarbon ages

5 samples spanning the peaty unit (Unit IV) in core MSBH01B were processed and analysed palynologically to verify the presence of coastal mangrove pollen, essentially dominated by *Rhizophora* and *Bruguiera spp* (Fig. 4.6). This puts the samples within the intertidal zone which minimises vertical uncertainties ameliorated by the mesotidal conditions in Singapore.

Figure 4.6. Linescan image of core segment OD3 with brown marine muds (Unit III), a highly-organic peaty unit (Unit IV) followed by pre-transgressive palaeosol at the bottom (Unit V). Radiocarbon samples obtained from top and bottom contacts are shown as red circles and samples for pollen analysis shown as yellow circles. Sample photographs of pollen from common mangrove species were found abundantly in all five samples and are shown on the right.

The 4 radiocarbon samples selected for producing new sea level index points are presented in Table 4.3 below.

Sample ID	Elevation (m below MSL)	Material	Lab code (NZA)	¹⁴ C age (CRA)	CRA error	Calibrated age (IntCal13)	Age 2σ Uncertainty +(cal a)	Age 2σ Uncertainty - (cal a)	Compaction correction (if any)	RSL (m)	RSL 2σ Uncertainty + (m)	RSL 2σ Uncertainty - (m)
113_OD3_9- 10	18.764	Charcoal	64445	8278	39	9282	151	130	1.732	-18.12	1.49	1.44
116_OD3_25- 26	18.924	Wood	63748	8208	34	9186	104	105	1.304	-18.708	1.38	1.33
124_OD3_66- 68	19.334	Charcoal	64446	8372	39	9433	112	71	0.179	-20.243	1.22	1.16
126_OD3_72- 74	19.394	Wood	63749	8421	35	9458	58	64	0	-20.482	1.22	1.16

Table 4.3. Radiocarbon samples obtained from basal peat sediment situated above pre-transgressive Holocene land surface. Only these data points are used in this study for producing sea level index points.

4.5.3. Recalibrated sea level index points

I present the new recalibrated dataset using data from Bird et al. (2007) and this study (Fig. 4.7). All dates have been recalibrated using IntCal13 and MarineCal13 (Reimer et al., 2013). The key difference between the 2 plots from this study and Bird et al (2010) is the magnitude of vertical uncertainty between the two datasets, as I assume all intertidal mangrove samples to potentially originate from anywhere within the habitation range of mangrove colonies (i.e. MTL – HAT).

Figure 4.7. Age-depth plot showing revised Sea Level Index Points (Green boxes) incorporating data from Bird et al. (2010) and 4 new early Holocene SLIPs from this study. Coral data from Hesp et al. (1998) were omitted from this study to eliminate elevation issues and potential reservoir effects. Blue Ts represent marine limiting points from the Geylang Core and red boxes are new SLIPs from MSBH01B.

The earliest evidence of Holocene marine transgression for Singapore is a piece of basal mangrove wood fragment dated at ~9.5 ka BP at the depth of -19.4 m MSL. RSL which was calculated to be -20.5 m below MSL with upper and lower vertical errors of 1.2 m and 1.16 m respectively. Data density is highest from 9 ka – 6 ka BP, reaching potentially a maximum elevation of ~5 m above modern levels 6000 years ago. I do not find suitable samples for the period between 2 ka and 6 ka BP, while 4 SLIPs found in inland peats constrain the last two millennia. I observe that 3 of the youngest samples lie beneath modern sea levels.

4.5.4. Compaction correction for intertidal mangrove peat

I corrected for compaction using Equation 2 where I calculated the original uncompact thickness of a given 2 cm segment within the peaty organic unit (Unit IV) in the sediment core. *OD3 10*, *OD3 26* and *OD3 66* (in bold) represent sample IDs and hence location of 3 samples, while the last sample is a basal samples at the bottom of *OD3 70*. The results are shown in Table 4.4 below.

Table 4.4. Results used for compaction corrections for intertidal peat samples. Results in bold show location of radiocarbon samples used to produce SLIPs.

Sample ID	Dry Bulk Density (g/cm³)	F<63um (%)	Total Organic Carbon (TOC%)	Original Length (cm)	Compression %
OD3 8	1.106862745	99.4382	3.379	8.1	303.4
OD3 10	0.990522876	97.3037	3.419	7.0	248.3
OD3 12	1.145424837	95.7032	4.106	8.1	307.2
OD3 14	0.783333333	99.1424	7.795	7.2	258.4
OD3 16	0.741176471	98.9174	6.561	6.4	217.8
OD3 18	0.802941176	98.9551	7.246	7.1	256.4
OD3 20	1.042156863	98.8321	6.770	9.0	350.8
OD3 22	0.66372549	99.4156	7.301	6.0	197.9
OD3 24	0.997712418	98.0714	5.654	8.0	302.2
OD3 26	0.837908497	97.4289	6.581	7.0	250.2

OD3 28	0.784640523	98.8461	7.042	6.9	244.2
OD3 30	0.816666667	99.0961	5.558	6.7	233.6
OD3 32	0.887254902	98.8909	5.508	7.2	260.2
OD3 34	0.881699346	98.6751	5.698	7.2	260.1
OD3 36	0.959150327	99.0021	4.870	7.5	277.1
OD3 38	0.941176471	98.5017	5.873	7.7	286.7
OD3 40	0.704575163	97.8728	5.793	5.7	185.1
OD3 42	0.560457516	99.0375	5.893	4.7	132.7
OD3 44	0.910130719	97.7224	6.076	7.5	272.7
OD3 46	0.971568627	92.1901	5.026	6.8	241.3
OD3 48	0.932352941	96.1946	6.015	7.4	270.4
OD3 50	0.900980392	98.7239	4.983	7.1	254.6
OD3 52	1.188888889	95.7373	4.481	8.6	331.7
OD3 54	1.17875817	98.3161	5.236	9.3	366.9
OD3 56	1.179084967	94.668	5.236	8.8	337.7
OD3 58	1.179084967	94.668	5.236	8.8	337.7
OD3 60	1.179084967	94.668	5.236	8.8	337.7
OD3 62	1.179411765	97.2478	1.224	7.2	261.6
OD3 64	1.54248366	97.6429	1.460	9.7	383.6
OD3 66	1.214705882	97.4583	1.955	7.8	291.9
OD3 68	1.168627451	94.9024	0.496	6.6	227.6
OD3 70	1.570915033	97.8149	0.842	9.5	374.3

4.5.5. A new Holocene sea level record for Singapore

I present the revised Singapore sea level record based on updated protocols and methodology, and extend the record to the earliest Holocene with four new index points from transgressive basal peat macrofossils from an offshore shallow marine environment (Fig. 4.8). The relatively uncomplicated sequence of late Quaternary sediments vis-à-vis nearshore stratigraphy is an important factor in our confidence in producing SLIPs for Holocene sea level change in Singapore (Bird et al., 2007).

This new sea level record is derived from 62 SLIPs and 15 marine limiting points obtained from an area ~20 km². All radiocarbon samples found in intertidal mangrove peat are wood or charcoal fragments, which contribute to better elevation and chronological accuracy (e.g. no reservoir corrections) (Woodroffe et al., 2016; Punwong et al., 2018).

The use of more conservative indicative meanings (Table 4.2) and the incorporation of more uncertainties (e.g. associated to levelling, equipment compaction etc) translated to broader uncertainty envelopes for each data point.

Figure. 4.8. (A) Relative sea level predictions for Singapore from the early Holocene to present generated by fitting the EIV-IGP model (Cahill et al., 2015a; Cahill et al., 2015b). Shading denotes 68% (grey) and 95% (blue) credible intervals for the posterior mean fit. (B) Rate of sea-level change in Singapore. Shading denotes 68% and 95% credible intervals for the posterior mean of the rate process. The average rate for each phase of the reconstruction is given (in mm/yr) with a 95% credible interval.

The sea level record is well constrained between 9.5 ka and 6 ka BP due to the high number of SLIPs, but due to the dearth of reliable mid-late Holocene highstand samples the RSL is potentially between 5 m and -3 m from 6 – 2 ka BP. 4 SLIPs constraining the late-Holocene RSL tightened the chronology toward the common era, albeit with the record lower than modern MTL due possibly to underestimated compaction from the intercalated peaty unit at this elevation (Bird et al., 2010).

Early Holocene sea level rise (9.5 ka – 9.2 ka BP) for Singapore was rapid, rising from a depth of -20 m up to -16 m within ~300 years at an average rate of >15 mm/yr. This segment is constrained mainly by the 4 basal peat samples at low elevations in MSBH01B. This period is followed by an abrupt slowdown that occurred following an inflection point at ~9 ka BP. The average rate of SLR decreased markedly over ~1200 years from the maxima of ~16 mm/yr to 5 mm/yr at ~8 ka BP. Though slower in rate sea level continued to rise during this timeframe increasing from -15 m to -4 m MTL.

A period of consistent sea level rise at an average rate of ~5 mm/yr was observed between 8 ka and 6 ka BP, with little internal variability. Relative sea level for Singapore reached modern levels at approximately 6.7 ka BP.

There is an apparent broad and minor peak in the rate of sea level change centred at approximately ~7.3 ka BP but this cannot be confirmed statistically.

The presence of an inflection point centred at 7.6 ka BP (Bird et al., 2010) may still exist but that cannot be verified using the existing data.

The mid-late Holocene highstand is particularly poorly constrained due to few credible SLIPs hence the broad uncertainty bands, and thus maximum highstand elevation could potentially, but highly unlikely to, reach 10 m above modern levels based on the model. If the mean value record is taken it shows sea level rising to a maximum elevation of ~3 m at ~5.2 ka BP before tapering gradually to modern levels possibly by 2 ka BP.

4.6. Discussion

I present a revised sea level record for Singapore based on recalibrated SLIPs, and extended the record to the early Holocene which provided the first evidence of post-LGM marine transgression for Singapore commencing at ~9.5 ka BP. The new record incorporates new and recalibrated data and shows the first observation of rapid sea level during the early Holocene before a slowdown at approximate 9 ka BP. Post 9 ka sea levels subsequently came to a slowstand between 8 ka and 6 ka BP at a relatively consistent rate of 5 mm/yr. Notably, the revised record shows a less pronounced inflection in sea level change as proposed by Bird et al (2007, 2010) and others (Liu et al., 2004; Yu et al., 2007). The rate of sea level change showed a relatively minor inflection at the same timeframe (~7.5 ka BP), although the magnitude of change is much lower (~0.5 mm/yr). I acknowledge however that the inflection could exist but is not supported by existing data in our revised sea level record. There appears to be

three phases in sea level change for Singapore during the Holocene, namely a rapid rise and abrupt fall in change rate during the earliest Holocene (9.5 ka – 8.5 ka BP), followed by a slow and relatively constant rate of sea level rise in the early-mid Holocene (8.5 ka – 7 ka BP), followed finally by a highstand and regression phase during the mid to late Holocene (7 ka BP to present).

4.6.1. Earliest Holocene (9.5 ka – 8.5 ka BP)

Rapid early Holocene sea level rise in the form of meltwater pulses have been postulated and supported at various sites globally, but the magnitude, timing and global effects are still debated (e.g. Fairbanks, 1989; Blanchon and Shaw, 1995; Bard et al., 1996; Turney and Brown, 2007; Bard et al., 2010; Cronin, 2012; Hodgson et al., 2016). To our best knowledge, the rapid rise and abrupt fall in sea level change rates in Singapore sea level spanning 9.5 ka to 9.0 ka BP is only congruent with synthesised sea level data augmented by sediment records within the South China Sea. Using data from the Yellow River delta, Liu et al. (2004) proposed the existence of minor pulses termed MWP-1c and 1d. The former is a rapid SLR from ~30 – 15 m from 9.5 ka – 9 ka BP while the latter gentler pulse from -10 m to modern sea levels from ~8 ka – 7 ka BP. An accelerated rise of RSL was also recorded from sediments in the Pearl River Delta (PRD), where sea level rose from 16.4 ± 6.1 mm/yr around 10.5 ka BP to maximum values of 33.0 ± 7.1 mm/yr around 9.5 ka BP before slowing down to 8.8 ± 1.9 mm/yr around 8.5 ka BP (Xiong et al., 2018). Though the timing potentially matches the trends observed for Singapore these rates appear

remarkable given that the SLIPs have been corrected for tectonic subsidence and post-depositional compaction.

Sea level data from the west coast of South Korea also show good agreement with Singapore, where RSL rose rapidly from -28 m to -8 m between 9.8 ka and 8.4 ka BP at a rate of ~14 mm/yr (Song et al., 2018), very close to RSL for Singapore rising from -20 m to -8 m from 9.5 ka to 8.4 ka BP at rates of up to 16 mm/yr. Depth comparisons also show similarities across these sites. Similar trends are observed from various locations within the Malay-Thai Peninsula where Holocene relative sea level from a minimum of -22 m at 9.7 ka – 9.25 ka BP, gradually increasing without internal fluctuations to ~-10 m at 8.5 ka BP (Horton et al., 2005).

Relative sea level of the Pearl River Delta reached 23.4 ± 1.1 m at 9.5 ka BP (Xiong et al., 2018), congruent with earlier work by Zong et al. (2012) showing RSL rising from -30 m in 10 ka BP to -10 m to -15 m by 8.5 ka BP. Records from the Caribbean showed highest rates of RSL change during the early Holocene, with a maximum of 10.9 ± 0.6 m/ka in Suriname and Guyana and minimum of 7.4 ± 0.7 m/ka in south Florida from 12 ka to 8 ka BP (Khan et al., 2017). Similar early Holocene sea level jumps were proposed elsewhere (Hori and Saito, 2007; Turney and Brown, 2007; Hodgson et al., 2016), with expected spatial and temporal variability due to differing mantle viscosity and response to loading (Peltier, 1999; Mitrovica, 2001; Khan et al., 2015; Milne, 2015).

The abrupt shift in rate of sea level change at ~9 ka BP could be the first support for a possible catastrophic inundation of the Singapore Straits caused by sudden breaching of the Singapore 'sills'. Bird et al. (2006) looked at modern bathymetric maps and observed that sills between 20 m and 30 m water depth exist at both the eastern and western bounds of the Singapore. These sills may have effectively prevented the Singapore Straits from marine intrusion and inundation from the South China Sea and Straits of Malacca respectively during the Holocene. A potentially catastrophic breaching of the sills at ~9.5 ka BP and associated initial erosion and downcutting, coincident with MWP 1-c, could conceivably have resulted in the pronounced surge and fall in rate of SLR.

4.6.2. Early-mid Holocene (8.5 ka – 7 ka)

RSL continued to rise during this timeframe but at a slower rate from a high of ~16 mm/yr, ultimately reaching a slowdown of between 7 ka and 8 ka BP at a rise rate of ~4 mm/yr with little variability. No substantial pulses or fluctuations in sea level are noted during this time frame, which is noteworthy because 2 sea level anomalies have been posited to have occurred at 8.2 ka and 7.6 ka BP. However, such pulses are hard to detect set against a backdrop of global sea level rise coincident with the final phase of North American deglaciation at ~6.7 - 7 ka BP (Smith et al., 2011; Ullman et al., 2016). Detection is further hindered by the short-lived nature of these events (e.g. in the order of 100 - 200 years for the 8.2 ka event) (Matero et al., 2017).

The first meltwater pulse is associated with the 8.2 climate anomaly, postulated to be caused by the catastrophic melting and collapse of the ice dam separating freshwater from proglacial lakes Agassiz and Ojibway from the Labrador Sea and the North Atlantic (Barber et al., 1999; Alley and Ágústsson, 2005), with recent modelling attributing an additional meltwater input from the collapsing ice saddle that linked domes over Hudson Bay (Matero et al., 2017). The freshwater discharge was modelled to contribute to a >1 m sea level pulse for farfield regions, including Singapore (Kendall et al., 2008), and could have occurred between ~8600 to 8400 yr ago (Clarke et al., 2004; Cronin et al., 2007; Hijma and Cohen, 2010), although models identified a possible meltwater pulse associated with deglacial collapse as early as 8.8 ka BP (Gregoire et al., 2012). Evidence for the pulse and related modelling have been done for both nearfield (Törnqvist et al., 2004; Cronin et al., 2007; Hillaire-Marcel et al., 2007) and farfield regions (e.g. Hori and Saito, 2007; Liu et al., 2007; Tamura et al., 2009; Nguyen et al., 2010; Tjallingii et al., 2014), although the precise timing and magnitude are not well resolved.

It is critical to note that locations proximal to Singapore such as Cambodia, Vietnam, and Southern China recorded episodes of rapid sea level rise that are perhaps coeval with the Hudson Bay discharge. An approximate 5 m abrupt sea level rise was detected at ~8.5 ka BP at the Cambodian lowlands (Tamura et al., 2009) while at a lower resolution an offset of RSL records at the Southern Vietnam shelf suggest rapid sea level rise from (~-28 m to -10 m), between 9.0 ka and 8.2 ka BP (Tjallingii et al., 2014). A 2 m rapid rise in RSL at ~8.6 ka BP was

observed in sediment cores from the southern Yangtze delta plain, China (Wang et al., 2012) along with evidence from Song Hong (Vietnam), Changjiang (China) and Kiso (Japan) delta systems inferring rapid sea level rise at ~9 ka – 8.5 ka BP coincident with a concomitant sharp decrease in sedimentation rate (Hori and Saito, 2007).

However, the sea level fingerprint has not been detected in this or other nearby studies (Bird et al., 2007; Bird et al., 2010; Zong et al., 2012; Liu et al., 2018; Xiong et al., 2018), although the central reason could be the dearth of suitable dates for this period of time. The 8.2 ka sea level rise is not supported either by coral records in Barbados, Tahiti or the Philippines (Fairbanks, 1989; Bard et al., 1996; Peltier and Fairbanks, 2006; Siringan et al., 2016), although arguably it could be within noise or due to localised phenomena (Lambeck et al., 2014).

A second pulse at 7.5 ka, preceded by a slow or stillstand, was postulated and observed in sites globally (Blanchon and Shaw, 1995; Blanchon et al., 2002; Yu et al., 2007; Tamura et al., 2009; Bird et al., 2010), and asserted to be the driver for worldwide delta initiation during the mid-Holocene (e.g. Stanley and Warne, 1994; Tanabe, 2003; Hanebuth et al., 2012; Pennington et al., 2017). Evidence of a stillstand from 8 ka - 7.5 ka BP followed by rapid sea level rise at 7.5 – 7 ka BP was found from mangrove peat in the Cambodian lowlands (Tamura et al., 2009). A similar ‘inflection’ at ~7.8 ka BP was also presented based on sediment cores from west coast of South Korea (Song et al., 2018).

The revised sea level record for Singapore shows a more constant and gradual sea level rise from 8.5 ka – 7 ka BP, and is congruent with RSL change records from the several sites in the northern South China Sea. Zong et al. (2012) reported a gradual and slightly decelerating sea level rise from 8 ka to 7 ka BP, where it reached modern sea levels, for the Pearl River delta. More recent sea level records from the same region showed similar trends of sea level rise rate decelerating gradually from 8.8 ± 1.9 mm/yr around 8.5 ka BP to 1.7 ± 1.3 mm/yr around 7.5 ka BP (Xiong et al., 2018). The difference of ~ 7 mm/yr between SLR rate maxima and minima matches well with Singapore, where RSL decelerated from ~ 12 mm/yr to 5 mm/yr during the same timeframe. Similarly, RSL at Yaojiang Valley, Eastern China showed a progressively slowing trend from 8.5 ka to 7.5 ka BP from -10 m to -6 m (Liu et al., 2018). Finally, ^{230}Th -dated coral ages from Paraoir, western Luzon provided no evidence of stepped sea level rise, instead showing gradual deglacial sea-level rise from -29 m to -8 m from 10.3 ka and 7.2 ka BP (Siringan et al., 2016).

4.6.3. Mid-late Holocene (7 ka BP to present)

RSL for Singapore reached modern MTL at approximately 7 ka BP, and potentially reached mid-Holocene highstand elevations, an effect of ‘equatorial ocean syphoning’ as well as ‘continental levering’ due to hydro-isostatic loading of oceanic regions (e.g. Mitrovica and Milne, 2002; Khan et al., 2015), of up to 3 m before slowly decreasing to modern levels as early as 2.5 ka BP. This late Holocene RSL portion of our record appears to dip below modern sea level which could be attributed to underestimation of true compaction values

(Törnqvist et al., 2008; Horton and Shennan, 2009; Brain et al., 2012; Brain, 2015). However a very recent study done near Kuala Terengganu, Peninsular Malaysia showed that local sea levels fell below MSL during the late Holocene, with the lowest at -0.6 ± 0.1 m at 800 cal yr BP (Tam et al., 2018) which may support the validity of the late-Holocene SLIPs in this study.

Studies and models from Singapore and the region suggest mid-Holocene maximum elevations of 3 – 5 m during the highstand phase dated at ~ 7 ka – 5 ka BP (e.g. Geyh et al., 1979; Tjia, 1996; Hesp et al., 1998; Horton et al., 2005; Bradley et al., 2016). Lower estimates of highstand elevations of between 1 - 3 m came from coral microatoll SLIPs from Belitung Island, Indonesia, which recorded a peak of 1.2 m at ~ 6.6 ka BP (Meltzner et al., 2017). RSL of 1.4 m - 3 m at 7 ka BP was proposed based on *in situ* fossil coral and shelly marine deposits from northeast Peninsular Malaysia (Parham et al., 2014). Stattegger et al. (2013) found maximum Holocene RSL at +1.4 m from 6.7 ka to 5.0 ka BP based on beachrock and beach-ridge deposits from Southeast Vietnam, while ridge crests and swale bases along the Andaman Sea coast of southern Thailand provided evidence of maximum RSL heights of +1.5 – 2.0 m above the present level around 5.3 ka BP (Scheffers et al., 2012), results which are similar to another farfield region along the northern coast of South America, where in Suriname and Guyana, RSL attained a reached a Holocene highstand maximum elevation of $\sim 1.0 \pm 1.1$ m between 5.3 ka and 5.2 ka BP (Khan et al., 2017).

There is some evidence of fluctuations and stepped sea levels from mid-Holocene highstand conditions to present (e.g. Tjia, 1996; Meltzner et al., 2017) but further work is required, potentially at outcrops and other stranded palaeo-indicators on offshore islands near Singapore, to resolve actual highstand sea level fluctuations for the region.

4.6.4. Base-of-Basal index points

Samples obtained from intertidal sediments are subject to compaction issues which potentially add greater vertical uncertainties to each index point (Horton and Shennan, 2009; Brain et al., 2012; Horton et al., 2013; Johnson et al., 2018). This renders it difficult to resolve small-scale sea level variability which can be lost within the noise, especially for relatively minor but critical sea level fluctuations (e.g. 8.2 ka event) which are important for understanding and modelling sea-ice interactions and dynamics (e.g. Okuno and Nakada, 1999; Wiersma et al., 2006; Bard et al., 2010; Hijma and Cohen, 2010; Bradley et al., 2016). Here I attempt to build a sea level record by distinguishing between base-of-basal (BoB), basal and intercalated SLIPs (Fig. 4.9). I define basal samples to be material obtained within intertidal sediments, and base-of-basal samples only from the interface between that unit and the relatively incompressible pre-transgressive land surface. Intercalated SLIPs refer to samples within intertidal sediment but bounded above and below by potentially compressible substrate (e.g. marine muds).

Figure. 4.9. Revised RSL plot differentiating between base of basal (BoB), basal and intercalated SLIPs.

Using only these base-of-basal samples, I constructed here a first compaction-free sea level record for Singapore (Fig. 4.10), albeit with the chronology constrained by only 13 data points from 7 ka to 9.5 ka BP. Nonetheless, this first compaction-free sea level record greatly improves data validity by minimising vertical uncertainties associated with autocompaction, and could potential reveal minor sea level perturbations. Even though it is not expressed statistically, a possible ~2 m, ~100 year sea level jump centred at ~8.4 ka BP can be interpreted from the data (Fig. 4.10). I also observe other independent pieces of evidence that may support this jump, for example the presence of two sand content peaks at ~8.3 ka BP which could be interpreted as sand incursions caused by a multi-staged 8.2 ka event (Peros et al., 2017), as well as geochemical and elemental proxy perturbations during this time period (see Chapter 5).

Further work is required on obtaining more BoB SLIPs for Singapore to produce a higher-resolution compaction-free sea level record in order to provide more evidence for stepped or oscillatory sea level rise during the early-mid Holocene.

Figure. 4.10. Sea level record composed only of base-of basal samples showing a possible ‘jump’ in sea level between the two clusters of SLIPs (dashed boxes)

4.7. Conclusion

In summary, I recalibrated all previously obtained SLIPs from the comprehensive work by Bird et al. (2007, 2010) and augmented the data set with 4 new SLIPs from a new deeper shallow marine sediment core, producing a revised sea level record for Singapore and the first extending to the earliest Holocene marine transgression. I showed using a Bayesian modelling approach that relative sea level rose rapidly from 9.5 ka – 9 ka BP followed by an abrupt slowdown from peak rate of 16 mm/yr to a slowstand from 8 ka – 6 ka BP at a consistent rate of ~4 mm/yr with little inherent variability. I concede the possibility of a more

pronounced inflection at ~7.5 ka BP however the model does not provide sufficient support for that postulation. RSL reached modern levels by ~7 ka BP and possibly reached maximum highstand elevations of ~3 m by 6 ka BP before gradually decreasing to modern levels.

However, both elevation and age uncertainties can be reduced using only BoB SLIPs to produce compaction-free sea level records, which may reveal minor fluctuations which would otherwise be lost in the noise. The relatively straightforward stratigraphy of Singapore where mangrove peats predictably sit atop incompressible pre-transgressive palaeosol highlights the potential of a high-resolution archive of SLIPs tracking Holocene sea level for as mangroves migrate in tandem with changing sea levels.

The earliest evidence of Holocene marine transgression for the southern coast of Singapore provide temporal constraints relevant to human dispersal patterns in this region, where *H. sapiens* could have arrived between ~45 - 60 ka BP along the Malaysia peninsula and moved along land bridges during periods of lowered sea levels to reach the Sahul shelf (Bird et al., 2005; O'Connell and Allen, 2015; Norman et al., 2018). Given Singapore's location at the tip of continental Asia, the earliest Holocene sea level rise and infilling of Singapore Straits would impede southward human dispersal from ~9.5 ka BP.

Accurate palaeo sea level data is crucial for improving sea level models for projecting future sea levels (e.g. Siddall and Milne, 2012; Woodroffe and

Murray-Wallace, 2012; Horton et al., 2018). A 'likely' range of 0.52 m to 0.98 m for sea-level projections by 2100 was proposed for the highest emission scenario (RCP8.5) (Pachauri et al., 2014), although experts pointed out a potential one-third probability of sea levels being higher than projected due to insufficient evidence (Church et al., 2013). Semi-empirical models complement existing models by being calibrated with palaeo-data and have shown evidence of being robust (Rahmstorf, 2007; Rahmstorf et al., 2007); alarmingly such models predict higher sea levels than IPCC AR5 scenarios by 2100 (e.g. Church and White, 2006; Rahmstorf, 2010; Jevrejeva et al., 2012; Schaeffer et al., 2012), in line with survey results by experts (Horton et al., 2014).

This new sea level record not only contributes to better understanding of sea level change in Singapore and the region during a critical but inadequately-studied timeframe, the data will help improve forecasting models for mitigation and adaptation for Singapore and the region (e.g. Nicholls et al., 2011; Hallegatte et al., 2013; Marzin et al., 2015; Horton et al., 2018), and augment tide-gauge records for Singapore (Tkalic et al., 2013).

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Chapter 5

Early Holocene paleoenvironments of a fluvio-deltaic sequence in Singapore

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Abstract

The early Holocene (11.6 – 7.0 ka BP) was a period of dramatic environmental change coincident with rapid sea level rise (SLR) that provides a valuable analogue for understanding coastal response to future environmental forcings. However, this critical timeframe remains inadequately studied in the tropics. Singapore lies near the tectonically-stable core of Sundaland, and the sediment sequence offshore from Kallang River system contains thick sequences of post-LGM (Last Glacial Maximum) deposits which record early Holocene fluvio-deltaic change.

I obtained a ~38.5 m sediment core to a depth of ~50 m below MSL from a coastal reclamation area in Singapore. The topmost 11.86 m of sediments are post-LGM transgressive sediments and I applied a multi-proxy approach comprising sediment and stable carbon isotope analyses and XRF-scanning at cm-scale within a Bayesian chronological framework of 23 ¹⁴C AMS dates.

Here, I present the first high-resolution coastal evolution model for Singapore during the early Holocene (~9.5 ka - ~7.3 ka BP). Our data suggest that coastal mangroves existed for ~300 years (9.5 ka – 9.2 ka BP), succeeded quickly by estuarine conditions (9.2 ka – 8.8 ka BP) coincident with a potentially wetter and warmer climate. Overlying the estuarine sequence are prodelta muds that were deposited from 8.8 ka to 8.25 ka BP and are associated with an increase in subtidal calcareous fauna. Delta front sediments were deposited from 8.25 ka - 7.8 ka BP, with possible rapid coastal accretion and a shallowing of the sequence due to rapid sediment accumulation. Superimposed here between 8.5 ka and 8

ka BP is a notable period of higher precipitation and weathering with a dip at 8.25 ka BP coeval with monsoon weakening possibly associated with the 8.2 ka event. The delta sequence coarsens upward indicative of seaward progradation of coarse, shelly deltaic sediment from 7.8 ka - 7.3 ka BP. This model fills in a significant knowledge gap and helps in planning and mitigating against coastal vulnerabilities for Singapore and other delta megacities.

5.1. Introduction

The early Holocene (11.65 ka to 7 ka BP) (Smith et al., 2011) was marked by abrupt shifts in climate (e.g. Mayewski et al., 2004) and rapid sea level rise (e.g. Mayewski et al., 2004; Törnqvist and Hijma, 2012) driven by catastrophic deglaciation events (Carlson et al., 2008; Ullman et al., 2016). Together such changes lead to significant global environmental change along coastal zones across the earth (e.g. Smith et al., 2011; Plag and Jules-Plag, 2013; Pedoja et al., 2014). In Southeast Asia this early Holocene period remains poorly studied even though it is likely highly relevant to understanding future ice-sea-climate interactions (Törnqvist and Hijma, 2012; Woodroffe and Murray-Wallace, 2012).

Solar insolation cycles and irradiance also contributed to millennial-scale climatic variability during the early Holocene, where radionuclide archives in ice cores and tree rings suggest stronger cosmic ray intensity from 9 ka to 7 ka BP relative to the rest of the Holocene (Steinhilber et al., 2012). Some studies suggest that solar insolation patterns are correlated with monsoon changes as well (e.g. Kutzbach, 1981; Wang et al., 2005; Cook and Jones, 2012). Periods of climatic instability (e.g. 8.2 ka event) (Alley et al., 1997; Alley and Ágústssdóttir, 2005) and monsoon variability (e.g. Gupta et al., 2003; Wang et al., 2005) were proposed but data gaps still remain in many parts of tropical Southeast Asia.

Sedimentary records play a crucial role in understanding past environmental change (e.g. Levac et al., 2015; Pico et al., 2016; Peros et al., 2017; Goslin et al.,

2018) as sedimentation rates and geochemical properties near marine margins are a function of climate (i.e. precipitation, weathering processes), sediment supply and sea level dynamics (e.g. Blum and Törnqvist, 2000; Xiong et al., 2018). Studies of sediment flux and coastal evolution proximal to coastal areas, especially near delta megacities, continue to generate great interest due to the potentially devastating socio-economic effects likely to be brought about by future changes climate and sea level change (e.g. Hallegatte et al., 2013; Pachauri et al., 2014).

This study aims to augment the current body of work with palaeoenvironment reconstruction of the small but important fluvio-deltaic system of the Kallang River in southern Singapore, where key downtown commercial and government buildings are located, all of which are vulnerable to future sea level rise (Nicholls and Cazenave, 2010). I focus on the early Holocene and interpret coastal evolution and possible environmental conditions using high-resolution analysis of sediment MSBH01B. Core MSBH01B is 38.5 m long and the Holocene sequence spans the time period of 9500 cal yr BP to almost present, with a chronological hiatus between ~700 and ~7300 cal yr BP. Three primary sediment facies are identified and this study focuses on the peat and marine facies which are dominated by highly-organic peaty silts and homogenous finely-laminated marine muds with variable sand content, respectively.

Knowledge of past coastal response to climate and sea level change is critical for Singapore and other nations within the inner Maritime Continent to properly

plan for future mitigation measures. There are few coastal evolution studies for this time frame and region, and though restricted by the dearth of quality proxy records we estimate that relative sea level reached ~ -15 m and -25 m MSL (Horton et al., 2005; Woodroffe and Horton, 2005; Sathiamurthy and Voris, 2006; Bird et al., 2007). This study thus covers a significant knowledge gap for past environmental change in the region.

5.2. Study area

Singapore is a small island state located between latitude $1^{\circ}09'N$ and $1^{\circ}29'N$ and longitude $103^{\circ}38'E$ and $104^{\circ}06'E$, a location that experiences equatorial climate with no distinct seasons. Rainfall, temperature and humidity are typically high year-round, and is shaped by alternating north-east (December – March) and southwest monsoons (June – September) seasons, convective systems where precipitation patterns (Fig. 5.1) are possibly linked to regional monsoon systems (Griffiths et al., 2010; Cook and Jones, 2012) and the Indo-Pacific Warm Pool (IPWP) (Wurtzel et al., 2018).

Figure. 5.1. Monthly rainfall for Singapore from Changi climate station (1981-2010).

The continental Sunda shelf was largely exposed when sea levels were ~120 m below MSL (Siddall et al., 2003; Hanebuth et al., 2009) during the Last Glacial Maximum (LGM) approximately 20,000 years ago. Subsequent post-glacial sea level rise led to the inundation and subsequent infilling of relict palaeochannels and coastal plains at the outer and middle Sunda shelf (e.g. Hanebuth et al., 2000; Hanebuth et al., 2011; Alqahtani et al., 2015)., Singapore has been considered tectonically stable as it is distal from major plate convergence/subduction zones (Tjia, 1996), though recent evidence suggests a low down-warping rate of a rate of 0.06 to 0.19 mm/year since the beginning of the LGM (Bird et al., 2006). Sea level studies from Singapore and the surrounding region have provided numerous index points spanning mid-late Holocene but fewer for the early Holocene (Geyh et al., 1979; Tjia, 1996; Hesp et al., 1998; Bird et al., 2007; Bird et al., 2010). We know from local stratigraphy that early Holocene mangrove muds and peats were overlain by mid-late

Holocene marine sediments, but the detailed chronology and process remain poorly understood. A savannah corridor has also been posited for the last glacial period, including the Singapore area, suggesting cooler and dryer conditions (Bird et al., 2005) extending to the younger Dryas as suggested by pollen from inland swampland (Taylor et al., 2001) but no further into the Holocene.

The rapid urbanisation of Singapore has indirectly benefitted this study, providing a tremendous amount of borehole data to better understand the geology of Singapore [Chapter 3 of this thesis; Chua et al. (2016)]. Intensive land reclamation projects on the coastlines of Singapore in recent decades (Bird et al., 2004) also meant that once shallow marine environments can now be accessed and cored by terrestrial boring methods. The Marina South area is a newly-reclaimed area (reclaimed by 1992) and was previously the shallow marine zone offshore relative to the Kallang River Basin (Fig. 5.2). Geological modelling of the area revealed possibly a low-energy broad foreshore with a gentle gradient making it a good location for palaeoenvironmental studies.

Figure 5.2. Map of Singapore showing approximate extent of the Kallang River Basin. The red square denotes location of MSBH01B. Note that the current coastline is reclaimed and further seaward than during the early Holocene.

5.3. Method

I obtained a continuous 38.5m (down to 50m below MSL) core MS-BH01B at 1.27266° N, 103.8653°E at Marina South on 11 March 2016 using a rotary drilling machine coupled with condition-appropriate combination of hydraulic piston and Selby thin-walled coring methods. The top ~12 m of sediment was identified as modern fill material and removed, while sediment samples starting 7.52 m below MSL were retained. Recovery of sediment was at least 90% with little slump loss or compaction. All core segments were CT (Computed Tomography)-scanned which provides a preliminary non-destructive technique to view internal structures and variability, and stored at ~4 °C to prevent sample deterioration.

5.3.1. CT (Computer-Tomography)-scanning

CT-Scanning allows for the rapid and non-destructive internal understanding of a sediment core, allowing for quantitative analysis of density variability, bedding, location of artefacts of interest etc (e.g. Orsi et al., 1994; Boespflug et al., 1995; Cnudde et al., 2006). All MSBH01B core segments were sent to the Singhealth Experimental Medicine Center (SEMC) for Computer-Tomography or CT-scanning using a PET/CT scanner (MultiScan LFER 150 PET/CT, Mediso) to acquire the CT images. The LFER 150 (Large Field of view Extreme Resolution) with 20 cm axial and 15 cm transaxial field of view, coupled with MobilCell modular imaging bed with 70 cm axial range, allowed the core sediment to be acquired in a horizontal position. Medium resolution of 192 μm voxel size was determined to be sufficient to differentiate the objects presented in the core sediment. Optimal energy level and exposure time are derived by scanning the same core with different energy setting (Figure 5.3) with parameters of 80 kVp, 230 μA , 200 ms setting provides the best image quality, in terms of signal-to-noise ratio. Each core segment was imaged twice in order to cover the entire length, with the middle portion overlapping of 1 – 2 cm.

Figure 5.3. Screenshot of CT-imaging software showing image outputs with differing settings : Starting from top left in clockwise direction : (a) 40kVp, 980uA, 200ms, (b) 60kVp, 320uA, 200ms, (c) 60kVp, 980uA, 90ms, (d) 80kVp, 230uA, 200ms and (e) 80kVp, 520uA, 90ms

Core segments were first split and logged visually. One half (archive half) is immediately line-scanned for colour parameters and subsequently XRF-scanned for elemental composition using an Avaatech micro-XRF Core Scanner housed at the Asian School of the Environment, Nanyang Technological University. Each core surface was carefully covered with 4 μm SPEXCerti Prep Ultralene® film and surface carefully smoothed. All core segments were scanned at 1 cm resolution with measurement slit size at 1 x 1 cm, at 10 keV and 30 keV settings to measure elemental abundance from Aluminum (Al) to Iron (Fe). Exposure time was 15 s for 10 kV and 25 s for 30 kV and downcore step size of 1 cm.

5.3.2. Sub-sampling of sediment core

The other half (working half) is subsampled at 1-cm resolution (Fig. 5.4) and dateable material collected and stored in centrifuge tubes. An aluminum U-channel is used to obtain accurate and consistent sediment volumes for bulk density values. I determine the organic and carbonate content using Heiri et al. (2001)'s method for loss-on-ignition (LOI) where heating the sample to different temperatures (i.e. 105°C, 550°C and 950°C) indicates the weight percent of water content, organic content and carbonate content, respectively. Particle-size analysis (PSA) of the sediment samples is ascertained by an initial two-stage pretreatment of approximately 10 g of sample with 10 v/v% hydrochloric acid (HCl) and 15 v/v% hydrogen peroxide (H₂O₂) to remove carbonate, organic matter and disassociate clays. Subsequently, I performed PSA using the Malvern Mastersizer 2000 where samples were first sonicated for 60 seconds and three replicates averaged (Blott et al., 2004; Ryżak and Bieganski, 2011). Any samples where the relative standard deviation of the mean grain size values exceeded 5% were re-analysed.

Figure. 5.4. Schematic of cross-sectional sub-sampling portions of split core for various analytical measurements. Bulk Density segment is sub-sampled using an aluminum U-channel. Sub-sampled slices are cut at 1-cm intervals.

I determined that the topmost 11.894 m of sediment, which represents the depth of 7.5 m to 19.4 m below MSL, are Holocene deposits as they sit atop a thick unit of 'stiff clay', interpreted as sub-aerially exposed, desiccated MIS 5 marine clay (Bird et al., 2007; DSTA, 2009). All depths recorded in this study will henceforth be relative to MSL, unless otherwise stated.

5.3.3. Radiocarbon dating

A total of 23 radiocarbon samples were cleaned with DI water and sonicated at least 3 times to remove sediment and other impurities. Selection was based on condition of material and preservation position within the stratigraphy (e.g. situated in undisturbed as opposed to bioturbated unit). Articulated bivalves (observed through CT-scanning) were also preferentially selected over gastropods. All samples were sent to Rafter Radiocarbon Laboratory, GNS Science in New Zealand for AMS ^{14}C dating. Conventional radiocarbon ages

(CRA) were calibrated using IntCal13 (Reimer et al., 2013a), and MarineCal13 (Reimer et al., 2013a) for carbonate samples. I found paired bivalve-wood samples dated at ~8.6 ka BP which I used to obtain a ΔR of -89 ± 94 yr (<http://calib.org/deltar/>), a value close to the other nearby ΔR values (Southon et al., 2002; Bird et al., 2010) and thus used to correct all carbonate ages in our sediment core.

5.3.4. Bulk Organic Carbon stable isotope analysis

Sediments were sampled at 2-cm resolution for stable (organic) carbon isotope analysis. 565 sediment samples were milled and acidified (HCl conc. 5%) before centrifuging (at least 4 washes) and dried at 60 °C. ~15 mg of sample was weighed and placed in tin capsules before loading onto an autosampling plate. Carbon and nitrogen abundances and isotope compositions were determined using an elemental analyzer (ECS 4010 CHNSO Analyzer; Costech Analytical Technologies INC, Valencia, CA, USA) fitted with a Costech Zero Blank Autosampler coupled via a ConFloIV to a Thermo Scientific Delta VPLUS using Continuous-Flow Isotope Ratio Mass Spectrometry (EA-IRMS) at the Advanced Analytical Centre housed in James Cook University, Cairns, Australia. Calibration curves for elemental abundances were determined for three in-house standards (HOC, LOC and Taipan) within the same analysis sequence, and standards linearity and drift were accounted for in calibration and reduction calculations. The C/N ratio was determined via weight percentage while $\delta^{13}\text{C}$ values are reported as per mil (‰) deviations from the VPDB reference scale, using the

same reference materials as for elemental abundances. Precision for all $\delta^{13}\text{C}$ results are ± 0.1 or better.

5.4. Results

5.4.1. Sedimentary facies succession

The sedimentology of the Holocene sediments is fairly simple, with three distinct units (Units I, III, IV), a gradational transitional contact (Unit II), and pre-Holocene land surface (Unit V) (Fig. 5.5). The units are described here from the top down.

Unit I (-7.52 m to -11.176 m) is composed of poorly-sorted, chaotic very coarse silt-medium silt with frequent shell and coral fragments. Inorganic carbon percentage is high relative to other units with maximum values of 15.79 % near the top before decreasing to 1.59 % (-9.7 m) as shell and coral decrease sharply. An inversion is observed for organic matter which show a gradual increase from a low of 3.66 % to 5.25 % at the base of this unit, displaying a sharp organic excursion (max = 14.21 %) proximal to the drop in carbonate at -9.72 m. Dry bulk density ranges from 1.63 g/cm³ to 0.89 g/cm³; the minimum value an outlier given mean dry bulk density of 1.25 g/cm³. Particle size distribution show concomitant high values of sand at the top of the unit (max = 60.46 %), decreasing drastically to ~7 % at the base, with silt (max = 70.81 %, min = 30.16 %) and Clay (max = 30.06 %, min = 9.38 %) fractions showing a reversed trend. This is demonstrated in the mean grain-size showing high variability from 59.19 μm to a low of 7.93 μm .

Figure 5.5. Sedimentological analysis, Organic and Inorganic Matter percentage of identified lithofacies Units I – V.

A transitional bedding contact, Unit II (-11.176 m to -12.531 m) is poorly-sorted medium-fine silt with less common occurrence of shell fragments and near absence of coral fragments. This unit coarsens up drops rapidly from to 1 % sand at the base at -12.53 m to > ~8 % at -11.18 m albeit with no significant change in dry bulk density which stays within a narrow band with mean value of 1.17 g/cm³. Other parameters also stay largely consistent, with average values for organic matter, inorganic carbon and mean grain size at 6.37 %, 2.27 % and 8.61 µm, respectively.

Unit III (-12.531 m to -18.734 m) is largely homogenous, non-laminated marine clay ranging from greenish grey (10GY 4/1) to grey (5G 5/1) in colour that contains occasional shells and organic streaks. The amount of organic matter shows little background variability (~6.8 %), except for a prominent broad peak of 10.89 % at -17.25 m and a smaller gradual peak of 9.2 % at -13.96 m observed. Shell occurrence is sporadic and uncommon, though gastropod and bivalve shell preservation is extraordinarily high where found. Apart from infrequent relatively shelly bands which produce carbonate spikes of between 4 % and 5.8 %, inorganic carbon is largely consistent at a low mean value of 2.58 %. Dry bulk density of the Holocene marine clay is lower than the above units, ranging from 1.59 g/cm³ to 0.75 g/cm³, with mean dry bulk density of 1.04 g/cm³. Particle size distribution is variable due to clay-silt inversions, in particular, with clear clay bias at the depth between -16.13 m and -17.71 m, resulting in mean grain size of 6.47 µm as opposed to 6.96 µm for the entire unit. Sand percentage

is generally low and constant (mean = 0.21 %), albeit punctuated by abrupt sand incursions of 4.39 % at -13.65 m and 3.49 % at -13.94 m.

Unit IV (-18.73 m to -19.39 m) is an organic-rich dark brown peaty (mangrove) medium-fine silt facies with macrofossils (wood, bark and root pieces) found abundantly throughout the unit. Average organic matter content is 12.24 % with a maximum of 25.66 %, accompanied by low average dry bulk density of 1.01 g/cm³, albeit skewed by high bulk density at the gradational interface between Units IV and V (-19.29 m to -19.39 m); average dry bulk density would have decreased to 0.94 g/cm³ if I disregard the transitional contact. Inorganic carbon is consistently low (average = 3.88 %). Clay-Silt-Sand percentage is also largely consistent downcore with average values of 27.62 %, 69.91 % and 2.47 %, respectively.

Unit V (-19.39 m downward) is a high-oxidised, dense stiff clay unit characterised by high dry bulk density (average = 1.41 g/cm³) and low organic (average = 4.92 %) and inorganic carbon (average = 3.38 %) content, with values decreasing downcore. This paper focuses on the early Holocene and hence Unit V (MIS 5 desiccated marine clay) will not be further discussed.

5.4.2. Chronology

I obtained 23 radiocarbon ages from charcoal, wood and shell material from 7.63 m to 19.39 m below MSL (the lowermost samples representing the basal peats just above interface with pre-transgressive land surface). Dates broadly

range from modern samples to the early Holocene, with a significant chronological hiatus between ~700 and ~7300 cal yr BP. I thus consider that a reliable chronology is established from ~7.3 ka BP at 9.21 m to a depth of 19.39 m for the early Holocene basal peat, representing 10.18 m of sediment accumulating over a timeframe of approximately 2.3 ka therefore suggesting an average sedimentation rate of 4.4mm/yr.

It is important to correct CRAs for local reservoir effects through obtaining a ΔR for Singapore, which can deviate in the Pacific Ocean from calibration curve values by up to 400 years (Hua et al., 2015). Palaeoclimate studies rely heavily on reliable chronological information, underpinned by accurate dating of marine samples, such as corals, molluscs and foraminifers, and correlating them with terrestrial and ice-core records (e.g. Hughen et al., 2004; Lewis et al., 2008; Hua, 2009; Reimer et al., 2013b). To this end I note a paucity of ΔR values in the central Sunda region, with only 2 rather disparate dates giving an averaged ΔR of -68 ± 49 (Southon et al., 2002) obtained from pre-bomb bivalve shells attributed to Singapore. Bird et al's (2007) collection of radiocarbon samples include a paired gastropod/wood of early-mid Holocene age producing a ΔR of -96 ± 72 yr. Similarly, I found paired bivalve-wood samples dated at ~8.6 ka BP which I used to obtain a ΔR of -89 ± 94 yr (<http://calib.org/deltar/>), a value close to the other studies and thus used to correct all carbonate ages in our sediment core. All corrected ages are shown in Table 5.1.

Table 5.1. 23 radiocarbon dates obtained from MSBH01B. A paired wood-shell sample at -14.47 m below MSL was used to obtain a reservoir age of ΔR of -89 ± 94 yr which was used to correct all shell samples.

Sample ID	Elevation (m MSL)	Material	Lab code (NZA-)	Lab ID	¹⁴ C age (CRA)	CRA error	Calibrated age	Corrected Age	error	Lower (1 σ)	Upper (1 σ)	$\delta^{13}C$
5_OD1_11-12	7.630	Charcoal	63508	41068/1	Background			Old carbon				-26.43
28_OD1_79-81	8.310	Charcoal	63509	41068/2	123	20	93	-	25	117	68	
35_P1_1-3	8.430	Charcoal	63510	41068/3	135	20	94	-	22	115	72	
36_P1_3-4	8.450	Shell	63511	41068/4	1212	26	745	623	36	780	709	0.14
46_P1_14-15	8.560	Charcoal	63512	41068/5	Background			Old carbon				-22.77
50_P1_43-44	8.850	Charcoal	63513	41068/6	8503	33	9510	-	18	9527	9492	
53_P1_79-80	9.210	Wood	63514	41068/7	6379	27	7294	-	29	7323	7265	
57_P2_20-22	9.517	Wood	63750	41068/8	6278	29	7199	-	23	7222	7176	-28.46
64_P3_46-47	10.625	Shell	64441	41111/1	7370	35	7843	7721	53	7895	7790	0.51
65_P4_22-23	11.226	Shell	64558	41122/1	7280	31	7735	7613	44	7778	7691	-0.4
66_P6_12-14	12.876	Shell	63515	41068/9	7804	35	8272	8150	50	8322	8222	-1.55
69_P6_78-79	13.536	Shell	64442	41111/2	7884	35	8350	8228	32	8382	8318	-2.74

73_P7_26-27	13.841	Shell	63516	41068/10	7904	33	8364	8242	32	8396	8332	-3.28
77_P8_6-8	14.476	Shell	63517	41068/11	8071	35	8525	8403	50	8574	8475	-5.39
78_P8_8-8.5	14.476	Wood	63746	41068/12	7843	33	8614		32	8646	8582	- 31.27
80_P8_12-14	14.516	Shell	63518	41068/13	8076	34	8531	8409	49	8579	8482	-2.3
87_P9_20-21	15.421	Wood	63747	41068/14	7887	33	8661		57	8718	8604	- 31.52
99_P11_41-42	17.309	Shell	64443	41111/3	8296	41	8865	8743	79	8943	8786	-3.36
107_OD2_14-15	17.914	Shell	64444	41111/4	8287	36	8853	8731	81	8933	8772	-3.82
113_OD3_9-10	18.764	Charcoal	64445	41111/5	8278	39	9282		41	9322	9241	- 28.25
116_OD3_25-26	18.924	Wood	63748	41068/15	8208	34	9186		67	9252	9119	- 30.21
124_OD3_66-68	19.334	Charcoal	64446	41111/6	8372	39	9433		33	9466	9400	- 28.41
126_OD3_72-74	19.394	Wood	63749	41068/16	8421	35	9458		26	9484	9432	-28.5

5.4.3. Age-depth model & sedimentation rate

Here I present an age-depth model (Fig. 5.6) using BChron (Parnell, 2014), an R-platform package utilising a Bayesian statistical approach for chronological reconstruction.

Figure. 5.6. Age-depth model constrained by lowest 17 ^{14}C AMS ages showing variability in sedimentation rate during the early Holocene.

Ages above 8.85 m below MSL were omitted as they are either very old carbon (background values) or modern. These topmost 6 ages were determined to be disturbed and/or reworked and discounted from further calculations and analysis. Historical bathymetric maps show that the coring site is within the 10 m isobath, suggesting that it was possibly seafloor at that depth which potentially accounts for mixing of old and modern carbon.

The age-depth model implies some variability in the sedimentation rate, with inflection points occurring every ~ 500 years. Average sedimentation rate was

relatively low from ~9.5 ka to ~8.8 ka BP at a rate of 2.7 mm/yr, followed by a significant increase to 9.1 mm/yr from ~8.8 ka to ~8.5 ka BP. Sedimentation rate abruptly slowed to 4.4 mm/yr from ~8.5 ka to ~7.8 ka BP, then decreased further to 3.7 mm/yr from ~7.8 ka to 7.3 ka BP.

5.4.4. Bulk Organic Carbon stable isotope composition

The stable carbon isotope geochemistry of organic matter recorded in stratigraphic sequences in nearshore sediment provided valuable information about both contemporary (modern analog) and palaeoenvironmental conditions and sea level dynamics (e.g. Anjar et al., 2012; Kemp et al., 2012; Olsen et al., 2013; Wendler et al., 2016; Rúa et al., 2017; Sen and Bhadury, 2017). C/N values are also often used in tandem (e.g. Wilson et al., 2005; Lamb et al., 2007; Zhan et al., 2011) to distinguish between coastal palaeoenvironments. Phytoplankton tends to be nitrogen rich, resulting in much lower C/N ratios of 5.0 – 7.0. On the other hand terrestrial organic matter has significantly higher C/N ratios (> 12) due to the predominant contribution of C₃ plant detritus from mangrove and tropical forest sources, with lower $\delta^{13}\text{C}$ values, compared to marine organic matter associated with phytoplankton (C/N = <10) (Lamb et al., 2007; Wilson, 2017). Thus, $\delta^{13}\text{C}$ values and C/N ratios can be used together to distinguish between coastal palaeoenvironments through understanding tidal frames and how the sediments were derived (e.g. supra-tidal zones will contain carbon derived predominantly from C₃ vascular plants as

opposed to sub-tidal sediments which receive tidal-influenced organic carbon, with intertidal sediments showing variability between these two end-members) (e.g. Wilson et al., 2005; Lamb et al., 2006).

Figure 5.7. Downcore plots of $\delta^{13}\text{C}$, TOC% and C/N. Demarcation line for $\delta^{13}\text{C}$ set at -27‰ which is the average value for C_3 terrestrial carbon sources; green represents greater terrestrial influence while blue represents greater marine influence.

$\delta^{13}\text{C}$, %TOC and C/N values show some downcore variability (Fig. 5.7), with some abrupt shifts associated with lithofacies transitions. The mangrove peat unit (Unit IV) show high values for TOC% values from 4.1 % to 7.8 % with an average of 5.8 % for the unit. Average $\delta^{13}\text{C}$ is -28.8 ‰ and largely stay within a narrow

range between -28.0 ‰ to -29.0 ‰ except for an anomalous peak of -26.4 ‰ at -19.08 m. C/N ratio are an order of > 2 relative to other portions of the sediment core, ranging from 34.4 to 45.9 with an average value of 40.7.

The $\delta^{13}\text{C}$ values of the Unit III marine muds show a generally increasing trend superimposed on some strong internal variability. Values initially remain low, oscillating within a narrow range of $\sim$ -27.5 ‰ and -27 ‰ from 18.8 m to 15.5 m except for a peak excursion of -30.34 ‰ at -16.6 m. A reversal occurred at -12.8 m, proximal to the upper contact with Unit II, where $\delta^{13}\text{C}$ values start decreasing. TOC% decreased gradually from $\sim$ 3 % to $\sim$ 1 % at -12.5 m with little intra-variability, with a similar decreasing trend for C/N from $\sim$ 25 to $\sim$ 15 except for two prominent peaks of 21.87 and 24.14 at depths of -14.28 m and -13.96 m respectively.

$\delta^{13}\text{C}$ values in Unit II decreased rapidly from $\sim$ -26 ‰ to $\sim$ -27 ‰ before increasing to $\sim$ -25.3 ‰ at the contact with Unit I. TOC and C/N values show little variability with average values of $\sim$ 1 % and 15 respectively. $\delta^{13}\text{C}$ values in Unit I continue to decrease from -25.5 ‰ to -28 ‰ at -9.2 m before increasing rapidly amid strong fluctuations to a peak value of $\sim$ -24 ‰ at 7.52 m below MSL. TOC% showed greater variability, oscillating within a range of 0.8 % and 2%. Upcore C/N values in Unit I appear coupled with $\delta^{13}\text{C}$ values in Unit I, increasing from

~25 to a minimum of ~12 at the same $\delta^{13}\text{C}$ minima at -9.2 m, before increasing slightly punctuated by abrupt C/N peaks of up to ~25.

Further analysis of isotopic data with sediment units associated with nearshore features shows the potential to characterise sediments in tropical, possibly mangrove coastlines (Fig. 5.8); such data is available typically for temperate salt-marshes (e.g. Chmura and Aharon, 1995; Kemp et al., 2015; Khan et al., 2015) but less common for tropical coastal settings. I present here the first organic carbon geochemistry characterisation for Singapore Holocene sediments.

Figure 5.8. Scatterplot of three interpreted coastal environments derived from organic geochemistry of sediments in MSBH01B.

In general, marine muds for nearshore marine environments in Singapore are relatively homogenous with $\delta^{13}\text{C}$ and C/N values of $\sim -25\text{‰}$ to -27.5‰ and ~ 12 – 25 respectively. Topset sandy silts have $\delta^{13}\text{C}$ and C/N values of -24‰ to -27.5‰ , with a wider spread of C/N values from ~ 12 to nearly 30 . Mangrove peats display the greatest variability demonstrated by the large range of C/N values from 8 to 46 , albeit with relatively narrow band of $\delta^{13}\text{C}$ values between -27‰ and -29‰ .

5.4.5. XRF-scanning

X-ray fluorescence (XRF) scanning provides a rapid, non-destructive understanding of sediment cores at high-resolution through elemental proxies (Jansen et al., 1998; Croudace et al., 2006; Richter et al., 2006). Elemental concentrations and proportions are useful first-order environmental proxies to better understand palaeoenvironmental changes through time (e.g. Böning et al., 2007; Nowaczyk et al., 2018; Wündsche et al., 2018). Traditionally elements such as calcium (Ca), iron (Fe), strontium (Sr), potassium (K) and titanium (Ti), are commonly measured as they are important constituents of marine sediments and common tracers for reconstructions (Böning et al., 2007; Rothwell and Croudace, 2015b). In general, biogenic calcium and strontium can be indicative of calcareous organisms which are typically composed of calcite or aragonite, while iron, potassium and titanium show occurrences of lithogenic

material or sulphides which have been diagenetically altered (Rothwell and Croudace, 2015a).

Figure. 5.9. Bi-plot of distribution of PCA loadings of geochemical elements. PC1 has been interpreted as representing marine versus terrigenous input.

Principal Component Analysis (PCA) was undertaken on the geochemical results to better understand sedimentary processes and identify possible elemental clusters based on sediment provenance. PC1 accounted for 56.39 % of the total variance (Fig. 5.9). The loadings of the elements on PC1 show two basic clusters for elements identified as terrigenous (Al, Si, K, Ti, Fe and Mn) and marine (Ca and Sr), which show strong negative correlation on PC1 (Fig. 5.10). Elements with the strongest correlation loadings (positive and negative) were highlighted and utilised for further interpretation of trends within the core.

Figure. 5.10. Loadings for PC1 showing strong correlation values for Al, Si, Ti, Fe, Ca and Sr.

To correct for drift of the XRF Core Scanner, the element counts were normalized to the total count numbers (Revel et al., 2010). Corrected elemental values for selected terrigenous (Fe, Al, K, Ti) and marine loadings (Ca, Sr) are shown in Fig. 5.10.

There are segments of sustained high counts (Fig. 5.11), in particular Al, Ti and K plots which show high and relatively constant counts between 17.75 m and 18.75 m, 15.1 m and 14.3 m and 11 m and 13.7 m, below MSL.

Figure. 5.11. Graph showing downcore raw counts of critical elements normalised to total counts. Dotted lines for Fe – K depict best-fit spline smoothing.

Fe generally show a steep decrease from 19.3 m to 15.8 m albeit with large fluctuations, before increasing abruptly to near original values at ~15.5 m and decreasing slowly upcore with fewer perturbations. Al, Ti and K show similar patterns, with sharply decreasing values with minima at ~17.6 m before increasing within large fluctuations to peak values at ~15.5 m. Further upcore there is a slight dip before plateauing at peak values from ~13.8 m to ~11.1 m. Al showed a decrease to low values while Ti and K remain stable within a narrow range.

The marine indicator elements of Ca and Sr show striking similarity, with low values accented by sudden peaks, with a common peak at ~13.2 m which is accompanied by concomitant reduced enrichment in terrigenous input. Ca and Sr show a slow background increase to maximum values punctuated by pulses from ~10 m to core top.

5.5. Interpretation and Discussion

The palaeoenvironmental proxies obtained from sediment core MSBH01B show downcore variability over time, superimposed upon a background of rising and possibly pulsed sea levels during the early Holocene (e.g. Hori and Saito, 2007; Smith et al., 2011; Gregoire et al., 2012; Törnqvist and Hijma, 2012). The high-recovery sediment core shows little evidence of reworking during this timeframe and should provide a near-continuous record useful for palaeoenvironmental reconstruction. In this section I will elaborate on the proxies used for interpretation and discuss the possible environmental forcings and factors contributing to geochemical and geomorphological changes in the fluvio-deltaic system of southern Singapore during the early Holocene.

Selection of precipitation and chemical weathering proxies require an understanding of the palaeohydrology and source rock mineralogy. Previous palaeochannel mapping studies (Mote et al., 2009) reveal fluvial systems originating predominantly from the granitic exposures and hills in Central

Singapore, with a secondary source of sediment from possible unlithified fluvial sediments of late Quaternary age (Gupta et al., 1987). The granite is described as an acidic igneous rock with mineralogy composed of quartz (30 %), feldspar (60 %), biotite and hornblende (Sharma et al., 1999). Field observations reveal rapid weathering and recomposition of surficial granite forming a deep residual soil profile (Zhao et al., 1994; Rahardjo et al., 2004). The predominant product of chemical weathering of granite in hot and humid tropical climates is kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$), a high-alumina clay (Rothwell and Croudace, 2015b), which can be readily remobilised and flushed into fluvial channels during periods of high rainfall. Al/Si is thus selected as a proxy for precipitation and as Al is normalised against other siliceous sources (e.g. quartz sand). Chemical weathering of the phyllosilicate mineral biotite releases K^+ into the environment. K/Al, where K is more water-soluble than Al, is used to interpret illite to kaolinite ratio where low values are indicative of more mechanical (illite) to chemical (kaolinite) weathering processes and hence potentially weathering intensities (Burnett et al., 2011; Davies et al., 2015).

The early Holocene has been postulated to be warmer and wetter globally (Marcott et al., 2013), which could have resulted in higher rates of chemical weathering and rainfall runoff in correlation with monsoonal strength (Miriayala et al., 2017). Singapore lies in the deep convection zone within monsoon belts controlled largely by north and southward shift of the ITCZ during the Holocene

(Haug et al., 2001; Wanner et al., 2008; Jin et al., 2014). I thus compare the elemental proxy records with 2 sets of speleothem records – the first set from Tangga Cave in Sumatra (Wurtzel et al., 2018) and Liang Luar cave in western Flores (Griffiths et al., 2013) geographically south of Singapore, while the second from the Dongge caves in Guizhou Province, southern China (Dykoski et al., 2005) and Gunung Buda cave in Borneo (Partin et al., 2007) which are located north of Singapore, to our sediment record to investigate possible early Holocene precipitation variability, postulated to be influenced by IPWP and Atlantic Meridional Overturning Circulation (AMOC) variability (Wurtzel et al., 2018), and even related to insolation and sea level change (Griffiths et al., 2009; Griffiths et al., 2013; Mohtadi et al., 2016).

I present a multi-proxy approach to interpret possible forcings and factors affecting sedimentological and geochemical changes for the early Holocene timeframe between 7.3 ka and 9.5 ka BP. I also compare with known coeval environmental forcings (i.e. sea level change, monsoon record, solar irradiation) to identify possible relationships between sediment signatures and regional to global trends. Plots comparing sediment (Fig. 5.11) and climate (Fig. 5.12) proxies with other palaeoenvironmental indicators over time are shown below.

Figure 5.12. Comparison between sediment proxies and palaeoenvironmental measurements during the early Holocene (9.5 – 7.3 ka BP). a) simplified relative sea level curve using SLIPs (black dots) from Bird et al (2010) and Chua et al. (2018). b) juxtaposed $\delta^{13}\text{C}$ (blue) and C/N (black line) plots. The light blue shaded region lies above -27‰ demarcating transition between stronger marine vs terrestrial influence. c) Dry bulk density (black line); Note : red lines for (b) and (c) are weighted averages. d) clay (grey region), silt (brown region) and sand (blue region) percentages. e) Sr/Ca plot indicating trends in biogenic versus detrital calcium. f) Fe/Ca plot which indicates relative terrestrial (Fe) to marine (Ca) influence.

Figure 5.13. Comparison between climate proxies and palaeoenvironmental measurements during the early Holocene (9.5 – 7.3 ka BP). a) total solar irradiance by Steinhilber et al. (2012) b) speleothem $\delta^{18}\text{O}$ data from Tangga Cave, Sumatra (Wurtzel et al., 2018) and c) Liang Luar, Flores (Griffiths et al., 2009) (located southward of Singapore and bounded in blue) d) speleothem $\delta^{18}\text{O}$ data from Dongge Cave, China (Dykoski et al., 2005) and e) Gunung Buda, Borneo (Partin et al., 2007) (located northward of Singapore and bounded in green) Note: red lines for (a) to (e) are weighted averages. (f) and (g) K/Al and Al/Si selected as chemical weathering and precipitation proxies respectively. Threshold lines are set at averaged dataset values and region in blue indicates periods of higher relative weathering and rainfall intensities. h) $\delta^{13}\text{C}$ (blue) record with weighted average in red. Orange dashed box indicate time (8.4 ka - 8 ka BP) where reversals are observed in monsoon and geochemical records possibly associated with the 8.2 ka event.

5.5.1. Phase 1 : 9.5 – 9.2 ka BP [Mangrove Coastline]

The earliest record of early Holocene marine transgression for Marina South, Singapore, is dated at 9462 ± 61 cal yr BP, obtained from charcoal from basal peat unit interpreted as an intertidal mangrove facies. This contact between the pre-transgressive land surface and transgressive peats is clear and unequivocally defined both visibly and geochemically – i.e. clear colour and textural changes, abrupt shift in Fe (oxidised palaeosol) accompanied by sharp increases in TOC%. The thin veneer of sandy deposits (~8 % sand) deposited at ~9.4 ka BP was probably deposited during the earliest highest tidal waters depositing littoral tidal sands, mixed easily with seaward mangrove-derived organic muds (Bird et al., 2007).

The increase in marine influence is also supported by an increase in $\delta^{13}\text{C}$ from 9.33 ka that continues until 9.09 ka BP from largely terrestrial (~-29.0 ‰ VPDB) to possibly estuarine conditions (~-27.1 ‰ VPDB), supported further by very high C/N values of up to ~46 (Bouillon et al., 2008). Some pulses of tidal sands were observed coupled with drastically decreasing Fe/Ca indicative of increasing marine influence due possibly to rapid marine intrusion.

Mangrove ecosystems have been promoted as coastal defences against storms and sea level change due to their resilience and ability to vertically 'keep pace' with rising seas (Alongi, 2008; Lovelock et al., 2015). However, the local

extinction of mangroves here within ~300 years indicates that the potential to accrete and keep pace with sea level rise on mangrove coasts may have been overestimated, where landward zonal migration by back-stepping is more likely assuming landward conditions are viable and available for mangrove growth (Woodroffe et al., 2016). The vertical accretion rate of the coastal mangrove system (confirmed by presence of mangrove pollen, see chapters 3 and 4) could not keep pace with the rising sea level and either migrated landward or mangrove dieback occurred and ultimately the entire system was back-stepped and permanently inundated. The geological model of the river basin (see chapter 3) supports the second hypothesis with little evidence of extensive peat deposits further inland, but rather mostly fringing mangroves located laterally along river banks.

5.5.2. Phase 2 : 9.2 – 8.8 ka BP [River-dominated Estuary]

Sea level rise continued to be rapid through this period of the early Holocene (Liu et al., 2004; Smith et al., 2011), albeit at a decelerating rate in Singapore (see chapter 4). This is supported by localised mangrove extinction and an abrupt transition from mangrove peats to shallow marine muds which possess a brown hue rather than predominantly grey muds further upcore.

The marine muds are very finely laminated and show no evidence of reworking, indicators of a low-energy coastal environment (i.e. estuary). It is surprising that

posited rapid SLR during this timeframe is not accompanied by increases in $\delta^{13}\text{C}$ and lower Fe/Ca associated with greater marine influence, although the increase in marine influence is muted due possibly to the slowdown in sea level rise. The sediment data reveals suppressed and stable $\delta^{13}\text{C}$ and higher than expected Fe/Ca, particularly from 9.1 ka to 8.9 ka BP, which also agrees well with a deceleration in sea level rise. $\delta^{13}\text{C}$ and C/N values showed a stable pattern oscillating within a narrow range of $\sim -27.5\text{‰}$ and 20 respectively, which suggest relatively strong, though much less depleted than from 9.5 ka to 9.2 ka BP, terrestrial input into this nearshore system. The generally low $\delta^{13}\text{C}$ and high C/N values could also be indicative of strong freshwater discharge in possibly river-dominated estuarine conditions (Zhan et al., 2011). This is coeval with a period of higher K/Al and Al/Si values from 9.1 ka to 8.95 ka BP, coincident with increasing precipitation as shown in the Tangga and Gunung Buda records.

The latter half of this estuarine phase commencing from ~ 8.95 ka BP is marked by increasing marine influence supported by sharp decrease in Fe/Ca, accompanied by generally reduced Al/Si and K/Al values which generally indicates lower precipitation and weathering intensities. It is surprising that this is coeval with a period of higher clay content ($\sim 5\%$ increase) from 8.95 ka to 8.83 ka BP where I would expect less weathered clays transported from the hinterland.

Nonetheless the relatively constant $\delta^{13}\text{C}$ value at $\sim 27.5\text{ ‰}$ would mean that terrestrial inputs remain high, and could suggest that fluvial discharge from tributaries in the Kallang River Basin remained high as well through this period. Sr/Ca started increasing between 8.8 ka and 9 ka BP with high peak values up to 8 times above baseline, indicating an increase in biogenic calcium that could be due to the initial proliferation of foraminifera or other nearshore calcareous biota.

5.5.3. Phase 3 : 8.8 – 8.25 ka BP [Prodelta]

This phase is marked by an abrupt increase in sedimentation rate (9.1 mm/yr) coincident with rapidly increasing $\delta^{13}\text{C}$ values and low and stable C/N values suggesting stronger marine influence with greater phytoplankton abundance (Lamb et al., 2007; Wilson, 2017). However, these C/N values of ~ 20 still suggest a mixed coastal environment with some possible contribution from C_3 plant detritus which are less nitrogen-rich (Lamb et al., 2006). Fe/Ca values remain low which support the possibility of a prodelta environment as the tidal frame moves further landward due to SLR, with the prodelta slope allowing for greater accommodation space to allow for heightened sedimentation flux. Further, bulk density is increasing with accompanying coarsening-upward sequence with occasional sand-rich inputs, with two significant peaks (4.4 % at ~ 8.37 ka BP and 3.49 % at ~ 8.43 ka BP), which could be caused by strong terrestrial runoff pulses, or possibly sand excursions associated with a multi-staged 8.2 ka event (Ellison

et al., 2006; Peros et al., 2017). Very strong Sr/Ca peaks observed from 8.8 ka - 8.7 ka BP represent the continuation of sustained biogenic calcium input contributed potentially by nearshore foraminifera.

The elemental proxy ratios suggest a drier phase from 8.8 ka to 8.5 ka BP, followed by a wetter phase from 8.5 ka to ~8.25 ka BP, shown by lower then peak K/Al and Al/Si values respectively. There is some agreement with the speleothem records from Tangga and Dongge caves, especially the former which is the most proximal record to Singapore. They show an enrichment of $\delta^{18}\text{O}$ from 8.8 ka to 8.5 ka BP followed by a small peak centred at 8.25 ka BP representing low moisture conditions. The wetter phase is accompanied by prominent peaks in clay content at 8.50 ka (~37.9 %) and 8.44 ka BP (~40.2 %) which could be caused by higher precipitation and weathering rates bringing more alumina-rich weathered clays from inland sources, supported by coincident Al/Si peaks within the same time period.

I do not observe clear and unequivocal evidence pointing to climatic shifts associated with the 8.2 ka climate event, nor clear sedimentological features linked to a sea level pulse from drainage from proglacial Lake Agassiz-Ojibway between 8.6 ka and 8.4 ka BP (e.g. Barber et al., 1999; Cronin et al., 2007; Hijma and Cohen, 2010). In Chapter 4 I have shown a possible sea level at ~8.2 ka BP, but lack unequivocal evidence for it. I do however note a minima at ~8.25 ka BP

during a sustained period of high precipitation (8.5 ka – 8 ka BP) represented by high Al/Si and K/Al signals which could be associated with the weakened summer monsoon due to a southward shift of the Inter-Tropical Convergence Zone (Haug et al., 2001; Wang et al., 2005; Cheng et al., 2009). However, our sediment record lacks the necessary resolution and source-to-sink precision to fingerprint this short-lived, and spatially and temporally variable climate event (Morrill and Jacobsen, 2005; Thomas et al., 2007)

5.5.4. Phase 4 : 8.25 ka – 7.8 ka BP [Subaqueous Delta Front]

In the upper part of the sequence sediments continue to coarsen-upward with concomitant increases in bulk density and sand content and more shell and first occurrences of coral fragments which suggests a shallow marine or nearshore environment. This is coeval with a period of decelerating accretion rate to 4.4 mm/yr which commenced at ~8.5 ka BP (Fig. 5.4), which could be due to a reduced amount of accommodation space or a redirection of delta sedimentation foci. This period is also characterised by a sudden increase to highest $\delta^{13}\text{C}$ and lowered Fe/Ca values which indicate higher marine influence. Maximum $\delta^{13}\text{C}$ values are also recorded during this period at ~25.23 ‰ at 7.8 ka BP, indicating peak marine influence during this portion of the early Holocene, supported by lowest Fe/Ca values which stay relatively constant from this point on.

Al/Si and K/Al signals are somewhat good agreement with the Tangga cave record, showing a wetter phase from 8.25 ka to 8 ka BP, followed by a drier phase from 8 ka to 7.8 ka BP as the monsoon weakens. This agrees well with gradually more depleted $\delta^{13}\text{C}$ records from 8.25 ka to 8.15 ka BP which could suggest more terrigenous inputs due to increased fluvial discharge (Yu et al., 2011). The other 3 records are decoupled from the Singapore sediment record, showing a generally flat followed by strengthening monsoon signals from 8 ka to 7.8 ka BP. This dry phase is captured in the sedimentary records as well, expressed as an abrupt visible pause in sand content increase.

5.5.5. Phase 5 : 7.8 ka – 7.3 ka BP [Delta formation and seaward progradation]

Coarse, poorly sorted chaotic sediment with frequent incursions of shell and coral fragments were deposited during this time frame. I also observe sub-vertical structures up to 10 cm in length infilled with coarser material which could be burrows. The upward-coarsening sequence is accompanied by a sudden and sustained depletion of $\delta^{13}\text{C}$ (broad decrease of $\sim 1\text{‰}$) and generally stable C/N values, suggesting stronger terrestrial influence and carbon input. This is supported by the consistently low Fe/Ca values which suggests high calcium inputs owing to presence of biogenic carbonates in the shallow marine environment, coupled with lesser detrital material (Fe) from terrestrial sources.

Precipitation signals (Al/Si) remain relatively low suggesting reduced freshwater river discharge which translate to lower terrestrial input. This should typically result in higher $\delta^{13}\text{C}$ values as marine influence strengthens, but a plausible reason could be concurrent seaward progradation of terrigenous sediments in tandem with decelerating sea level rise. The records from Liang Luar, Dongge and Gunung Buda caves show a slow monsoon strengthening associated with increased precipitation which is not observed in the Singapore records. There is however some agreement between the Tangga record and Al/Si values that show two minor peaks at ~7.55 ka and 7.36 ka BP which in phase with two broad peaks in the Tangga record preceding the sedimentary records by ~50 years.

Sediments of this unit (Unit I) are deltaic and this period is characterised by seaward delta progradation from the Kallang River system. This postulation is likely as it is synchronous with global delta initiation and growth (e.g. Hori & Saito, 2007, Hanebuth et al., 2012) where favourable conditions were due to decelerating sea level rise (Stanley and Warne, 1994). Many major river deltas experienced early growth between 8 ka and 6 ka BP due to RSL slowdown or even stillstands in Asia, including the Mekong (Tamura et al., 2009; Nguyen et al., 2010; Hanebuth et al., 2012), the Pearl River (Zong et al., 2012), and the Yangtze (Hori and Saito, 2007; Wang et al., 2012) deltas. Sea level in Singapore was postulated to have decelerated during this period with an inflection between 7.8 and 7.4 ka BP (Bird et al., 2010), which could conceivably have

provided stable nearshore conditions for seaward sediment accretion and progradation.

5.5.6. Hydroclimate of Singapore

The elemental proxy dataset matches best with the nearby Tangga cave record (Wurtzel et al., 2018) situated only ~400 km from Singapore, with potentially well-matched high-precipitation periods centred at ~9.1 ka BP, 8.35 ka BP and 8.05 ka BP. This strong association would suggest that just like Sumatra, Singapore's moisture is derived from multiple sources which includes, in order of dominance, the Indian Monsoon, East-Asian Summer Monsoon and Australian-Indonesian Summer Monsoon (Wurtzel et al., 2018). The strong precipitation influence by the Indian Monsoon could help explain some similarities between the Singapore and the Dongge cave records, which was considered strongly influenced by the Indian Monsoon (Dykoski et al., 2005). More work is needed to understand how global and regional-scale climate systems and events (e.g. IPWP, ENSO variability) affects the palaeo-hydroclimate of Singapore.

5.6 Conclusion

This study presents the first study of early Holocene palaeoenvironmental evolution of the mouth of the Kallang River Basin, Singapore interpreted based on high-resolution sedimentological and geochemical data from sediment core

MSBH01B. The sediment record shows that coastal mangroves existed during the early Holocene (9.5 ka BP) when post-LGM sea level rise was high enough (~20 m below MSL) to introduce saline conditions to the largely fluvial system (Bird et al., 2006). The early Holocene marine transgression characterised by rapid sea level rise likely led to localised mangrove extinction within ~300 years, succeeded quickly by high sea level and possibly a river-dominated estuary from 9.2 ka – 8.8 ka BP under potentially wetter and warmer conditions. The submerged delta structure begins with prodelta muds that were deposited from 8.8 ka – 8.25 ka BP accompanied by an increase in subtidal calcareous fauna. Coarsening upward delta front sediments were deposited between 8.25 ka and 7.8 ka BP, with possible rapid coastal retreat and seabed shallowing. Superimposed here between 8.5 ka and 8 ka BP is a period of higher precipitation and weathering with dips ($\delta^{18}\text{O}$ enrichment) in the Dongge and Gunung Buda speleothem records coeval with monsoon weakening possibly associated with the 8.2 ka event (Cheng et al., 2009). With postulated SLR deceleration beginning from ~8 ka BP, a delta plain started forming with seaward progradation of coarse, shelly deltaic sediment from 7.8 ka to 7.3 ka BP. I generally see good agreement between the elemental proxy records and the cave records from Tangga in Sumatra, the most proximal high-resolution paleoclimate record to Singapore at a distance of < 500 km.

This study fills an important spatial/temporal data gap in understanding for the inner Sunda shelf palaeoenvironmental conditions during the early Holocene. It also provides a coastal evolution model for tropical marginal marine coasts in response to a changing climate and rising sea levels. Understanding past sedimentation and geomorphological processes helps us in planning and mitigating against coastal vulnerabilities exacerbated by sediment deficits (e.g. damming), nearshore erosion and urban encroachment on coastal zones which threaten not just Singapore but other cities built on floodplain and/or delta systems.

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Chapter 6

Synthesis

Through this thesis I have managed to reconstruct some key aspects of Quaternary palaeoenvironmental change for Singapore. In particular I provide key insights into the early Holocene at high resolution and a new model for Quaternary stratigraphic and morphological change of the Kallang River Basin, Singapore, over centennial timescales. I also produced an updated and extended Holocene sea level record and provided a reconstruction of the early Holocene palaeoenvironmental evolution of the Kallang River fluvio-deltaic system.

6.1. Key Results

6.1.1. New stratigraphical and chronological insights into Singapore's Quaternary deposits

In Chapter 3, I presented the first high-resolution 3-D geological model of the Quaternary deposits in the Kallang River Basin, Singapore. The model was constructed using 161 borehole logs to create 14 cross-sections augmented by the first chronological constraints on the geological units based on ^{14}C AMS and OSL dating of a ~38.5 m sediment core from Marina South (1.2726°N, 103.8653°E), and supplemented by ^{14}C AMS ages from the Geylang core (1.3137°N; 103.8917°E) (Bird et al., 2010).

The new model helped update the official understanding of Singapore's geology (DSTA, 2009) for government agencies. The Quaternary stratigraphy of the Kallang River Basin comprise the Bedok Formation (formerly Old Alluvium) interpreted as fluvial deposits of postulated Plio-Pleistocene age (Gupta et al., 1987). The Bedok Formation is unconformably overlain by a thin veneer of Tekong/Jalan Besar Formation most probably at the onset of MIS 5e (~125 ka BP), based on possibly underestimated OSL ages of ~45 ka BP. The coastal sands are coeval with the Tanjung Rhu member (Lower Marine Clay) deposited during higher sea levels at MIS 5e. Subsequent subaerial exposure of the LIG marine clays during the last interglacial produced the 'stiff clay' layer which is subsequently overlain by Holocene transgressive sands (Jalan Besar Formation) and nearshore peats (Kranji Formation) deposited around 9.5 ka BP. This sequence is overlain by the Upper Marine clay (Rochor member) which becomes prominent at ~9.2 ka BP. The marine muds are partially overlain by a sequence of regressive inland peats that were deposited ~1.2 ka BP as sea levels receded from marine highstand levels between ~2-4 ka BP.

Notably, I observed at least 3 recurrent units of the Kallang Alluvial member (new name = Jalan Besar Formation) which potentially have a ~100 ka gap in depositional age between the oldest and youngest unit. I have proposed segregating them into Jalan Besar Formation I, II and III from oldest (possible ~125 ka BP) to youngest (<2 ka BP) to recognise their similar depositional and

sedimentological properties but different time frames. We also argue ascribing the 'stiff clay' unit, which we interpret as desiccated, oxidised Lower Marine Clay (new name = Tanjung Rhu Formation), a unique name to distinguish it from the current geoengineering nomenclature of F1/F2 or fluvial sand/clay. Using an understanding of glacial-scale sea level change I provide a framework for linking facies and time (See Chapter 3 Fig. 3.7). As part of the National Stratigraphy Committee led by the Building and Construction Authority (BCA), this chapter should serve as the peer-reviewed publication introducing the reclassification of late Quaternary deposits of Singapore (i.e. Bedok Formation and Kallang Group).

The new geological model I produced also revealed a more complex geology than currently described as it comprises interdigitating sequences of mangrove peat, coastal sands and fluvio-alluvial units deposited during marine transgressive and regressive phases. Notably, I observed that the Kallang river mouth system consisted of two distinct major palaeochannels during the late Pleistocene (MIS-5e?). These contrast with the gentler single floodplain system after the LGM and into the Holocene. Such subsurface complexities underpins the dynamic changes experienced by the Kallang River Basin, as well as accentuates the difficulties and challenges for geoengineering work in this area which forms an important part of Singapore's Downtown Area.

6.1.2. Revised Holocene sea-level curve and high-resolution coastal evolution model

In chapters 3, 4 and 5 I describe a newly recovered ~38.5 m sediment core (MSBH01B) from Marina South that provided an unprecedented high-resolution window into the early Holocene, as it reached basal peats associated with the post-LGM marine transgression.

I produced 4 new sea level index points (SLIPs) obtained from basal peats from MSBH01B extended the hitherto best sea-level record for Singapore (Bird et al., 2010) into the earliest Holocene (Chapter 4). The recalibration of his data points coupled with a Bayesian modelling approach for all SLIPs produced an extended, updated and statistically-robust sea level history for Singapore. This new record reveals a period of rapid sea level rise ($> 15\text{mm/yr}$) from 9.5 ka before a slowdown at ~9 ka BP, and a 2nd slowdown between 8 ka and 6 ka BP at ~4 mm/yr. The revised curve shows a minor inflection at ~7.5 ka BP, albeit of a lower magnitude (~0.5 mm/yr) than proposed by Bird et al. (2010). We find no unequivocal evidence for notable meltwater pulses posited at 8.2 ka and 7.5 ka observed elsewhere (e.g. Liu et al., 2004; Cronin et al., 2007; Hori and Saito, 2007).

Sediment core MSBH01B contains a continuous archive of undisturbed marine and nearshore sedimentary record of coastal change from ~9.5 ka to 7.3 ka BP, which we couple with high-resolution sedimentological and geochemical

techniques to produce a coastal evolution model for Singapore during the early Holocene (~9.5 ka - 7.3 ka BP) (Chapter 5). Sediment accretion rates in the Kallang River Basin is high at an average rate of 0.47 mm/yr, which at our cm-resolution analysis translates to a palaeoenvironmental record at sub-decadal resolution.

A mangrove coast existed from ~9.5 ka – 9.2 ka BP, but became locally extinct within 300 years as estuarine conditions set in from ~9.2 ka– 8.8 ka BP, coincident with a perhaps coeval with wetter and warmer climate. Continued sea-level rise led to vertical succession to prodelta muds deposited from ~8.8 ka to 8.25 ka BP coincident with an increase in subtidal calcareous fauna. Lateral migration resulted in delta front sediments being deposited from ~8.25 ka - 7.8 ka BP. A period between 8.5 – 8 ka BP with markedly higher precipitation and weathering rates coupled with a dip coeval with monsoon weakening is a possible local expression of the 8.2 ka climate event. Finally, seaward progradation of coarse, shelly deltaic sediment occurred from 7.8 ka - 7.3 ka BP, coeval with global delta initiation (e.g. Hori and Saito, 2007; Tamura et al., 2009; Nguyen et al., 2010; Hanebuth et al., 2012; Pennington et al., 2017).

6.2 Limitations

The chief limitation pertaining to the geological modelling of the Kallang River basin (Chapter 3) is the quality of the original borehole logs. The soil investigation studies used were conducted over four decades by separate

geoengineering companies and government agencies. Thus, logging standards and rigour, the relative understanding of Singapore's geology, differing project requirements and so on, are highly variable and manifest as a body of generally poor borehole log quality. In response I attempted to mitigate this through careful borehole selection, avoiding unit descriptions that lack the necessary detail and attempting to standardize those that required more accurate interpretation, for example between Tekong (littoral) and Jalan Besar (fluvial/alluvial) Formations.

Further, several large data gaps exist between transects F – F' and G - G' which cannot currently be addressed due to insufficient borehole data for these regions (i.e. Tanjung Rhu, Marine Parade, East Coast Road). This spatial gap may hide complex coastal geology which developed soon after the initial transgression phases of each interglacial sea-level maximum.

The chronology of the Holocene units is well constrained by ^{14}C dates, but those associated with MIS 5e remain poorly dated as they exceed radiocarbon limits. Although the OSL dates of the littoral deposits of the basal contact with the Bedok Formation gave a minimum age, the problem of incomplete bleaching and variable dose rates associated with wet sediments meant that we did not obtain an accurate result to confidently ascribe an MIS-5e age.

We have two data gaps for the Holocene sea-level record (Chapter 4), the most obvious being the Holocene highstand records which have been largely eradicated due to the pervasive urbanisation and construction projects in the past decades. Such work has removed all natural surficial material. Past records were obtained from coral and other biological indicators (Tjia, 1996; Hesp et al., 1998), but these are poorly constrained due to elevation uncertainties of these samples and uncertain reservoir ages. Another data gap is located at depths of between 10 and 15 m below MSL which spans the period between 8 ka and 9 ka BP which is critical for detecting postulated sea level change events associated with the 8.2 ka event. We further attempted to produce a compaction-free sea-level curve. The initial results look promising but we lack an adequate number of compaction-free basal SLIPs.

The sediment archives in Chapter 5 contain independent palaeoclimate proxy records through the elemental and stable isotope data. However, the climate events (e.g. monsoons) are often at annual and sub-annual scale which cannot be resolved at our current sampling resolution. The use of bulk organic stable isotope data, although used extensively in sea level and palaeoenvironmental reconstruction (e.g. Wilson et al., 2005; Lamb et al., 2007; Yu et al., 2011; Zhan et al., 2011; Khan et al., 2015), is nonetheless a non-specific indicator useful at coarse scales for coastline and/or carbon source proximity (Bouillon et al., 2008).

6.3. Future Studies

The Quaternary deposits of the Kallang River basin provide insights into late Pleistocene and Holocene geomorphological changes as well as early Holocene sea level, coastal change and palaeoenvironments. Developing an understanding of local and regional palaeoenvironmental evolution has both scientific and geoengineering implications. In the future it may be beneficial to do the following in order to improve our findings and refine our conclusions:

- (1) It would be good to obtain new borehole data to create a new transect between transects F – F' and G - G' as well as update existing transects with more recent borehole logs. To improve chronology, it may be beneficial to aim to complement the OSL chronologies for the Tanjung Rhu member with oxygen isotope ($\delta^{18}\text{O}$) records obtained from foraminifera, where we will compare with other palaeoclimate records to refine our chronology. Some early attempts have been made but thus far failed to find good foraminiferal specimen for isotopic analysis.
- (2) Apart from MSBH01B, we obtained high-recovery sediment cores from 3 other sites in Singapore (see Table 6.1) along 3 different palaeochannels. These cores all contain intertidal peats of varying depths which have the potential to fill in data gaps in the sea level curve, in particular between -10 to 15 m (~8 and 9 ka BP). We also hope to identify highstand regressive peats of ~3 m in height to better constrain the timing of the Holocene highstand and sea level elevations for

Singapore and the region. Some papers postulate fluctuations in sea level during the mid-Holocene conditions (Tjia, 1996; Meltzner et al., 2017) which can potentially be addressed if we obtain sufficient viable samples.

Table 6.1. Locations of 8 sediment cores obtained at 4 locations in the Kallang River basin

Location ID	Start Depth (above MSL)	Final Depth	Latitude	Longitude
MS-BH-01	4.214m	32.63m	1.272667447	103.8653
MS-BH-01B	4.079m	50.09m	1.272678553	103.8653
KA-BH-02	3.100m	22.92m	1.319526586	103.8795
KA-BH-02B	3.020m	23.88m	1.319524506	103.8795
GR-BH-03	2.815m	25.00m	1.309357034	103.8852
GR-BH-03B	2.720m	24.42m	1.309347448	103.8852
BR-BH-04	1.700m	23.78m	1.29715953	103.8579
BR-BH-04B	1.740m	23.30m	1.297172644	103.8579

(3) The sediment cores we obtained from Marina South, Beach Road, Guillemard Road and Kolam Ayer, augmented with data from 5 sediment cores by Bird et al. (2007) within the Kallang River Basin (KRB), potentially provide reliable stratigraphic and chronological constraints to enable the production of a high-resolution time-sliced evolution model for the KRB. This model will test the coastal evolution hypothesis, and answer other science questions pertaining to morphological changes of the KRB coastal plain, palaeohydrological changes, palaeochannel mapping and sediment flux and source.

- (4) Dating and analyzing the most inland sediment core (KABH01) at cm-scale resolution will extend our current understanding of coastal evolution of the fluvio-deltaic KRB by covering the mid or even late Holocene. A current project aims to augment the KRB dataset with a separate study on the Jurong Lake area using similar protocols. As that area is currently undergoing intensive redevelopment, it may be possible to acquire new borehole data and sediment core samples to compare with results here to provide spatial confirmation. Mid-Holocene peat samples have already been identified in sediment cores in Jurong which will contain vertical highstand elevations and address the question about multi-staged or more linear sea level fall during the mid-late Holocene.
- (5) The results hint of the 8.2 ka event (Alley et al., 1997) being recorded in the sediments, both in terms of possible rapid sea level change (Chapter 4) and sedimentological properties (Chapter 5) during that time period. One future aim may be to focus on this important window by obtaining more ^{14}C AMS dates from the relevant core segment, and XRF-scanning the segment at higher resolution (i.e. mm-scale) which have been successful in Cuba (Peros et al., 2017). By analysing the CT-scans (Computed Tomography) of the core segment we aim to identify micro-laminations and features associated with sudden sea level rise and/or sediment flux associated with atmospheric cooling/monsoon weakening

(Li et al., 2014; Oster et al., 2017). To improve on the palaeoclimate proxies, it may be beneficial to obtain more specific geochemical indicators, for example isolating and analyzing lipid biomarkers from phytoplankton (e.g. Gong and Zhang, 2015) or long-chain n-alkanes (e.g. Hu et al., 2003) derived from leaf waxes of higher vascular plants found in sediments, or $\delta^{18}\text{O}$ records from benthic foraminifera (e.g. Wendler et al., 2016) specifically from this portion of the core.

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APPENDIX 1

Raw data from sediment core MSBH01B

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
OD1	11.60	7.52	-	-	-	-	-	5.401	11.204	1.749	1.278	26.916
OD1	11.61	7.53	-	-	-	-	-	5.901	11.190	1.758	1.267	27.934
OD1	11.62	7.54	-	-	-	-	-	6.209	11.642	2.020	1.483	26.567
OD1	11.63	7.55	-	-	-	-	-	5.073	12.368	1.677	1.246	25.657
OD1	11.64	7.56	-	-	-	-	-	5.216	12.937	1.717	1.279	25.524
OD1	11.65	7.57	-	-	-	-	-	5.727	12.156	1.682	1.252	25.575
OD1	11.66	7.58	-	-	-	-	-	3.659	12.734	1.655	1.233	25.499
OD1	11.67	7.59	-	-	-	-	-	5.194	13.215	1.512	1.105	26.945
OD1	11.68	7.60	-	-	-	-	-	5.069	11.438	1.861	1.368	26.464
OD1	11.69	7.61	-	-	-	-	-	4.703	11.243	1.770	1.314	25.762
OD1	11.70	7.62	-	-	-	-	-	4.705	10.844	1.760	1.299	26.173
OD1	11.71	7.63	-	-	-	-	-	8.837	11.337	1.864	1.390	25.447
OD1	11.72	7.64	-	-	-	-	-	4.927	11.429	1.685	1.240	26.412
OD1	11.73	7.65	-	-	-	-	-	4.719	12.805	1.665	1.238	25.681
OD1	11.74	7.66	-	-	-	-	-	4.401	11.836	1.819	1.360	25.241
OD1	11.75	7.67	-	-	-	-	-	3.915	12.829	2.036	1.539	24.423
OD1	11.76	7.68	-	-	-	-	-	4.035	13.129	1.506	1.155	23.320
OD1	11.77	7.69	-	-	-	-	-	4.217	13.104	1.760	1.346	23.531
OD1	11.78	7.70	-	-	-	-	-	4.967	12.235	1.748	1.316	24.720
OD1	11.79	7.71	-	-	-	-	-	4.275	11.022	1.772	1.322	25.399
OD1	11.80	7.72	-	-	-	-	-	5.124	13.634	1.724	1.220	29.250
OD1	11.81	7.73	-	-	-	-	-	4.047	11.779	1.642	1.241	24.408
OD1	11.82	7.74	-	-	-	-	-	5.153	11.352	1.567	1.122	28.377
OD1	11.83	7.75	-	-	-	-	-	5.371	10.672	1.663	1.179	29.091
OD1	11.84	7.76	-	-	-	-	-	5.403	10.941	1.779	1.280	28.074
OD1	11.85	7.77	-	-	-	-	-	4.568	12.043	1.680	1.243	26.029
OD1	11.86	7.78	-	-	-	-	-	4.341	13.316	1.715	1.292	24.689
OD1	11.87	7.79	-	-	-	-	-	5.018	11.673	1.638	1.198	26.842
OD1	11.88	7.80	-	-	-	-	-	4.611	12.477	1.667	1.232	26.086
OD1	11.89	7.81	-	-	-	-	-	4.062	12.919	1.773	1.341	24.361

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
OD1	11.90	7.82	-	-	-	-	-	3.778	12.031	1.733	1.323	23.669
OD1	11.91	7.83	-	-	-	-	-	3.775	13.455	1.958	1.485	24.139
OD1	11.92	7.84	-	-	-	-	-	4.162	13.230	1.727	1.317	23.733
OD1	11.93	7.85	-	-	-	-	-	4.118	11.672	1.698	1.289	24.126
OD1	11.94	7.86	-	-	-	-	-	4.059	13.360	1.845	1.397	24.252
OD1	11.95	7.87	-	-	-	-	-	3.931	13.408	1.833	1.395	23.926
OD1	11.96	7.88	-	-	-	-	-	3.801	15.789	1.709	1.306	23.566
OD1	11.97	7.89	-	-	-	-	-	4.102	13.038	1.811	1.360	24.873
OD1	11.98	7.90	-	-	-	-	-	4.099	12.661	1.934	1.455	24.757
OD1	11.99	7.91	-	-	-	-	-	3.754	13.017	1.958	1.491	23.852
OD1	12.00	7.92	-	-	-	-	-	4.104	12.382	1.688	1.242	26.407
OD1	12.01	7.93	-	-	-	-	-	4.378	9.760	1.785	1.295	27.443
OD1	12.02	7.94	-	-	-	-	-	4.064	11.661	1.697	1.233	27.343
OD1	12.03	7.95	-	-	-	-	-	4.317	14.242	1.367	1.012	25.969
OD1	12.04	7.96	-	-	-	-	-	3.972	13.331	1.620	1.207	25.510
OD1	12.05	7.97	-	-	-	-	-	4.213	12.224	1.503	1.088	27.618
OD1	12.06	7.98	-	-	-	-	-	3.821	13.104	1.522	1.125	26.074
OD1	12.07	7.99	-	-	-	-	-	3.828	12.216	1.963	1.456	25.819
OD1	12.08	8.00	-	-	-	-	-	4.495	10.470	1.658	1.212	26.918
OD1	12.09	8.01	-	-	-	-	-	4.352	11.495	1.982	1.454	26.623
OD1	12.10	8.02	-	-	-	-	-	4.117	12.553	1.838	1.370	25.440
OD1	12.11	8.03	-	-	-	-	-	4.097	12.182	1.648	1.221	25.936
OD1	12.12	8.04	-	-	-	-	-	4.494	11.080	1.807	1.304	27.802
OD1	12.13	8.05	-	-	-	-	-	4.490	11.520	1.373	0.987	28.160
OD1	12.14	8.06	-	-	-	-	-	4.611	11.055	1.677	1.217	27.402
OD1	12.15	8.07	-	-	-	-	-	4.097	11.464	1.671	1.229	26.478
OD1	12.16	8.08	-	-	-	-	-	4.718	11.283	1.485	1.043	29.789
OD1	12.17	8.09	-	-	-	-	-	4.256	8.347	1.949	1.410	27.648
OD1	12.18	8.10	-	-	-	-	-	4.097	11.464	1.671	1.229	26.478
OD1	12.19	8.11	-	-	-	-	-	4.478	9.278	1.829	1.334	27.040

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
OD1	12.20	8.12	-	-	-	-	-	3.894	9.988	2.127	1.620	23.859
OD1	12.21	8.13	-	-	-	-	-	4.959	8.774	1.763	1.236	29.855
OD1	12.22	8.14	-	-	-	-	-	5.120	9.893	1.669	1.165	30.218
OD1	12.23	8.15	-	-	-	-	-	5.010	11.464	1.792	1.298	27.584
OD1	12.24	8.16	-	-	-	-	-	4.927	11.265	1.706	1.220	28.507
OD1	12.25	8.17	-	-	-	-	-	4.928	10.899	1.348	0.972	27.923
OD1	12.26	8.18	-	-	-	-	-	5.475	7.624	1.664	1.144	31.235
OD1	12.27	8.19	-	-	-	-	-	5.376	8.891	1.809	1.259	30.420
OD1	12.28	8.20	-	-	-	-	-	6.094	8.672	1.315	0.909	30.867
OD1	12.29	8.21	-	-	-	-	-	6.769	6.942	1.680	1.130	32.756
OD1	12.30	8.22	-	-	-	-	-	5.346	7.490	1.564	1.082	30.819
OD1	12.31	8.23	-	-	-	-	-	5.272	7.880	1.662	1.153	30.633
OD1	12.32	8.24	-	-	-	-	-	5.141	8.047	1.690	1.170	30.787
OD1	12.33	8.25	-	-	-	-	-	4.929	7.742	1.857	1.313	29.316
OD1	12.34	8.26	-	-	-	-	-	4.905	6.940	1.818	1.278	29.683
OD1	12.35	8.27	-	-	-	-	-	5.050	5.617	1.662	1.152	30.706
OD1	12.36	8.28	-	-	-	-	-	5.065	5.312	1.719	1.187	30.918
OD1	12.37	8.29	-	-	-	-	-	5.198	4.778	1.590	1.088	31.607
OD1	12.38	8.30	-	-	-	-	-	5.444	7.301	1.826	1.267	30.625
OD1	12.39	8.31	-	-	-	-	-	5.520	6.452	1.819	1.261	30.656
OD1	12.40	8.32	-	-	-	-	-	5.269	4.611	1.654	1.141	31.015
OD1	12.41	8.33	-	-	-	-	-	4.964	5.455	1.617	1.132	29.972
OD1	12.42	8.34	-	-	-	-	-	4.922	7.397	1.686	1.202	28.726
OD1	12.43	8.35	-	-	-	-	-	5.010	7.960	1.832	1.298	29.140
OD1	12.44	8.36	-	-	-	-	-	5.103	7.483	1.758	1.236	29.716
OD1	12.45	8.37	-	-	-	-	-	5.084	4.102	1.656	1.131	31.689
P1	12.50	8.42	-24.40	1.31	12.20	256.1	-	6.014	8.322	1.378	1.005	27.078
P1	12.51	8.43				387	-	5.988	6.222	1.667	1.197	28.198
P1	12.52	8.44	-24.71	1.02	12.00	588	-	5.485	8.974	1.971	1.424	27.757
P1	12.53	8.45				822	-	6.128	3.718	1.688	1.160	31.277

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P1	12.54	8.46	-24.78	0.97	12.50	1014.1	-	6.062	3.472	1.748	1.186	32.143
P1	12.55	8.47				1223	-	5.934	3.535	1.902	1.294	31.970
P1	12.56	8.48	-25.15	0.94	12.80	1458	-	5.756	3.955	1.600	1.093	31.678
P1	12.57	8.49				1700.1	-	5.261	4.648	1.829	1.266	30.802
P1	12.58	8.50	-26.71	1.24	18.00	1940.4	-	5.128	5.934	1.924	1.338	30.428
P1	12.59	8.51				2180.1	-	5.656	7.791	1.516	1.081	28.727
P1	12.60	8.52	-24.28	1.05	11.60	2407.6	-	5.571	7.502	1.460	1.039	28.836
P1	12.61	8.53				2643.4	-	5.429	7.661	1.809	1.288	28.793
P1	12.62	8.54	-24.81	1.30	12.80	2854.1	-	5.413	5.061	1.692	1.201	29.013
P1	12.63	8.55				3060.1	-	5.602	3.168	1.496	1.032	31.057
P1	12.64	8.56	-24.62	0.86	11.70	3254.5	-	5.840	2.994	1.625	1.102	32.146
P1	12.65	8.57				3455.1	-	5.632	5.125	1.594	1.097	31.187
P1	12.66	8.58	-24.00	1.18	11.40	3638.5	-	5.403	8.801	2.055	1.458	29.071
P1	12.67	8.59				3838.9	-	4.543	9.086	1.666	1.218	26.847
P1	12.68	8.60	-24.25	1.15	11.70	3998.5	-	4.769	8.297	2.007	1.492	25.624
P1	12.69	8.61				4145.2	-	5.728	8.358	1.402	1.027	26.756
P1	12.70	8.62	-24.13	1.06	11.30	4322	-	5.692	9.040	1.599	1.171	26.738
P1	12.71	8.63				4459.3	-	5.975	4.472	1.475	1.015	31.192
P1	12.72	8.64	-24.73	0.94	12.40	4586	-	5.693	5.100	1.821	1.269	30.318
P1	12.73	8.65				4724.3	-	5.320	4.206	1.666	1.173	29.580
P1	12.74	8.66	-25.06	0.89	13.10	4855.6	-	5.359	3.572	1.656	1.153	30.406
P1	12.75	8.67				5000.5	-	5.080	4.125	1.862	1.312	29.504
P1	12.76	8.68	-25.60	1.08	13.80	5125.2	-	5.193	4.202	1.747	1.221	30.129
P1	12.77	8.69				5248	-	5.456	4.163	1.800	1.264	29.780
P1	12.78	8.70	-26.60	1.05	16.00	5370.5	-	4.996	3.903	1.750	1.256	28.235
P1	12.79	8.71				5491.3	-	5.111	3.927	1.812	1.298	28.355
P1	12.80	8.72	-25.05	0.60	13.20	5612.5	-	4.918	4.862	1.612	1.170	27.448
P1	12.81	8.73				5735.3	-	4.649	7.061	2.062	1.504	27.064
P1	12.82	8.74	-25.31	0.85	14.10	5856.2	-	4.367	6.078	1.704	1.280	24.895
P1	12.83	8.75				5980.2	-	3.786	5.845	1.962	1.501	23.484

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P1	12.84	8.76	-25.33	0.62	14.00	6106.1	-	3.949	5.451	1.769	1.335	24.517
P1	12.85	8.77				6230	-	4.165	5.199	1.465	1.088	25.714
P1	12.86	8.78	-25.32	0.81	14.60	6344	-	3.702	5.289	2.045	1.576	22.938
P1	12.87	8.79				6462	-	4.467	5.419	1.699	1.262	25.751
P1	12.88	8.80	-25.68	1.09	14.80	6583	-	5.054	4.321	1.697	1.227	27.673
P1	12.89	8.81				6717	-	5.548	4.203	1.665	1.178	29.257
P1	12.90	8.82	-26.56	1.31	18.90	6854.1	-	5.542	4.395	1.782	1.247	30.029
P1	12.91	8.83				6995.1	-	5.529	4.631	1.708	1.188	30.437
P1	12.92	8.84	-25.65	0.97	14.30	7136	-	5.406	3.473	1.434	0.997	30.431
P1	12.93	8.85				7270	-	5.143	3.591	1.557	1.079	30.690
P1	12.94	8.86	-25.91	1.09	14.80	7283	-	4.823	3.798	1.817	1.308	28.009
P1	12.95	8.87				7285	-	4.853	3.667	1.698	1.212	28.618
P1	12.96	8.88	-25.15	0.86	13.60	7286.1	-	5.020	4.174	1.738	1.237	28.827
P1	12.97	8.89				7288	-	5.334	3.133	1.813	1.262	30.377
P1	12.98	8.90	-26.49	1.47	19.60	7289	-	5.662	2.805	1.809	1.247	31.100
P1	12.99	8.91				7290	-	6.140	2.608	1.774	1.203	32.185
P1	13.00	8.92	-26.01	1.15	16.20	7292	-	5.549	2.732	1.679	1.160	30.907
P1	13.01	8.93				7293	-	5.834	2.890	1.781	1.221	31.431
P1	13.02	8.94	-25.85	1.00	15.30	7294.1	-	5.913	3.000	1.642	1.122	31.654
P1	13.03	8.95				7296	-	5.895	2.766	1.889	1.308	30.781
P1	13.04	8.96	-26.57	1.26	19.00	7297	-	5.965	2.845	1.545	1.068	30.873
P1	13.05	8.97				7298	-	5.835	2.843	1.575	1.092	30.650
P1	13.06	8.98	-25.86	1.03	15.40	7299	-	5.604	2.919	1.598	1.120	29.939
P1	13.07	8.99				7300.1	-	5.485	2.811	1.675	1.186	29.224
P1	13.08	9.00	-26.12	0.90	15.30	7302	-	5.250	3.413	1.758	1.264	28.136
P1	13.09	9.01				7303.1	-	5.284	3.630	1.627	1.166	28.301
P1	13.10	9.02	-26.29	1.00	16.80	7304	-	5.542	3.231	1.716	1.218	29.042
P1	13.11	9.03				7305.1	-	5.390	3.179	1.626	1.159	28.723
P1	13.12	9.04	-26.11	1.10	17.20	7307	-	4.873	3.350	1.321	0.966	26.875
P1	13.13	9.05				7308	-	5.300	3.225	1.421	1.024	27.983

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P1	13.14	9.06	-26.60	0.90	16.90	7309	-	5.482	2.775	1.358	0.966	28.864
P1	13.15	9.07				7310	-	5.044	4.588	1.476	1.075	27.126
P1	13.16	9.08	-26.24	1.00	16.30	7310.1	-	5.734	2.713	1.508	1.060	29.692
P1	13.17	9.09				7311.1	-	5.842	2.827	1.480	1.041	29.713
P1	13.18	9.10	-26.48	1.10	16.90	7313	-	5.534	2.849	1.677	1.205	28.190
P1	13.19	9.11				7314	-	5.571	3.005	1.343	0.968	27.932
P1	13.20	9.12	-27.76	1.50	22.00	7315	-	5.274	3.347	1.687	1.221	27.644
P1	13.21	9.13				7317	-	5.466	3.567	1.579	1.136	28.063
P1	13.22	9.14	-26.68	0.60	17.40	7318	-	5.218	4.253	1.734	1.265	27.032
P1	13.23	9.15				7319	-	5.398	4.341	1.616	1.175	27.321
P1	13.24	9.16	-27.42	1.40	23.70	7320	-	5.567	3.495	1.825	1.309	28.259
P1	13.25	9.17				7322	-	5.737	2.922	1.714	1.219	28.898
P1	13.26	9.18	-27.35	1.40	22.00	7323	-	6.343	3.462	1.541	1.123	27.120
P1	13.27	9.19				7325.1	-	6.122	3.036	1.882	1.324	29.670
P1	13.28	9.20	-27.99	1.50	23.60	7328	-	6.478	2.793	1.563	1.100	29.661
P1	13.29	9.21				7331	11	6.648	2.454	1.662	1.145	31.099
P1	13.30	9.22	-27.39	1.60	24.10	7336	6	5.584	3.348	1.692	1.229	27.352
P1	13.31	9.23				7341	3	5.106	3.849	1.660	1.248	24.838
P1	13.32	9.24	-27.38	1.10	22.30	7344.1	3	4.332	6.142	1.641	1.309	20.244
P1	13.33	9.25				7348	2	3.720	7.088	1.377	1.150	16.487
P1	13.34	9.26	-26.93	1.20	22.90	7351	2	4.578	6.253	1.867	1.463	21.604
P1	13.35	9.27				7353.1	2	5.368	4.959	1.485	1.120	24.576
P1	13.36	9.28				7355.1	2	6.965	10.366	1.342	0.999	25.524
P2	13.396	9.317	-26.67	1.50	20.10	7363	2	5.568	3.312	1.608	1.156	28.090
P2	13.406	9.327				7365	2	5.542	4.125	1.477	1.048	29.028
P2	13.416	9.337	-26.00	1.00	15.50	7367.1	2	5.970	4.887	1.614	1.117	30.802
P2	13.426	9.347				7369.1	2	7.893	2.937	1.854	1.279	30.977
P2	13.436	9.357	-26.38	1.10	18.50	7371.1	2	7.620	2.568	1.718	1.184	31.101
P2	13.446	9.367				7373	2	8.197	2.352	1.978	1.375	30.464
P2	13.456	9.377	-27.00	1.30	20.50	7375.1	2	7.245	2.406	1.839	1.263	31.313

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P2	13.466	9.387				7377	2	6.911	2.446	1.776	1.229	30.769
P2	13.476	9.397	-25.47	0.98	14.10	7380	2	7.205	2.333	1.837	1.262	31.290
P2	13.486	9.407				7381.1	2	7.819	2.248	1.850	1.295	29.993
P2	13.496	9.417	-26.02	1.10	17.60	7384	2	7.238	2.041	1.927	1.363	29.260
P2	13.506	9.427				7386	2	7.383	2.186	1.727	1.214	29.685
P2	13.516	9.437	-26.00	1.10	17.50	7388.1	2	7.895	2.114	2.101	1.500	28.611
P2	13.526	9.447				7391	2	7.784	2.137	2.032	1.453	28.502
P2	13.536	9.457	-25.87	0.90	15.90	7394	2	7.039	2.143	1.770	1.235	30.225
P2	13.546	9.467				7396	2	7.909	1.935	1.937	1.368	29.379
P2	13.556	9.477	-25.98	0.90	16.40	7398	2	7.230	2.832	1.853	1.315	29.012
P2	13.566	9.487				7401	3	8.409	2.571	2.140	1.551	27.524
P2	13.576	9.497	-26.07	1.10	17.60	7403	3	7.713	2.498	2.048	1.492	27.174
P2	13.586	9.507				7406	6	7.727	3.036	2.004	1.442	28.022
P2	13.596	9.517	-27.46	1.70	25.70	7410	14	5.643	5.352	2.011	1.459	27.441
P2	13.606	9.527				7416	21	5.830	4.575	1.758	1.250	28.903
P2	13.616	9.537	-25.50	0.90	15.10	7423	23	5.335	3.910	1.380	0.986	28.534
P2	13.626	9.547				7429.1	19	6.490	4.708	2.248	1.631	27.442
P2	13.636	9.557	-26.09	0.90	17.10	7437	16	10.131	2.565	1.777	1.237	30.400
P2	13.646	9.567				7448.1	14	8.206	2.060	1.398	0.955	31.669
P2	13.656	9.577	-25.77	1.00	16.40	7460	13	9.390	2.512	2.122	1.541	27.403
P2	13.666	9.587				7471	12	7.873	2.980	2.019	1.459	27.761
P2	13.676	9.597	-27.28	1.40	28.50	7480	12	8.582	2.622	1.927	1.416	26.523
P2	13.686	9.607				7487.2	11	5.059	3.030	1.761	1.311	25.532
P2	13.696	9.617	-25.92	0.90	15.50	7497.1	11	8.432	1.924	1.846	1.349	26.935
P2	13.706	9.627				7507.1	10	9.258	1.621	1.811	1.305	27.967
P2	13.716	9.637	-26.08	0.90	16.80	7516.2	10	10.923	1.788	1.832	1.308	28.606
P2	13.726	9.647				7526.1	9	11.673	1.789	1.944	1.433	26.302
P2	13.736	9.657	-26.19	1.00	17.70	7533	9	10.985	1.732	1.720	1.240	27.925
P2	13.746	9.667				7541.1	9	13.659	1.603	1.880	1.379	26.648
P2	13.756	9.677	-25.74	1.00	15.60	7548.1	9	11.969	1.983	1.859	1.373	26.129

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P2	13.766	9.687				7556	8	9.917	2.640	1.801	1.347	25.191
P2	13.776	9.697	-26.05	1.00	16.80	7561.1	8	10.693	1.944	1.794	1.331	25.762
P2	13.786	9.707				7570	8	12.971	1.592	2.003	1.504	24.907
P2	13.796	9.717	-26.17	0.90	17.50	7575	8	14.211	1.695	2.055	1.546	24.768
P2	13.806	9.727				7580.1	8	5.507	2.534	1.916	1.328	30.711
P2	13.816	9.737	-26.01	0.90	15.70	7586	8	5.934	2.260	1.815	1.260	30.606
P2	13.826	9.747				7590.2	8	6.220	1.989	1.848	1.285	30.468
P2	13.836	9.757	-26.10	0.80	15.00	7594.1	7	5.835	2.501	1.850	1.281	30.775
P2	13.846	9.767				7599	7	6.606	2.017	1.855	1.283	30.809
P2	13.856	9.777	-26.42	1.10	17.50	7603	7	6.474	2.277	1.836	1.264	31.124
P2	13.866	9.787				7607	7	6.204	2.185	1.772	1.211	31.618
P2	13.876	9.797	-26.37	1.00	15.90	7611	7	6.624	2.092	1.922	1.312	31.712
P2	13.886	9.807				7615	7	6.607	1.969	1.769	1.212	31.498
P2	13.896	9.817	-26.46	1.00	16.50	7618.1	7	6.884	2.141	1.947	1.343	31.012
P2	13.906	9.827				7625	7	6.652	1.908	1.884	1.302	30.893
P2	13.916	9.837	-26.41	1.00	16.80	7629.1	7	6.742	1.856	1.903	1.338	29.705
P2	13.926	9.847				7634.1	7	6.382	1.912	1.803	1.265	29.840
P2	13.936	9.857	-26.58	1.00	18.20	7637.1	7	6.947	1.952	1.854	1.289	30.490
P2	13.946	9.867				7641	7	7.192	2.081	1.855	1.272	31.425
P2	13.956	9.877	-26.07	0.80	14.80	7644.1	7	4.927	11.037	1.816	1.326	26.957
P2	13.966	9.887				7648.1	6	5.583	9.107	1.828	1.317	27.959
P2	13.976	9.897	-25.72	1.40	15.50	7652.1	6	4.619	9.875	1.906	1.436	24.640
P2	13.986	9.907				7657	6	4.583	6.111	1.949	1.469	24.641
P2	13.996	9.917	-26.42	0.79	21.43	7660	6	6.945	2.025	1.801	1.275	29.183
P2	14.006	9.927				7663.1	7	8.381	1.844	1.912	1.365	28.640
P2	14.016	9.937	-26.56	0.84	21.59	7666	7	6.880	1.751	1.871	1.325	29.158
P2	14.026	9.947				7669	7	6.158	2.178	1.712	1.215	29.013
P2	14.036	9.957	-26.20	1.30	16.30	7671	7	8.806	1.820	1.881	1.347	28.388
P2	14.046	9.967				7676.1	6	8.805	1.946	1.837	1.310	28.678
P2	14.056	9.977	-26.34	1.10	16.00	7681	7	8.879	1.868	1.868	1.347	27.887

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P2	14.066	9.987				7683	6	7.814	2.264	2.053	1.472	28.276
P2	14.076	9.997	-26.26	1.00	15.90	7686	6	7.385	2.040	1.626	1.137	30.050
P2	14.086	10.007				7688.1	6	8.199	2.025	1.888	1.339	29.051
P2	14.096	10.017	-26.36	1.10	16.50	7691.1	7	8.786	2.028	1.782	1.257	29.452
P2	14.106	10.027				7694.1	6	8.199	2.025	1.888	1.339	29.051
P2	14.116	10.037	-26.38	0.90	16.60	7697.2	6	7.385	2.040	1.626	1.137	30.050
P2	14.126	10.047				7700.2	6	8.236	1.947	1.969	1.393	29.273
P2	14.136	10.057	-25.98	0.90	15.60	7704.1	6	6.649	2.016	1.558	1.086	30.285
P2	14.146	10.067				7708	7	7.127	2.029	1.830	1.289	29.589
P2	14.156	10.077	-26.15	0.90	16.00	7710	6	6.268	3.269	1.869	1.329	28.856
P2	14.166	10.087				7713	7	6.386	2.203	1.683	1.172	30.355
P2	14.176	10.097	-26.04	0.90	15.70	7715	6	7.465	1.872	1.869	1.292	30.885
P2	14.186	10.107				7718	6	7.371	2.088	1.512	1.033	31.684
P2	14.196	10.117	-26.00	0.90	15.50	7721	6	7.518	2.175	1.530	1.052	31.233
P2	14.206	10.127				7723	6	6.900	2.045	1.298	0.895	31.060
P3	14.244	10.165	-25.84	1.00	13.80	7731	6	5.337	1.894	2.173	1.519	30.110
P3	14.254	10.175				7733	6	5.495	1.979	1.821	1.255	31.084
P3	14.264	10.185	-26.08	1.00	15.80	7736	6	5.349	1.979	1.768	1.222	30.874
P3	14.274	10.195				7738.1	6	5.280	2.064	1.783	1.219	31.617
P3	14.284	10.205	-26.31	1.00	17.20	7741	7	5.614	1.803	1.854	1.269	31.541
P3	14.294	10.215				7744	6	5.536	1.768	1.867	1.275	31.712
P3	14.304	10.225	-26.00	0.90	15.00	7746	6	5.460	1.900	1.780	1.221	31.412
P3	14.314	10.235				7749	6	5.549	1.985	1.993	1.366	31.459
P3	14.324	10.245	-26.24	0.90	16.00	7751	7	5.568	1.922	1.952	1.326	32.044
P3	14.334	10.255				7753	7	6.333	1.999	2.013	1.357	32.581
P3	14.344	10.265	-25.98	0.90	15.60	7756	6	6.105	2.170	1.919	1.295	32.505
P3	14.354	10.275				7759	7	6.073	2.075	1.902	1.292	32.108
P3	14.364	10.285	-26.27	0.90	15.80	7761	7	6.099	2.277	1.731	1.163	32.830
P3	14.374	10.295				7764	7	5.717	2.585	1.982	1.315	33.658
P3	14.384	10.305	-26.31	0.90	17.40	7766	7	5.940	2.186	1.892	1.271	32.832

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P3	14.394	10.315				7770	7	5.513	2.077	1.946	1.322	32.074
P3	14.404	10.325	-26.25	1.00	17.00	7773	7	5.804	2.552	1.942	1.306	32.744
P3	14.414	10.335				7775	7	5.652	2.170	1.784	1.220	31.630
P3	14.424	10.345	-26.10	1.00	17.30	7778.1	7	5.930	2.015	2.041	1.411	30.884
P3	14.434	10.355				7781	7	5.689	1.808	1.972	1.356	31.245
P3	14.444	10.365	-26.03	1.00	15.90	7784	7	5.513	2.058	1.809	1.239	31.533
P3	14.454	10.375				7787	7	5.587	1.990	1.883	1.281	31.956
P3	14.464	10.385	-26.48	1.00	17.60	7789	7	5.052	2.068	1.812	1.248	31.122
P3	14.474	10.395				7792	7	5.970	1.998	2.058	1.407	31.634
P3	14.484	10.405	-26.41	1.10	17.90	7795	8	5.472	1.971	1.846	1.260	31.740
P3	14.494	10.415				7798	8	5.837	2.053	1.934	1.321	31.683
P3	14.504	10.425	-25.94	1.00	15.60	7801	8	5.791	2.077	2.075	1.416	31.748
P3	14.514	10.435				7805	8	5.960	2.068	1.966	1.343	31.654
P3	14.524	10.445	-25.23	1.10	17.00	7809	8	6.586	2.114	1.954	1.345	31.164
P3	14.534	10.455				7813	8	6.238	2.199	1.984	1.367	31.094
P3	14.544	10.465	-25.43	0.90	15.30	7817	8	6.328	2.386	1.912	1.301	31.943
P3	14.554	10.475				7820	8	6.009	2.207	1.796	1.229	31.568
P3	14.564	10.485	-25.64	1.20	17.10	7824	9	6.076	2.157	2.058	1.409	31.534
P3	14.574	10.495				7828	9	6.828	2.261	2.043	1.402	31.377
P3	14.584	10.505	-25.62	1.00	17.50	7832	9	6.333	2.288	1.975	1.357	31.287
P3	14.594	10.515				7836	9	5.964	2.200	1.949	1.337	31.417
P3	14.604	10.525	-25.33	1.20	17.30	7840	10	4.949	2.188	1.814	1.255	30.854
P3	14.614	10.535				7844	10	6.031	2.473	1.980	1.387	29.927
P3	14.624	10.545	-25.28	1.10	16.10	7848	11	5.987	2.156	1.855	1.288	30.550
P3	14.634	10.555				7852	12	5.647	2.146	2.078	1.447	30.382
P3	14.644	10.565	-25.25	0.90	15.70	7857	12	5.125	2.347	1.946	1.365	29.862
P3	14.654	10.575				7861	13	6.086	2.145	1.884	1.310	30.472
P3	14.664	10.585	-25.53	1.00	16.70	7866	14	4.905	2.954	1.802	1.239	31.230
P3	14.674	10.595				7870	15	4.637	3.339	1.806	1.233	31.705
P3	14.684	10.605	-25.38	0.90	14.20	7875	18	4.814	3.054	1.851	1.263	31.792

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P3	14.694	10.615				7880	21	5.285	2.865	1.746	1.175	32.728
P3	14.704	10.625	-25.44	0.90	15.80	7886	26.1	5.265	3.153	1.602	1.068	33.367
P3	14.714	10.635				7892	23	5.698	3.043	1.658	1.095	33.951
P3	14.724	10.645	-25.58	1.10	16.70	7898	13	5.010	2.614	1.769	1.200	32.132
P3	14.734	10.655				7902	10	5.090	3.152	1.860	1.265	32.010
P3	14.744	10.665	-25.79	1.00	17.00	7907	8	5.318	3.252	1.766	1.186	32.834
P3	14.754	10.675				7910	7	5.530	2.779	1.804	1.211	32.832
P3	14.764	10.685	-25.64	0.90	14.50	7915	7	5.269	2.765	1.848	1.253	32.214
P3	14.774	10.695				7919	6	5.580	2.640	1.774	1.201	32.326
P3	14.784	10.705	-25.53	1.00	15.80	7921	6	5.739	2.594	1.827	1.247	31.760
P3	14.794	10.715				7925	5.1	5.667	2.413	1.747	1.205	31.027
P3	14.804	10.725	-25.53	0.90	15.40	7928	5	5.444	2.322	1.783	1.225	31.323
P3	14.814	10.735				7934	5	5.308	2.394	1.825	1.256	31.191
P3	14.824	10.745	-25.55	1.00	15.10	7937	5	5.609	2.400	1.829	1.253	31.529
P3	14.834	10.755				7941	5	5.437	2.330	1.789	1.220	31.799
P3	14.844	10.765	-25.90	0.90	15.30	7945	4	5.927	2.317	1.789	1.213	32.201
P3	14.854	10.775				7948	4	5.983	2.403	1.876	1.278	31.864
P3	14.864	10.785	-25.51	0.90	13.90	7953	4	5.611	2.474	1.880	1.281	31.832
P3	14.874	10.795				7956	4	5.635	2.305	1.680	1.148	31.661
P3	14.884	10.805	-25.71	1.00	15.20	7959.1	4	5.696	2.401	1.870	1.279	31.580
P3	14.894	10.815				7964	4	5.437	2.345	1.798	1.226	31.819
P3	14.904	10.825	-25.69	1.00	15.00	7967	4	5.675	2.095	1.795	1.232	31.349
P3	14.914	10.835				7970	4	5.929	2.193	1.765	1.207	31.618
P3	14.924	10.845	-25.60	1.00	15.50	7973	4	5.255	1.994	1.959	1.393	28.891
P3	14.934	10.855				7977	4	5.168	2.008	1.591	1.107	30.429
P3	14.944	10.865	-25.73	1.00	15.20	7981	4	5.580	1.937	1.840	1.265	31.231
P3	14.954	10.875				7983.1	4	5.473	2.312	1.850	1.272	31.237
P3	14.964	10.885	-25.49	0.90	13.00	7986	4	5.333	1.972	1.716	1.176	31.455
P3	14.974	10.895				7989.1	4	5.180	2.035	1.793	1.237	31.050
P3	14.984	10.905	-25.18	0.90	13.40	7992	4	5.093	2.195	1.727	1.206	30.161

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P3	14.994	10.915				7995.1	3	4.869	2.200	1.585	1.114	29.697
P3	15.004	10.925	-25.96	0.90	14.80	7998.1	4	5.104	2.059	1.638	1.159	29.264
P3	15.014	10.935				8001	4	5.583	2.124	1.548	1.077	30.405
P4	15.085	11.006	-25.43	0.90	13.60	8018	3	4.851	3.501	1.733	1.186	31.599
P4	15.095	11.016				8021	3	4.934	2.509	1.720	1.159	32.592
P4	15.105	11.026	-25.73	0.90	14.40	8023.1	3	5.066	2.854	1.872	1.271	32.117
P4	15.115	11.036				8027	3	4.949	2.663	1.662	1.129	32.055
P4	15.125	11.046	-25.74	1.10	14.70	8030	3	4.624	2.622	1.624	1.109	31.663
P4	15.135	11.056				8032	3	5.273	2.407	1.791	1.208	32.518
P4	15.145	11.066	-25.82	1.10	15.20	8033	3	5.301	2.421	1.908	1.282	32.774
P4	15.155	11.076				8036	3	5.265	2.261	1.633	1.099	32.720
P4	15.165	11.086	-25.38	1.00	14.60	8038	3	4.893	2.703	1.814	1.209	33.375
P4	15.175	11.096				8041	3	5.000	2.485	1.588	1.065	32.908
P4	15.185	11.106	-25.89	1.10	16.50	8043	3	5.169	2.404	1.888	1.264	33.028
P4	15.195	11.116				8044	3	5.391	2.244	1.579	1.049	33.602
P4	15.205	11.126	-25.36	1.00	14.00	8046	3	5.067	2.440	1.834	1.219	33.547
P4	15.215	11.136				8047	3	4.967	2.426	1.722	1.132	34.276
P4	15.225	11.146	-25.47	0.90	14.80	8049	3	5.641	2.238	1.609	1.037	35.574
P4	15.235	11.156				8051	3	5.373	2.269	1.902	1.253	34.112
P4	15.245	11.166	-25.51	1.00	16.10	8053.1	3	5.056	2.071	1.816	1.215	33.081
P4	15.255	11.176				8054.1	3	5.251	2.205	1.707	1.126	34.003
P4	15.265	11.186	-25.33	1.00	15.60	8056	3	5.245	2.092	1.736	1.140	34.319
P4	15.275	11.196				8059	3	4.988	1.624	1.646	1.127	31.547
P4	15.285	11.206	-25.37	0.90	14.10	8062	3	5.242	2.709	1.945	1.303	33.025
P4	15.295	11.216				8064	3	5.455	2.132	1.564	1.042	33.361
P4	15.305	11.226	-25.56	1.00	15.70	8065.1	3	5.474	1.774	1.664	1.087	34.689
P4	15.315	11.236				8067.1	3	5.209	1.901	1.985	1.324	33.317
P4	15.325	11.246	-25.86	1.00	16.00	8069	3	5.549	1.934	1.570	1.031	34.346
P4	15.335	11.256				8070	3	5.523	2.182	1.834	1.213	33.844
P4	15.345	11.266	-25.52	0.90	15.10	8072	3	5.565	2.266	1.725	1.139	33.940

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P4	15.355	11.276				8074.1	3	5.235	2.111	1.737	1.161	33.139
P4	15.365	11.286	-25.54	1.00	14.20	8077	3	5.290	2.279	1.765	1.161	34.185
P4	15.375	11.296				8078	3	5.463	2.000	1.672	1.095	34.519
P4	15.385	11.306	-25.47	0.90	14.30	8079.1	3	5.335	2.139	1.765	1.176	33.364
P4	15.395	11.316				8081	3	5.544	2.317	1.703	1.114	34.568
P4	15.405	11.326	-25.41	0.90	14.50	8082	3	5.259	2.220	1.868	1.237	33.811
P4	15.415	11.336				8084	3	5.603	2.130	1.528	0.997	34.731
P4	15.425	11.346	-25.79	1.00	14.60	8085.1	3	5.813	2.259	1.809	1.186	34.429
P4	15.435	11.356				8087	3	5.771	2.354	1.732	1.138	34.283
P4	15.445	11.366	-26.62	1.00	15.60	8089	3	5.373	2.484	1.730	1.131	34.605
P4	15.455	11.376				8091	3	5.333	2.328	1.981	1.305	34.103
P4	15.465	11.386	-25.53	0.90	13.50	8092	3	5.497	2.472	1.864	1.242	33.357
P4	15.475	11.396				8094	3	5.649	2.694	1.698	1.128	33.577
P4	15.485	11.406	-26.19	1.10	15.90	8094.1	3	6.131	2.590	1.860	1.237	33.532
P4	15.495	11.416				8096	3	5.662	2.818	1.901	1.264	33.517
P4	15.505	11.426	-25.92	1.04	15.57	8097	3	6.299	2.769	1.820	1.204	33.878
P4	15.515	11.436				8098	3	6.169	2.411	1.885	1.261	33.125
P4	15.525	11.446	-26.34	1.00	15.90	8099	3	5.832	2.472	1.557	1.031	33.788
P4	15.535	11.456				8100.1	3	6.219	2.556	1.888	1.240	34.320
P4	15.545	11.466	-26.31	1.00	14.40	8102.1	3	6.047	2.596	1.737	1.146	34.048
P4	15.555	11.476				8104	3	6.112	2.466	1.881	1.246	33.785
P4	15.565	11.486	-25.71	1.10	16.00	8106	3	6.506	2.430	1.821	1.210	33.525
P4	15.575	11.496				8107	3	5.700	2.466	1.774	1.192	32.775
P4	15.585	11.506	-26.44	1.00	15.40	8108	3	6.207	2.344	1.843	1.227	33.452
P4	15.595	11.516				8109	3	6.029	2.334	1.768	1.176	33.487
P4	15.605	11.526	-25.84	1.00	14.70	8110	3	5.846	2.269	1.838	1.224	33.393
P4	15.615	11.536				8111.1	3	5.905	2.222	1.669	1.118	33.000
P4	15.625	11.546	-25.54	1.00	14.90	8113	3	6.486	2.171	1.805	1.204	33.279
P4	15.635	11.556				8114	3	6.654	2.218	1.777	1.179	33.670
P4	15.645	11.566	-25.61	0.90	14.00	8116	3	6.743	2.257	1.692	1.115	34.125

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P4	15.655	11.576				8118	3	6.839	2.170	1.824	1.190	34.761
P4	15.665	11.586	-25.40	0.90	13.60	8119	3	6.629	2.272	1.860	1.223	34.276
P4	15.675	11.596				8120	3	6.310	2.332	1.807	1.191	34.075
P4	15.685	11.606	-25.92	1.00	15.40	8121	3	6.629	2.391	1.912	1.257	34.251
P4	15.695	11.616				8122	3	5.748	2.277	1.727	1.148	33.523
P4	15.705	11.626	-26.37	1.10	15.70	8124	3	6.080	2.206	1.910	1.274	33.311
P4	15.715	11.636				8125.1	3	6.987	2.347	1.805	1.183	34.450
P4	15.725	11.646	-25.89	0.90	14.00	8127	3	7.016	2.473	1.847	1.216	34.171
P4	15.735	11.656				8128	3	6.601	2.316	1.723	1.129	34.472
P4	15.745	11.666	-25.55	0.80	14.10	8129	3	6.528	2.347	1.834	1.211	33.957
P4	15.755	11.676				8129.1	3	6.248	2.299	1.676	1.109	33.834
P4	15.765	11.686	-25.24	0.80	14.00	8131	3	6.024	2.356	1.652	1.096	33.683
P4	15.775	11.696				8132	3	6.658	2.327	1.825	1.208	33.817
P4	15.785	11.706	-26.05	0.80	13.00	8133	3	6.524	2.312	1.792	1.187	33.729
P4	15.795	11.716				8134	3	6.672	2.252	1.805	1.190	34.058
P4	15.805	11.726	-26.04	1.00	14.60	8135	3	6.433	2.047	1.680	1.118	33.489
P4	15.815	11.736				8136	3	6.892	2.220	1.892	1.266	33.080
P4	15.825	11.746	-26.08	1.00	15.20	8137	3	6.637	2.307	1.865	1.260	32.428
P4	15.835	11.756				8138	3	7.323	2.450	1.867	1.241	33.567
P5	15.940	11.861	-26.91	1.00	15.40	8147	3	6.602	2.489	1.946	1.308	32.774
P5	15.950	11.871				8148	3	6.544	2.164	1.617	1.079	33.255
P5	15.960	11.881	-26.40	1.00	15.40	8149	3	6.767	2.082	1.942	1.297	33.200
P5	15.970	11.891				8149.1	3	6.921	2.087	1.743	1.156	33.677
P5	15.980	11.901	-26.23	0.90	14.30	8151	3	6.450	2.075	1.699	1.132	33.391
P5	15.990	11.911				8152	3	6.684	2.228	1.833	1.218	33.583
P5	16.000	11.921	-26.76	1.10	16.00	8153	3	6.781	2.109	1.622	1.064	34.395
P5	16.010	11.931				8154	3	6.673	2.134	1.943	1.281	34.036
P5	16.020	11.941	-25.60	1.00	14.70	8155	3	6.674	2.207	1.994	1.336	33.022
P5	16.030	11.951				8157	3	6.700	2.134	1.638	1.079	34.105
P5	16.040	11.961	-26.08	0.98	15.88	8157	3	6.753	2.013	1.669	1.096	34.325

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P5	16.050	11.971				8159	3	7.171	1.929	1.628	1.056	35.113
P5	16.060	11.981	-26.17	0.99	15.43	8160	3	6.973	2.531	1.796	1.169	34.923
P5	16.070	11.991				8161	3	7.028	1.908	1.800	1.167	35.149
P5	16.080	12.001	-26.19	0.95	16.11	8162	3	7.094	2.167	1.673	1.079	35.463
P5	16.090	12.011				8163	3	7.051	2.009	1.735	1.125	35.136
P5	16.100	12.021	-26.21	1.02	16.03	8164	3	7.177	1.900	1.706	1.090	36.123
P5	16.110	12.031				8166	3	6.991	1.832	1.747	1.120	35.900
P5	16.120	12.041	-26.05	1.01	15.17	8167	3	6.887	2.061	1.656	1.062	35.857
P5	16.130	12.051				8168	3	6.922	1.864	1.640	1.059	35.405
P5	16.140	12.061	-26.39	1.05	17.06	8169	3	6.667	1.799	1.748	1.141	34.705
P5	16.150	12.071				8170	3	6.905	1.739	1.587	1.024	35.502
P5	16.160	12.081	-26.15	1.01	15.92	8171	3	6.811	1.795	1.813	1.175	35.194
P5	16.170	12.091				8172	3	6.681	1.962	1.803	1.165	35.375
P5	16.180	12.101	-26.17	1.06	15.64	8173.1	3	6.879	1.770	1.904	1.233	35.267
P5	16.190	12.111				8174	3	7.132	1.720	1.821	1.171	35.703
P5	16.200	12.121	-26.10	1.01	15.28	8175	3	6.718	1.967	1.700	1.087	36.075
P5	16.210	12.131				8176	3	6.847	1.956	1.760	1.134	35.585
P5	16.220	12.141	-26.29	0.97	15.67	8177	3	7.022	1.851	1.819	1.176	35.346
P5	16.230	12.151				8177.1	3	6.869	1.816	1.762	1.146	34.948
P5	16.240	12.161	-26.06	0.97	15.54	8178	3	7.081	1.591	1.864	1.222	34.443
P5	16.250	12.171				8178.1	3	7.002	1.727	1.882	1.230	34.647
P5	16.260	12.181	-26.05	1.05	15.58	8179.1	3	7.273	1.714	1.803	1.181	34.463
P5	16.270	12.191				8180.1	3	6.955	1.974	1.828	1.197	34.549
P5	16.280	12.201	-26.32	1.10	16.68	8182	3	6.978	1.784	1.817	1.195	34.227
P5	16.290	12.211				8183	3	7.068	1.708	1.837	1.210	34.122
P5	16.300	12.221	-25.95	0.97	14.58	8184	3	7.161	1.753	1.839	1.215	33.932
P5	16.310	12.231				8185	3	7.029	1.674	1.777	1.164	34.492
P5	16.320	12.241	-26.10	1.01	15.40	8186	3	7.015	1.742	1.734	1.133	34.647
P5	16.330	12.251				8187	3	6.811	1.876	1.884	1.239	34.253
P5	16.340	12.261	-25.96	0.98	14.57	8188	3	7.072	2.233	1.685	1.091	35.247

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P5	16.350	12.271				8189	3	6.755	2.093	1.679	1.070	36.279
P5	16.360	12.281	-25.87	1.00	14.83	8190	3	5.959	2.612	1.840	1.175	36.099
P5	16.370	12.291				8191	3	5.895	3.242	1.769	1.130	36.117
P5	16.380	12.301	-26.05	1.01	15.21	8192.1	3	5.979	2.918	1.872	1.196	36.121
P5	16.390	12.311				8194	3	6.527	4.425	1.693	1.078	36.293
P5	16.400	12.321	-26.26	1.01	15.92	8194	3	6.019	2.752	1.970	1.273	35.401
P5	16.410	12.331				8196	3	5.910	3.096	1.914	1.226	35.923
P5	16.420	12.341	-26.24	1.06	15.86	8197	3	6.037	2.845	1.654	1.050	36.515
P5	16.430	12.351				8198	3	5.996	2.541	1.729	1.108	35.898
P5	16.440	12.361	-25.94	0.97	14.86	8199	3	5.878	2.753	1.805	1.162	35.644
P5	16.450	12.371				8200	3	5.950	2.727	1.729	1.108	35.917
P5	16.460	12.381	-25.71	0.95	14.32	8201	3	6.577	2.432	1.723	1.098	36.255
P5	16.470	12.391				8202	3	6.563	2.481	1.817	1.162	36.014
P5	16.480	12.401	-25.96	0.97	15.15	8203	3	6.283	2.356	1.690	1.074	36.453
P5	16.490	12.411				8203	3	6.483	2.960	1.829	1.172	35.930
P5	16.500	12.421	-25.90	0.98	14.85	8204.1	3	6.275	3.038	1.904	1.234	35.170
P5	16.510	12.431				8205.1	3	6.849	2.615	1.733	1.121	35.320
P5	16.520	12.441	-25.76	0.95	14.93	8207	3	6.882	2.669	1.709	1.105	35.385
P5	16.530	12.451				8208	3	6.882	2.235	1.775	1.149	35.249
P5	16.540	12.461	-26.12	0.98	15.47	8209	3	6.546	2.577	1.728	1.117	35.363
P5	16.550	12.471				8210	3	6.279	2.485	1.850	1.210	34.581
P5	16.560	12.481	-26.04	0.96	15.43	8212	3	6.089	3.044	1.780	1.161	34.778
P5	16.570	12.491				8213	3	6.332	2.375	1.443	1.177	18.433
P5	16.580	12.501	-26.06	0.96	15.71	8214	3	6.344	2.379	1.521	1.048	31.092
P5	16.590	12.511				8215	3	5.973	2.583	1.872	1.191	36.354
P5	16.600	12.521	-26.02	0.98	15.35	8216	3	6.338	2.579	2.254	1.145	49.188
P5	16.610	12.531				8217.1	3	7.036	1.990	1.503	1.257	16.391
P5	16.620	12.541	-25.86	1.01	15.42	8219	3	6.794	2.105	1.893	1.079	43.000
P5	16.630	12.551				8220	4	6.889	2.044	2.061	1.338	35.114
P5	16.640	12.561	-25.69	0.97	15.63	8221	3	6.992	2.331	1.717	1.235	28.074

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P5	16.650	12.571				8223	4	6.918	2.123	2.269	1.229	45.816
P5	16.660	12.581	-25.82	0.99	15.38	8224	4	6.294	2.098	1.683	1.071	36.369
P5	16.670	12.591				8225	4	7.067	2.052	1.773	1.189	32.971
P5	16.680	12.601	-25.88	1.05	15.69	8227	3	6.899	2.381	1.850	1.162	37.184
P5	16.690	12.611				8228	4	7.272	2.335	1.821	1.228	32.568
P5	16.700	12.621	-25.84	1.07	15.17	8229	3	7.618	2.217	1.691	1.141	32.541
P5	16.710	12.631				8230	4	6.809	2.057	1.853	1.272	31.388
P5	16.720	12.641	-25.82	1.05	15.95	8231	4	6.225	2.165	1.648	1.117	32.209
P5	16.730	12.651				8233	4	6.076	2.781	1.826	1.253	31.407
P6	16.835	12.756	-25.49	0.93	14.83	8247	4	6.602	2.489	1.737	1.159	33.292
P6	16.845	12.766				8249	4	6.544	2.164	1.829	1.216	33.536
P6	16.855	12.776	-25.74	1.00	15.38	8250	5	6.767	2.082	1.711	1.121	34.513
P6	16.865	12.786				8252	5	6.921	2.087	1.723	1.128	34.510
P6	16.875	12.796	-26.13	1.25	18.30	8253	5	6.450	2.075	1.478	0.981	33.643
P6	16.885	12.806				8255	5	6.684	2.228	1.823	1.191	34.664
P6	16.895	12.816	-25.74	0.98	15.24	8257	6	6.781	2.109	1.946	1.254	35.566
P6	16.905	12.826				8259	6	6.673	2.134	1.805	1.169	35.246
P6	16.915	12.836	-25.67	1.03	16.11	8261	7	6.674	2.207	1.633	1.060	35.101
P6	16.925	12.846				8263	7	6.700	2.134	1.596	1.031	35.396
P6	16.935	12.856	-25.87	0.94	15.40	8266	8	6.753	2.013	1.688	1.104	34.630
P6	16.945	12.866				8269	10	7.171	1.929	1.611	1.043	35.233
P6	16.955	12.876	-25.85	0.99	15.27	8272	12	6.973	2.531	1.711	1.118	34.670
P6	16.965	12.886				8274	11	7.028	1.908	1.666	1.082	35.060
P6	16.975	12.896	-25.93	1.07	15.98	8276.1	7	7.094	2.167	1.726	1.121	35.056
P6	16.985	12.906				8279	5	7.051	2.009	1.590	1.028	35.334
P6	16.995	12.916	-25.99	1.18	15.48	8280	4	7.177	1.900	1.740	1.141	34.448
P6	17.005	12.926				8282	3	6.991	1.832	1.617	1.059	34.499
P6	17.015	12.936	-25.99	1.07	15.53	8283	3	6.887	2.061	1.681	1.104	34.299
P6	17.025	12.946				8284	3	6.922	1.864	1.777	1.172	34.069
P6	17.035	12.956	-25.99	1.06	15.19	8286	3	6.667	1.799	1.672	1.092	34.669

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P6	17.045	12.966				8287	3	6.905	1.739	1.775	1.168	34.194
P6	17.055	12.976	-25.94	1.03	15.47	8289	3	6.811	1.795	1.604	1.060	33.904
P6	17.065	12.986				8290	3	6.681	1.962	1.699	1.122	33.987
P6	17.075	12.996	-26.03	1.12	15.82	8291	2.1	6.879	1.770	1.524	0.994	34.742
P6	17.085	13.006				8292	2	7.132	1.720	1.634	1.079	33.980
P6	17.095	13.016	-26.01	1.08	15.29	8294	2	6.718	1.967	1.532	0.997	34.933
P6	17.105	13.026				8294	2	6.847	1.956	1.649	1.087	34.106
P6	17.115	13.036	-25.94	1.05	15.20	8295	2	7.022	1.851	1.551	1.033	33.397
P6	17.125	13.046				8296	2	6.869	1.816	1.743	1.178	32.409
P6	17.135	13.056	-26.05	1.03	15.29	8297	2	7.081	1.591	1.557	1.039	33.270
P6	17.145	13.066				8299	2	7.002	1.727	1.539	1.035	32.767
P6	17.155	13.076	-26.07	1.07	15.67	8300	2	7.273	1.714	1.676	1.139	32.086
P6	17.165	13.086				8301	2	6.955	1.974	1.557	1.047	32.752
P6	17.175	13.096	-25.95	1.10	15.27	8301.1	2	6.978	1.784	1.727	1.178	31.782
P6	17.185	13.106				8303	2	7.068	1.708	1.606	1.099	31.549
P6	17.195	13.116	-26.12	1.03	15.25	8304	2	7.161	1.753	1.659	1.154	30.454
P6	17.205	13.126				8304	2	7.029	1.674	1.602	1.105	31.043
P6	17.215	13.136	-26.05	1.02	16.08	8305	2	7.015	1.742	1.651	1.144	30.716
P6	17.225	13.146				8306	2	6.811	1.876	1.470	1.006	31.571
P6	17.235	13.156	-26.02	1.04	15.63	8307	2	7.072	2.233	1.598	1.071	32.969
P6	17.245	13.166				8308	2	6.755	2.093	1.517	1.000	34.060
P6	17.255	13.176	-26.23	1.18	16.25	8309	2	5.959	2.612	1.570	1.037	33.986
P6	17.265	13.186				8310	2	5.895	3.242	1.509	0.989	34.446
P6	17.275	13.196	-26.41	1.32	17.29	8311	2	5.979	2.918	1.455	0.941	35.294
P6	17.285	13.206				8312	2	6.527	4.425	1.508	0.978	35.114
P6	17.295	13.216	-26.19	1.07	16.27	8313.1	2	6.019	2.752	1.703	1.106	35.019
P6	17.305	13.226				8314	2	5.910	3.096	1.624	1.066	34.381
P6	17.315	13.236	-26.36	1.11	16.77	8315	2	6.037	2.845	1.601	1.071	33.101
P6	17.325	13.246				8316	2	5.996	2.541	1.711	1.168	31.687
P6	17.335	13.256	-26.12	1.06	15.68	8317	2	5.878	2.753	1.684	1.150	31.735

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P6	17.345	13.266				8318	2	5.950	2.727	1.637	1.111	32.120
P6	17.355	13.276	-26.06	0.97	15.60	8319	2	6.577	2.432	1.742	1.191	31.671
P6	17.365	13.286				8320	2	6.563	2.481	1.553	1.057	31.962
P6	17.375	13.296	-26.14	1.03	15.65	8321	2	6.283	2.356	1.646	1.135	31.032
P6	17.385	13.306				8322	2	6.483	2.960	1.593	1.104	30.695
P6	17.395	13.316	-26.05	0.99	15.36	8323	2	6.275	3.038	1.602	1.101	31.286
P6	17.405	13.326				8324	2	6.849	2.615	1.442	0.986	31.648
P6	17.415	13.336	-26.14	1.02	15.43	8325	2	6.882	2.669	1.592	1.093	31.353
P6	17.425	13.346				8326	2	6.882	2.235	1.686	1.168	30.749
P6	17.435	13.356	-25.95	1.00	15.28	8327	2	6.546	2.577	1.696	1.173	30.815
P6	17.445	13.366				8328	2	6.279	2.485	1.651	1.148	30.477
P6	17.455	13.376	-26.11	0.98	15.74	8330	2	6.089	3.044	1.812	1.282	29.221
P6	17.465	13.386				8331	2	6.332	2.375	1.605	1.122	30.110
P6	17.475	13.396	-26.02	0.97	15.41	8332	2	6.344	2.379	1.742	1.197	31.282
P6	17.485	13.406				8334	2	5.973	2.583	1.776	1.238	30.335
P6	17.495	13.416	-26.04	0.96	15.46	8335	2	6.338	2.579	1.723	1.175	31.759
P6	17.505	13.426				8336	2	7.036	1.990	1.669	1.157	30.664
P6	17.515	13.436	-26.02	0.97	15.61	8337	3	6.794	2.105	1.740	1.217	30.021
P6	17.525	13.446				8339	3	6.889	2.044	1.613	1.105	31.489
P6	17.535	13.456	-25.91	0.98	15.89	8340.1	3	6.992	2.331	1.738	1.209	30.431
P6	17.545	13.466				8342	3	6.918	2.123	1.741	1.215	30.186
P6	17.555	13.476	-26.18	1.06	16.78	8343	3	6.294	2.098	1.714	1.182	31.071
P6	17.565	13.486				8345	3	7.067	2.052	1.616	1.120	30.712
P6	17.575	13.496	-26.06	1.02	15.65	8346	3	6.899	2.381	1.738	1.222	29.692
P6	17.585	13.506				8348	3	7.272	2.335	1.650	1.157	29.901
P6	17.595	13.516	-26.16	0.94	15.90	8350	4	7.618	2.217	1.760	1.250	28.983
P6	17.605	13.526				8351.1	5	6.809	2.057	1.618	1.134	29.947
P7	17.660	13.581	-26.03	0.96	15.36	8363	3	6.791	2.838	1.469	0.967	34.149
P7	17.670	13.591				8364	3	6.753	2.617	1.795	1.161	35.288
P7	17.680	13.601	-26.22	0.95	15.82	8366	2	6.968	2.413	1.499	0.961	35.862

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P7	17.690	13.611				8367	2	7.251	2.355	1.635	1.055	35.486
P7	17.700	13.621	-26.17	0.97	16.19	8369	2	7.616	2.483	2.087	1.356	35.040
P7	17.710	13.631				8370	2	7.115	2.372	1.432	0.923	35.517
P7	17.720	13.641	-26.11	0.95	15.85	8372	2	7.125	2.394	1.819	1.174	35.459
P7	17.730	13.651				8374	2	6.892	2.479	1.867	1.200	35.732
P7	17.740	13.661	-26.30	0.99	16.09	8375	2	7.177	2.435	1.600	1.020	36.241
P7	17.750	13.671				8377	2	7.783	2.603	2.069	1.331	35.656
P7	17.760	13.681	-25.95	0.97	15.97	8378	2	6.684	2.384	1.430	0.905	36.760
P7	17.770	13.691				8380	2	7.351	5.862	1.626	1.031	36.563
P7	17.780	13.701	-26.11	0.97	15.94	8381.1	2	7.029	2.506	1.594	1.004	37.003
P7	17.790	13.711				8383	2	6.974	2.706	1.855	1.172	36.828
P7	17.800	13.721	-26.16	0.97	16.22	8385	2	6.498	2.859	1.401	0.880	37.182
P7	17.810	13.731				8387	2	6.758	2.710	1.631	1.025	37.159
P7	17.820	13.741	-26.15	0.96	16.44	8389	2	7.179	2.504	1.723	1.083	37.133
P7	17.830	13.751				8390	2	6.628	2.376	1.258	0.784	37.672
P7	17.840	13.761	-26.22	1.00	14.52	8392	2	7.243	2.395	1.787	1.119	37.370
P7	17.850	13.771				8394	2	7.428	2.890	1.917	1.210	36.880
P7	17.860	13.781	-26.18	0.98	16.21	8396	2	6.900	2.205	1.667	1.037	37.789
P7	17.870	13.791				8397.1	3	6.968	2.512	1.735	1.093	37.013
P7	17.880	13.801	-26.30	1.02	16.17	8399	3	7.241	2.362	1.676	1.052	37.271
P7	17.890	13.811				8401	3	6.749	2.217	1.602	1.002	37.434
P7	17.900	13.821	-26.39	0.97	16.04	8403	3	7.188	2.197	1.643	1.041	36.622
P7	17.910	13.831				8406	4	7.012	1.948	1.325	0.839	36.695
P7	17.920	13.841	-26.41	0.99	16.49	8408	6	7.521	2.232	1.936	1.230	36.489
P7	17.930	13.851				8411	9	7.712	2.371	1.816	1.144	36.998
P7	17.940	13.861	-26.32	1.01	16.53	8415	8	7.705	2.262	1.587	0.997	37.204
P7	17.950	13.871				8418	6	7.870	2.183	1.686	1.063	36.945
P7	17.960	13.881	-26.39	0.98	16.28	8420	5	7.176	2.632	1.669	1.043	37.529
P7	17.970	13.891				8423	5	7.695	2.458	1.777	1.117	37.134
P7	17.980	13.901	-26.42	1.07	16.79	8425	4	7.584	2.202	1.704	1.069	37.284

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P7	17.990	13.911				8427	4	8.462	2.242	1.858	1.166	37.221
P7	18.000	13.921	-26.39	1.00	16.06	8429	4	7.729	2.587	1.648	1.036	37.128
P7	18.010	13.931				8431	4	8.355	2.420	1.551	0.986	36.465
P7	18.020	13.941	-26.41	1.04	16.47	8432	4	8.410	2.498	1.828	1.177	35.603
P7	18.030	13.951				8434	3	7.337	2.101	1.576	1.011	35.849
P7	18.040	13.961	-27.49	1.36	24.14	8436	3	9.198	2.071	2.369	1.592	32.780
P7	18.050	13.971				8437	3	7.453	2.306	1.670	1.063	36.354
P7	18.060	13.981	-26.15	0.95	15.98	8439	3	7.131	2.386	1.649	1.048	36.458
P7	18.070	13.991				8441	3	7.514	2.231	1.533	0.968	36.861
P7	18.080	14.001	-26.49	1.13	17.40	8442	3	8.194	2.326	1.731	1.099	36.515
P7	18.090	14.011				8444	3	7.834	2.172	1.701	1.081	36.476
P7	18.100	14.021	-26.35	1.02	16.24	8446	3	8.331	2.111	1.680	1.070	36.311
P7	18.110	14.031				8448	3	7.706	2.324	1.538	0.971	36.848
P7	18.120	14.041	-26.35	1.07	16.13	8450	3	8.368	2.196	1.581	1.001	36.666
P7	18.130	14.051				8452	3	8.682	2.247	1.837	1.163	36.655
P7	18.140	14.061	-26.56	0.96	15.88	8453.1	3	7.897	2.388	1.569	0.989	36.979
P7	18.150	14.071				8456	3	9.054	2.271	1.508	0.959	36.371
P7	18.160	14.081	-26.41	1.06	17.13	8457	3	9.000	2.193	1.661	1.062	36.036
P7	18.170	14.091				8459	3	8.694	2.379	1.586	1.020	35.675
P7	18.180	14.101	-26.36	1.05	16.44	8461	3	8.640	2.362	1.623	1.041	35.858
P7	18.190	14.111				8463	3	8.717	2.408	1.598	1.021	36.105
P7	18.200	14.121	-26.39	1.04	16.59	8464	3	8.805	2.330	1.599	1.029	35.675
P7	18.210	14.131				8466	3	6.305	2.232	1.503	0.964	35.901
P7	18.220	14.141	-26.39	1.03	16.62	8467.1	3	6.367	2.215	1.384	0.881	36.347
P7	18.230	14.151				8469	3	6.411	2.331	1.403	0.891	36.501
P7	18.240	14.161	-26.07	1.07	16.47	8471	3	6.338	2.310	1.500	0.953	36.465
P7	18.250	14.171				8472	3	6.492	2.217	1.518	0.977	35.629
P7	18.260	14.181	-25.95	1.06	16.21	8474	3	6.111	2.372	1.442	0.920	36.230
P7	18.270	14.191				8476	3	6.252	2.184	1.581	1.019	35.541
P7	18.280	14.201	-26.30	1.10	16.54	8478	3	6.190	2.239	1.624	1.057	34.961

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P7	18.290	14.211				8481	3	6.297	2.424	1.536	0.995	35.213
P7	18.300	14.221	-26.16	1.08	16.42	8483	3	6.246	2.732	1.564	1.011	35.349
P7	18.310	14.231				8485	3	6.026	2.599	1.473	0.949	35.616
P7	18.320	14.241	-25.95	1.08	16.18	8487	3	6.215	2.471	1.907	1.247	34.573
P7	18.330	14.251				8489	3	6.457	2.825	1.462	0.940	35.717
P7	18.340	14.261	-26.09	1.11	16.54	8491	3	6.343	2.595	1.795	1.192	33.618
P7	18.350	14.271				8494	3	5.943	2.724	1.351	0.880	34.842
P7	18.360	14.281	-27.15	1.42	21.87	8496	3	6.321	2.844	1.616	1.068	33.906
P7	18.370	14.291				8498	3	6.395	3.553	1.658	1.102	33.550
P7	18.380	14.301	-26.51	1.17	17.28	8501	3	6.571	2.906	1.596	1.057	33.770
P7	18.390	14.311				8503	3	6.144	2.839	1.721	1.158	32.688
P7	18.400	14.321	-26.17	1.13	16.55	8505.1	3	6.486	2.752	1.581	1.062	32.830
P7	18.410	14.331				8508	3	6.438	2.981	1.629	1.123	31.039
P7	18.420	14.341	-26.68	1.07	15.65	8510	3	6.283	3.085	1.609	1.101	31.594
P7	18.430	14.351				8512	3	6.230	2.886	1.579	1.077	31.802
P8	18.475	14.396	-26.41	0.95	15.38	8521	4	7.196	2.399	2.170	1.403	35.322
P8	18.485	14.406				8523	4	6.687	2.328	1.890	1.207	36.123
P8	18.495	14.416	-26.11	0.99	15.76	8525	4	6.836	2.379	1.530	0.975	36.253
P8	18.505	14.426				8527	5	6.394	2.583	1.625	1.038	36.155
P8	18.515	14.436	-26.10	1.01	15.62	8530	5	6.263	3.326	1.784	1.136	36.341
P8	18.525	14.446				8532.1	5	6.597	2.506	1.620	1.030	36.406
P8	18.535	14.456	-26.17	1.02	15.78	8536	6	6.278	2.613	1.548	0.983	36.514
P8	18.545	14.466				8539	8	5.986	3.350	1.819	1.173	35.528
P8	18.555	14.476	-26.27	1.00	15.44	8545.1	21	5.792	2.763	1.497	0.962	35.716
P8	18.565	14.486				8592	56	6.001	3.157	1.745	1.116	36.061
P8	18.575	14.496	-26.62	1.07	16.40	8607	34	6.457	3.053	1.706	1.081	36.626
P8	18.585	14.506				8619	15	6.166	2.741	1.468	0.926	36.914
P8	18.595	14.516	-26.12	1.01	16.00	8630	15	6.104	2.990	1.633	1.029	36.985
P8	18.605	14.526				8637	11	6.607	2.792	1.636	1.023	37.459
P8	18.615	14.536	-26.14	1.09	15.98	8640	6	6.719	2.793	1.456	0.906	37.778

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P8	18.625	14.546				8642	4	6.546	2.811	1.395	0.866	37.896
P8	18.635	14.556	-25.76	1.04	15.44	8643	4	7.094	2.896	1.591	0.985	38.119
P8	18.645	14.566				8645	3	6.634	3.015	1.481	0.912	38.396
P8	18.655	14.576	-26.00	1.06	16.75	8647	3	6.263	2.850	1.494	0.920	38.432
P8	18.665	14.586				8649	3	6.507	2.822	1.583	0.975	38.430
P8	18.675	14.596	-26.87	1.12	16.72	8650	3	6.544	2.449	1.319	0.806	38.901
P8	18.685	14.606				8651	2.1	6.845	2.938	1.627	1.007	38.122
P8	18.695	14.616	-26.20	1.06	16.11	8653	2	6.605	2.999	1.651	1.024	37.965
P8	18.705	14.626				8654	2	6.561	2.725	1.566	0.971	37.993
P8	18.715	14.636	-26.24	1.06	16.55	8655	2	6.552	2.950	1.550	0.953	38.528
P8	18.725	14.646				8657	2	6.308	2.746	1.434	0.881	38.568
P8	18.735	14.656	-26.46	1.08	16.76	8658	2	6.856	2.701	1.540	0.953	38.092
P8	18.745	14.666				8659	2	7.103	2.866	1.689	1.049	37.875
P8	18.755	14.676	-26.25	1.08	16.26	8660	2	6.465	2.749	1.362	0.844	38.043
P8	18.765	14.686				8661.1	2	7.369	2.871	1.765	1.104	37.438
P8	18.775	14.696	-26.76	1.09	16.59	8663	2	7.318	2.842	1.603	1.000	37.607
P8	18.785	14.706				8664	2	6.959	2.573	1.453	0.902	37.930
P8	18.795	14.716	-26.30	1.10	17.56	8665	2	6.996	2.752	1.761	1.116	36.623
P8	18.805	14.726				8667	2	6.686	2.655	1.591	0.997	37.325
P8	18.815	14.736	-26.39	1.18	18.04	8667	2	6.487	2.454	1.535	0.972	36.648
P8	18.825	14.746				8668	2	7.498	2.956	1.454	0.907	37.663
P8	18.835	14.756	-26.26	1.17	17.65	8669	2	6.837	2.888	1.454	0.894	38.526
P8	18.845	14.766				8670	2	7.650	2.938	1.727	1.068	38.153
P8	18.855	14.776	-26.45	1.15	17.67	8671	2	7.285	2.807	1.463	0.902	38.384
P8	18.865	14.786				8671	2	6.647	2.761	1.432	0.882	38.384
P8	18.875	14.796	-26.82	1.15	17.58	8672	2	6.508	3.103	1.406	0.864	38.549
P8	18.885	14.806				8673	2	6.590	3.171	1.298	0.793	38.887
P8	18.895	14.816	-26.46	1.20	17.16	8674	2	6.774	3.024	1.321	0.810	38.659
P8	18.905	14.826				8675	2	7.035	2.910	1.446	0.887	38.630
P8	18.915	14.836	-26.50	1.30	17.51	8676	2	6.671	3.213	1.515	0.936	38.244

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P8	18.925	14.846				8676.1	2	6.906	2.874	1.405	0.862	38.648
P8	18.935	14.856	-26.52	1.34	18.74	8677	2	7.010	2.851	1.491	0.917	38.490
P8	18.945	14.866				8678	2	6.771	2.653	1.682	1.040	38.134
P8	18.955	14.876	-26.52	1.30	18.86	8679	2	6.846	2.724	1.673	1.040	37.869
P8	18.965	14.886				8680	2	6.788	2.596	1.581	0.979	38.094
P8	18.975	14.896	-27.46	1.19	18.33	8681.1	2	6.635	2.396	1.417	0.887	37.431
P8	18.985	14.906				8683	2	6.674	2.555	1.376	0.857	37.720
P8	18.995	14.916	-26.56	1.20	17.31	8684	2	6.274	2.551	1.524	0.948	37.787
P8	19.005	14.926				8685	2	6.336	2.609	1.418	0.877	38.165
P8	19.015	14.936	-26.68	1.23	17.71	8686	2	6.500	2.578	1.565	0.972	37.874
P8	19.025	14.946				8686	2	6.969	2.540	1.696	1.058	37.650
P8	19.035	14.956	-26.74	1.30	18.48	8687	2	6.524	2.412	1.404	0.870	38.015
P8	19.045	14.966				8688	2	6.449	2.176	1.431	0.885	38.140
P8	19.055	14.976	-26.78	1.33	18.66	8689	2	6.808	2.530	1.563	0.976	37.561
P8	19.065	14.986				8690	2	6.548	2.485	1.642	1.036	36.940
P8	19.075	14.996	-27.14	1.14	18.34	8691	2	6.818	2.485	1.803	1.135	37.023
P8	19.085	15.006				8693	2	6.476	2.448	1.613	1.014	37.128
P8	19.095	15.016	-26.85	1.29	18.24	8694	2	6.658	2.570	1.675	1.055	37.020
P8	19.105	15.026				8694	2	7.165	2.481	1.687	1.054	37.544
P8	19.115	15.036	-26.77	1.31	18.65	8695	2	6.885	2.810	1.698	1.058	37.652
P8	19.125	15.046				8696	2	6.993	2.597	1.569	0.981	37.438
P8	19.135	15.056	-26.71	1.26	17.49	8697	2	6.456	2.582	1.601	1.012	36.763
P8	19.145	15.066				8698	2	6.721	2.610	1.721	1.089	36.695
P8	19.155	15.076	-26.77	1.24	18.11	8699	2	6.796	2.698	1.539	0.957	37.834
P8	19.165	15.086				8700	2	7.386	2.440	1.588	0.978	38.436
P8	19.175	15.096	-27.47	1.15	17.54	8701	2	7.300	2.649	1.640	1.012	38.290
P8	19.185	15.106				8702	2	7.131	2.781	1.615	0.999	38.130
P8	19.195	15.116	-26.60	1.21	17.51	8703	2	7.150	2.810	1.493	0.919	38.463
P8	19.205	15.126				8704	2	7.866	1.914	1.529	0.939	38.585
P8	19.215	15.136	-26.68	1.32	18.13	8706	2	6.948	2.689	1.524	0.936	38.567

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P8	19.225	15.146				8707	2	6.314	3.774	1.505	0.926	38.436
P8	19.235	15.156	-26.51	1.30	18.04	8709	2	7.214	2.760	1.442	0.888	38.446
P8	19.245	15.166				8710	2	6.956	2.613	1.604	0.987	38.502
P8	19.255	15.176	-26.65	1.24	17.40	8711	2	7.109	2.341	1.545	0.960	37.906
P9	19.300	15.221	-27.20	1.16	18.67	8716	2	5.976	2.939	2.061	1.334	35.252
P9	19.310	15.231				8717.1	2	6.087	3.123	1.611	1.025	36.336
P9	19.320	15.241	-26.70	1.29	18.09	8719	2	6.445	3.026	1.713	1.080	36.940
P9	19.330	15.251				8720	2	6.492	2.750	1.640	1.022	37.697
P9	19.340	15.261	-26.70	1.31	18.07	8721	2	6.573	2.799	1.607	1.004	37.515
P9	19.350	15.271				8723	2	6.616	2.665	1.658	1.042	37.163
P9	19.360	15.281	-26.79	1.28	17.47	8724	2	6.369	2.800	1.700	1.062	37.512
P9	19.370	15.291				8726	2	6.381	2.804	1.640	1.014	38.175
P9	19.380	15.301	-27.03	1.32	18.32	8727	2	6.195	2.621	1.557	0.960	38.342
P9	19.390	15.311				8729	2	6.488	2.641	1.625	1.002	38.327
P9	19.400	15.321	-27.20	1.26	19.67	8730	2	6.143	2.168	1.578	0.995	36.977
P9	19.410	15.331				8731	2	6.116	2.115	1.802	1.143	36.532
P9	19.420	15.341	-27.23	1.33	17.78	8733	3	6.061	1.950	1.672	1.089	34.864
P9	19.430	15.351				8734	3	6.160	2.326	1.618	0.997	38.343
P9	19.440	15.361	-26.84	1.31	17.73	8735	3	6.839	2.683	1.630	0.999	38.745
P9	19.450	15.371				8736.1	3	6.620	2.753	1.535	0.938	38.884
P9	19.460	15.381	-26.79	1.30	17.93	8738	3	7.351	2.753	1.655	1.009	39.033
P9	19.470	15.391				8739	4	6.855	2.819	1.665	1.020	38.724
P9	19.480	15.401	-26.90	1.32	17.27	8741	4	6.944	2.881	1.756	1.078	38.619
P9	19.490	15.411				8743	5	6.828	2.862	1.558	0.948	39.168
P9	19.500	15.421	-27.32	1.22	18.82	8746	7	7.227	2.801	1.567	0.945	39.687
P9	19.510	15.431				8748.1	6	7.386	2.825	1.597	0.960	39.881
P9	19.520	15.441	-26.58	1.22	15.96	8750	5	7.050	2.697	1.676	1.006	40.000
P9	19.530	15.451				8751	4	7.163	2.853	1.741	1.054	39.459
P9	19.540	15.461	-26.68	1.33	17.40	8752	4	7.125	2.521	1.486	0.894	39.820
P9	19.550	15.471				8753	3	7.108	2.567	1.642	0.993	39.498

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P9	19.560	15.481	-26.81	1.31	17.61	8755	3	7.121	2.875	1.617	0.977	39.539
P9	19.570	15.491				8756	3	7.089	2.697	1.562	0.945	39.498
P9	19.580	15.501	-26.92	1.34	17.96	8757	3	7.335	2.633	1.715	1.042	39.227
P9	19.590	15.511				8758	2	7.099	2.716	1.484	0.902	39.198
P9	19.600	15.521	-27.48	1.19	18.74	8758	2	7.377	2.620	1.780	1.085	39.031
P9	19.610	15.531				8759	2	7.238	2.424	1.531	0.930	39.253
P9	19.620	15.541	-27.01	1.31	17.53	8760	2	6.606	2.408	1.659	1.004	39.460
P9	19.630	15.551				8761	2	6.846	2.683	1.559	0.950	39.069
P9	19.640	15.561	-26.86	1.23	16.86	8761.1	2	6.482	2.410	1.633	1.003	38.575
P9	19.650	15.571				8762.1	2	6.510	2.381	1.752	1.084	38.109
P9	19.660	15.581	-26.87	1.31	17.94	8763	2	6.917	2.635	1.627	0.992	39.012
P9	19.670	15.591				8764	2	7.066	2.995	1.598	0.971	39.210
P9	19.680	15.601	-27.01	1.25	17.30	8764.1	2	6.675	3.500	1.648	1.008	38.794
P9	19.690	15.611				8765	2	6.819	3.253	1.706	1.045	38.755
P9	19.700	15.621	-26.79	1.26	19.70	8766	2	6.882	3.066	1.649	1.002	39.251
P9	19.710	15.631				8767	2	7.190	2.946	1.528	0.932	39.016
P9	19.720	15.641	-26.91	1.36	18.24	8767	2	7.229	2.892	1.556	0.949	38.983
P9	19.730	15.651				8768	2	6.282	2.945	1.365	0.832	39.009
P9	19.740	15.661	-26.93	1.38	18.13	8769	2	6.207	3.337	1.728	1.048	39.361
P9	19.750	15.671				8770	2	6.246	3.437	1.642	0.989	39.757
P9	19.760	15.681	-27.20	1.41	17.91	8770	2	6.334	3.448	1.458	0.872	40.179
P9	19.770	15.691				8771	2	6.356	3.433	1.596	0.961	39.762
P9	19.780	15.701	-27.29	1.34	16.58	8771	2	6.660	3.487	1.727	1.040	39.762
P9	19.790	15.711				8772	2	6.957	3.146	1.780	1.080	39.306
P9	19.800	15.721	-27.41	1.3	19.9	8772.1	2	6.445	3.152	1.520	0.923	39.269
P9	19.810	15.731				8773	2	6.543	3.069	1.583	0.969	38.803
P9	19.820	15.741	-27.18	1.32	17.04	8774	2	6.771	3.206	1.785	1.091	38.898
P9	19.830	15.751				8774	2	7.278	2.948	1.490	0.898	39.737
P9	19.840	15.761	-26.85	1.27	16.02	8775	2	6.948	3.189	1.889	1.148	39.249
P9	19.850	15.771				8776	2	6.706	3.169	1.463	0.887	39.393

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P9	19.860	15.781	-27.06	1.31	16.52	8776	2	6.639	2.986	1.686	1.029	38.992
P9	19.870	15.791				8777	2	6.112	3.871	1.581	0.962	39.115
P9	19.880	15.801	-27.05	1.28	16.66	8778	2	6.206	3.183	1.675	1.016	39.341
P9	19.890	15.811				8778.1	2	6.924	2.958	1.594	0.972	39.024
P9	19.900	15.821	-27.21	1.3	19.6	8779	2	7.191	2.665	1.658	1.018	38.596
P9	19.910	15.831				8780	2	6.874	2.710	1.616	0.989	38.819
P9	19.920	15.841	-27.07	1.37	17.16	8780	2	6.652	2.846	1.514	0.919	39.327
P9	19.930	15.851				8781	2	6.667	2.967	1.677	1.025	38.913
P9	19.940	15.861	-27.14	1.37	17.26	8782	2	6.689	2.918	1.639	0.997	39.182
P9	19.950	15.871				8782	2	6.753	3.194	1.612	0.982	39.051
P9	19.960	15.881	-27.16	1.38	17.19	8782	2	6.288	3.073	1.525	0.925	39.327
P9	19.970	15.891				8783	2	7.010	2.750	1.393	0.844	39.432
P9	19.980	15.901	-27.15	1.36	16.61	8783.1	2	7.234	2.927	1.628	0.994	38.948
P9	19.990	15.911				8784	2	6.400	3.114	1.554	0.955	38.536
P9	20.000	15.921	-27.75	1.5	24.1	8784	2	7.194	2.830	1.572	0.958	39.036
P9	20.010	15.931				8785	2	6.974	2.929	1.538	0.937	39.044
P9	20.020	15.941	-27.20	1.35	18.02	8785	2	7.245	2.879	1.739	1.056	39.309
P9	20.030	15.951				8786	2	6.902	3.163	1.493	0.909	39.111
P9	20.040	15.961	-27.00	1.23	16.59	8786	2	6.344	3.243	1.526	0.926	39.317
P9	20.050	15.971				8787	2	7.083	3.048	1.766	1.083	38.695
P9	20.060	15.981	-26.95	1.24	16.22	8787	2	7.050	2.623	1.568	0.959	38.808
P9	20.070	15.991				8788	2	7.018	2.739	1.558	0.955	38.712
P9	20.080	16.001	-27.01	1.23	16.19	8789	2	7.293	2.924	1.682	1.040	38.209
P9	20.090	16.011				8789	2	7.175	2.921	1.674	1.029	38.501
P9	20.100	16.021	-27.07	1.2	18.8	8790	2	7.145	2.748	1.471	0.892	39.369
P9	20.110	16.031				8790	1	6.645	2.969	1.515	0.925	38.978
P9	20.120	16.041	-27.18	1.29	16.91	8791	2	7.442	2.772	1.776	1.085	38.933
P9	20.130	16.051				8791.1	1	6.681	2.706	1.272	0.773	39.250
P9	20.140	16.061	-27.12	1.32	16.69	8792	2	6.376	3.053	1.395	0.846	39.377
P10	20.190	16.111	-27.23	1.3	21.0	8795	1	6.654	2.740	1.965	1.252	36.261

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P10	20.200	16.121				8796	2	6.842	2.535	1.675	1.070	36.142
P10	20.210	16.131	-27.11	1.35	17.48	8796	2	7.189	2.648	1.756	1.123	36.051
P10	20.220	16.141				8797	2	7.449	2.390	1.662	1.053	36.662
P10	20.230	16.151	-27.21	1.36	18.17	8797.1	2	7.522	2.566	1.775	1.121	36.844
P10	20.240	16.161				8798	2	7.262	2.735	1.724	1.075	37.600
P10	20.250	16.171	-27.34	1.40	18.19	8799	2	7.500	2.435	1.629	1.007	38.227
P10	20.260	16.181				8799	2	7.365	2.543	1.613	0.990	38.655
P10	20.270	16.191	-27.21	1.39	17.75	8800	2	6.981	2.951	1.485	0.908	38.829
P10	20.280	16.201				8800	2	7.230	2.816	1.827	1.125	38.401
P10	20.290	16.211	-27.30	1.3	20.6	8801	2	7.514	3.092	1.338	1.057	21.026
P10	20.300	16.221				8801	2	7.350	2.609	1.833	0.889	51.489
P10	20.310	16.231	-27.37	1.37	18.39	8802	2	7.529	2.950	1.728	1.063	38.464
P10	20.320	16.241				8802	2	7.048	2.906	1.710	1.057	38.169
P10	20.330	16.251	-27.22	1.37	17.76	8803	2	7.181	2.647	1.605	0.988	38.477
P10	20.340	16.261				8803	2	7.298	2.511	1.590	0.976	38.590
P10	20.350	16.271	-27.27	1.37	18.02	8804	2	7.299	2.311	1.771	1.075	39.325
P10	20.360	16.281				8804	2	7.857	2.688	1.538	0.948	38.347
P10	20.370	16.291	-27.31	1.44	18.71	8805	2	7.191	3.366	1.736	1.068	38.467
P10	20.380	16.301				8805	2	7.291	2.828	1.561	0.959	38.573
P10	20.390	16.311	-27.30	1.3	21.1	8806	2	7.334	3.020	1.721	1.060	38.390
P10	20.400	16.321				8806	2	7.226	2.777	1.783	1.094	38.607
P10	20.410	16.331	-27.38	1.44	18.61	8807	2	7.002	2.981	1.526	0.943	38.236
P10	20.420	16.341				8807	2	7.663	2.650	1.651	1.024	38.005
P10	20.430	16.351	-27.30	1.38	18.77	8808	2	6.816	2.882	1.556	0.964	38.046
P10	20.440	16.361				8808	2	7.567	2.774	1.744	1.084	37.837
P10	20.450	16.371	-27.29	1.40	18.78	8809	2	7.353	2.551	1.590	0.987	37.945
P10	20.460	16.381				8809	2	8.018	2.836	1.605	1.003	37.541
P10	20.470	16.391	-27.49	1.53	19.88	8810	2	8.092	2.687	1.725	1.070	37.962
P10	20.480	16.401				8810	2	7.525	2.923	1.690	1.051	37.819
P10	20.490	16.411	-27.53	1.4	22.0	8811	2	6.893	2.574	1.692	1.061	37.292

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P10	20.500	16.421				8811	2	6.951	2.410	1.794	1.109	38.179
P10	20.510	16.431	-27.42	1.44	18.87	8812	2	6.806	2.282	1.655	1.029	37.796
P10	20.520	16.441				8812	2	6.644	2.544	1.333	0.828	37.852
P10	20.530	16.451	-27.35	1.46	18.32	8812.1	2	6.633	2.483	1.975	1.242	37.090
P10	20.540	16.461				8813	2	6.629	2.557	1.694	1.068	36.972
P10	20.550	16.471	-27.48	1.53	18.79	8814	2	6.537	2.530	1.491	0.931	37.536
P10	20.560	16.481				8814	2	8.505	2.714	1.730	1.090	36.973
P10	20.570	16.491	-27.46	1.51	19.64	8814.1	2	6.855	2.167	1.558	0.979	37.143
P10	20.580	16.501				8815	2	6.916	2.254	1.828	1.156	36.783
P10	20.590	16.511	-27.25	1.4	22.6	8816	2	6.604	2.444	1.378	0.875	36.519
P10	20.600	16.521				8816.1	2	7.009	1.932	1.769	1.126	36.345
P10	20.610	16.531	-27.52	1.46	19.25	8817	2	6.708	2.665	1.625	1.044	35.740
P10	20.620	16.541				8817.1	2	6.936	1.912	1.634	1.037	36.520
P10	20.630	16.551	-27.54	1.50	19.21	8818	2	7.302	2.063	1.721	1.094	36.403
P10	20.640	16.561				8819	2	6.939	1.854	1.570	0.991	36.865
P10	20.650	16.571	-27.06	1.36	17.97	8819.1	2	7.003	1.814	1.590	1.001	37.027
P10	20.660	16.581				8820	2	6.942	1.893	1.727	1.093	36.696
P10	20.670	16.591	-27.21	1.49	18.95	8821	2	6.491	3.448	1.782	1.142	35.937
P10	20.680	16.601				8822	2	6.953	1.858	1.740	1.113	36.014
P10	20.690	16.611	-30.34	1.5	22.9	8822.1	2	6.891	1.736	1.587	1.005	36.676
P10	20.700	16.621				8823	2	6.879	1.846	1.647	1.046	36.456
P10	20.710	16.631	-27.16	1.45	18.28	8824	2	6.487	2.049	1.664	1.058	36.423
P10	20.720	16.641				8824	2	6.398	2.190	1.542	0.979	36.533
P10	20.730	16.651	-27.16	1.39	18.74	8825	2	6.651	1.981	1.870	1.202	35.733
P10	20.740	16.661				8825	2	6.715	1.937	1.684	1.077	36.005
P10	20.750	16.671	-27.13	1.39	18.72	8826	2	6.778	2.010	1.674	1.073	35.923
P10	20.760	16.681				8827	2	5.939	2.969	1.704	1.091	35.949
P10	20.770	16.691	-27.26	1.48	18.79	8827	2	6.660	1.937	1.733	1.106	36.199
P10	20.780	16.701				8828	2	6.737	1.709	1.460	0.924	36.764
P10	20.790	16.711	-27.37	1.3	20.6	8828	2	6.583	1.808	1.645	1.043	36.611

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P10	20.800	16.721				8829	2	6.832	2.484	1.697	1.085	36.055
P10	20.810	16.731	-27.26	1.46	18.94	8829.1	2	6.824	1.638	1.737	1.117	35.704
P10	20.820	16.741				8830	2	6.773	1.683	1.651	1.055	36.072
P10	20.830	16.751	-27.27	1.46	18.77	8831	2	6.790	1.808	1.638	1.042	36.425
P10	20.840	16.761				8831	1	7.014	1.805	1.619	1.035	36.052
P10	20.850	16.771	-27.41	1.48	19.32	8832	2	6.843	1.870	1.729	1.111	35.740
P10	20.860	16.781				8832	2	6.817	1.835	1.752	1.127	35.646
P10	20.870	16.791	-27.38	1.53	20.18	8833	2	6.940	2.028	1.612	1.040	35.475
P10	20.880	16.801				8834	2	6.894	2.462	1.490	0.965	35.249
P10	20.890	16.811	-27.01	1.5	18.4	8834	2	6.745	2.437	1.708	1.123	34.277
P10	20.900	16.821				8835	1.1	6.891	1.957	1.771	1.166	34.158
P10	20.910	16.831	-27.21	1.38	18.68	8835.1	2	7.065	2.081	1.790	1.185	33.790
P11	20.978	16.899	-27.05	1.4	17.7	8840	2	6.928	2.492	2.137	1.193	44.150
P11	20.988	16.909				8840	2	6.532	3.075	2.042	1.325	35.132
P11	20.998	16.919	-27.25	1.42	18.45	8840.1	2	6.428	2.848	1.369	0.875	36.073
P11	21.008	16.929				8841.1	2	6.119	3.963	1.623	1.031	36.488
P11	21.018	16.939	-27.17	1.37	18.43	8842	2	7.248	2.194	1.879	1.177	37.374
P11	21.028	16.949				8843	2	7.570	2.071	1.546	0.963	37.743
P11	21.038	16.959	-27.18	1.43	18.78	8843	2	7.343	2.072	1.729	1.073	37.958
P11	21.048	16.969				8844	2	6.900	2.557	1.506	0.933	38.029
P11	21.058	16.979	-27.15	1.43	19.08	8845	2	6.763	2.948	1.820	1.131	37.870
P11	21.068	16.989				8845	2	7.037	2.720	1.785	1.105	38.070
P11	21.078	16.999	-26.63	1.4	18.7	8846	2	7.450	2.224	1.424	0.882	38.077
P11	21.088	17.009				8847	2	7.732	2.223	1.637	1.014	38.019
P11	21.098	17.019	-27.17	1.62	19.52	8848	2	7.715	2.092	1.613	1.000	38.014
P11	21.108	17.029				8849	2	7.337	2.312	1.849	1.145	38.077
P11	21.118	17.039	-27.23	1.60	19.71	8850	2	7.005	2.602	1.576	0.980	37.840
P11	21.128	17.049				8851	2	7.801	2.022	1.650	1.018	38.317
P11	21.138	17.059	-27.00	1.53	19.98	8851	2	7.363	2.077	1.693	1.039	38.672
P11	21.148	17.069				8852	2	7.262	1.983	1.666	1.022	38.682

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P11	21.158	17.079	-27.12	1.45	19.45	8853	2	7.328	1.888	1.662	1.021	38.569
P11	21.168	17.089				8854	2	6.726	2.203	1.374	0.845	38.463
P11	21.178	17.099	-26.85	1.5	19.0	8855	2	7.159	2.165	1.854	1.132	38.950
P11	21.188	17.109				8855	2	7.159	1.872	1.460	0.890	39.033
P11	21.198	17.119	-27.23	1.58	19.71	8856	2	6.947	2.071	1.679	1.025	38.914
P11	21.208	17.129				8857	2	6.930	2.278	1.670	1.019	39.002
P11	21.218	17.139	-27.08	1.42	18.55	8858	2	7.011	2.013	1.607	0.974	39.374
P11	21.228	17.149				8859	2	7.267	1.741	1.234	0.751	39.142
P11	21.238	17.159	-27.16	1.60	20.05	8859.1	2	7.652	1.925	1.944	1.196	38.498
P11	21.248	17.169				8860	2	7.712	1.944	1.877	1.158	38.286
P11	21.258	17.179	-27.11	1.42	18.42	8861	2	7.174	1.942	1.502	0.916	39.014
P11	21.268	17.189				8862	2	7.425	1.972	1.723	1.061	38.441
P11	21.278	17.199	-26.93	1.3	17.5	8863	2	4.977	2.101	1.638	1.011	38.268
P11	21.288	17.209				8864	2	7.250	2.095	1.607	0.983	38.857
P11	21.298	17.219	-27.10	1.45	19.06	8864	2.1	7.685	2.068	1.725	1.059	38.625
P11	21.308	17.229				8865	3	7.634	2.109	1.267	0.775	38.860
P11	21.318	17.239	-27.12	1.46	18.58	8866	3	7.836	2.218	1.844	1.134	38.501
P11	21.328	17.249				8867	3	10.891	1.810	1.584	0.975	38.436
P11	21.338	17.259	-27.07	1.44	18.71	8868	3	7.614	1.830	1.627	1.000	38.554
P11	21.348	17.269				8869	3.1	7.566	1.819	1.826	1.132	38.039
P11	21.358	17.279	-27.19	1.49	19.49	8870	4	7.246	1.882	1.674	1.042	37.747
P11	21.368	17.289				8871	4.1	7.798	1.814	1.433	0.901	37.112
P11	21.378	17.299	-26.90	1.5	18.5	8872	5	7.357	1.795	1.759	1.110	36.887
P11	21.388	17.309				8874	6	7.564	4.055	1.562	1.015	34.986
P11	21.398	17.319	-27.28	1.55	20.54	8876	6	8.466	2.889	1.769	1.131	36.073
P11	21.408	17.329				8878	5	6.934	2.857	1.480	0.938	36.617
P11	21.418	17.339	-27.29	1.50	19.66	8879	4	8.114	2.458	1.530	0.971	36.579
P11	21.428	17.349				8881	4	8.473	2.515	1.710	1.092	36.186
P11	21.438	17.359	-27.31	1.51	19.84	8883	3	8.089	2.464	1.776	1.127	36.529
P11	21.448	17.369				8884	3	8.079	2.744	1.667	1.060	36.437

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P11	21.458	17.379	-27.33	1.56	19.74	8885	3	8.572	2.264	1.712	1.083	36.775
P11	21.468	17.389				8886	3	7.861	2.564	1.528	0.969	36.626
P11	21.478	17.399	-26.85	1.4	18.7	8888	3	9.081	2.242	1.802	1.152	36.090
P11	21.488	17.409				8889.1	3	9.041	2.555	1.780	1.139	36.050
P11	21.498	17.419	-27.32	1.51	19.86	8891	3	8.435	2.510	1.478	0.938	36.569
P11	21.508	17.429				8892	2	9.081	2.509	1.865	1.198	35.746
P11	21.518	17.439	-27.37	1.51	19.97	8893	2	8.909	2.294	1.724	1.097	36.367
P11	21.528	17.449				8894	2	8.204	2.519	1.596	1.012	36.596
P11	21.538	17.459	-27.33	1.49	19.33	8896	2	7.411	3.515	1.746	1.116	36.115
P11	21.548	17.469				8897	2	8.330	2.914	1.508	0.953	36.793
P11	21.558	17.479	-27.15	1.54	19.42	8898	2	8.652	3.222	1.708	1.095	35.871
P11	21.568	17.489				8900	2	8.241	3.650	1.785	1.146	35.781
P11	21.578	17.499	-27.05	1.4	18.1	8901	2	9.671	2.492	1.728	1.102	36.240
P11	21.588	17.509				8902	2	8.591	2.733	1.580	1.004	36.429
P11	21.598	17.519	-27.30	1.51	20.06	8903	2	8.032	2.930	1.555	0.993	36.136
P11	21.608	17.529				8904.1	2	8.536	3.251	1.920	1.237	35.591
P11	21.618	17.539	-27.22	1.43	18.96	8906	2	8.228	3.213	1.704	1.088	36.121
P11	21.628	17.549				8907	2	9.344	2.272	1.797	1.151	35.982
P11	21.638	17.559	-27.25	1.53	20.02	8908	2	8.554	2.892	1.677	1.074	35.977
P11	21.648	17.569				8909	2	7.700	2.970	1.489	0.946	36.435
P11	21.658	17.579	-27.16	1.48	19.19	8910	2	9.140	2.711	1.956	1.266	35.299
P11	21.668	17.589				8911	2	8.426	2.706	1.647	1.063	35.463
P11	21.678	17.599	-27.00	1.4	18.0	8912	2	8.315	2.740	1.618	1.038	35.872
P11	21.688	17.609				8913	2	9.473	2.541	1.831	1.183	35.362
P11	21.698	17.619	-27.17	1.45	18.93	8915	2	9.315	2.314	1.668	1.074	35.639
P11	21.708	17.629				8916	2	9.035	2.573	1.661	1.067	35.779
P11	21.718	17.639	-27.25	1.52	19.46	8917	2	8.670	2.821	1.709	1.101	35.590
P11	21.728	17.649				8918	2	9.675	2.397	1.779	1.145	35.624
P11	21.738	17.659	-27.42	1.63	20.55	8920	2	9.046	2.543	1.764	1.131	35.890
P11	21.748	17.669				8921	2	9.142	2.110	1.793	1.162	35.210

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
P11	21.758	17.679	-27.41	1.62	20.38	8922	2	8.917	2.802	1.492	0.957	35.882
P11	21.768	17.689				8923	2	10.484	2.434	1.813	1.181	34.830
P11	21.778	17.699	-26.83	1.4	18.3	8924	2	9.553	3.136	1.729	1.125	34.921
P11	21.788	17.709				8926	2	8.847	3.545	1.677	1.097	34.574
P11	21.798	17.719	-27.41	1.58	19.56	8927	2	9.522	2.891	1.572	1.040	33.846
OD2	21.853	17.774	-26.94	1.4	18.2	8933	2	6.856	3.398	1.563	1.068	31.710
OD2	21.863	17.784				8935	2	7.476	2.807	1.830	1.246	31.929
OD2	21.873	17.794	-27.38	1.59	19.57	8936	2	7.139	2.945	1.623	1.099	32.300
OD2	21.883	17.804				8938	2	6.851	3.193	1.387	0.936	32.503
OD2	21.893	17.814	-27.36	1.55	19.60	8940	2	7.296	3.278	1.793	1.216	32.180
OD2	21.903	17.824				8941	2	7.550	3.050	1.745	1.179	32.405
OD2	21.913	17.834	-27.43	1.54	19.18	8943	3	6.733	3.140	1.484	0.993	33.091
OD2	21.923	17.844				8945	3	7.092	3.240	1.746	1.175	32.704
OD2	21.933	17.854	-27.44	1.53	19.36	8947	3	6.726	3.299	1.703	1.141	32.991
OD2	21.943	17.864				8948	3	6.659	3.416	1.508	1.008	33.179
OD2	21.953	17.874	-27.00	1.4	18.6	8950	3	7.548	3.009	1.693	1.133	33.054
OD2	21.963	17.884				8952	3	7.122	2.954	1.407	0.931	33.876
OD2	21.973	17.894	-27.40	1.54	19.35	8954	4	8.205	2.630	1.770	1.178	33.451
OD2	21.983	17.904				8956	4	7.406	2.870	1.618	1.068	34.013
OD2	21.993	17.914	-27.63	1.58	18.88	8959	6	7.279	3.062	1.643	1.086	33.884
OD2	22.003	17.924				8963	11	7.304	3.178	1.589	1.047	34.147
OD2	22.013	17.934	-27.39	1.54	19.70	8967	12	7.448	2.885	1.698	1.113	34.496
OD2	22.023	17.944				8972	10	7.310	2.865	1.530	0.998	34.770
OD2	22.033	17.954	-27.37	1.61	19.92	8976	9	7.717	2.653	1.666	1.089	34.630
OD2	22.043	17.964				8980	8	6.749	3.918	1.768	1.154	34.709
OD2	22.053	17.974	-27.03	1.5	18.4	8984	7	7.234	2.966	1.494	0.964	35.481
OD2	22.063	17.984				8988	7	7.541	2.865	1.679	1.080	35.697
OD2	22.073	17.994	-27.39	1.55	19.51	8993	6.1	7.265	2.797	1.344	0.856	36.358
OD2	22.083	18.004				8997	6	7.359	2.501	1.571	1.003	36.156
OD2	22.093	18.014	-27.41	1.54	20.09	9000	6	6.751	3.060	1.447	0.925	36.063

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
OD2	22.103	18.024				9004	6	7.583	2.425	1.633	1.047	35.912
OD2	22.113	18.034	-27.33	1.56	19.45	9008	5	7.393	2.592	1.602	1.018	36.459
OD2	22.123	18.044				9012	5	7.251	2.541	1.530	0.968	36.750
OD2	22.133	18.054	-27.39	1.61	19.89	9016	5	7.184	2.586	1.478	0.939	36.483
OD2	22.143	18.064				9020	5	7.411	2.512	1.522	0.967	36.478
OD2	22.153	18.074	-26.99	1.5	18.6	9024	5	7.801	2.457	1.536	0.976	36.456
OD2	22.163	18.084				9027	5	7.683	2.571	1.500	0.956	36.271
OD2	22.173	18.094	-27.33	1.57	20.23	9030	5	7.740	2.429	1.459	0.926	36.526
OD2	22.183	18.104				9033	5	7.787	2.271	1.461	0.924	36.741
OD2	22.193	18.114	-27.43	1.60	19.85	9037	5	7.595	2.522	1.609	1.022	36.440
OD2	22.203	18.124				9040	5	7.584	2.574	1.375	0.874	36.445
OD2	22.213	18.134	-27.43	1.64	20.00	9042.1	5	8.095	2.513	1.608	1.026	36.181
OD2	22.223	18.144				9045	4	7.599	2.629	1.477	0.935	36.683
OD2	22.233	18.154	-27.41	1.53	19.45	9048	4	7.251	3.189	1.410	0.893	36.657
OD2	22.243	18.164				9050	4	7.507	2.954	1.564	0.994	36.419
OD2	22.253	18.174	-27.08	1.5	18.6	9052	4	7.891	2.428	1.473	0.938	36.304
OD2	22.263	18.184				9054	4	8.168	2.325	1.506	0.954	36.619
OD2	22.273	18.194	-27.46	1.58	19.98	9057	4	8.341	2.426	1.553	0.988	36.351
OD2	22.283	18.204				9059	4	6.805	2.716	1.481	0.938	36.627
OD2	22.293	18.214	-27.48	1.54	19.93	9061.1	4	6.847	2.764	1.523	0.955	37.323
OD2	22.303	18.224				9063.1	4	6.736	2.780	1.467	0.917	37.490
OD2	22.313	18.234	-27.47	1.63	19.26	9065.1	4	7.069	2.744	1.477	0.929	37.122
OD2	22.323	18.244				9067.1	4	7.341	2.414	1.529	0.959	37.235
OD2	22.333	18.254	-27.46	1.52	19.91	9070	4	7.276	2.310	1.465	0.920	37.189
OD2	22.343	18.264				9072	4	7.025	2.514	1.459	0.921	36.842
OD2	22.353	18.274	-27.16	1.5	19.4	9074	4	6.275	2.852	1.754	1.112	36.577
OD2	22.363	18.284				9076	4	6.733	2.316	1.632	1.027	37.065
OD2	22.373	18.294	-27.50	1.55	19.39	9078	4	6.895	2.298	1.515	0.952	37.131
OD2	22.383	18.304				9080	4	6.632	3.258	1.709	1.091	36.192
OD2	22.393	18.314	-27.46	1.53	19.65	9082	4	7.078	2.408	1.381	0.870	37.032

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
OD2	22.403	18.324				9085	4	7.200	2.767	1.666	1.066	35.993
OD2	22.413	18.334	-27.57	1.56	20.38	9086	4	6.087	3.061	1.419	0.902	36.435
OD2	22.423	18.344				9088	4	6.571	2.890	1.636	1.043	36.249
OD2	22.433	18.354	-27.47	1.53	19.77	9090	4	6.657	2.585	1.406	0.896	36.282
OD2	22.443	18.364				9092	4	6.599	3.060	1.546	0.995	35.638
OD2	22.453	18.374	-27.07	1.5	18.6	9093.1	4	6.540	2.930	1.666	1.072	35.638
OD2	22.463	18.384				9096	4	6.490	2.718	1.446	0.934	35.432
OD2	22.473	18.394	-27.27	1.6	20.3	9097	4	6.853	2.233	1.594	1.023	35.795
OD2	22.483	18.404				9100	4	6.800	2.400	1.602	1.031	35.631
OD2	22.493	18.414	-27.25	1.5	20.2	9102	4	6.962	2.382	1.595	1.025	35.720
OD2	22.503	18.424				9104	4	6.863	2.437	1.440	0.925	35.815
OD2	22.513	18.434	-27.27	1.5	20.2	9105	4	6.708	2.699	1.912	1.235	35.430
OD2	22.523	18.444				9107	4	6.709	2.655	1.688	1.088	35.552
OD2	22.533	18.454	-27.26	1.5	19.9	9109	4	6.945	2.478	1.512	0.973	35.648
OD2	22.543	18.464				9111	4	7.272	2.548	1.580	1.021	35.382
OD2	22.553	18.474	-27.06	1.5	20.0	9113	4	6.566	2.317	1.666	1.068	35.910
OD2	22.563	18.484				9115	4	7.402	2.417	1.623	1.050	35.276
OD2	22.573	18.494	-27.21	1.5	19.3	9116	4	6.802	2.546	1.408	0.910	35.413
OD2	22.583	18.504				9118	4	7.499	2.727	1.636	1.070	34.562
OD2	22.593	18.514	-27.22	1.6	20.0	9120	4	7.037	2.673	1.433	0.938	34.558
OD2	22.603	18.524				9122	4	6.906	2.872	1.419	0.928	34.593
OD2	22.613	18.534	-27.27	1.6	19.3	9124	4	6.955	2.937	1.597	1.047	34.461
OD2	22.623	18.544				9126	4	6.626	3.186	1.552	1.016	34.550
OD2	22.633	18.554	-27.25	1.5	19.8	9128	4	7.475	3.048	1.534	1.009	34.254
OD2	22.643	18.564				9130	4	7.755	3.066	1.635	1.087	33.487
OD2	22.653	18.574	-27.23	1.5	20.1	9132	4	7.484	2.987	1.594	1.061	33.449
OD2	22.663	18.584				9134	5	7.718	3.021	1.632	1.092	33.060
OD2	22.673	18.594	-27.26	1.6	19.9	9136	5	7.325	2.973	1.576	1.066	32.345
OD3	22.753	18.674	-27.00	1.4	19.8	9153	5.1	6.409	3.468	1.912	1.300	32.006
OD3	22.763	18.684				9155.1	6	6.225	3.326	1.707	1.150	32.657

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
OD3	22.773	18.694	-27.35	1.6	20.6	9158	6	6.559	3.358	1.866	1.256	32.715
OD3	22.783	18.704				9160.1	7	6.305	3.565	1.841	1.228	33.268
OD3	22.793	18.714	-27.47	1.9	21.6	9163	7	6.166	3.264	1.501	0.991	33.979
OD3	22.803	18.724				9166	8	6.795	3.810	1.955	1.270	35.044
OD3	22.813	18.734	-27.62	2.3	25.2	9168	8	7.398	3.731	1.594	1.016	36.265
OD3	22.823	18.744				9171	10	8.916	3.691	1.773	1.107	37.578
OD3	22.833	18.754	-27.99	3.4	32.1	9174.1	11	10.718	3.798	1.705	1.015	40.445
OD3	22.843	18.764				9178	14	7.720	3.728	1.578	0.991	37.233
OD3	22.853	18.774	-27.86	3.4	31.7	9183	12	7.818	3.909	1.760	1.104	37.300
OD3	22.863	18.784				9189	8	9.101	4.137	1.870	1.145	38.734
OD3	22.873	18.794	-28.00	4.1	35.2	9194	7	10.010	3.850	1.626	0.976	39.960
OD3	22.883	18.804				9199	7	15.937	3.713	1.497	0.783	47.664
OD3	22.893	18.814	-28.34	7.8	45.1	9204	7	16.065	3.380	1.649	0.860	47.810
OD3	22.903	18.824				9209	6	15.608	3.924	1.365	0.741	45.716
OD3	22.913	18.834	-28.27	6.6	42.7	9214	6	13.864	3.961	1.691	0.941	44.386
OD3	22.923	18.844				9219	6	19.536	4.029	1.562	0.803	48.609
OD3	22.933	18.854	-28.43	7.2	44.6	9225	6	15.779	3.741	1.484	0.804	45.849
OD3	22.943	18.864				9231	6	12.292	4.610	1.770	1.042	41.119
OD3	22.953	18.874	-28.48	6.8	42.0	9236	6	13.567	3.938	1.747	0.988	43.461
OD3	22.963	18.884				9242	6	17.430	3.545	1.283	0.664	48.281
OD3	22.973	18.894	-28.15	7.3	44.3	9248	7	16.201	3.297	1.732	0.912	47.358
OD3	22.983	18.904				9255	7	14.183	4.029	1.799	0.998	44.551
OD3	22.993	18.914	-28.52	5.7	40.3	9261	7	13.961	3.972	1.513	0.847	43.984
OD3	23.003	18.924				9268.1	8	15.094	3.978	1.531	0.838	45.272
OD3	23.013	18.934	-28.43	6.6	44.2	9274	11	14.323	3.981	1.582	0.878	44.463
OD3	23.023	18.944				9279	13	18.159	3.623	1.533	0.785	48.828
OD3	23.033	18.954	-28.44	7.0	45.7	9283	11	25.264	3.817	1.466	0.651	55.608
OD3	23.043	18.964				9286	9	18.007	4.322	1.580	0.817	48.325
OD3	23.053	18.974	-28.17	5.6	41.2	9290	8	14.804	4.230	1.481	0.819	44.717
OD3	23.063	18.984				9293	8	14.991	3.831	1.601	0.887	44.569

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
OD3	23.073	18.994	-28.58	5.5	43.4	9296	7	14.407	4.053	1.575	0.887	43.705
OD3	23.083	19.004				9300	6	17.828	4.596	1.684	0.882	47.652
OD3	23.093	19.014	-28.73	5.7	45.9	9303	6	14.740	4.269	1.476	0.811	45.018
OD3	23.103	19.024				9306	6	14.821	4.123	1.742	0.959	44.934
OD3	23.113	19.034	-28.70	4.9	39.5	9310	6	14.366	4.173	1.445	0.814	43.633
OD3	23.123	19.044				9313	6	16.979	4.340	1.750	0.941	46.208
OD3	23.133	19.054	-28.93	5.9	42.5	9316	6	20.847	4.556	1.429	0.710	50.320
OD3	23.143	19.064				9319	5	20.130	4.592	1.427	0.705	50.641
OD3	23.153	19.074	-26.44	5.8	39.5	9322	5	18.694	4.225	1.510	0.766	49.297
OD3	23.163	19.084				9325	5	25.656	4.490	1.264	0.560	55.662
OD3	23.173	19.094	-29.01	5.9	44.8	9329	5	17.079	4.364	1.498	0.779	48.003
OD3	23.183	19.104				9332	5	14.111	4.237	1.614	0.910	43.623
OD3	23.193	19.114	-28.85	6.1	41.0	9336	5	15.671	4.255	1.462	0.799	45.373
OD3	23.203	19.124				9340	5	13.791	4.339	1.697	0.972	42.750
OD3	23.213	19.134	-28.75	5.0	39.0	9343	5	12.174	4.248	1.532	0.915	40.264
OD3	23.223	19.144				9347	5	13.109	4.241	1.595	0.932	41.537
OD3	23.233	19.154	-28.96	6.0	41.7	9350	5	11.340	3.883	1.580	0.951	39.826
OD3	23.243	19.164				9354	5	12.913	3.990	1.563	0.901	42.370
OD3	23.253	19.174	-28.70	5.0	42.2	9358	5	10.909	4.071	1.348	0.827	38.682
OD3	23.263	19.184				9362	5	9.208	3.573	1.867	1.189	36.321
OD3	23.273	19.194	-28.81	4.5	34.4	9366	5	9.103	3.614	1.510	0.958	36.515
OD3	23.283	19.204				9370	5	9.648	3.881	1.836	1.179	35.784
OD3	23.293	19.214	-28.99	5.2	34.5	9374	5	9.008	3.589	1.806	1.179	34.691
OD3	23.303	19.224				9378	5	9.007937907	3.589327055	1.805882353	1.179084967	34.6906413
OD3	23.313	19.234	-28.99	5.2	34.5	9382	6	9.007937907	3.589327055	1.805882353	1.179084967	34.6906413
OD3	23.323	19.244				9386	6	9.007937907	3.589327055	1.805882353	1.179084967	34.6906413
OD3	23.333	19.254	-28.99	5.2	34.5	9390	6	9.007937907	3.589327055	1.805882353	1.179084967	34.6906413
OD3	23.343	19.264				9394	6	9.007937907	3.589327055	1.805882353	1.179084967	34.6906413
OD3	23.353	19.274	-28.99	5.2	34.5	9398	6	9.007937907	3.589327055	1.805882353	1.179084967	34.6906413
OD3	23.363	19.284				9402	6	8.367968966	3.297312275	1.776143791	1.179411765	33.5970561

Segment	Depth (m) Surface	Depth (m) MSL	d13C (‰VPDB)	%TOC	C/N	Modelled age	Sed rate (yr/cm)	Organic carbon (%)	Inorganic carbon (%)	Wet Bulk Density (g/cm3)	Dry Bulk Density (g/cm3)	Water content (%)
OD3	23.373	19.294	-28.68	1.2	25.3	9406	7	4.889193512	1.964816084	1.908823529	1.430392157	25.0642013
OD3	23.383	19.304				9411	8	4.004237288	1.694915254	1.968627451	1.54248366	21.6467463
OD3	23.393	19.314	-28.46	1.5	20.9	9415	9	4.346861832	1.885118652	1.918627451	1.473529412	23.1987736
OD3	23.403	19.324				9419	11	5.972558515	2.986279257	1.687908497	1.214705882	28.03485
OD3	23.413	19.334	-28.53	2.0	23.3	9424	15	5.481446588	3.725670728	2.086699346	1.52624183	26.8585658
OD3	23.423	19.344				9433	18	6.403803132	4.697986577	1.652287582	1.168627451	29.2721519
OD3	23.433	19.354	-26.77	0.5	8.5	9444	20	4.847775176	6.042154567	1.730065359	1.395424837	19.3426521
OD3	23.443	19.364				9456	19	4.535053048	4.514250052	2.107843137	1.570915033	25.4728682
OD3	23.453	19.374	-28.09	0.8	17.2	9469	19	4.623655914	4.967741935	2.020915033	1.519607843	24.8059508
OD3	23.463	19.384				9485.1	20	4.62091865	3.154399557	1.562745098	1.181045752	24.4249268
OD3	23.473	19.394	-26.58	0.29	6.57	9503	18	4.638058084	2.81751192	1.972875817	1.507843137	23.5713103
OD3	23.483	19.404				9518	15	4.595500239	2.943992341	1.794117647	1.365359477	23.8979964
OD3	23.493	19.414	-26.15	0.28	6.35			5.002284148	2.603928735	1.897385621	1.430718954	24.5952463

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
OD1	18.348	58.483	23.169	2.371	11.608	163.564	18.96	5.209	0.236	0.978	Coarse Silt	Very Poorly Sorted
OD1	14.7077	61.188	24.105	2.976	12.163	171.233	20.99	4.886	0.290	0.917	Coarse Silt	Very Poorly Sorted
OD1	16.379	60.437	23.184	2.629	12.451	169.561	20.26	5.090	0.237	1.001	Coarse Silt	Very Poorly Sorted
OD1	12.4051	53.471	34.124	3.357	15.834	205.198	25.85	5.077	0.237	0.690	Coarse Silt	Very Poorly Sorted
OD1	14.8917	42.88	42.228	2.74	25.055	237.029	30.36	5.820	0.002	0.711	Coarse Silt	Very Poorly Sorted
OD1	13.9361	49.563	36.501	3.034	16.615	220.089	26.16	5.442	0.198	0.693	Coarse Silt	Very Poorly Sorted
OD1	14.6151	48.921	36.464	2.843	18.324	202.828	26.35	5.382	0.116	0.696	Coarse Silt	Very Poorly Sorted
OD1	12.8679	53.584	33.548	3.238	15.964	209.732	25.79	5.191	0.227	0.711	Coarse Silt	Very Poorly Sorted
OD1	13.4075	49.175	37.417	3.134	17.842	203.144	26.72	5.190	0.158	0.673	Coarse Silt	Very Poorly Sorted
OD1	14.1851	45.706	40.109	2.92	20.111	215.393	27.96	5.465	0.094	0.688	Coarse Silt	Very Poorly Sorted
OD1	16.975	46.743	36.282	2.503	15.013	205.471	23.69	5.700	0.179	0.679	Coarse Silt	Very Poorly Sorted
OD1	13.4421	55.259	31.299	3.17	14.049	187.483	23.69	4.993	0.259	0.694	Coarse Silt	Very Poorly Sorted
OD1	13.0786	57.186	29.736	3.241	14.064	183.358	23.58	4.887	0.263	0.709	Coarse Silt	Very Poorly Sorted
OD1	14.9766	47.885	37.139	2.788	17.516	199.943	25.64	5.395	0.130	0.692	Coarse Silt	Very Poorly Sorted
OD1	13.3912	44.96	41.649	3.05	22.716	209.352	29.50	5.298	0.042	0.691	Coarse Silt	Very Poorly Sorted
OD1	13.5207	43.666	42.814	3.054	22.276	218.884	29.59	5.401	0.062	0.678	Coarse Silt	Very Poorly Sorted
OD1	11.9318	33.161	54.907	3.314	85.583	226.33	49.65	5.273	-0.543	0.718	Very Coarse Silt	Very Poorly Sorted
OD1	12.0254	37.5945	50.38	3.339	66.136	231.044	45.08	5.323	-0.414	0.689	Very Coarse Silt	Very Poorly Sorted
OD1	13.192	35.917	50.891	2.99	69.48	231.368	45.04	5.544	-0.451	0.710	Very Coarse Silt	Very Poorly Sorted
OD1	12.7908	37.394	49.815	3.144	61.604	224.296	42.90	5.390	-0.399	0.695	Very Coarse Silt	Very Poorly Sorted
OD1	20.4409	60.025	19.534	2.134	10.671	140.306	16.30	5.018	0.210	1.056	Coarse Silt	Very Poorly Sorted
OD1	15.4129	39.208	45.379	2.655	29.427	213.102	31.20	5.642	-0.105	0.681	Coarse Silt	Very Poorly Sorted
OD1	24.0559	66.299	9.645	1.918	8.29	58.794	9.704	3.670	0.108	1.326	Medium Silt	Poorly Sorted
OD1	12.1135	39.051	48.835	3.355	51.33	224.938	40.76	5.266	-0.303	0.677	Very Coarse Silt	Very Poorly Sorted
OD1	13.0427	39.05	47.908	3.108	41.223	232.037	37.63	5.490	-0.207	0.689	Very Coarse Silt	Very Poorly Sorted
OD1	9.3825	30.157	60.461	4.117	105.312	253.316	59.19	5.034	-0.576	0.728	Very Coarse Silt	Very Poorly Sorted
OD1	13.6144	44.297	42.089	3.046	23.012	205.821	29.29	5.285	0.030	0.680	Coarse Silt	Very Poorly Sorted
OD1	11.1876	34.722	54.091	3.558	85.264	237.618	50.65	5.235	-0.516	0.687	Very Coarse Silt	Very Poorly Sorted
OD1	11.8184	37.497	50.685	3.391	68.338	230.681	45.77	5.286	-0.427	0.687	Very Coarse Silt	Very Poorly Sorted
OD1	11.2399	36.129	52.631	3.537	79.696	240.896	49.70	5.281	-0.482	0.691	Very Coarse Silt	Very Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
OD1	13.125	40.574	46.301	3.132	28.321	220.96	32.63	5.374	-0.042	0.668	Very Coarse Silt	Very Poorly Sorted
OD1	12.5289	36.239	51.232	3.204	72.078	232.681	46.13	5.417	-0.458	0.692	Very Coarse Silt	Very Poorly Sorted
OD1	13.226	45.175	41.599	3.122	22.363	205.091	29.25	5.216	0.050	0.678	Coarse Silt	Very Poorly Sorted
OD1	13.0153	45.236	41.749	3.15	22.094	210.904	29.54	5.248	0.065	0.681	Coarse Silt	Very Poorly Sorted
OD1	12.8535	56.959	30.187	3.288	14.478	183.998	23.99	4.868	0.253	0.701	Coarse Silt	Very Poorly Sorted
OD1	14.5759	49.205	36.22	2.912	16.348	202.271	25.27	5.332	0.175	0.683	Coarse Silt	Very Poorly Sorted
OD1	13.6753	46.088	40.236	3.049	19.634	205.577	27.65	5.268	0.107	0.678	Coarse Silt	Very Poorly Sorted
OD1	13.0858	51.35	35.565	3.242	15.311	192.016	24.93	5.008	0.230	0.667	Coarse Silt	Very Poorly Sorted
OD1	14.1754	48.745	37.08	2.919	18.28	195.117	26.19	5.246	0.118	0.702	Coarse Silt	Very Poorly Sorted
OD1	15.6743	46.15	38.176	2.635	17.574	201.866	25.42	5.536	0.117	0.695	Coarse Silt	Very Poorly Sorted
OD1	14.7839	46.855	38.361	2.801	18.98	197.503	26.38	5.361	0.092	0.696	Coarse Silt	Very Poorly Sorted
OD1	14.6341	55.602	29.764	2.964	13.743	177.789	22.62	5.017	0.240	0.705	Coarse Silt	Very Poorly Sorted
OD1	13.8625	45.487	40.65	3.058	17.002	194.604	25.68	5.168	0.165	0.671	Coarse Silt	Very Poorly Sorted
OD1	17.2924	60.276	22.432	2.61	10.581	165.561	18.92	5.067	0.309	1.124	Coarse Silt	Very Poorly Sorted
OD1	16.2712	42.115	41.614	2.494	20.4175	210.926	26.76	5.760	0.052	0.690	Coarse Silt	Very Poorly Sorted
OD1	15.2191	46.833	37.948	2.782	15.869	201.824	24.86	5.441	0.178	0.673	Coarse Silt	Very Poorly Sorted
OD1	15.4499	49.408	35.142	2.761	14.281	193.617	23.43	5.368	0.217	0.685	Coarse Silt	Very Poorly Sorted
OD1	15.1643	42.861	41.975	2.702	19.702	222.781	27.63	5.714	0.092	0.686	Coarse Silt	Very Poorly Sorted
OD1	12.5804	40.347	47.073	3.211	32.755	242.211	35.48	5.509	-0.080	0.697	Very Coarse Silt	Very Poorly Sorted
OD1	19.0784	49.452	31.47	2.348	11.778	186.885	20.46	5.620	0.253	0.676	Coarse Silt	Very Poorly Sorted
OD1	17.2557	54.545	28.2	2.508	12.385	180.962	20.95	5.392	0.241	0.730	Coarse Silt	Very Poorly Sorted
OD1	18.6975	45.25	36.052	2.182	15.841	201.507	23.14	5.927	0.118	0.693	Coarse Silt	Very Poorly Sorted
OD1	16.2208	31.476	52.303	2.271	76.771	235.015	43.50	6.149	-0.519	0.721	Very Coarse Silt	Very Poorly Sorted
OD1	18.2966	42.769	38.934	2.205	18.411	201.748	24.58	5.914	0.054	0.691	Coarse Silt	Very Poorly Sorted
OD1	15.7205	46.359	37.921	2.605	18.706	201.916	26.01	5.549	0.086	0.696	Coarse Silt	Very Poorly Sorted
OD1	16.2582	59.015	24.727	2.727	11.782	168.022	20.15	5.027	0.276	0.845	Coarse Silt	Very Poorly Sorted
OD1	15.7341	54.116	30.15	2.783	13.077	184.4	22.08	5.214	0.251	0.704	Coarse Silt	Very Poorly Sorted
OD1	20.8911	59.838	19.271	2.075	10.511	142.062	16.24	5.080	0.213	1.132	Coarse Silt	Very Poorly Sorted
OD1	19.0314	56.331	24.638	2.212	12.27	183.008	19.66	5.645	0.218	0.898	Coarse Silt	Very Poorly Sorted
OD1	21.1861	60.033	18.781	1.987	10.196	144.566	15.91	5.172	0.218	1.216	Coarse Silt	Very Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
OD1	16.9405	55.307	27.753	2.586	11.896	184.465	20.92	5.356	0.272	0.727	Coarse Silt	Very Poorly Sorted
OD1	19.533	57.543	22.924	2.229	10.866	162.355	18.21	5.317	0.249	1.007	Coarse Silt	Very Poorly Sorted
OD1	17.4165	58.253	24.331	2.47	12.369	171.067	20.10	5.242	0.227	0.901	Coarse Silt	Very Poorly Sorted
OD1	14.917	55.606	29.477	2.928	13.044	184.913	22.38	5.119	0.267	0.703	Coarse Silt	Very Poorly Sorted
OD1	23.5893	57.179	19.232	1.822	9.481	140.398	15.00	5.306	0.225	1.112	Medium Silt	Very Poorly Sorted
OD1	18.323	58.868	22.809	2.371	11.427	159.487	18.73	5.159	0.238	0.996	Coarse Silt	Very Poorly Sorted
OD1	19.2194	62.467	18.313	2.295	10.646	138.253	16.42	4.810	0.227	1.226	Coarse Silt	Very Poorly Sorted
OD1	20.4004	63.96	15.64	2.196	9.816	128.058	13.45	4.333	0.196	1.332	Medium Silt	Very Poorly Sorted
OD1	19.1384	56.348	24.514	2.269	11.473	166.987	18.91	5.370	0.234	0.861	Coarse Silt	Very Poorly Sorted
OD1	24.9345	62.452	12.614	1.736	8.878	93.721	10.75	4.197	0.114	1.217	Medium Silt	Very Poorly Sorted
OD1	22.6932	55.365	21.942	1.833	10.556	146.231	16.29	5.459	0.193	0.958	Coarse Silt	Very Poorly Sorted
OD1	23.0851	61.314	15.601	1.889	9.419	114.253	13.01	4.571	0.174	1.188	Medium Silt	Very Poorly Sorted
OD1	20.346	57.026	22.628	2.102	10.809	156.539	17.61	5.353	0.229	1.005	Coarse Silt	Very Poorly Sorted
OD1	21.1377	56.34	22.522	2.079	10.373	161.952	17.38	5.453	0.248	1.016	Coarse Silt	Very Poorly Sorted
OD1	13.5203	59.01	27.47	3.163	14.945	166.01	23.03	4.723	0.204	0.748	Coarse Silt	Very Poorly Sorted
OD1	20.6242	66.291	13.084	2.114	10.327	88.99	12.42	3.916	0.089	1.208	Medium Silt	Poorly Sorted
OD1	22.4803	66.02	11.499	1.964	9.461	76.196	11.06	3.802	0.078	1.222	Medium Silt	Poorly Sorted
OD1	22.3686	63.349	14.282	1.939	9.6	93.628	12.54	4.235	0.135	1.192	Medium Silt	Very Poorly Sorted
OD1	21.0095	64.56	14.431	2.095	9.949	102.777	12.83	4.165	0.143	1.240	Medium Silt	Very Poorly Sorted
OD1	21.0095	64.56	14.431	2.095	9.949	102.777	12.83	4.165	0.143	1.240	Medium Silt	Very Poorly Sorted
OD1	19.8895	62.774	17.336	2.187	11.187	121.884	15.56	4.609	0.160	1.126	Medium Silt	Very Poorly Sorted
OD1	20.6311	64.94	14.429	2.114	10.521	96.375	13.39	4.160	0.117	1.169	Medium Silt	Very Poorly Sorted
OD1	17.3047	66.143	16.553	2.505	12.975	106.992	16.41	4.175	0.094	1.042	Coarse Silt	Very Poorly Sorted
OD1	20.9119	63.726	15.362	2.077	10.348	106.354	13.75	4.366	0.146	1.189	Medium Silt	Very Poorly Sorted
OD1	20.7142	62.605	16.681	2.118	10.38	108.026	14.54	4.493	0.168	1.119	Medium Silt	Very Poorly Sorted
OD1	19.0293	62.735	18.236	2.316	11.041	126.694	16.20	4.638	0.195	1.146	Coarse Silt	Very Poorly Sorted
P1	21.47	58.83	19.7	2.017	10.316	133.066	15.74	5.028	0.207	1.076	Coarse Silt	Very Poorly Sorted
P1	26.2662	65.168	8.566	1.704	8.058	48.823	9.061	3.645	0.062	1.253	Medium Silt	Poorly Sorted
P1	21.9929	64.336	13.671	1.97	9.999	93.697	12.41	4.158	0.109	1.190	Medium Silt	Very Poorly Sorted
P1	21.5963	60.253	18.151	2.008	10.374	128.465	15.21	4.894	0.190	1.128	Medium Silt	Very Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P1	19.4915	64.371	16.138	2.321	10.561	107.964	14.68	4.273	0.180	1.158	Medium Silt	Very Poorly Sorted
P1	18.8338	61.275	19.892	2.388	10.733	131.916	16.79	4.711	0.233	1.088	Coarse Silt	Very Poorly Sorted
P1	25.3015	66.366	8.332	1.715	8.956	51.225	9.875	3.664	0.011	1.130	Medium Silt	Poorly Sorted
P1	26.2304	65.053	8.716	1.674	8.465	53.545	9.590	3.741	0.045	1.156	Medium Silt	Poorly Sorted
P1	21.4419	60.457	18.101	1.996	10.451	130.994	15.23	4.940	0.189	1.134	Medium Silt	Very Poorly Sorted
P1	19.1876	64.271	16.541	2.351	10.856	113.527	15.11	4.331	0.179	1.124	Medium Silt	Very Poorly Sorted
P1	22.0006	61.141	16.858	1.919	11.108	108.476	14.53	4.670	0.112	1.037	Medium Silt	Very Poorly Sorted
P1	22.4242	66.106	11.47	1.925	9.877	74.846	11.52	3.917	0.064	1.182	Medium Silt	Poorly Sorted
P1	24.528	62.162	13.31	1.739	9.352	92.191	11.53	4.318	0.108	1.163	Medium Silt	Very Poorly Sorted
P1	24.528	62.162	13.31	1.739	9.352	92.191	11.53	4.318	0.108	1.163	Medium Silt	Very Poorly Sorted
P1	22.2093	68.927	8.864	1.933	10.312	55.689	11.35	3.683	-0.003	1.111	Medium Silt	Poorly Sorted
P1	24.5184	64.736	10.746	1.745	9.083	68.153	10.67	3.930	0.065	1.158	Medium Silt	Poorly Sorted
P1	24.0157	61.169	14.815	1.776	9.456	102.176	12.44	4.530	0.141	1.160	Medium Silt	Very Poorly Sorted
P1	23.9542	59.148	16.897	1.766	9.665	121.668	13.68	4.947	0.174	1.138	Medium Silt	Very Poorly Sorted
P1	19.5726	59.038	21.389	2.239	11.162	142.03	17.31	4.997	0.212	0.986	Coarse Silt	Very Poorly Sorted
P1	20.4875	65.14	14.372	2.244	9.628	103.019	12.83	4.060	0.183	1.265	Medium Silt	Very Poorly Sorted
P1	20.7871	63.465	15.748	2.051	11.209	100.256	14.40	4.395	0.103	1.050	Medium Silt	Very Poorly Sorted
P1	23.2008	61.472	15.328	1.82	10.07	101.737	13.17	4.563	0.124	1.107	Medium Silt	Very Poorly Sorted
P1	22.7582	61.869	15.373	1.908	9.735	105.523	13.14	4.498	0.155	1.155	Medium Silt	Very Poorly Sorted
P1	21.9372	61.296	16.766	1.958	10.568	114.784	14.38	4.683	0.147	1.099	Medium Silt	Very Poorly Sorted
P1	24.1399	63.491	12.369	1.755	9.449	82.084	11.36	4.161	0.084	1.155	Medium Silt	Very Poorly Sorted
P1	18.4153	58.897	22.688	2.389	11.989	144.974	18.31	4.927	0.201	0.900	Coarse Silt	Very Poorly Sorted
P1	18.3448	64.647	17.008	2.446	11.388	121.331	15.87	4.372	0.180	1.131	Coarse Silt	Very Poorly Sorted
P1	20.7108	59.832	19.457	2.056	11.13	130.823	16.12	4.940	0.171	1.050	Coarse Silt	Very Poorly Sorted
P1	20.8181	59.475	19.707	2.047	10.899	132.395	16.08	4.978	0.182	1.042	Coarse Silt	Very Poorly Sorted
P1	22.3681	60.102	17.53	1.885	10.528	115.581	14.52	4.815	0.147	1.058	Medium Silt	Very Poorly Sorted
P1	21.4859	62.418	16.0965	1.9765	10.7215	102.2465	14.18	4.498	0.122	1.069	Medium Silt	Very Poorly Sorted
P1	23.477	64.103	12.42	1.818	9.712	80.465	11.72	4.124	0.081	1.139	Medium Silt	Very Poorly Sorted
P1	21.4622	61.982	16.555	1.966	10.704	110.209	14.38	4.617	0.135	1.111	Medium Silt	Very Poorly Sorted
P1	20.5326	56.986	22.482	2.013	12.139	140.472	17.36	5.178	0.144	0.894	Coarse Silt	Very Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P1	17.0521	61.782	21.166	2.517	14.209	124.886	18.69	4.532	0.100	0.909	Coarse Silt	Very Poorly Sorted
P1	20.014	60.465	19.521	2.173	11.665	117.358	16.20	4.668	0.145	0.946	Coarse Silt	Very Poorly Sorted
P1	21.5652	61.105	17.33	1.952	10.746	109.661	14.65	4.670	0.136	1.050	Medium Silt	Very Poorly Sorted
P1	20.1403	63.737	16.123	2.167	10.678	103.754	14.53	4.369	0.152	1.112	Medium Silt	Very Poorly Sorted
P1	21.1698	65.684	13.147	1.98	11.106	84.466	13.14	4.138	0.052	1.112	Medium Silt	Very Poorly Sorted
P1	23.6467	62.26	14.093	1.77	10.421	85.789	12.86	4.396	0.070	1.016	Medium Silt	Very Poorly Sorted
P1	25.7593	63.205	11.036	1.636	8.878	70.981	10.29	4.023	0.060	1.161	Medium Silt	Very Poorly Sorted
P1	23.6094	65.367	11.023	1.787	9.54	70.548	11.03	3.948	0.052	1.173	Medium Silt	Poorly Sorted
P1	22.4128	61.865	15.722	1.859	10.731	101.302	13.78	4.564	0.102	1.073	Medium Silt	Very Poorly Sorted
P1	26.2993	61.027	12.674	1.549	9.242	85.245	11.01	4.437	0.077	1.110	Medium Silt	Very Poorly Sorted
P1	23.8503	61.735	14.414	1.753	10.254	92.336	12.75	4.480	0.087	1.059	Medium Silt	Very Poorly Sorted
P1	25.5295	61.705	12.765	1.646	9.181	81.414	11.36	4.339	0.094	1.103	Medium Silt	Very Poorly Sorted
P1	24.0984	59.133	16.769	1.711	10.228	106.884	13.61	4.842	0.122	1.023	Medium Silt	Very Poorly Sorted
P1	24.768	60.774	14.458	1.696	10.044	90.773	12.56	4.523	0.087	1.023	Medium Silt	Very Poorly Sorted
P1	20.8776	66.822	12.3	2.139	10.356	82.604	12.34	3.888	0.090	1.176	Medium Silt	Poorly Sorted
P1	21.9919	62.862	15.146	1.992	10.124	100.08	13.43	4.395	0.143	1.108	Medium Silt	Very Poorly Sorted
P1	22.9549	63.699	13.346	1.846	10.047	87.246	12.34	4.245	0.088	1.129	Medium Silt	Very Poorly Sorted
P1	22.2042	62.758	15.038	1.903	10.344	97.469	13.39	4.439	0.115	1.104	Medium Silt	Very Poorly Sorted
P1	23.2893	61.31	15.401	1.826	9.931	100.247	13.16	4.566	0.133	1.091	Medium Silt	Very Poorly Sorted
P1	23.2973	63.041	13.662	1.839	9.529	90.929	12.12	4.293	0.121	1.172	Medium Silt	Very Poorly Sorted
P1	23.3731	61.05	15.577	1.8	9.903	101.051	13.18	4.593	0.132	1.100	Medium Silt	Very Poorly Sorted
P1	21.9962	62.118	15.886	1.944	10.23	103.128	13.78	4.522	0.142	1.106	Medium Silt	Very Poorly Sorted
P1	21.9397	63.372	14.688	1.952	10.227	97.136	13.22	4.364	0.124	1.139	Medium Silt	Very Poorly Sorted
P1	25.0395	63.829	11.131	1.7	9.039	72.1	10.58	4.030	0.071	1.170	Medium Silt	Very Poorly Sorted
P1	20.9385	65.141	13.921	2.115	10.169	93.827	12.98	4.109	0.131	1.180	Medium Silt	Very Poorly Sorted
P1	18.7297	58.703	22.567	2.312	12.113	136.179	17.84	4.865	0.174	0.871	Coarse Silt	Very Poorly Sorted
P1	19.0485	61.307	19.644	2.334	11.144	124.846	16.47	4.641	0.198	0.989	Coarse Silt	Very Poorly Sorted
P1	21.6359	62.167	16.197	1.969	10.566	106.433	14.13	4.559	0.136	1.087	Medium Silt	Very Poorly Sorted
P1	22.5997	61.982	15.419	1.866	10.104	101.507	13.37	4.540	0.132	1.111	Medium Silt	Very Poorly Sorted
P1	20.0353	61.259	18.706	2.228	10.434	124.618	15.69	4.688	0.213	1.075	Coarse Silt	Very Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P1	19.5955	55.513	24.892	2.215	12.01	155.183	18.55	5.225	0.194	0.811	Coarse Silt	Very Poorly Sorted
P1	21.5606	61.326	17.113	2.069	9.909	118.514	14.44	4.648	0.201	1.133	Medium Silt	Very Poorly Sorted
P1	19.6549	59.203	21.142	2.227	11.148	137.372	17.01	4.928	0.204	0.959	Coarse Silt	Very Poorly Sorted
P1	19.9843	62.286	17.73	2.195	10.934	114.654	15.39	4.551	0.168	1.060	Medium Silt	Very Poorly Sorted
P1	20.7213	62.075	17.204	2.085	10.752	112.104	14.89	4.577	0.156	1.069	Medium Silt	Very Poorly Sorted
P1	20.1317	64.304	15.565	2.183	10.597	104.167	14.22	4.304	0.152	1.138	Medium Silt	Very Poorly Sorted
P1	16.4297	63.989	19.582	2.642	14.077	131.741	18.66	4.464	0.121	0.986	Coarse Silt	Very Poorly Sorted
P1	21.6426	61.674	16.683	1.935	10.657	107.889	14.34	4.635	0.133	1.067	Medium Silt	Very Poorly Sorted
P1	17.867	57.301	24.832	2.39	13.099	141.295	19.08	4.911	0.157	0.818	Coarse Silt	Very Poorly Sorted
P1	21.0646	57.657	21.278	1.973	11.625	132.526	16.55	5.100	0.148	0.924	Coarse Silt	Very Poorly Sorted
P1	19.9228	59.625	20.452	2.211	10.957	129.939	16.50	4.833	0.200	0.971	Coarse Silt	Very Poorly Sorted
P1	20.9338	57.12	21.946	2.039	10.901	148.894	17.05	5.280	0.207	0.972	Coarse Silt	Very Poorly Sorted
P1	22.0845	60.354	17.562	1.932	10.286	115.586	14.54	4.775	0.164	1.087	Medium Silt	Very Poorly Sorted
P1	23.3512	67.954	8.695	1.964	8.283	39.779	9.106	3.418	0.065	1.428	Medium Silt	Poorly Sorted
P1	24.2268	69.439	6.335	1.885	7.971	28.581	8.553	3.198	0.017	1.373	Medium Silt	Poorly Sorted
P1	24.5246	63.261	12.215	1.756	8.917	80.512	10.92	4.107	0.106	1.206	Medium Silt	Very Poorly Sorted
P1	22.6532	63.628	13.719	1.886	9.901	92.419	12.35	4.240	0.107	1.170	Medium Silt	Very Poorly Sorted
P1	22.3129	61.6	16.088	1.875	10.502	105.874	13.88	4.607	0.122	1.091	Medium Silt	Very Poorly Sorted
P1	18.6355	58.659	22.706	2.31	12.295	132.673	17.92	4.830	0.164	0.870	Coarse Silt	Very Poorly Sorted
P1	20.4455	61.835	17.72	2.167	10.466	109.787	15.04	4.527	0.179	1.072	Medium Silt	Very Poorly Sorted
P1	19.406	60.023	20.571	2.245	11.396	121.962	16.64	4.710	0.174	0.951	Coarse Silt	Very Poorly Sorted
P1	19.1362	58.116	22.748	2.27	11.646	131.404	17.44	4.858	0.183	0.859	Coarse Silt	Very Poorly Sorted
P1	21.1944	59.166	19.639	2.069	10.364	125.153	15.61	4.867	0.201	1.021	Medium Silt	Very Poorly Sorted
P2	20.4246	67.277	12.298	2.286	9.516	80.503	11.92	3.695	0.142	1.235	Medium Silt	Poorly Sorted
P2	16.12	52.082	31.798	2.635	15.404	166.157	22.39	5.080	0.140	0.725	Coarse Silt	Very Poorly Sorted
P2	22.4097	61.141	16.449	1.933	10.124	101.949	13.89	4.560	0.148	1.064	Medium Silt	Very Poorly Sorted
P2	21.803	61.29	16.907	1.958	10.797	97.361	14.40	4.499	0.113	1.000	Medium Silt	Very Poorly Sorted
P2	19.5072	63.24	17.253	2.285	11.196	97.768	15.28	4.269	0.140	0.993	Medium Silt	Very Poorly Sorted
P2	23.2446	60.889	15.866	1.865	9.688	99.052	13.30	4.549	0.152	1.085	Medium Silt	Very Poorly Sorted
P2	23.8125	63.683	12.505	1.805	9.546	77.011	11.82	4.110	0.084	1.097	Medium Silt	Very Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P2	21.3151	66.019	12.666	2.162	9.53	81.503	12.02	3.827	0.133	1.202	Medium Silt	Poorly Sorted
P2	23.2007	63.213	13.586	1.85	9.997	82.498	12.58	4.225	0.088	1.066	Medium Silt	Very Poorly Sorted
P2	24.0558	62.889	13.055	1.785	9.437	81	11.85	4.190	0.096	1.117	Medium Silt	Very Poorly Sorted
P2	20.6427	62.817	16.54	2.153	10.776	94.103	14.60	4.286	0.132	0.997	Medium Silt	Very Poorly Sorted
P2	19.9456	60.146	19.908	2.202	11.152	106.863	15.90	4.523	0.154	0.895	Coarse Silt	Very Poorly Sorted
P2	20.6032	64.151	15.246	2.15	10.79	87.48	14.18	4.159	0.112	1.002	Medium Silt	Very Poorly Sorted
P2	23.534	61.992	14.474	1.797	9.893	84.753	12.85	4.369	0.101	1.025	Medium Silt	Very Poorly Sorted
P2	23.6363	62.091	14.273	1.803	9.57	83.529	12.64	4.331	0.113	1.058	Medium Silt	Very Poorly Sorted
P2	19.0407	61.013	19.946	2.304	11.753	101.563	16.25	4.374	0.129	0.857	Coarse Silt	Very Poorly Sorted
P2	18.3904	60.649	20.961	2.373	12.436	111.723	17.15	4.479	0.130	0.867	Coarse Silt	Very Poorly Sorted
P2	20.6154	61.984	17.401	2.165	10.469	100.884	14.78	4.407	0.165	1.004	Medium Silt	Very Poorly Sorted
P2	23.5636	62.08	14.356	1.811	9.765	84.749	12.76	4.352	0.109	1.032	Medium Silt	Very Poorly Sorted
P2	16.1073	42.394	41.499	2.46	29.642	201.96	29.98	5.629	-0.133	0.720	Coarse Silt	Very Poorly Sorted
P2	19.2964	53.937	26.767	2.268	12.111	155.104	18.93	5.220	0.198	0.760	Coarse Silt	Very Poorly Sorted
P2	27.149	65.324	7.527	1.621	7.785	43.059	8.658	3.546	0.038	1.225	Medium Silt	Poorly Sorted
P2	23.1185	64.784	12.097	1.995	8.818	77.723	10.98	3.776	0.124	1.205	Medium Silt	Poorly Sorted
P2	24.0347	62.503	13.462	1.78	9.321	81.047	12.13	4.265	0.112	1.084	Medium Silt	Very Poorly Sorted
P2	23.9694	62.047	13.984	1.762	9.612	81.235	12.53	4.331	0.100	1.026	Medium Silt	Very Poorly Sorted
P2	23.6741	61.73	14.596	1.791	9.617	84.416	12.77	4.377	0.114	1.030	Medium Silt	Very Poorly Sorted
P2	23.4189	63.367	13.214	1.816	9.655	78.761	12.33	4.190	0.093	1.069	Medium Silt	Very Poorly Sorted
P2	23.1981	62.515	14.287	1.84	9.772	82.898	12.84	4.296	0.107	1.036	Medium Silt	Very Poorly Sorted
P2	20.2643	64.517	15.219	2.219	10.281	85.48	14.06	4.090	0.143	1.026	Medium Silt	Very Poorly Sorted
P2	23.2993	62.665	14.036	1.818	9.913	81.576	12.79	4.286	0.093	1.026	Medium Silt	Very Poorly Sorted
P2	22.6616	64.255	13.084	1.868	10.263	77.614	12.75	4.145	0.067	1.031	Medium Silt	Very Poorly Sorted
P2	23.415	64.017	12.568	1.84	9.545	75.524	12.09	4.095	0.090	1.071	Medium Silt	Very Poorly Sorted
P2	23.5611	61.997	14.442	1.818	9.664	83.259	12.79	4.331	0.112	1.024	Medium Silt	Very Poorly Sorted
P2	20.7007	65.898	13.402	2.174	10.018	79.3	13.15	3.938	0.125	1.093	Medium Silt	Poorly Sorted
P2	20.5946	65.918	13.487	2.187	10.136	79.619	13.28	3.946	0.123	1.080	Medium Silt	Poorly Sorted
P2	19.6678	62.373	17.959	2.247	11.192	92.491	15.32	4.245	0.125	0.894	Medium Silt	Very Poorly Sorted
P2	21.5259	65.512	12.962	2.083	9.801	76.885	12.76	3.954	0.118	1.085	Medium Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P2	22.9157	66.592	10.492	2.016	8.799	65.787	10.85	3.645	0.108	1.182	Medium Silt	Poorly Sorted
P2	21.4875	64.985	13.527	2.102	9.573	80.623	12.83	4.012	0.145	1.111	Medium Silt	Very Poorly Sorted
P2	21.0527	65.346	13.601	2.126	10.142	78.572	13.31	3.994	0.115	1.038	Medium Silt	Poorly Sorted
P2	21.2504	67.186	11.564	2.115	9.722	71.664	12.06	3.762	0.099	1.143	Medium Silt	Poorly Sorted
P2	22.5433	67.694	9.762	2.017	9.066	61.782	11.00	3.603	0.083	1.151	Medium Silt	Poorly Sorted
P2	21.9072	66.004	12.089	2.068	9.432	72.458	12.29	3.871	0.122	1.097	Medium Silt	Poorly Sorted
P2	22.2167	68.491	9.292	2.051	9.11	59.156	10.84	3.519	0.072	1.167	Medium Silt	Poorly Sorted
P2	22.0015	66.015	11.984	2.056	9.504	71.974	12.27	3.867	0.114	1.085	Medium Silt	Poorly Sorted
P2	23.7157	63.304	12.98	1.786	9.663	76.924	12.26	4.197	0.085	1.043	Medium Silt	Very Poorly Sorted
P2	22.097	64.37	13.533	2.041	9.502	78.05	12.83	4.050	0.138	1.049	Medium Silt	Very Poorly Sorted
P2	24.5349	64.035	11.43	1.766	8.984	69.816	11.32	4.017	0.091	1.082	Medium Silt	Very Poorly Sorted
P2	24.3732	64.151	11.476	1.736	9.333	70.082	11.47	4.051	0.068	1.068	Medium Silt	Very Poorly Sorted
P2	24.8646	64.041	11.095	1.716	9.092	68.404	11.15	4.020	0.071	1.078	Medium Silt	Very Poorly Sorted
P2	23.4578	62.832	13.71	1.798	9.846	79.715	12.64	4.266	0.088	1.026	Medium Silt	Very Poorly Sorted
P2	23.9947	63.605	12.4	1.746	9.601	74.174	11.96	4.155	0.071	1.057	Medium Silt	Very Poorly Sorted
P2	23.6977	63.716	12.586	1.786	9.588	74.32	12.16	4.147	0.082	1.041	Medium Silt	Very Poorly Sorted
P2	23.4363	63.446	13.117	1.798	9.849	76.727	12.48	4.200	0.078	1.026	Medium Silt	Very Poorly Sorted
P2	23.7301	63.529	12.741	1.777	9.772	75.234	12.27	4.177	0.073	1.028	Medium Silt	Very Poorly Sorted
P2	22.7139	64.668	12.618	1.859	10.252	74.696	12.63	4.099	0.058	1.023	Medium Silt	Very Poorly Sorted
P2	24.1	63.15	12.75	1.752	9.46	75.486	12.04	4.192	0.086	1.052	Medium Silt	Very Poorly Sorted
P2	22.306	60.296	17.398	1.881	10.437	98.129	14.25	4.602	0.124	0.972	Medium Silt	Very Poorly Sorted
P2	22.6078	62.106	15.286	1.878	10.261	87.748	13.48	4.381	0.104	0.997	Medium Silt	Very Poorly Sorted
P2	19.3525	59.769	20.879	2.251	11.639	105.754	16.35	4.491	0.138	0.841	Coarse Silt	Very Poorly Sorted
P2	21.5695	63.965	14.466	2.06	9.981	84.104	13.35	4.139	0.130	1.055	Medium Silt	Very Poorly Sorted
P2	20.7067	65.967	13.327	2.156	10.368	79.498	13.28	3.959	0.106	1.070	Medium Silt	Poorly Sorted
P2	21.739	67.441	10.82	2.077	9.569	67.203	11.79	3.715	0.089	1.119	Medium Silt	Poorly Sorted
P2	24.682	64.396	10.922	1.72	9.258	67.404	11.22	3.995	0.058	1.066	Medium Silt	Poorly Sorted
P2	21.1969	66.476	12.327	2.127	10.015	74.165	12.71	3.867	0.102	1.072	Medium Silt	Poorly Sorted
P2	23.2202	67.762	9.017	1.974	8.962	57.454	10.52	3.534	0.063	1.148	Medium Silt	Poorly Sorted
P2	23.5062	66.529	9.964	1.815	9.625	62.82	11.23	3.819	0.032	1.084	Medium Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P2	23.6531	67.092	9.255	1.854	9.268	58.847	10.69	3.672	0.036	1.121	Medium Silt	Poorly Sorted
P2	23.9101	66.67	9.42	1.814	9.21	59.863	10.70	3.721	0.039	1.115	Medium Silt	Poorly Sorted
P2	23.66365	65.836	10.5	1.813	9.446	65.3405	11.38	3.882	0.054	1.078	Medium Silt	Poorly Sorted
P2	21.7707	64.029	14.2	1.95	10.59	81.097	13.48	4.182	0.076	1.004	Medium Silt	Very Poorly Sorted
P2	24.6821	65.574	9.744	1.758	8.821	61.716	10.59	3.801	0.062	1.117	Medium Silt	Poorly Sorted
P2	24.3741	65.408	10.218	1.751	9.175	64.034	11.05	3.895	0.055	1.080	Medium Silt	Poorly Sorted
P2	21.4528	66.662	11.885	2.094	9.789	71.857	12.36	3.808	0.097	1.094	Medium Silt	Poorly Sorted
P2	21.1601	67.811	11.029	2.123	9.886	68.223	12.11	3.710	0.081	1.109	Medium Silt	Poorly Sorted
P2	19.3397	68.83	11.83	2.293	10.898	70.972	13.41	3.716	0.068	1.051	Medium Silt	Poorly Sorted
P2	21.3414	68.3	10.359	2.149	9.554	64.975	11.52	3.586	0.084	1.149	Medium Silt	Poorly Sorted
P2	23.9114	67.231	8.858	1.813	9.475	57.17	10.85	3.711	0.018	1.072	Medium Silt	Poorly Sorted
P2	23.5799	68.612	7.808	1.922	8.818	50.943	10.13	3.450	0.039	1.148	Medium Silt	Poorly Sorted
P2	21.0911	63.461	15.448	2.081	10.555	89.473	14.02	4.253	0.120	1.017	Medium Silt	Very Poorly Sorted
P2	19.4268	63.193	17.381	2.257	11.473	99.807	15.46	4.330	0.126	0.984	Medium Silt	Very Poorly Sorted
P2	21.4874	68.598	9.914	2.087	9.939	62.582	11.82	3.637	0.052	1.088	Medium Silt	Poorly Sorted
P3	22.4722	65.713	11.814	1.894	10.23	69.776	12.62	3.994	0.051	0.999	Medium Silt	Poorly Sorted
P3	23.3361	67.644	9.02	1.854	9.786	58.044	11.10	3.695	0.009	1.070	Medium Silt	Poorly Sorted
P3	24.2266	67.946	7.828	1.798	9.121	51.576	10.23	3.569	0.006	1.109	Medium Silt	Poorly Sorted
P3	23.4124	67.32	9.267	1.851	9.748	59.512	11.23	3.739	0.018	1.059	Medium Silt	Poorly Sorted
P3	22.8829	67.019	10.098	1.865	10.165	63.473	11.71	3.820	0.015	1.052	Medium Silt	Poorly Sorted
P3	21.8959	69.939	8.165	2.085	9.406	52.813	10.75	3.402	0.035	1.143	Medium Silt	Poorly Sorted
P3	21.9755	70.812	7.212	2.084	9.393	46.465	10.48	3.317	0.014	1.142	Medium Silt	Poorly Sorted
P3	25.8976	67.507	6.595	1.677	8.45	43.857	9.348	3.497	-0.001	1.120	Medium Silt	Poorly Sorted
P3	23.8748	67.592	8.533	1.788	9.48	55.459	10.71	3.686	0.006	1.085	Medium Silt	Poorly Sorted
P3	25.1306	66.813	8.056	1.699	8.872	53.031	10.08	3.668	0.015	1.102	Medium Silt	Poorly Sorted
P3	25.5458	66.52	7.934	1.691	8.802	51.979	9.951	3.662	0.015	1.092	Medium Silt	Poorly Sorted
P3	24.7221	67.51	7.768	1.751	8.938	50.9	10.05	3.593	0.010	1.111	Medium Silt	Poorly Sorted
P3	28.1091	63.845	8.046	1.553	7.941	51.363	9.046	3.715	0.039	1.118	Medium Silt	Poorly Sorted
P3	25.1024	67.34	7.558	1.71	8.973	49.818	9.973	3.608	-0.002	1.098	Medium Silt	Poorly Sorted
P3	25.0285	66.161	8.811	1.72	8.858	56.947	10.30	3.737	0.036	1.102	Medium Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P3	20.8126	69.016	10.171	1.964	11.254	63.699	12.80	3.792	-0.018	1.028	Medium Silt	Poorly Sorted
P3	24.2747	65.851	9.874	1.757	9.297	62.392	10.95	3.842	0.040	1.086	Medium Silt	Poorly Sorted
P3	24.2028	66.817	8.98	1.749	9.514	58.072	10.86	3.771	0.010	1.068	Medium Silt	Poorly Sorted
P3	24.6479	66.124	9.228	1.752	9.095	59.195	10.65	3.777	0.038	1.083	Medium Silt	Poorly Sorted
P3	23.7346	66.879	9.387	1.778	9.625	60.059	11.08	3.790	0.016	1.077	Medium Silt	Poorly Sorted
P3	22.4496	68.421	9.129	1.888	10.14	59.15	11.65	3.723	0.005	1.049	Medium Silt	Poorly Sorted
P3	23.3038	67.437	9.259	1.823	10.107	59.339	11.39	3.777	-0.002	1.045	Medium Silt	Poorly Sorted
P3	25.3342	65.898	8.768	1.689	8.827	56.65	10.22	3.758	0.033	1.101	Medium Silt	Poorly Sorted
P3	25.2982	67.081	7.621	1.698	8.837	50.386	9.921	3.622	0.007	1.100	Medium Silt	Poorly Sorted
P3	25.7855	65.917	8.298	1.669	8.663	53.678	9.842	3.689	0.024	1.111	Medium Silt	Poorly Sorted
P3	24.4278	67.874	7.699	1.746	9.113	50.764	10.12	3.584	-0.004	1.114	Medium Silt	Poorly Sorted
P3	25.2993	66.653	8.048	1.682	9.07	53.068	10.15	3.687	0.001	1.077	Medium Silt	Poorly Sorted
P3	26.5551	66.887	6.558	1.619	8.088	42.658	8.921	3.477	0.003	1.156	Medium Silt	Poorly Sorted
P3	25.1769	64.236	10.587	1.661	9.664	65.606	11.33	4.047	0.026	1.006	Medium Silt	Very Poorly Sorted
P3	22.9464	70.37	6.683	1.98	9.217	43.447	10.08	3.302	-0.006	1.137	Medium Silt	Poorly Sorted
P3	29.9988	63.613	6.388	1.467	7.322	41.028	8.196	3.576	0.027	1.116	Medium Silt	Poorly Sorted
P3	26.5474	66.432	7.02	1.588	8.411	47.289	9.335	3.613	-0.001	1.108	Medium Silt	Poorly Sorted
P3	30.0588	64.145	5.796	1.458	7.182	36.993	7.928	3.478	0.015	1.138	Medium Silt	Poorly Sorted
P3	25.3609	62.889	11.75	1.641	9.503	70.558	11.58	4.181	0.051	0.999	Medium Silt	Very Poorly Sorted
P3	24.6223	66.962	8.416	1.745	9.001	54.843	10.28	3.668	0.020	1.109	Medium Silt	Poorly Sorted
P3	25.4659	68.37	6.164	1.71	8.508	41.375	9.309	3.418	-0.014	1.130	Medium Silt	Poorly Sorted
P3	25.3465	66.028	8.626	1.66	8.927	55.617	10.09	3.739	0.014	1.111	Medium Silt	Poorly Sorted
P3	25.2752	66.73	7.995	1.674	8.815	52.154	9.874	3.647	0.007	1.123	Medium Silt	Poorly Sorted
P3	25.7205	66.626	7.653	1.7	8.49	49.966	9.587	3.578	0.021	1.131	Medium Silt	Poorly Sorted
P3	26.1904	66.532	7.277	1.653	8.33	47.283	9.285	3.552	0.011	1.143	Medium Silt	Poorly Sorted
P3	23.6517	64.194	12.155	1.781	9.797	72.999	12.05	4.105	0.061	1.049	Medium Silt	Very Poorly Sorted
P3	25.636	65.92	8.444	1.674	8.614	54.678	9.883	3.698	0.031	1.120	Medium Silt	Poorly Sorted
P3	24.9663	64.541	10.493	1.694	9.096	65.419	10.92	3.959	0.055	1.084	Medium Silt	Poorly Sorted
P3	24.2051	66.879	8.916	1.763	9.329	57.456	10.68	3.737	0.019	1.088	Medium Silt	Poorly Sorted
P3	26.3916	66.885	6.724	1.64	8.248	44.99	9.189	3.523	0.006	1.132	Medium Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P3	25.3172	66.482	8.2	1.698	8.687	53.308	9.915	3.659	0.025	1.123	Medium Silt	Poorly Sorted
P3	25.9513	67.563	6.486	1.659	8.467	43.827	9.336	3.501	-0.006	1.114	Medium Silt	Poorly Sorted
P3	24.727	70.009	5.264	1.894	8.006	34.081	8.813	3.118	0.007	1.199	Medium Silt	Poorly Sorted
P3	25.3929	66.04	8.568	1.724	8.568	55.278	9.944	3.676	0.044	1.131	Medium Silt	Poorly Sorted
P3	24.1183	66.991	8.891	1.784	9.221	57.166	10.55	3.693	0.022	1.109	Medium Silt	Poorly Sorted
P3	25.012	67.602	7.386	1.727	8.7	49.402	9.827	3.561	0.013	1.121	Medium Silt	Poorly Sorted
P3	25.1686	66.625	8.206	1.694	8.856	53.684	10.13	3.706	0.023	1.105	Medium Silt	Poorly Sorted
P3	25.6547	67.435	6.911	1.66	8.783	46.526	9.654	3.570	-0.013	1.096	Medium Silt	Poorly Sorted
P3	25.0622	67.92	7.018	1.711	9.038	47.237	9.931	3.565	-0.015	1.086	Medium Silt	Poorly Sorted
P3	25.6257	65.448	8.926	1.679	8.715	57.662	10.19	3.776	0.041	1.094	Medium Silt	Poorly Sorted
P3	26.5588	66.25	7.191	1.587	8.544	48.626	9.524	3.663	-0.001	1.086	Medium Silt	Poorly Sorted
P3	26.262	65.833	7.905	1.614	8.723	52.183	9.817	3.725	0.009	1.077	Medium Silt	Poorly Sorted
P3	26.3715	66.064	7.565	1.596	8.829	50.442	9.780	3.713	-0.006	1.063	Medium Silt	Poorly Sorted
P3	27.0686	65.549	7.382	1.555	8.523	49.493	9.519	3.724	0.003	1.065	Medium Silt	Poorly Sorted
P3	26.274	65.538	8.188	1.637	8.631	53.48	9.823	3.729	0.023	1.087	Medium Silt	Poorly Sorted
P3	24.8326	66.713	8.455	1.704	9.15	54.804	10.30	3.712	0.007	1.099	Medium Silt	Poorly Sorted
P3	24.9405	67.668	7.392	1.707	8.962	49.065	9.933	3.586	-0.006	1.106	Medium Silt	Poorly Sorted
P3	24.9586	65.793	9.248	1.68	9.11	59.111	10.45	3.807	0.022	1.103	Medium Silt	Poorly Sorted
P3	25.5844	67.138	7.278	1.698	8.56	48.066	9.581	3.549	0.010	1.123	Medium Silt	Poorly Sorted
P3	26.1883	67.052	6.76	1.659	8.323	45.297	9.284	3.520	0.008	1.124	Medium Silt	Poorly Sorted
P3	23.4003	66.381	10.218	1.791	10.055	64.006	11.62	3.886	0.014	1.045	Medium Silt	Poorly Sorted
P3	25.3816	66.615	8.003	1.697	8.62	52.864	9.900	3.648	0.028	1.117	Medium Silt	Poorly Sorted
P3	23.541	69.399	7.06	1.961	8.628	45.146	9.734	3.309	0.032	1.174	Medium Silt	Poorly Sorted
P3	26.5705	65.501	7.929	1.596	8.441	52.445	9.634	3.725	0.024	1.095	Medium Silt	Poorly Sorted
P3	25.0091	65.898	9.093	1.723	8.819	58.247	10.28	3.747	0.042	1.118	Medium Silt	Poorly Sorted
P3	23.4699	66.538	9.992	1.838	9.462	62.96	11.13	3.784	0.043	1.102	Medium Silt	Poorly Sorted
P3	24.6884	66.741	8.571	1.747	8.891	54.819	10.08	3.646	0.024	1.139	Medium Silt	Poorly Sorted
P3	24.4186	64.749	10.833	1.742	9.334	67.061	11.22	3.962	0.055	1.076	Medium Silt	Poorly Sorted
P3	24.3014	61.859	13.839	1.757	9.263	85.767	12.11	4.361	0.124	1.110	Medium Silt	Very Poorly Sorted
P3	20.464	63.628	15.908	2.165	10.829	88.001	14.45	4.181	0.118	0.973	Medium Silt	Very Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P3	22.7442	70.066	7.189	2.03	8.833	45.371	9.889	3.273	0.028	1.191	Medium Silt	Poorly Sorted
P3	24.7851	65.093	10.122	1.723	9.026	63.606	10.77	3.885	0.054	1.101	Medium Silt	Poorly Sorted
P3	23.8123	64.797	11.39	1.804	9.309	69.603	11.54	3.981	0.077	1.092	Medium Silt	Poorly Sorted
P4	23.8021	66.653	9.545	1.8	9.461	60.673	10.87	3.746	0.024	1.105	Medium Silt	Poorly Sorted
P4	24.0981	67.421	8.481	1.906	8.953	54.77	10.26	3.520	0.041	1.121	Medium Silt	Poorly Sorted
P4	24.7849	66.313	8.902	1.737	9.314	57.465	10.56	3.743	0.013	1.073	Medium Silt	Poorly Sorted
P4	24.9635	67.068	7.968	1.72	9.267	52.386	10.26	3.661	-0.007	1.073	Medium Silt	Poorly Sorted
P4	24.6717	65.791	9.537	1.719	9.485	60.717	10.87	3.843	0.018	1.060	Medium Silt	Poorly Sorted
P4	25.5742	66.46	7.966	1.681	8.884	52.072	9.932	3.662	0.007	1.092	Medium Silt	Poorly Sorted
P4	22.2572	69.555	8.188	2.035	9.377	52.847	10.64	3.424	0.030	1.146	Medium Silt	Poorly Sorted
P4	22.4567	69.595	7.949	2.014	9.544	52.509	10.82	3.449	0.019	1.099	Medium Silt	Poorly Sorted
P4	25.2641	64.552	10.184	1.68	9.021	63.88	10.78	3.937	0.052	1.075	Medium Silt	Poorly Sorted
P4	24.1541	69.4015	6.4445	1.895	8.568	42.886	9.541	3.301	0.014	1.156	Medium Silt	Poorly Sorted
P4	24.1133	68.278	7.609	1.771	9.573	50.415	10.46	3.602	-0.022	1.074	Medium Silt	Poorly Sorted
P4	25.6902	70.434	3.876	1.796	8.168	31.418	8.739	3.088	-0.046	1.095	Medium Silt	Poorly Sorted
P4	25.5703	66.639	7.791	1.685	8.669	50.627	9.725	3.618	0.013	1.122	Medium Silt	Poorly Sorted
P4	28.3863	65.427	6.187	1.528	7.742	41.548	8.608	3.540	0.010	1.110	Medium Silt	Poorly Sorted
P4	26.1796	66.378	7.443	1.647	8.45	48.703	9.464	3.604	0.014	1.117	Medium Silt	Poorly Sorted
P4	25.4192	66.616	7.965	1.708	8.958	52.669	10.18	3.688	0.015	1.062	Medium Silt	Poorly Sorted
P4	26.4266	65.645	7.928	1.6	8.517	51.707	9.585	3.705	0.015	1.106	Medium Silt	Poorly Sorted
P4	23.1747	63.764	13.061	1.809	10.147	76.862	12.60	4.185	0.065	1.019	Medium Silt	Very Poorly Sorted
P4	25.7011	65.964	8.335	1.615	8.952	55.068	10.18	3.791	0.009	1.068	Medium Silt	Poorly Sorted
P4	26.8797	67.73	5.391	1.537	8.46	40.293	9.086	3.516	-0.043	1.071	Medium Silt	Poorly Sorted
P4	25.8797	66.258	7.863	1.664	8.764	51.86	9.879	3.678	0.012	1.082	Medium Silt	Poorly Sorted
P4	26.3569	66.727	6.916	1.644	8.386	45.749	9.285	3.544	0.003	1.116	Medium Silt	Poorly Sorted
P4	27.2911	66.813	5.896	1.59	8.071	39.453	8.779	3.456	-0.013	1.115	Medium Silt	Poorly Sorted
P4	26.0576	65.405	8.537	1.619	8.754	55.538	9.998	3.785	0.021	1.085	Medium Silt	Poorly Sorted
P4	25.451	63.617	10.932	1.668	9.101	67.348	11.06	4.048	0.061	1.051	Medium Silt	Very Poorly Sorted
P4	25.0951	66.087	8.818	1.691	9.028	57.082	10.35	3.759	0.022	1.090	Medium Silt	Poorly Sorted
P4	24.3202	70.888	4.791	1.869	8.532	36.552	9.297	3.177	-0.024	1.122	Medium Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P4	27.8001	66.909	5.29	1.585	7.858	37.893	8.637	3.415	-0.009	1.095	Medium Silt	Poorly Sorted
P4	27.3461	66.716	5.938	1.582	8.076	41.169	8.908	3.500	-0.006	1.099	Medium Silt	Poorly Sorted
P4	26.9106	66.898	6.191	1.622	8.11	41.747	8.962	3.477	0.001	1.117	Medium Silt	Poorly Sorted
P4	25.77825	67.391	6.831	1.644	8.71	46.7675	9.628	3.580	-0.010	1.091	Medium Silt	Poorly Sorted
P4	26.6527	67.914	5.434	1.628	8.151	38.057	8.885	3.395	-0.020	1.112	Medium Silt	Poorly Sorted
P4	28.2076	67.456	4.337	1.531	7.623	31.789	8.146	3.282	-0.041	1.119	Medium Silt	Poorly Sorted
P4	27.3414	66.622	6.036	1.564	8.121	42.267	8.988	3.538	-0.006	1.094	Medium Silt	Poorly Sorted
P4	26.756	68.773	4.471	1.768	7.7	32.217	8.485	3.141	-0.003	1.121	Medium Silt	Poorly Sorted
P4	26.0225	67.979	5.999	1.66	8.315	41.921	9.189	3.446	-0.008	1.121	Medium Silt	Poorly Sorted
P4	24.3817	70.948	4.67	1.873	8.419	35.425	9.187	3.149	-0.023	1.132	Medium Silt	Poorly Sorted
P4	26.4784	67.486	6.036	1.619	8.303	41.909	9.136	3.488	-0.012	1.109	Medium Silt	Poorly Sorted
P4	25.8674	67.422	6.71	1.664	8.478	45.069	9.390	3.518	-0.002	1.120	Medium Silt	Poorly Sorted
P4	23.0872	67.691	9.222	1.891	9.852	59.289	11.38	3.715	0.022	1.046	Medium Silt	Poorly Sorted
P4	26.48	67.417	6.103	1.605	8.362	42.711	9.181	3.511	-0.015	1.104	Medium Silt	Poorly Sorted
P4	27.9343	66.094	5.972	1.569	7.636	42.077	8.658	3.492	0.023	1.127	Medium Silt	Poorly Sorted
P4	23.8282	71.824	4.347	1.912	8.6	34.563	9.327	3.106	-0.036	1.118	Medium Silt	Poorly Sorted
P4	25.522	70.87	3.608	1.834	7.885	30.322	8.586	3.019	-0.031	1.122	Medium Silt	Poorly Sorted
P4	28.9168	66.535	4.548	1.483	7.66	34.831	8.282	3.406	-0.031	1.074	Medium Silt	Poorly Sorted
P4	25.0182	72.296	2.685	1.88	7.954	27.93	8.561	2.893	-0.061	1.093	Medium Silt	Poorly Sorted
P4	25.3979	72	2.602	1.831	7.901	27.319	8.438	2.898	-0.072	1.093	Medium Silt	Poorly Sorted
P4	28.6507	67.344	4.005	1.499	7.586	32.985	8.175	3.319	-0.040	1.087	Medium Silt	Poorly Sorted
P4	27.5606	68.015	4.425	1.558	7.925	35.44	8.579	3.355	-0.037	1.087	Medium Silt	Poorly Sorted
P4	24.402	72.339	3.259	1.883	8.241	30.008	8.843	2.971	-0.057	1.112	Medium Silt	Poorly Sorted
P4	24.9646	72.027	3.009	1.846	8.168	29.333	8.731	2.968	-0.066	1.089	Medium Silt	Poorly Sorted
P4	26.6235	68.811	4.565	1.612	8.107	35.486	8.736	3.317	-0.040	1.107	Medium Silt	Poorly Sorted
P4	26.8922	67.608	5.499	1.606	8.115	40.973	9.002	3.460	-0.008	1.094	Medium Silt	Poorly Sorted
P4	25.0279	69.617	5.356	1.681	8.939	42.6	9.774	3.463	-0.039	1.059	Medium Silt	Poorly Sorted
P4	24.4121	72.761	2.827	1.889	8.21	28.911	8.789	2.922	-0.069	1.094	Medium Silt	Poorly Sorted
P4	25.0018	72.398	2.6	1.86	7.984	28.429	8.605	2.916	-0.062	1.091	Medium Silt	Poorly Sorted
P4	28.1502	68.651	3.199	1.54	7.529	30.309	8.087	3.187	-0.055	1.090	Medium Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P4	25.6698	71.761	2.569	1.797	7.918	28.365	8.502	2.949	-0.068	1.077	Medium Silt	Poorly Sorted
P4	24.7235	72.922	2.354	1.895	8.197	29.107	8.847	2.916	-0.070	1.046	Medium Silt	Poorly Sorted
P4	27.5824	68.224	4.193	1.551	7.819	35.441	8.525	3.342	-0.032	1.091	Medium Silt	Poorly Sorted
P4	24.3881	73.148	2.464	1.91	8.091	27.477	8.659	2.854	-0.076	1.093	Medium Silt	Poorly Sorted
P4	24.3702	72.605	3.025	1.884	8.244	30.52	8.893	2.976	-0.056	1.103	Medium Silt	Poorly Sorted
P4	25.0768	71.755	3.168	1.87	7.844	29.906	8.608	2.968	-0.030	1.125	Medium Silt	Poorly Sorted
P4	24.3181	72.963	2.719	1.882	8.271	29.802	8.893	2.951	-0.067	1.088	Medium Silt	Poorly Sorted
P4	25.8527	71.682	2.466	1.788	7.717	27.386	8.293	2.917	-0.064	1.107	Medium Silt	Poorly Sorted
P4	26.2207	71.444	2.335	1.801	7.408	25.18	7.987	2.825	-0.062	1.123	Medium Silt	Poorly Sorted
P4	24.7666	72.143	3.091	1.792	8.574	32.508	9.141	3.097	-0.076	1.058	Medium Silt	Poorly Sorted
P4	32.2456	66.677	1.077	1.383	6.412	21.867	6.768	2.905	-0.100	1.030	Fine Silt	Poorly Sorted
P4	25.4767	70.805	3.718	1.755	8.142	32.52	8.789	3.125	-0.046	1.111	Medium Silt	Poorly Sorted
P4	27.2332	68.525	4.242	1.567	8.006	34.975	8.630	3.333	-0.045	1.087	Medium Silt	Poorly Sorted
P4	24.0141	71.564	4.422	1.861	8.697	37.377	9.503	3.195	-0.034	1.101	Medium Silt	Poorly Sorted
P4	25.9568	71.983	2.06	1.787	7.715	26.049	8.227	2.858	-0.084	1.078	Medium Silt	Poorly Sorted
P4	26.0537	71.259	2.688	1.676	8.079	30.661	8.612	3.090	-0.076	1.071	Medium Silt	Poorly Sorted
P4	27.298	70.474	2.228	1.676	7.416	25.709	7.899	2.916	-0.077	1.095	Medium Silt	Poorly Sorted
P4	23.7057	73.43	2.864	1.853	8.977	32.947	9.508	3.073	-0.094	1.045	Medium Silt	Poorly Sorted
P4	25.2155	72.783	2.001	1.783	8.204	27.754	8.642	2.923	-0.107	1.049	Medium Silt	Poorly Sorted
P5	26.6742	66.516	6.81	1.56	8.796	44.5	9.472	3.671	-0.028	1.077	Medium Silt	Poorly Sorted
P5	25.6367	69.361	5.002	1.717	8.694	36.967	9.298	3.332	-0.048	1.070	Medium Silt	Poorly Sorted
P5	26.5627	69.295	4.142	1.617	8.491	35.345	9.001	3.327	-0.068	1.045	Medium Silt	Poorly Sorted
P5	25.6159	71.724	2.66	1.795	8.249	30.227	8.809	3.020	-0.075	1.037	Medium Silt	Poorly Sorted
P5	25.8768	70.726	3.398	1.696	8.814	34.484	9.282	3.240	-0.089	0.999	Medium Silt	Poorly Sorted
P5	26.7311	69.298	3.971	1.628	8.317	33.315	8.809	3.263	-0.069	1.051	Medium Silt	Poorly Sorted
P5	26.3478	70.327	3.326	1.644	8.473	32.541	8.886	3.207	-0.089	1.032	Medium Silt	Poorly Sorted
P5	26.9927	70.074	2.933	1.602	8.13	30.34	8.510	3.152	-0.094	1.042	Medium Silt	Poorly Sorted
P5	24.8615	73.109	2.029	1.857	8.44	28.803	8.909	2.924	-0.102	1.017	Medium Silt	Poorly Sorted
P5	28.1925	68.328	3.479	1.516	8.031	33.039	8.492	3.315	-0.073	1.024	Medium Silt	Poorly Sorted
P5	24.7627	73.099	2.138	1.845	8.616	30.66	9.133	2.994	-0.095	1.006	Medium Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P5	24.6156	71.908	3.476	1.844	8.433	32.269	9.076	3.069	-0.057	1.082	Medium Silt	Poorly Sorted
P5	23.355	73.84	2.805	1.973	8.784	31.291	9.399	2.953	-0.078	1.047	Medium Silt	Poorly Sorted
P5	24.4127	73.157	2.43	1.889	8.386	29.415	8.938	2.931	-0.082	1.056	Medium Silt	Poorly Sorted
P5	24.09905	73.7495	2.1515	1.948	8.3185	28.145	8.894	2.848	-0.084	1.049	Medium Silt	Poorly Sorted
P5	25.0202	73.443	1.537	1.884	7.991	25.928	8.488	2.790	-0.101	1.040	Medium Silt	Poorly Sorted
P5	26.637	72.014	1.349	1.754	7.576	24.616	8.032	2.804	-0.103	1.041	Medium Silt	Poorly Sorted
P5	25.4103	72.899	1.691	1.839	7.84	25.438	8.314	2.792	-0.100	1.054	Medium Silt	Poorly Sorted
P5	27.1153	70.024	2.861	1.6325	7.738	31.3055	8.386	3.139	-0.050	1.076	Medium Silt	Poorly Sorted
P5	26.7039	70.509	2.787	1.692	7.691	29.77	8.328	3.054	-0.050	1.093	Medium Silt	Poorly Sorted
P5	24.6654	72.878	2.457	1.867	7.935	27.089	8.492	2.857	-0.074	1.113	Medium Silt	Poorly Sorted
P5	24.7808	73.076	2.144	1.818	8.528	30.692	9.062	3.007	-0.092	1.025	Medium Silt	Poorly Sorted
P5	24.8525	72.153	2.995	1.814	8.379	30.914	8.947	3.033	-0.072	1.067	Medium Silt	Poorly Sorted
P5	27.8656	70.263	1.872	1.686	7.096	24.808	7.650	2.861	-0.061	1.109	Fine Silt	Poorly Sorted
P5	26.1746	72.194	1.631	1.742	7.914	26.846	8.369	2.906	-0.102	1.035	Medium Silt	Poorly Sorted
P5	27.8656	70.263	1.872	1.686	7.096	24.808	7.650	2.861	-0.061	1.109	Fine Silt	Poorly Sorted
P5	26.7762	71.558	1.665	1.742	7.523	25.682	8.046	2.858	-0.081	1.062	Medium Silt	Poorly Sorted
P5	27.4133	70.982	1.605	1.655	7.563	26.205	8.024	2.928	-0.094	1.038	Medium Silt	Poorly Sorted
P5	26.4335	71.952	1.614	1.744	7.644	25.618	8.124	2.855	-0.094	1.059	Medium Silt	Poorly Sorted
P5	25.7065	72.739	1.555	1.789	7.791	25.449	8.250	2.822	-0.104	1.062	Medium Silt	Poorly Sorted
P5	25.0351	73.251	1.714	1.841	7.973	26.681	8.501	2.843	-0.093	1.062	Medium Silt	Poorly Sorted
P5	25.0351	73.251	1.714	1.841	7.973	26.681	8.501	2.843	-0.093	1.062	Medium Silt	Poorly Sorted
P5	26.5686	70.772	2.659	1.616	8.019	30.132	8.493	3.118	-0.087	1.061	Medium Silt	Poorly Sorted
P5	25.6156	72.843	1.542	1.794	7.805	25.284	8.253	2.813	-0.107	1.062	Medium Silt	Poorly Sorted
P5	25.3984	72.679	1.923	1.816	7.743	25.958	8.267	2.833	-0.084	1.096	Medium Silt	Poorly Sorted
P5	26.2178	72.506	1.277	1.771	7.634	24.624	8.089	2.792	-0.106	1.049	Medium Silt	Poorly Sorted
P5	27.779	70.391	1.83	1.63	7.395	26.208	7.901	2.948	-0.081	1.061	Medium Silt	Poorly Sorted
P5	26.9842	71.176	1.84	1.663	7.683	26.105	8.084	2.927	-0.103	1.053	Medium Silt	Poorly Sorted
P5	26.6176	71.767	1.615	1.701	7.646	25.369	8.072	2.870	-0.105	1.061	Medium Silt	Poorly Sorted
P5	27.5044	71.307	1.188	1.635	7.481	24.088	7.820	2.845	-0.124	1.036	Medium Silt	Poorly Sorted
P5	26.8756	69.412	3.712	1.644	7.934	30.278	8.450	3.143	-0.064	1.078	Medium Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P5	29.7764	69.017	1.206	1.533	6.876	22.108	7.209	2.819	-0.115	1.038	Fine Silt	Poorly Sorted
P5	26.1561	72.123	1.721	1.744	7.733	25.955	8.204	2.870	-0.097	1.064	Medium Silt	Poorly Sorted
P5	24.9448	73.247	1.809	1.832	8.067	26.827	8.540	2.855	-0.099	1.064	Medium Silt	Poorly Sorted
P5	26.1946	72.17	1.635	1.778	7.648	25.237	8.135	2.822	-0.095	1.060	Medium Silt	Poorly Sorted
P5	25.2938	72.978	1.728	1.824	7.99	26.613	8.475	2.851	-0.098	1.052	Medium Silt	Poorly Sorted
P5	25.4068	73.294	1.3	1.826	7.774	23.83	8.163	2.730	-0.124	1.056	Medium Silt	Poorly Sorted
P5	29.0327	69.307	1.66	1.586	7.147	26.237	7.714	2.974	-0.068	1.036	Fine Silt	Poorly Sorted
P5	28.1047	69.64	2.255	1.463	7.752	28.102	8.024	3.142	-0.115	1.045	Medium Silt	Poorly Sorted
P5	28.7623	69.487	1.75	1.496	7.378	25.819	7.697	3.017	-0.108	1.046	Fine Silt	Poorly Sorted
P5	26.2391	71.921	1.84	1.752	7.635	25.2	8.086	2.840	-0.095	1.079	Medium Silt	Poorly Sorted
P5	25.4882	72.719	1.793	1.77	7.944	26.18	8.363	2.864	-0.109	1.066	Medium Silt	Poorly Sorted
P5	28.0055	70.918	1.076	1.644	7.334	23.834	7.726	2.830	-0.114	1.025	Fine Silt	Poorly Sorted
P5	30.3275	68.128	1.545	1.344	7.151	26.961	7.481	3.165	-0.103	1.022	Fine Silt	Poorly Sorted
P5	30.3045	67.763	1.933	1.474	6.935	25.814	7.420	3.041	-0.071	1.048	Fine Silt	Poorly Sorted
P5	24.8921	73.431	1.677	1.822	8.251	27.56	8.709	2.888	-0.109	1.039	Medium Silt	Poorly Sorted
P5	29.4332	68.209	2.358	1.421	7.475	30.781	7.988	3.266	-0.071	1.013	Medium Silt	Poorly Sorted
P5	24.3681	73.755	1.877	1.854	8.284	28.61	8.833	2.907	-0.091	1.062	Medium Silt	Poorly Sorted
P5	25.929	72.385	1.686	1.743	7.885	27.016	8.366	2.909	-0.096	1.055	Medium Silt	Poorly Sorted
P5	26.9253	71.814	1.261	1.638	7.726	26.08	8.118	2.924	-0.115	1.032	Medium Silt	Poorly Sorted
P5	24.9107	72.978	2.111	1.779	8.227	29.093	8.739	2.969	-0.091	1.071	Medium Silt	Poorly Sorted
P5	26.656	71.328	2.016	1.681	7.746	26.625	8.188	2.932	-0.098	1.051	Medium Silt	Poorly Sorted
P5	26.6066	71.51	1.884	1.71	7.694	26.208	8.157	2.897	-0.095	1.051	Medium Silt	Poorly Sorted
P5	28.451	70.23	1.319	1.628	7.169	24.586	7.660	2.873	-0.087	1.043	Fine Silt	Poorly Sorted
P5	30.5515	67.555	1.894	1.381	7.123	29.34	7.662	3.238	-0.066	1.011	Fine Silt	Poorly Sorted
P5	31.8742	66.652	1.474	1.39	6.566	24.465	7.033	3.023	-0.074	1.028	Fine Silt	Poorly Sorted
P5	24.936	74.29	0.774	1.848	8.058	24.879	8.437	2.754	-0.133	1.025	Medium Silt	Poorly Sorted
P5	26.8812	71.806	1.313	1.677	7.681	26.793	8.184	2.927	-0.095	1.029	Medium Silt	Poorly Sorted
P5	28.5933	70.587	0.819	1.595	7.268	24.502	7.687	2.881	-0.106	1.010	Fine Silt	Poorly Sorted
P5	27.0431	72.065	0.891	1.686	7.578	24.629	7.978	2.834	-0.117	1.024	Medium Silt	Poorly Sorted
P5	27.2111	71.688	1.1	1.683	7.477	24.676	7.918	2.839	-0.106	1.035	Medium Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P5	28.1776	70.64	1.183	1.602	7.276	24.775	7.720	2.892	-0.099	1.041	Fine Silt	Poorly Sorted
P5	29.5752	69.861	0.563	1.55	6.847	22.141	7.235	2.796	-0.112	1.033	Fine Silt	Poorly Sorted
P5	27.8591	71.7	0.441	1.658	7.248	22.738	7.634	2.759	-0.124	1.021	Fine Silt	Poorly Sorted
P5	29.0603	70.33	0.61	1.625	6.823	21.756	7.277	2.738	-0.102	1.047	Fine Silt	Poorly Sorted
P5	27.5861	71.84	0.574	1.653	7.276	22.266	7.612	2.741	-0.136	1.034	Fine Silt	Poorly Sorted
P5	29.5228	69.525	0.952	1.594	6.74	22.182	7.213	2.782	-0.089	1.063	Fine Silt	Poorly Sorted
P5	24.5093	74.694	0.797	1.813	8.532	27.405	8.874	2.872	-0.140	1.007	Medium Silt	Poorly Sorted
P5	22.1337	77.291	0.575	2.035	8.997	26.422	9.298	2.722	-0.163	1.025	Medium Silt	Poorly Sorted
P5	25.2417	74.21	0.549	1.836	7.701	22.351	8.043	2.648	-0.147	1.046	Medium Silt	Poorly Sorted
P6	25.1336	74.563	0.303	1.902	7.589	21.062	7.918	2.554	-0.152	1.038	Medium Silt	Poorly Sorted
P6	26.1465	73.72	0.133	1.808	7.559	21.575	7.847	2.622	-0.154	1.013	Medium Silt	Poorly Sorted
P6	26.5524	73.056	0.392	1.784	7.381	21.287	7.706	2.623	-0.145	1.028	Fine Silt	Poorly Sorted
P6	26.0737	73.731	0.195	1.841	7.317	20.399	7.657	2.552	-0.148	1.040	Fine Silt	Poorly Sorted
P6	25.5373	74.273	0.19	1.834	7.748	22.311	8.044	2.642	-0.154	1.015	Medium Silt	Poorly Sorted
P6	27.2962	72.217	0.487	1.737	7.208	20.906	7.528	2.630	-0.142	1.029	Fine Silt	Poorly Sorted
P6	27.5147	72.251	0.234	1.741	7.045	19.971	7.367	2.581	-0.145	1.038	Fine Silt	Poorly Sorted
P6	26.2775	73.505	0.218	1.78	7.416	21.183	7.724	2.618	-0.151	1.036	Fine Silt	Poorly Sorted
P6	27.1886	72.273	0.539	1.752	7.261	21.248	7.602	2.638	-0.138	1.021	Fine Silt	Poorly Sorted
P6	26.978	72.847	0.175	1.737	7.422	21.651	7.708	2.662	-0.151	1.010	Fine Silt	Poorly Sorted
P6	27.2328	72.434	0.333	1.706	7.303	21.307	7.585	2.664	-0.150	1.026	Fine Silt	Poorly Sorted
P6	28.0626	71.699	0.238	1.717	6.947	19.563	7.250	2.571	-0.149	1.025	Fine Silt	Poorly Sorted
P6	27.7191	72.095	0.186	1.685	7.196	20.661	7.452	2.644	-0.156	1.018	Fine Silt	Poorly Sorted
P6	26.1559	73.733	0.111	1.82	7.402	21.043	7.747	2.592	-0.147	1.028	Fine Silt	Poorly Sorted
P6	26.0526	73.726	0.222	1.793	7.462	20.739	7.727	2.589	-0.164	1.032	Fine Silt	Poorly Sorted
P6	26.9866	72.743	0.27	1.741	7.444	22.319	7.787	2.693	-0.139	1.008	Fine Silt	Poorly Sorted
P6	26.7794	71.977	1.244	1.739	7.598	23.432	7.955	2.751	-0.132	1.010	Medium Silt	Poorly Sorted
P6	30.4328	69.352	0.215	1.589	6.605	20.092	6.975	2.674	-0.122	1.004	Fine Silt	Poorly Sorted
P6	27.9856	71.687	0.327	1.651	7.096	20.214	7.330	2.642	-0.161	1.030	Fine Silt	Poorly Sorted
P6	29.3171	70.419	0.264	1.614	6.848	20.083	7.138	2.658	-0.144	1.010	Fine Silt	Poorly Sorted
P6	30.8646	68.809	0.327	1.557	6.489	19.375	6.817	2.655	-0.129	1.012	Fine Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P6	28.1946	71.486	0.32	1.658	7.241	21.55	7.519	2.705	-0.149	0.995	Fine Silt	Poorly Sorted
P6	29.2471	70.607	0.146	1.624	6.891	20.759	7.240	2.687	-0.133	1.003	Fine Silt	Poorly Sorted
P6	28.889	70.675	0.436	1.619	7.098	21.496	7.393	2.727	-0.142	0.995	Fine Silt	Poorly Sorted
P6	27.3323	72.48	0.188	1.702	7.229	20.548	7.496	2.629	-0.160	1.026	Fine Silt	Poorly Sorted
P6	27.8673	71.921	0.211	1.679	7.138	20.455	7.404	2.638	-0.156	1.019	Fine Silt	Poorly Sorted
P6	27.5779	72.125	0.297	1.698	7.264	21.313	7.566	2.671	-0.148	1.013	Fine Silt	Poorly Sorted
P6	27.5402	72.254	0.206	1.704	7.203	20.776	7.495	2.642	-0.152	1.022	Fine Silt	Poorly Sorted
P6	26.9235	72.844	0.233	1.78	7.075	19.691	7.414	2.547	-0.148	1.051	Fine Silt	Poorly Sorted
P6	27.4231	71.912	0.665	1.697	7.208	20.999	7.509	2.658	-0.147	1.037	Fine Silt	Poorly Sorted
P6	28.0998	71.619	0.281	1.692	6.93	19.662	7.235	2.590	-0.148	1.037	Fine Silt	Poorly Sorted
P6	26.6705	73.089	0.24	1.773	7.267	20.484	7.581	2.589	-0.152	1.036	Fine Silt	Poorly Sorted
P6	27.2867	72.594	0.12	1.72	7.445	22.353	7.771	2.706	-0.143	0.996	Fine Silt	Poorly Sorted
P6	27.5631	72.212	0.225	1.717	7.163	20.607	7.471	2.625	-0.149	1.020	Fine Silt	Poorly Sorted
P6	26.8336	72.947	0.22	1.758	7.185	20.228	7.504	2.584	-0.151	1.045	Fine Silt	Poorly Sorted
P6	26.1772	73.488	0.334	1.777	7.669	22.34	7.955	2.674	-0.155	1.008	Medium Silt	Poorly Sorted
P6	27.8487	71.921	0.23	1.684	7.251	21.355	7.538	2.679	-0.148	1.003	Fine Silt	Poorly Sorted
P6	27.1111	72.594	0.295	1.734	7.327	21.161	7.625	2.642	-0.151	1.016	Fine Silt	Poorly Sorted
P6	28.4625	71.187	0.351	1.622	7.028	20.559	7.291	2.675	-0.151	1.024	Fine Silt	Poorly Sorted
P6	26.874	72.755	0.371	1.713	7.43	21.595	7.700	2.672	-0.156	1.022	Fine Silt	Poorly Sorted
P6	27.3028	72.469	0.228	1.705	7.171	20.423	7.464	2.624	-0.155	1.041	Fine Silt	Poorly Sorted
P6	26.3767	73.472	0.151	1.78	7.329	20.447	7.626	2.585	-0.159	1.040	Fine Silt	Poorly Sorted
P6	26.0189	73.693	0.288	1.786	7.464	20.908	7.747	2.605	-0.162	1.041	Fine Silt	Poorly Sorted
P6	26.9575	72.757	0.285	1.688	7.316	20.871	7.568	2.653	-0.163	1.042	Fine Silt	Poorly Sorted
P6	26.947	72.422	0.631	1.701	7.228	20.937	7.535	2.648	-0.149	1.056	Fine Silt	Poorly Sorted
P6	27.6498	72.119	0.231	1.634	7.165	20.894	7.430	2.682	-0.156	1.045	Fine Silt	Poorly Sorted
P6	26.5075	73.2	0.292	1.732	7.391	21.116	7.672	2.639	-0.158	1.041	Fine Silt	Poorly Sorted
P6	26.2709	73.284	0.445	1.74	7.458	21.137	7.715	2.637	-0.163	1.045	Fine Silt	Poorly Sorted
P6	26.5083	73.081	0.41	1.741	7.467	21.667	7.758	2.662	-0.154	1.032	Fine Silt	Poorly Sorted
P6	26.2677	73.28	0.452	1.773	7.433	21.256	7.737	2.627	-0.153	1.039	Fine Silt	Poorly Sorted
P6	26.3385	73.517	0.145	1.755	7.547	21.508	7.809	2.647	-0.164	1.018	Fine Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P6	25.9801	73.596	0.424	1.761	7.685	22.078	7.931	2.669	-0.165	1.023	Medium Silt	Poorly Sorted
P6	26.8468	72.639	0.514	1.723	7.434	21.62	7.718	2.672	-0.155	1.024	Fine Silt	Poorly Sorted
P6	26.5736	73.012	0.414	1.749	7.366	20.968	7.657	2.627	-0.156	1.039	Fine Silt	Poorly Sorted
P6	25.3906	74.052	0.558	1.839	7.652	21.218	7.912	2.592	-0.165	1.033	Medium Silt	Poorly Sorted
P6	23.6218	75.033	1.345	1.959	8.127	23.512	8.490	2.641	-0.144	1.057	Medium Silt	Poorly Sorted
P6	27.5684	71.908	0.523	1.706	7.098	20.133	7.381	2.610	-0.153	1.040	Fine Silt	Poorly Sorted
P6	27.0452	72.702	0.253	1.752	7.218	20.329	7.516	2.594	-0.155	1.030	Fine Silt	Poorly Sorted
P6	27.1106	72.639	0.25	1.725	7.257	20.085	7.490	2.593	-0.170	1.023	Fine Silt	Poorly Sorted
P6	25.997	73.824	0.179	1.757	7.734	21.899	7.933	2.663	-0.175	1.014	Medium Silt	Poorly Sorted
P6	26.6392	72.741	0.62	1.745	7.393	20.951	7.658	2.627	-0.160	1.029	Fine Silt	Poorly Sorted
P6	27.15715	72.089	0.754	1.7045	7.2945	21.177	7.573	2.660	-0.151	1.035	Fine Silt	Poorly Sorted
P6	25.3948	74.384	0.221	1.829	7.567	20.659	7.818	2.567	-0.170	1.042	Medium Silt	Poorly Sorted
P6	27.8316	71.727	0.441	1.695	7.041	20.223	7.343	2.621	-0.147	1.040	Fine Silt	Poorly Sorted
P6	26.9886	72.247	0.765	1.74	7.181	20.336	7.483	2.601	-0.150	1.049	Fine Silt	Poorly Sorted
P6	28.2233	71.1	0.677	1.689	6.877	19.793	7.210	2.603	-0.138	1.048	Fine Silt	Poorly Sorted
P6	26.1073	73.317	0.575	1.77	7.482	21.149	7.752	2.623	-0.160	1.041	Fine Silt	Poorly Sorted
P6	27.2539	72.185	0.561	1.709	7.255	20.883	7.540	2.644	-0.153	1.030	Fine Silt	Poorly Sorted
P6	28.0454	71.955	0	1.665	7.057	19.662	7.282	2.603	-0.169	1.019	Fine Silt	Poorly Sorted
P6	28.584	71.125	0.291	1.633	6.937	19.933	7.199	2.636	-0.153	1.026	Fine Silt	Poorly Sorted
P6	29.9284	69.626	0.446	1.564	6.664	20.587	7.028	2.710	-0.120	1.035	Fine Silt	Poorly Sorted
P6	27.6139	72.369	0.017	1.718	7.01	19.445	7.302	2.563	-0.159	1.035	Fine Silt	Poorly Sorted
P6	27.5399	72.439	0.021	1.7	7.093	19.624	7.348	2.582	-0.168	1.030	Fine Silt	Poorly Sorted
P6	27.5113	72.39	0.099	1.684	7.129	19.693	7.358	2.593	-0.172	1.030	Fine Silt	Poorly Sorted
P6	29.1196	70.812	0.069	1.596	6.857	19.488	7.087	2.631	-0.162	1.012	Fine Silt	Poorly Sorted
P6	29.8675	70.069	0.063	1.549	6.714	19.16	6.931	2.641	-0.162	1.012	Fine Silt	Poorly Sorted
P6	29.2479	70.723	0.029	1.568	6.976	20.211	7.177	2.685	-0.164	0.995	Fine Silt	Poorly Sorted
P6	28.4014	71.593	0.006	1.631	7.013	19.649	7.228	2.620	-0.170	1.015	Fine Silt	Poorly Sorted
P7	25.5965	74.389	0.014	1.877	7.393	19.681	7.678	2.498	-0.169	1.033	Fine Silt	Poorly Sorted
P7	28.7961	70.324	0.88	1.559	7.156	21.697	7.393	2.770	-0.154	1.008	Fine Silt	Poorly Sorted
P7	27.2283	72.772	0	1.742	7.242	20.185	7.512	2.589	-0.164	1.010	Fine Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P7	28.1116	71.568	0.32	1.685	7.084	20.183	7.358	2.622	-0.156	1.008	Fine Silt	Poorly Sorted
P7	27.2566	72.738	0.005	1.716	7.273	20.095	7.491	2.597	-0.174	1.011	Fine Silt	Poorly Sorted
P7	25.8602	73.725	0.415	1.821	7.484	20.495	7.752	2.567	-0.168	1.029	Fine Silt	Poorly Sorted
P7	27.1827	72.681	0.136	1.725	7.32	20.865	7.594	2.632	-0.159	1.010	Fine Silt	Poorly Sorted
P7	24.8711	70.735	4.393	1.762	8.637	37.285	9.292	3.244	-0.047	1.094	Medium Silt	Poorly Sorted
P7	26.4529	72.599	0.948	1.757	7.67	22.366	7.914	2.690	-0.156	1.006	Medium Silt	Poorly Sorted
P7	26.9725	72.251	0.777	1.715	7.536	22.052	7.775	2.696	-0.158	1.006	Fine Silt	Poorly Sorted
P7	24.8396	74.053	1.108	1.822	8.316	25.222	8.559	2.780	-0.153	1.009	Medium Silt	Poorly Sorted
P7	27.2063	72.559	0.235	1.683	7.475	21.831	7.703	2.700	-0.163	1.004	Fine Silt	Poorly Sorted
P7	28.7402	70.775	0.485	1.605	7.072	21.234	7.345	2.719	-0.145	1.010	Fine Silt	Poorly Sorted
P7	26.5907	72.891	0.518	1.768	7.457	21.625	7.764	2.646	-0.149	1.017	Fine Silt	Poorly Sorted
P7	27.3935	71.8	0.807	1.701	7.241	21.023	7.526	2.657	-0.149	1.031	Fine Silt	Poorly Sorted
P7	28.6073	71.371	0.022	1.632	6.948	19.654	7.183	2.622	-0.163	1.019	Fine Silt	Poorly Sorted
P7	29.2467	70.654	0.099	1.619	6.847	20.122	7.157	2.656	-0.144	1.009	Fine Silt	Poorly Sorted
P7	30.0326	69.754	0.214	1.527	6.828	20.329	7.065	2.721	-0.154	0.997	Fine Silt	Poorly Sorted
P7	31.9659	67.861	0.174	1.426	6.41	19.559	6.650	2.743	-0.143	0.999	Fine Silt	Poorly Sorted
P7	27.2957	72.455	0.249	1.637	7.372	21.168	7.560	2.691	-0.172	1.026	Fine Silt	Poorly Sorted
P7	29.3656	70.151	0.484	1.565	6.757	19.6	7.010	2.658	-0.152	1.038	Fine Silt	Poorly Sorted
P7	28.4591	71.431	0.11	1.631	7.055	20.429	7.309	2.664	-0.157	1.014	Fine Silt	Poorly Sorted
P7	28.089	71.777	0.134	1.634	7.096	20.042	7.315	2.640	-0.170	1.021	Fine Silt	Poorly Sorted
P7	29.0735	70.699	0.228	1.585	6.963	20.229	7.194	2.679	-0.160	1.006	Fine Silt	Poorly Sorted
P7	30.0763	69.856	0.068	1.481	6.865	20.743	7.070	2.768	-0.157	1.002	Fine Silt	Poorly Sorted
P7	29.2347	70.113	0.652	1.532	7.09	21.428	7.294	2.772	-0.157	1.001	Fine Silt	Poorly Sorted
P7	29.904	69.937	0.159	1.5	7.002	21.536	7.226	2.798	-0.153	0.983	Fine Silt	Poorly Sorted
P7	29.0435	70.852	0.105	1.569	6.967	20.257	7.184	2.689	-0.162	1.014	Fine Silt	Poorly Sorted
P7	30.7569	68.967	0.277	1.479	6.673	20.221	6.918	2.746	-0.147	1.003	Fine Silt	Poorly Sorted
P7	30.6788	69.287	0.034	1.478	6.78	20.821	7.028	2.778	-0.148	0.986	Fine Silt	Poorly Sorted
P7	32.8886	66.332	0.779	1.366	6.166	19.287	6.434	2.769	-0.128	1.027	Fine Silt	Poorly Sorted
P7	28.9053	70.906	0.189	1.614	6.853	19.669	7.113	2.630	-0.154	1.024	Fine Silt	Poorly Sorted
P7	31.5073	67.923	0.57	1.433	6.505	19.577	6.710	2.739	-0.151	1.002	Fine Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P7	28.9408	71.027	0.032	1.586	6.983	20.209	7.208	2.675	-0.162	1.007	Fine Silt	Poorly Sorted
P7	33.5624	66.264	0.173	1.423	5.991	17.87	6.272	2.657	-0.131	1.009	Fine Silt	Poorly Sorted
P7	29.1464	70.836	0.017	1.579	6.934	20.807	7.225	2.708	-0.145	1.007	Fine Silt	Poorly Sorted
P7	34.5195	61.984	3.497	1.283	6.246	26.467	6.793	3.283	-0.021	1.041	Fine Silt	Poorly Sorted
P7	34.4114	65.549	0.039	1.318	5.88	17.852	6.094	2.723	-0.139	1.018	Fine Silt	Poorly Sorted
P7	33.1051	66.768	0.127	1.386	6.206	19.496	6.491	2.768	-0.129	0.995	Fine Silt	Poorly Sorted
P7	32.339	67.486	0.175	1.447	6.33	19.507	6.624	2.731	-0.131	0.993	Fine Silt	Poorly Sorted
P7	31.6075	68.293	0.099	1.428	6.544	20.092	6.778	2.771	-0.146	0.992	Fine Silt	Poorly Sorted
P7	40.2081	59.768	0.024	1.154	5.076	16.949	5.379	2.805	-0.096	0.969	Fine Silt	Poorly Sorted
P7	30.8345	69.019	0.147	1.482	6.614	19.63	6.831	2.710	-0.154	1.005	Fine Silt	Poorly Sorted
P7	28.0891	71.898	0.013	1.612	7.129	20.08	7.310	2.652	-0.176	1.021	Fine Silt	Poorly Sorted
P7	29.9847	69.992	0.023	1.542	6.716	19.644	6.959	2.671	-0.153	1.011	Fine Silt	Poorly Sorted
P7	28.4158	71.551	0.034	1.632	7.023	20.35	7.292	2.656	-0.155	1.015	Fine Silt	Poorly Sorted
P7	28.5358	71.437	0.027	1.639	6.913	19.304	7.147	2.600	-0.166	1.024	Fine Silt	Poorly Sorted
P7	28.8491	71.109	0.042	1.609	6.888	19.437	7.109	2.622	-0.165	1.020	Fine Silt	Poorly Sorted
P7	29.9975	69.945	0.058	1.528	6.766	19.72	6.980	2.685	-0.160	1.006	Fine Silt	Poorly Sorted
P7	28.3161	71.575	0.109	1.613	7.048	20.11	7.266	2.654	-0.166	1.025	Fine Silt	Poorly Sorted
P7	27.9351	71.971	0.094	1.626	7.321	21.851	7.565	2.732	-0.157	1.003	Fine Silt	Poorly Sorted
P7	30.1312	69.693	0.175	1.528	6.721	20.018	6.976	2.702	-0.147	1.012	Fine Silt	Poorly Sorted
P7	28.361	71.512	0.127	1.63	7.016	20.136	7.266	2.646	-0.159	1.021	Fine Silt	Poorly Sorted
P7	27.6931	72.145	0.162	1.668	7.168	20.386	7.409	2.639	-0.163	1.025	Fine Silt	Poorly Sorted
P7	30.5031	69.301	0.196	1.48	6.719	20.118	6.925	2.739	-0.154	1.008	Fine Silt	Poorly Sorted
P7	28.992	70.876	0.132	1.586	7.001	20.307	7.210	2.681	-0.161	1.004	Fine Silt	Poorly Sorted
P7	28.0846	71.915	0	1.608	6.977	18.948	7.134	2.592	-0.185	1.040	Fine Silt	Poorly Sorted
P7	30.3996	69.6	0	1.489	6.653	19.187	6.838	2.679	-0.166	1.011	Fine Silt	Poorly Sorted
P7	28.1889	71.715	0.096	1.644	7.05	19.784	7.266	2.620	-0.169	1.018	Fine Silt	Poorly Sorted
P7	28.9806	71.019	0	1.592	6.832	19.143	7.044	2.615	-0.168	1.025	Fine Silt	Poorly Sorted
P7	29.5043	70.44	0.055	1.595	6.799	19.86	7.085	2.652	-0.148	1.004	Fine Silt	Poorly Sorted
P7	29.2117	70.558	0.23	1.585	6.798	19.161	7.013	2.622	-0.165	1.024	Fine Silt	Poorly Sorted
P7	31.2457	68.754	0	1.42	6.55	19.458	6.716	2.737	-0.162	1.008	Fine Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P7	31.0416	68.86	0.099	1.465	6.578	19.489	6.780	2.713	-0.156	1.004	Fine Silt	Poorly Sorted
P7	30.5056	69.45	0.044	1.495	6.598	18.931	6.787	2.664	-0.164	1.017	Fine Silt	Poorly Sorted
P7	30.6447	69.169	0.186	1.479	6.575	18.742	6.740	2.662	-0.169	1.014	Fine Silt	Poorly Sorted
P7	31.4579	68.527	0.015	1.428	6.47	18.936	6.640	2.706	-0.163	1.009	Fine Silt	Poorly Sorted
P7	31.0338	68.732	0.234	1.433	6.604	19.524	6.762	2.733	-0.164	1.006	Fine Silt	Poorly Sorted
P7	31.4428	68.207	0.35	1.413	6.575	19.771	6.741	2.762	-0.159	0.997	Fine Silt	Poorly Sorted
P7	29.8785	69.994	0.128	1.47	6.989	20.997	7.132	2.788	-0.166	0.996	Fine Silt	Poorly Sorted
P7	35.895	64.05	0.055	1.233	5.727	17.698	5.891	2.778	-0.144	0.988	Fine Silt	Poorly Sorted
P7	33.6598	66.222	0.118	1.309	6.109	18.641	6.269	2.773	-0.151	0.998	Fine Silt	Poorly Sorted
P7	37.9403	62	0.059	1.133	5.513	18.233	5.658	2.903	-0.130	0.956	Fine Silt	Poorly Sorted
P7	34.5945	65.37	0.036	1.245	6.043	18.963	6.174	2.842	-0.151	0.977	Fine Silt	Poorly Sorted
P7	32.1599	67.794	0.046	1.308	6.793	21.323	6.810	2.923	-0.173	0.947	Fine Silt	Poorly Sorted
P7	30.9011	69.099	0	1.479	6.597	19.294	6.795	2.692	-0.160	0.997	Fine Silt	Poorly Sorted
P7	30.0571	69.918	0.025	1.516	6.672	18.81	6.842	2.642	-0.171	1.016	Fine Silt	Poorly Sorted
P7	32.9212	66.892	0.187	1.284	6.444	20.42	6.550	2.891	-0.157	0.976	Fine Silt	Poorly Sorted
P8	28.9916	71.008	0	1.623	6.971	19.569	7.165	2.625	-0.170	0.995	Fine Silt	Poorly Sorted
P8	26.8627	73.137	0	1.751	7.456	20.603	7.656	2.605	-0.176	0.997	Fine Silt	Poorly Sorted
P8	27.1052	72.872	0.023	1.738	7.281	19.887	7.489	2.575	-0.176	1.012	Fine Silt	Poorly Sorted
P8	26.7527	73.247	0	1.738	7.443	20.414	7.623	2.600	-0.180	1.007	Fine Silt	Poorly Sorted
P8	27.4433	72.557	0	1.691	7.46	20.953	7.616	2.654	-0.179	0.985	Fine Silt	Poorly Sorted
P8	26.9772	73.023	0	1.722	7.413	20.15	7.557	2.595	-0.186	1.003	Fine Silt	Poorly Sorted
P8	28.3559	71.644	0	1.656	7.204	20.691	7.423	2.663	-0.164	0.983	Fine Silt	Poorly Sorted
P8	26.9226	73.077	0	1.717	7.565	21.088	7.717	2.645	-0.182	0.990	Fine Silt	Poorly Sorted
P8	27.2097	72.79	0	1.703	7.358	20.194	7.522	2.609	-0.183	1.006	Fine Silt	Poorly Sorted
P8	27.7783	72.222	0	1.696	7.125	19.224	7.298	2.563	-0.182	1.008	Fine Silt	Poorly Sorted
P8	29.2759	70.724	0	1.608	6.883	19.249	7.076	2.615	-0.170	0.995	Fine Silt	Poorly Sorted
P8	28.6659	71.334	0	1.638	6.937	19.067	7.124	2.588	-0.175	1.008	Fine Silt	Poorly Sorted
P8	28.9673	71.033	0	1.593	6.918	19.067	7.073	2.612	-0.180	1.008	Fine Silt	Poorly Sorted
P8	29.645	69.059	1.296	1.537	6.909	20.875	7.161	2.743	-0.146	1.005	Fine Silt	Poorly Sorted
P8	29.9335	70.067	0	1.506	6.917	20.076	7.066	2.717	-0.174	0.986	Fine Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P8	29.4767	70.523	0	1.557	6.84	19.321	7.020	2.645	-0.172	1.006	Fine Silt	Poorly Sorted
P8	29.36	70.64	0	1.55	6.895	19.761	7.088	2.670	-0.169	1.003	Fine Silt	Poorly Sorted
P8	29.3332	70.667	0	1.565	6.863	19.179	7.023	2.633	-0.176	1.006	Fine Silt	Poorly Sorted
P8	30.48	69.495	0.025	1.5	6.677	19.169	6.852	2.674	-0.168	1.000	Fine Silt	Poorly Sorted
P8	29.6963	70.304	0	1.525	6.939	20.361	7.124	2.719	-0.165	0.989	Fine Silt	Poorly Sorted
P8	29.0461	70.954	0	1.574	6.925	19.589	7.107	2.648	-0.172	1.010	Fine Silt	Poorly Sorted
P8	30.2931	69.707	0	1.522	6.662	19.014	6.857	2.652	-0.165	1.005	Fine Silt	Poorly Sorted
P8	30.0282	69.972	0	1.533	6.69	18.786	6.864	2.632	-0.171	1.009	Fine Silt	Poorly Sorted
P8	30.6224	69.213	0.165	1.49	6.605	19.475	6.832	2.695	-0.154	1.012	Fine Silt	Poorly Sorted
P8	28.7721	71.182	0.046	1.61	6.913	19.864	7.169	2.643	-0.158	1.021	Fine Silt	Poorly Sorted
P8	30.9218	69.049	0.029	1.45	6.712	20.031	6.886	2.752	-0.162	0.988	Fine Silt	Poorly Sorted
P8	29.3004	70.676	0.023	1.52	6.817	18.996	6.956	2.647	-0.182	1.030	Fine Silt	Poorly Sorted
P8	31.6632	68.262	0.075	1.443	6.396	18.303	6.566	2.665	-0.167	1.006	Fine Silt	Poorly Sorted
P8	30.8764	69.057	0.066	1.457	6.621	19.485	6.804	2.717	-0.163	1.004	Fine Silt	Poorly Sorted
P8	33.0429	66.838	0.119	1.337	6.249	18.838	6.410	2.765	-0.158	0.993	Fine Silt	Poorly Sorted
P8	31.6486	68.324	0.027	1.434	6.418	18.764	6.611	2.694	-0.160	1.006	Fine Silt	Poorly Sorted
P8	31.2879	68.636	0.076	1.435	6.54	19.262	6.719	2.720	-0.162	1.003	Fine Silt	Poorly Sorted
P8	32.4569	67.51	0.033	1.356	6.335	18.767	6.478	2.745	-0.165	1.000	Fine Silt	Poorly Sorted
P8	32.173	67.8	0.027	1.378	6.46	19.501	6.624	2.771	-0.160	0.986	Fine Silt	Poorly Sorted
P8	31.674	68.273	0.053	1.39	6.534	19.53	6.684	2.762	-0.165	0.995	Fine Silt	Poorly Sorted
P8	29.9594	70.011	0.03	1.482	7.01	21.715	7.231	2.815	-0.154	0.982	Fine Silt	Poorly Sorted
P8	30.4559	69.544	0	1.48	6.701	19.396	6.867	2.696	-0.169	1.002	Fine Silt	Poorly Sorted
P8	32.6337	67.309	0.057	1.391	6.287	18.98	6.506	2.736	-0.148	0.996	Fine Silt	Poorly Sorted
P8	32.5586	67.4	0.041	1.366	6.322	18.958	6.497	2.748	-0.157	0.994	Fine Silt	Poorly Sorted
P8	30.1675	69.833	0	1.483	6.743	19.225	6.886	2.685	-0.177	1.007	Fine Silt	Poorly Sorted
P8	31.8237	68.091	0.085	1.371	6.536	19.599	6.672	2.779	-0.167	0.990	Fine Silt	Poorly Sorted
P8	32.0324	67.968	0	1.371	6.482	19.523	6.632	2.774	-0.163	0.988	Fine Silt	Poorly Sorted
P8	30.0398	69.93	0.03	1.499	6.808	19.982	6.995	2.716	-0.164	1.004	Fine Silt	Poorly Sorted
P8	28.6129	71.387	0	1.596	7.099	20.382	7.296	2.677	-0.170	0.999	Fine Silt	Poorly Sorted
P8	31.1326	68.867	0	1.46	6.626	19.272	6.778	2.703	-0.169	0.981	Fine Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P8	30.8154	68.721	0.464	1.492	6.61	19.43	6.813	2.693	-0.155	1.001	Fine Silt	Poorly Sorted
P8	32.1017	67.508	0.391	1.404	6.397	18.947	6.567	2.725	-0.159	0.995	Fine Silt	Poorly Sorted
P8	30.8337	69.166	0	1.495	6.599	19.137	6.798	2.675	-0.161	0.996	Fine Silt	Poorly Sorted
P8	30.2852	69.689	0.026	1.529	6.709	19.69	6.945	2.682	-0.155	0.997	Fine Silt	Poorly Sorted
P8	30.8883	69.112	0	1.477	6.646	19.461	6.827	2.704	-0.163	0.992	Fine Silt	Poorly Sorted
P8	30.4827	69.503	0.014	1.467	6.718	19.716	6.883	2.720	-0.166	1.002	Fine Silt	Poorly Sorted
P8	28.7963	71.17	0.034	1.524	7.095	20.57	7.240	2.727	-0.176	1.014	Fine Silt	Poorly Sorted
P8	29.2364	70.742	0.021	1.554	6.909	19.638	7.080	2.663	-0.173	1.010	Fine Silt	Poorly Sorted
P8	29.6823	70.261	0.057	1.544	6.817	19.262	6.982	2.652	-0.173	1.006	Fine Silt	Poorly Sorted
P8	31.0284	68.972	0	1.47	6.637	19.45	6.812	2.708	-0.164	0.987	Fine Silt	Poorly Sorted
P8	29.725	70.275	0	1.515	6.9	20.075	7.071	2.710	-0.169	0.998	Fine Silt	Poorly Sorted
P8	29.224	70.776	0	1.579	6.914	19.759	7.119	2.656	-0.167	1.003	Fine Silt	Poorly Sorted
P8	31.2602	68.74	0	1.476	6.548	19.324	6.766	2.699	-0.155	0.991	Fine Silt	Poorly Sorted
P8	27.9109	71.918	0.171	1.603	7.262	20.433	7.388	2.674	-0.183	1.013	Fine Silt	Poorly Sorted
P8	27.1944	72.806	0	1.65	7.417	20.669	7.550	2.658	-0.186	1.012	Fine Silt	Poorly Sorted
P8	27.3261	72.65	0.024	1.621	7.525	21.415	7.635	2.711	-0.186	1.002	Fine Silt	Poorly Sorted
P8	28.1164	71.854	0.03	1.608	7.073	19.964	7.266	2.646	-0.173	1.028	Fine Silt	Poorly Sorted
P8	27.9284	72.042	0.029	1.603	7.227	20.532	7.389	2.680	-0.177	1.018	Fine Silt	Poorly Sorted
P8	28.4299	71.57	0	1.524	7.096	20.007	7.203	2.692	-0.189	1.027	Fine Silt	Poorly Sorted
P8	33.8773	66.102	0.021	1.382	6.062	18.824	6.347	2.736	-0.127	0.981	Fine Silt	Poorly Sorted
P8	31.4728	68.383	0.144	1.407	6.695	21.156	6.905	2.840	-0.145	0.977	Fine Silt	Poorly Sorted
P8	29.9902	70.01	0	1.501	6.951	20.753	7.134	2.756	-0.163	0.980	Fine Silt	Poorly Sorted
P8	27.3772	72.611	0.011	1.625	7.538	21.535	7.651	2.715	-0.185	0.996	Fine Silt	Poorly Sorted
P8	32.2007	67.759	0.04	1.403	6.498	19.776	6.678	2.771	-0.154	0.970	Fine Silt	Poorly Sorted
P8	30.442	69.521	0.037	1.496	6.717	19.354	6.878	2.685	-0.169	0.995	Fine Silt	Poorly Sorted
P8	30.7644	69.236	0	1.493	6.639	19.293	6.827	2.685	-0.163	0.994	Fine Silt	Poorly Sorted
P8	32.5869	67.042	0.371	1.404	6.326	19.36	6.567	2.750	-0.142	0.989	Fine Silt	Poorly Sorted
P8	30.5995	69.401	0	1.501	6.72	19.497	6.894	2.690	-0.166	0.984	Fine Silt	Poorly Sorted
P8	30.3928	69.607	0	1.489	6.774	19.552	6.922	2.699	-0.173	0.988	Fine Silt	Poorly Sorted
P8	30.0063	69.994	0	1.561	6.764	19.347	6.979	2.645	-0.163	0.989	Fine Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P8	30.7105	69.289	0	1.483	6.618	18.751	6.767	2.661	-0.174	0.999	Fine Silt	Poorly Sorted
P8	30.671	69.28	0.049	1.502	6.58	18.865	6.781	2.656	-0.163	1.006	Fine Silt	Poorly Sorted
P8	30.5523	69.448	0	1.532	6.578	18.557	6.783	2.622	-0.165	1.001	Fine Silt	Poorly Sorted
P8	29.4256	70.574	0	1.566	6.894	19.513	7.069	2.651	-0.173	0.997	Fine Silt	Poorly Sorted
P9	27.6089	72.391	0	1.719	7.304	20.353	7.51793114	2.6102862	-0.17196799	0.985391911	Fine Silt	Poorly Sorted
P9	28.1039	71.896	0	1.676	7.186	20.09	7.39034372	2.6213182	-0.17324839	0.989850324	Fine Silt	Poorly Sorted
P9	28.2798	71.68	0.041	1.692	6.992	19.248	7.22155805	2.5680926	-0.1670749	1.004314844	Fine Silt	Poorly Sorted
P9	27.9423	72.058	0	1.673	7.153	19.481	7.31957985	2.5909442	-0.18383206	1.002831686	Fine Silt	Poorly Sorted
P9	28.6615	71.251	0.088	1.646	7.038	19.586	7.22026594	2.6112978	-0.17271745	0.992063586	Fine Silt	Poorly Sorted
P9	29.703	70.125	0.171	1.576	6.826	19.299	7.01307828	2.6361145	-0.16780738	0.993239505	Fine Silt	Poorly Sorted
P9	30.4874	69.513	0	1.498	6.744	19.299	6.8933337	2.6829506	-0.17374235	0.986737143	Fine Silt	Poorly Sorted
P9	30.2012	69.799	0	1.51	6.826	19.852	7.00039791	2.7027972	-0.16831524	0.98377317	Fine Silt	Poorly Sorted
P9	29.2334	70.552	0.215	1.49	7.422	23.534	7.58634058	2.90252	-0.15924894	0.967126717	Fine Silt	Poorly Sorted
P9	30.0333	69.939	0.028	1.531	6.948	21.671	7.24905387	2.7848134	-0.14010118	0.974769587	Fine Silt	Poorly Sorted
P9	29.8085	70.192	0	1.557	6.848	19.928	7.07832516	2.6783519	-0.16021141	0.988308216	Fine Silt	Poorly Sorted
P9	28.8609	71.139	0	1.596	7.062	20.511	7.28759466	2.6853882	-0.1632396	0.992624764	Fine Silt	Poorly Sorted
P9	30.0925	69.907	0	1.49	6.792	19.624	6.95037272	2.700741	-0.1724689	1.001136802	Fine Silt	Poorly Sorted
P9	34.1294	65.871	0	1.328	6.09	18.739	6.30499459	2.7701055	-0.14484377	0.971250639	Fine Silt	Poorly Sorted
P9	31.3647	68.569	0.066	1.427	6.477	18.774	6.64129535	2.6977961	-0.16742436	1.010215913	Fine Silt	Poorly Sorted
P9	30.1251	69.875	0	1.505	6.651	18.788	6.82565813	2.6470681	-0.17153243	1.018788795	Fine Silt	Poorly Sorted
P9	33.2655	66.705	0.029	1.364	6.09	18.162	6.30215286	2.705433	-0.14783948	1.010286249	Fine Silt	Poorly Sorted
P9	32.4409	67.481	0.078	1.396	6.259	18.658	6.46874465	2.7126777	-0.15022061	1.008835422	Fine Silt	Poorly Sorted
P9	33.7909	66.028	0.181	1.4	5.943	17.924	6.23208051	2.6725747	-0.12798201	1.01517041	Fine Silt	Poorly Sorted
P9	32.5362	67.372	0.092	1.41	6.331	19.131	6.55971469	2.7322741	-0.14748207	0.983800267	Fine Silt	Poorly Sorted
P9	31.3583	68.642	0	1.48	6.52	19.393	6.76102432	2.6991373	-0.14987286	0.989316544	Fine Silt	Poorly Sorted
P9	30.2274	69.257	0.516	1.522	6.697	19.4	6.90700742	2.6736369	-0.15995184	1.007468789	Fine Silt	Poorly Sorted
P9	31.4924	68.508	0	1.476	6.351	18.021	6.5603429	2.625188	-0.16223094	1.012365259	Fine Silt	Poorly Sorted
P9	34.914	65.031	0.055	1.329	5.841	18.388	6.14172847	2.748006	-0.12097435	0.995851214	Fine Silt	Poorly Sorted
P9	33.1801	66.802	0.018	1.349	6.225	19.351	6.45417539	2.7837925	-0.14206366	0.990363814	Fine Silt	Poorly Sorted
P9	34.1693	65.831	0	1.33	6.008	18.351	6.2274269	2.7443268	-0.14221246	0.989276076	Fine Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P9	30.6607	69.266	0.073	1.486	6.62	19.723	6.86086741	2.7091803	-0.15156899	1.006930899	Fine Silt	Poorly Sorted
P9	29.3347	70.514	0.151	1.56	7.025	20.991	7.26782446	2.7319664	-0.15517919	0.987429992	Fine Silt	Poorly Sorted
P9	33.917	66.051	0.032	1.252	6.219	19.717	6.34527362	2.8754388	-0.15422242	0.972428439	Fine Silt	Poorly Sorted
P9	34.6398	65.267	0.093	1.273	5.99	18.8	6.17882706	2.811748	-0.14164409	0.983703177	Fine Silt	Poorly Sorted
P9	29.0525	70.936	0.011	1.571	7.033	20.674	7.26413066	2.7076338	-0.16036766	0.995923843	Fine Silt	Poorly Sorted
P9	32.8509	66.856	0.293	1.359	6.329	19.883	6.55855412	2.8065605	-0.13984825	0.986766451	Fine Silt	Poorly Sorted
P9	32.2307	67.342	0.428	1.383	6.435	20.092	6.66237554	2.7997204	-0.14196365	0.990338036	Fine Silt	Poorly Sorted
P9	31.8621	68.107	0.031	1.453	6.418	19.579	6.69676637	2.726997	-0.13923906	0.99374486	Fine Silt	Poorly Sorted
P9	31.437	68.41	0.153	1.462	6.507	19.778	6.76403324	2.7309256	-0.14209921	0.998298875	Fine Silt	Poorly Sorted
P9	32.5374	67.39	0.072	1.375	6.385	19.362	6.57173265	2.7663354	-0.15512769	0.981096006	Fine Silt	Poorly Sorted
P9	29.409	70.591	0	1.531	6.975	20.041	7.13047499	2.6982314	-0.17565493	0.997029689	Fine Silt	Poorly Sorted
P9	28.7745	71.2	0.025	1.525	7.459	22.718	7.59951287	2.8364636	-0.17193334	0.966595555	Fine Silt	Poorly Sorted
P9	28.8896	71.055	0.056	1.544	7.142	20.973	7.31074114	2.7382902	-0.16980895	0.999021661	Fine Silt	Poorly Sorted
P9	29.5158	70.415	0.069	1.51	7.033	21.288	7.23808827	2.774157	-0.1581416	0.991542703	Fine Silt	Poorly Sorted
P9	30.2652	69.66	0.074	1.488	6.792	20.95	7.05353684	2.7726442	-0.14342166	1.00230492	Fine Silt	Poorly Sorted
P9	30.1837	69.631	0.185	1.5	6.771	20.04	6.98103808	2.7190845	-0.15807079	1.00377676	Fine Silt	Poorly Sorted
P9	31.5164	68.484	0	1.462	6.603	20.284	6.86622851	2.7613057	-0.14373202	0.974504767	Fine Silt	Poorly Sorted
P9	30.0974	69.873	0.03	1.515	6.903	21.545	7.20932803	2.7877314	-0.1401683	0.98209328	Fine Silt	Poorly Sorted
P9	34.4315	65.529	0.04	1.323	6.041	18.86	6.27660736	2.7824026	-0.13703072	0.97206019	Fine Silt	Poorly Sorted
P9	32.9437	66.977	0.079	1.388	6.304	19.53	6.54941067	2.7686066	-0.1401896	0.97591377	Fine Silt	Poorly Sorted
P9	37.5024	62.401	0.096	1.211	5.478	18.113	5.77151476	2.8241227	-0.10786496	0.982950906	Fine Silt	Poorly Sorted
P9	35.0142	64.853	0.133	1.293	5.897	18.763	6.15775901	2.7958821	-0.1272105	0.982234169	Fine Silt	Poorly Sorted
P9	30.4615	69.538	0	1.72	6.819	21.23	7.30917863	2.6597565	-0.10082554	0.917613702	Fine Silt	Poorly Sorted
P9	29.9563	70	0.044	1.551	6.728	19.325	6.95192103	2.651037	-0.16045314	1.005892109	Fine Silt	Poorly Sorted
P9	29.4599	70.54	0	1.693	6.925	19.928	7.22944461	2.6079514	-0.14576223	0.956412884	Fine Silt	Poorly Sorted
P9	33.4328	66.535	0.033	1.269	6.269	19.341	6.3716602	2.8404202	-0.1638076	0.983854631	Fine Silt	Poorly Sorted
P9	33.3781	66.605	0.017	1.273	6.317	19.572	6.42167987	2.8502578	-0.16443419	0.97423512	Fine Silt	Poorly Sorted
P9	30.1598	69.767	0.073	1.542	6.811	20.387	7.07137902	2.7142835	-0.14785964	0.988293751	Fine Silt	Poorly Sorted
P9	36.8441	62.965	0.191	1.294	5.589	18.181	5.94187212	2.7707231	-0.10280154	0.968707223	Fine Silt	Poorly Sorted
P9	28.5322	71.45	0.018	1.661	7.009	20.262	7.30244575	2.6392926	-0.15130813	1.004616358	Fine Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P9	37.617	62.191	0.192	1.131	5.611	19.69	5.83205634	2.9909868	-0.11247015	0.954508201	Fine Silt	Poorly Sorted
P9	32.463	67.297	0.24	1.295	6.447	20.037	6.55214379	2.8569073	-0.16160608	0.996310965	Fine Silt	Poorly Sorted
P9	35.4553	64.417	0.127	1.349	5.638	16.714	5.90849572	2.6372413	-0.12999535	1.015233076	Fine Silt	Poorly Sorted
P9	36.056	63.831	0.113	1.166	5.89	20.47	6.10064107	2.9957993	-0.12155344	0.959815085	Fine Silt	Poorly Sorted
P9	29.9672	70.033	0	1.717	6.818	20.523	7.2386165	2.6247571	-0.11506127	0.943536498	Fine Silt	Poorly Sorted
P9	28.2115	71.788	0	1.809	7.55	22.969	7.92994348	2.6915748	-0.1292792	0.904791891	Medium Silt	Poorly Sorted
P9	28.7333	71.189	0.077	1.65	6.871	19.651	7.16014121	2.6102617	-0.1511209	1.017887135	Fine Silt	Poorly Sorted
P9	27.3135	72.686	0	1.851	7.741	23.713	8.1465425	2.7007707	-0.12671851	0.913437038	Medium Silt	Poorly Sorted
P9	25.1431	74.848	0.009	1.971	8.322	24.623	8.65042327	2.6755601	-0.1455399	0.924236064	Medium Silt	Poorly Sorted
P9	28.9035	71.096	0	1.755	7.174	21.412	7.54355595	2.6475001	-0.12963332	0.933301136	Fine Silt	Poorly Sorted
P9	28.7246	71.275	0	1.787	6.904	19.5	7.2696166	2.5348772	-0.1353399	0.967761329	Fine Silt	Poorly Sorted
P9	28.6481	71.352	0	1.777	7.048	20.211	7.39671884	2.5761623	-0.13741077	0.954469348	Fine Silt	Poorly Sorted
P9	28.8246	71.175	0	1.779	6.886	19.768	7.27547407	2.5523245	-0.12825587	0.970254593	Fine Silt	Poorly Sorted
P9	28.8277	71.172	0	1.774	7.045	20.675	7.43742136	2.6022085	-0.12745714	0.947941713	Fine Silt	Poorly Sorted
P9	26.1979	73.694	0.108	1.766	7.575	21.863	7.86746627	2.6555225	-0.15859286	1.017118829	Medium Silt	Poorly Sorted
P9	32.3119	67.607	0.082	1.386	6.216	18.571	6.43384679	2.7105446	-0.14753853	1.030871267	Fine Silt	Poorly Sorted
P9	29.7078	70.292	0	1.724	6.76	19.631	7.14146064	2.5750726	-0.12724154	0.961555011	Fine Silt	Poorly Sorted
P9	34.3219	65.484	0.194	1.343	5.934	18.709	6.22979021	2.7553034	-0.12063254	1.004062654	Fine Silt	Poorly Sorted
P9	30.4654	69.535	0	1.708	6.678	20.03	7.11319595	2.6045319	-0.11215912	0.943022834	Fine Silt	Poorly Sorted
P9	34.0792	65.921	0	1.512	6.003	19.019	6.46212758	2.6690839	-0.09062109	0.953123782	Fine Silt	Poorly Sorted
P9	31.2461	68.754	0	1.676	6.497	19.788	6.9649935	2.6101057	-0.1019185	0.946674654	Fine Silt	Poorly Sorted
P9	29.0541	70.946	0	1.766	7.109	21.839	7.55918518	2.6607787	-0.11230163	0.932346599	Fine Silt	Poorly Sorted
P9	30.1831	69.817	0	1.742	6.687	20.208	7.16850112	2.5956013	-0.10244926	0.946258706	Fine Silt	Poorly Sorted
P9	28.1832	71.817	0	1.833	7.133	20.808	7.5530274	2.5759719	-0.12287251	0.949795819	Fine Silt	Poorly Sorted
P9	25.7115	74.289	0	1.967	7.701	21.735	8.07031837	2.5501794	-0.14117842	0.956252436	Medium Silt	Poorly Sorted
P9	27.8407	72.159	0	1.815	7.415	21.577	7.74807395	2.6224711	-0.14123599	0.93670939	Fine Silt	Poorly Sorted
P9	28.3966	71.603	0	1.782	7.277	21.174	7.60672281	2.6222203	-0.14094183	0.935442658	Fine Silt	Poorly Sorted
P9	28.5807	71.419	0	1.792	7.123	20.787	7.50571719	2.5979832	-0.13041667	0.943428753	Fine Silt	Poorly Sorted
P9	29.0536	70.946	0	1.789	6.827	19.49	7.22629715	2.5338882	-0.12593429	0.962970719	Fine Silt	Poorly Sorted
P10	29.7705	70.229	0	1.545	7.064	21.693	7.32119686	2.7768662	-0.14962006	0.965348229	Fine Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P10	29.2385	70.608	0.153	1.573	7.198	22.246	7.462559	2.7867131	-0.14710464	0.96872242	Fine Silt	Poorly Sorted
P10	37.0352	62.905	0.06	1.26	5.504	17.967	5.83498093	2.7763094	-0.10301933	0.992324567	Fine Silt	Poorly Sorted
P10	35.9694	63.978	0.053	1.314	5.615	17.342	5.90662694	2.698233	-0.11963208	1.0009786	Fine Silt	Poorly Sorted
P10	33.2295	66.564	0.207	1.374	6.256	20.361	6.57808033	2.8240739	-0.11889946	0.982314756	Fine Silt	Poorly Sorted
P10	33.5451	66.385	0.07	1.349	6.229	20.614	6.55142978	2.8552123	-0.11685091	0.976139459	Fine Silt	Poorly Sorted
P10	31.309	68.659	0.032	1.477	6.553	20.016	6.82765392	2.735301	-0.13993359	0.992247505	Fine Silt	Poorly Sorted
P10	30.8136	69.064	0.122	1.46	6.705	21.386	7.01289493	2.8130643	-0.13117715	0.998626062	Fine Silt	Poorly Sorted
P10	32.3918	67.353	0.255	1.484	6.119	18.878	6.49927062	2.6726058	-0.10977928	1.037799402	Fine Silt	Poorly Sorted
P10	31.8	68.048	0.152	1.414	6.539	21.442	6.8566099	2.8479921	-0.12129674	0.993740164	Fine Silt	Poorly Sorted
P10	38.0961	61.7	0.204	1.217	5.374	17.906	5.68899213	2.8118182	-0.09694344	0.986513808	Fine Silt	Poorly Sorted
P10	33.8317	65.967	0.202	1.32	6.147	20.693	6.46198079	2.8793821	-0.11093869	0.992759978	Fine Silt	Poorly Sorted
P10	36.571	63.256	0.173	1.24	5.618	18.61	5.91025077	2.8292908	-0.10731205	0.99344381	Fine Silt	Poorly Sorted
P10	35.4675	64.417	0.115	1.261	5.813	18.958	6.07121309	2.8317505	-0.11944631	0.995442809	Fine Silt	Poorly Sorted
P10	38.4716	61.386	0.143	1.158	5.294	18.461	5.6119864	2.8853134	-0.08842948	1.015129594	Fine Silt	Poorly Sorted
P10	35.1817	64.78	0.038	1.291	5.795	19.106	6.11359823	2.8151493	-0.10663295	1.014811819	Fine Silt	Poorly Sorted
P10	34.0795	65.791	0.13	1.46	5.831	18.133	6.2435645	2.6506007	-0.09687672	1.024057216	Fine Silt	Poorly Sorted
P10	32.9475	66.936	0.117	1.349	6.174	19.54	6.44428152	2.7903456	-0.12911973	1.023164788	Fine Silt	Poorly Sorted
P10	38.7528	61.086	0.161	1.238	5.181	17.797	5.59669891	2.7855585	-0.06652055	1.035191563	Fine Silt	Poorly Sorted
P10	37.8153	62.069	0.116	1.218	5.322	17.538	5.6438131	2.7816848	-0.09531881	1.03263785	Fine Silt	Poorly Sorted
P10	37.5144	62.3	0.185	1.275	5.347	17.813	5.74152705	2.7581904	-0.07977025	1.034858459	Fine Silt	Poorly Sorted
P10	33.0198	66.702	0.278	1.285	6.333	21.783	6.6187053	2.9570463	-0.11796294	1.005678011	Fine Silt	Poorly Sorted
P10	36.3427	63.442	0.216	1.229	5.702	20.042	6.0526067	2.9185954	-0.0915416	0.993613592	Fine Silt	Poorly Sorted
P10	35.8171	63.878	0.305	1.303	5.647	19.748	6.0857204	2.8436433	-0.07224381	1.037416013	Fine Silt	Poorly Sorted
P10	32.207	67.56	0.233	1.439	6.263	20.041	6.61815544	2.7622233	-0.11096729	1.031788305	Fine Silt	Poorly Sorted
P10	31.55	68.274	0.176	1.382	6.486	20.839	6.75238201	2.8333	-0.13111096	1.027283445	Fine Silt	Poorly Sorted
P10	34.2738	65.506	0.22	1.288	6.056	20.512	6.35517452	2.8937167	-0.11067809	1.000379154	Fine Silt	Poorly Sorted
P10	32.3104	67.479	0.211	1.4	6.315	20.418	6.63653422	2.8054479	-0.11776415	1.021252159	Fine Silt	Poorly Sorted
P10	35.6776	64.058	0.264	1.305	5.635	19.053	6.03924564	2.8043824	-0.0830249	1.047927576	Fine Silt	Poorly Sorted
P10	31.5412	68.261	0.198	1.521	6.392	20.171	6.78424226	2.7188583	-0.1081548	1.015242104	Fine Silt	Poorly Sorted
P10	30.8404	68.905	0.254	1.56	6.506	20.241	6.89548829	2.6997556	-0.11156918	1.020401762	Fine Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P10	30.6093	69.09	0.301	1.497	6.625	21.308	6.99489569	2.787272	-0.11519943	1.027455539	Fine Silt	Poorly Sorted
P10	34.465	65.28	0.255	1.398	5.808	18.576	6.19522796	2.7150681	-0.09459936	1.0352581	Fine Silt	Poorly Sorted
P10	29.8066	69.983	0.21	1.723	6.638	20.061	7.10492134	2.5998995	-0.10112537	0.99360899	Fine Silt	Poorly Sorted
P10	28.1696	71.59	0.24	1.713	6.952	21.17	7.39293675	2.655151	-0.11446359	1.033404877	Fine Silt	Poorly Sorted
P10	31.5348	68.168	0.297	1.524	6.302	20.045	6.73018329	2.710959	-0.0983087	1.042524859	Fine Silt	Poorly Sorted
P10	33.4371	66.33	0.233	1.327	6.231	21.52	6.57605897	2.915268	-0.10304819	0.997921624	Fine Silt	Poorly Sorted
P10	31.6486	68.013	0.339	1.466	6.348	20.845	6.75633473	2.783592	-0.09905947	1.041935326	Fine Silt	Poorly Sorted
P10	32.194	67.465	0.341	1.406	6.38	21.445	6.74780887	2.8545692	-0.10376547	1.016482638	Fine Silt	Poorly Sorted
P10	28.9424	70.794	0.263	1.764	6.706	19.791	7.15999748	2.5642138	-0.10624988	1.016646801	Fine Silt	Poorly Sorted
P10	30.3299	69.256	0.414	1.61	6.477	20.245	6.9276163	2.6699979	-0.09751411	1.04501534	Fine Silt	Poorly Sorted
P10	34.0288	65.48	0.491	1.39	5.92	19.653	6.3312319	2.779624	-0.08667163	1.039513614	Fine Silt	Poorly Sorted
P10	38.9166	60.418	0.665	1.143	5.303	22.284	5.8282769	3.1126755	-0.02824642	1.02005711	Fine Silt	Poorly Sorted
P10	34.898	64.428	0.674	1.27	5.959	23.103	6.45223052	3.0418898	-0.05929137	1.021151321	Fine Silt	Poorly Sorted
P10	35.8384	63.54	0.621	1.223	5.808	23.15	6.31413413	3.0813413	-0.05308847	1.017895653	Fine Silt	Poorly Sorted
P10	33.1304	66.079	0.79	1.401	6.14	22.952	6.70664033	2.9342375	-0.05247903	1.048407262	Fine Silt	Poorly Sorted
P10	40.3023	59.344	0.354	1.219	4.938	16.839	5.34336664	2.7518485	-0.05535723	1.065835993	Fine Silt	Poorly Sorted
P10	34.4454	65.239	0.315	1.425	5.79	18.162	6.18247658	2.6761142	-0.09680426	1.031429848	Fine Silt	Poorly Sorted
P10	42.6811	56.986	0.333	1.257	4.63	15.442	5.10123375	2.6402354	-0.03315265	1.048433172	Fine Silt	Poorly Sorted
P10	41.7883	58.011	0.201	1.238	4.759	15.626	5.18759097	2.6639915	-0.0554397	1.027438575	Fine Silt	Poorly Sorted
P10	35.6817	64.104	0.214	1.365	5.627	17.844	6.00196828	2.6980513	-0.09629233	1.021526796	Fine Silt	Poorly Sorted
P10	35.2792	64.426	0.295	1.262	5.785	19.498	6.09388346	2.8598013	-0.10188919	1.028351222	Fine Silt	Poorly Sorted
P10	35.8676	63.902	0.231	1.278	5.674	18.716	5.98861373	2.806915	-0.10196847	1.01824368	Fine Silt	Poorly Sorted
P10	34.4821	65.303	0.215	1.33	5.918	19.735	6.2824343	2.8219366	-0.09961143	1.015132488	Fine Silt	Poorly Sorted
P10	38.5458	61.229	0.225	1.208	5.26	17.937	5.61556	2.8206631	-0.08142913	1.019214333	Fine Silt	Poorly Sorted
P10	33.622	66.244	0.134	1.548	5.863	17.321	6.26718868	2.5537905	-0.10198533	1.008638457	Fine Silt	Poorly Sorted
P10	26.5765	73.344	0.08	1.877	7.379	21.678	7.81734732	2.5933861	-0.12327676	0.990227186	Medium Silt	Poorly Sorted
P10	39.4246	60.167	0.409	1.165	5.19	19.665	5.63470539	2.9583669	-0.04961603	1.01149674	Fine Silt	Poorly Sorted
P10	40.3043	59.426	0.27	1.188	5.022	18.289	5.47564074	2.86105	-0.04777865	1.015406504	Fine Silt	Poorly Sorted
P10	38.7561	60.991	0.253	1.167	5.303	18.929	5.65199279	2.9145723	-0.07757556	0.997324668	Fine Silt	Poorly Sorted
P10	41.8145	57.819	0.366	1.125	4.852	18.148	5.28148918	2.9135873	-0.04254016	1.004642423	Fine Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P10	31.5697	68.051	0.379	1.437	6.387	20.979	6.75924331	2.8082513	-0.1058016	1.045013144	Fine Silt	Poorly Sorted
P10	31.439	68.339	0.221	1.664	6.147	17.712	6.56985933	2.5114265	-0.10508611	1.027748421	Fine Silt	Poorly Sorted
P10	28.6441	71.32	0.035	1.794	6.783	19.565	7.21824369	2.5344266	-0.11718406	0.998806805	Fine Silt	Poorly Sorted
P10	27.6796	72.266	0.055	1.833	7.243	21.482	7.66906516	2.6065209	-0.11997487	0.965895764	Fine Silt	Poorly Sorted
P10	37.0199	62.658	0.322	1.269	5.53	19.854	5.98207274	2.8798024	-0.06438363	1.006905873	Fine Silt	Poorly Sorted
P10	32.0035	67.738	0.259	1.372	6.429	20.958	6.6987998	2.849155	-0.12470578	1.020413777	Fine Silt	Poorly Sorted
P10	30.5364	69.04	0.423	1.406	6.89	22.274	7.10188487	2.8951766	-0.14216771	1.006600194	Fine Silt	Poorly Sorted
P10	35.1636	64.475	0.361	1.282	5.771	20.842	6.20345888	2.9115259	-0.07154835	1.050564262	Fine Silt	Poorly Sorted
P10	35.2925	64.312	0.395	1.302	5.819	21.201	6.27733372	2.922138	-0.06750358	1.021113365	Fine Silt	Poorly Sorted
P10	26.9102	73.015	0.075	1.877	7.426	21.76	7.83302055	2.5972875	-0.12686839	0.965574004	Medium Silt	Poorly Sorted
P10	29.2567	70.658	0.085	1.761	6.738	19.595	7.15578038	2.5537948	-0.11745194	0.983980235	Fine Silt	Poorly Sorted
P10	36.5127	62.447	1.04	1.273	5.645	20.58	6.09478427	2.9235297	-0.06237729	1.009857752	Fine Silt	Poorly Sorted
P11	29.409	70.336	0.255	1.589	7.071	22.298	7.4128809	2.7822373	-0.12959147	0.980377357	Fine Silt	Poorly Sorted
P11	30.3084	69.559	0.133	1.543	6.907	21.898	7.24072617	2.7904962	-0.12904055	0.96940741	Fine Silt	Poorly Sorted
P11	28.5982	71.226	0.176	1.605	7.31	22.799	7.61261374	2.7947726	-0.14134071	0.97954347	Fine Silt	Poorly Sorted
P11	27.1151	72.842	0.043	1.681	7.917	23.884	8.09665896	2.7995553	-0.16816662	0.955791897	Medium Silt	Poorly Sorted
P11	30.1243	69.827	0.048	1.529	6.981	22.105	7.29031734	2.8065176	-0.13596986	0.965677631	Fine Silt	Poorly Sorted
P11	31.6154	68.337	0.047	1.448	6.671	21.413	6.96887607	2.8281991	-0.13098102	0.963317369	Fine Silt	Poorly Sorted
P11	32.9702	66.909	0.121	1.402	6.278	19.969	6.58378609	2.7843071	-0.12414179	0.982876613	Fine Silt	Poorly Sorted
P11	30.814	69.117	0.069	1.5	6.784	21.561	7.10327074	2.8004234	-0.1301237	0.97322928	Fine Silt	Poorly Sorted
P11	37.414	62.328	0.258	1.285	5.334	16.71	5.65833916	2.6841075	-0.10151742	1.029780614	Fine Silt	Poorly Sorted
P11	36.1185	63.815	0.066	1.286	5.76	19.232	6.10879165	2.8329985	-0.10394023	0.964077234	Fine Silt	Poorly Sorted
P11	31.1696	68.713	0.117	1.469	6.761	21.507	7.04335307	2.8200032	-0.13469235	0.968613097	Fine Silt	Poorly Sorted
P11	32.7823	67.081	0.136	1.386	6.448	21.278	6.76239274	2.8650049	-0.12106639	0.96467827	Fine Silt	Poorly Sorted
P11	54.1651	45.744	0.091	0.965	3.518	13.952	4.01256566	2.7866651	0.03397517	1.011610603	Fine Silt	Poorly Sorted
P11	30.9017	68.847	0.251	1.481	6.641	20.2	6.88941574	2.7438308	-0.14345352	1.001621588	Fine Silt	Poorly Sorted
P11	28.9355	70.859	0.205	1.564	7.07	20.962	7.28062545	2.7285927	-0.15810089	1.009209449	Fine Silt	Poorly Sorted
P11	31.4984	68.347	0.154	1.43	6.644	20.935	6.8929616	2.8157886	-0.13938859	0.9825367	Fine Silt	Poorly Sorted
P11	41.9447	57.869	0.186	1.162	4.795	17.298	5.25465106	2.8228745	-0.04334937	1.007937993	Fine Silt	Poorly Sorted
P11	36.3315	63.438	0.231	1.286	5.607	18.518	5.94790097	2.7904929	-0.0972079	1.005742566	Fine Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P11	33.9192	65.767	0.314	1.316	6.213	21.059	6.5139432	2.9051334	-0.11320176	0.97294634	Fine Silt	Poorly Sorted
P11	39.3795	60.508	0.113	1.198	5.246	19.159	5.70546762	2.9047962	-0.06050986	0.96205074	Fine Silt	Poorly Sorted
P11	31.3255	68.489	0.186	1.466	6.636	20.98	6.93890391	2.7945722	-0.13106446	0.983451641	Fine Silt	Poorly Sorted
P11	30.2006	69.655	0.144	1.493	6.915	21.426	7.15466483	2.7970478	-0.1469662	0.98628772	Fine Silt	Poorly Sorted
P11	32.4467	67.416	0.137	1.362	6.54	20.689	6.72509563	2.8508667	-0.14641774	0.968330355	Fine Silt	Poorly Sorted
P11	34.2112	65.589	0.199	1.402	5.936	18.14	6.238534	2.6892782	-0.1217925	0.997374804	Fine Silt	Poorly Sorted
P11	40.3131	59.551	0.136	1.182	5.01	16.82	5.35969074	2.7778719	-0.07939394	1.003499284	Fine Silt	Poorly Sorted
P11	33.4483	66.42	0.132	1.379	6.195	19.644	6.48708442	2.7836616	-0.12606082	0.980281483	Fine Silt	Poorly Sorted
P11	33.7821	66.064	0.154	1.365	6.093	19.048	6.37214692	2.7600422	-0.12926135	0.986236339	Fine Silt	Poorly Sorted
P11	31.2506	68.591	0.158	1.447	6.725	21.61	7.01557211	2.8359068	-0.13319963	0.972977879	Fine Silt	Poorly Sorted
P11	31.4398	68.533	0.028	1.461	6.638	21.096	6.94710507	2.8020566	-0.13059144	0.974073254	Fine Silt	Poorly Sorted
P11	32.6	67.385	0.015	1.419	6.311	19.269	6.57042654	2.7338631	-0.14010789	0.983611433	Fine Silt	Poorly Sorted
P11	34.8967	65.066	0.037	1.299	5.977	19.217	6.23069523	2.8190942	-0.12690877	0.968996244	Fine Silt	Poorly Sorted
P11	31.3208	68.492	0.188	1.458	6.61	20.718	6.90246208	2.785875	-0.1347906	0.990333712	Fine Silt	Poorly Sorted
P11	44.4394	55.561	0	1.092	4.502	15.625	4.87901714	2.7786225	-0.05905791	0.978710109	Fine Silt	Poorly Sorted
P11	34.5988	65.361	0.04	1.322	5.978	18.825	6.23971052	2.7796455	-0.1300037	0.977972904	Fine Silt	Poorly Sorted
P11	38.8635	61.12	0.017	1.204	5.328	18.007	5.67147211	2.8312724	-0.09430344	0.949264769	Fine Silt	Poorly Sorted
P11	37.8404	61.99	0.169	1.225	5.487	18.421	5.81493833	2.8387272	-0.09999878	0.957884334	Fine Silt	Poorly Sorted
P11	34.2715	65.638	0.091	1.324	6.119	20.4	6.44035728	2.8649736	-0.11399855	0.969058448	Fine Silt	Poorly Sorted
P11	35.8314	64.045	0.123	1.308	5.71	18.65	6.06478147	2.7809407	-0.10341878	0.989219085	Fine Silt	Poorly Sorted
P11	31.31	68.445	0.245	1.417	6.742	21.38	6.96042637	2.8463007	-0.14356148	0.979831614	Fine Silt	Poorly Sorted
P11	35.4833	64.262	0.255	1.275	5.869	19.559	6.18065914	2.8592425	-0.11119376	0.977131286	Fine Silt	Poorly Sorted
P11	34.8328	65.012	0.155	1.313	5.871	18.57	6.15092799	2.7694075	-0.12322492	0.998057878	Fine Silt	Poorly Sorted
P11	33.5608	66.113	0.326	1.335	6.253	20.845	6.55653705	2.881062	-0.11710208	0.980610236	Fine Silt	Poorly Sorted
P11	32.7602	66.782	0.458	1.324	6.722	24.016	7.01787672	3.0534466	-0.11530034	0.944507701	Fine Silt	Poorly Sorted
P11	28.4995	70.995	0.505	1.543	7.473	23.637	7.68603561	2.8717929	-0.15093475	0.988871655	Fine Silt	Poorly Sorted
P11	26.5221	73.276	0.202	1.664	7.989	24.135	8.16600264	2.8192338	-0.17207429	0.987507782	Medium Silt	Poorly Sorted
P11	30.7889	68.781	0.43	1.442	6.827	22.103	7.0900336	2.8671625	-0.13275801	0.996042272	Fine Silt	Poorly Sorted
P11	29.7489	69.89	0.361	1.462	7.145	23.036	7.36529864	2.8951785	-0.144543	0.990262413	Fine Silt	Poorly Sorted
P11	30.9775	68.462	0.56	1.433	6.725	22.066	7.02893717	2.8701325	-0.12347928	1.006545783	Fine Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P11	32.3586	67.291	0.35	1.373	6.53	22.102	6.85762115	2.9148028	-0.1158435	0.981549138	Fine Silt	Poorly Sorted
P11	33.6711	66.046	0.283	1.345	6.15	21.135	6.55615355	2.8847848	-0.0974555	0.998083629	Fine Silt	Poorly Sorted
P11	39.2374	60.555	0.207	1.159	5.265	18.39	5.6063294	2.8918113	-0.08696607	0.966312157	Fine Silt	Poorly Sorted
P11	28.6279	71.017	0.355	1.546	7.326	22.362	7.52641443	2.8095843	-0.16067903	0.995720362	Fine Silt	Poorly Sorted
P11	32.104	67.667	0.229	1.407	6.419	19.75	6.66416906	2.7661589	-0.14327259	0.994927301	Fine Silt	Poorly Sorted
P11	31.0492	68.75	0.201	1.45	6.785	21.628	7.04863984	2.8351979	-0.13755203	0.974638791	Fine Silt	Poorly Sorted
P11	29.383	70.401	0.216	1.525	7.14	22.113	7.37378263	2.8080586	-0.15082948	0.986200149	Fine Silt	Poorly Sorted
P11	33.5663	66.054	0.38	1.347	6.214	20.741	6.53711481	2.8661712	-0.11135606	0.989054964	Fine Silt	Poorly Sorted
P11	35.7146	63.936	0.35	1.255	5.753	18.862	6.0236991	2.8337608	-0.11380403	1.004454986	Fine Silt	Poorly Sorted
P11	30.1793	69.551	0.269	1.463	7.022	22.47	7.25903941	2.8679283	-0.14329235	0.983152885	Fine Silt	Poorly Sorted
P11	29.4939	70.201	0.305	1.497	7.122	22.229	7.33802248	2.830361	-0.15122122	0.990534129	Fine Silt	Poorly Sorted
P11	28.0667	71.622	0.312	1.573	7.489	23.233	7.71514556	2.8316632	-0.15480092	0.993391374	Fine Silt	Poorly Sorted
P11	30.6955	69.059	0.246	1.455	6.787	21.571	7.05852804	2.8273601	-0.13714026	0.99472858	Fine Silt	Poorly Sorted
P11	30.0767	69.588	0.335	1.495	6.909	21.537	7.16300997	2.8002714	-0.14281728	0.995817384	Fine Silt	Poorly Sorted
P11	34.5696	65.152	0.279	1.336	5.893	19.092	6.23447428	2.7841089	-0.10880752	1.011124861	Fine Silt	Poorly Sorted
P11	34.3511	65.325	0.324	1.254	6.128	21.165	6.399742	2.958134	-0.11357125	0.989930344	Fine Silt	Poorly Sorted
P11	36.1604	63.492	0.347	1.182	5.769	20.468	6.0430733	2.9788199	-0.10185294	0.994429896	Fine Silt	Poorly Sorted
P11	33.7584	65.937	0.304	1.3	6.171	20.496	6.43585454	2.8844473	-0.1211046	0.996648114	Fine Silt	Poorly Sorted
P11	34.4468	65.214	0.339	1.257	6.102	21.599	6.43025555	2.9768428	-0.10223944	0.990569471	Fine Silt	Poorly Sorted
P11	29.2728	70.424	0.303	1.432	7.321	23.528	7.46280384	2.9321741	-0.15763934	0.992623022	Fine Silt	Poorly Sorted
P11	37.6047	61.897	0.499	1.196	5.526	20.636	5.93870119	2.9847333	-0.067135	0.990543847	Fine Silt	Poorly Sorted
P11	36.9476	62.524	0.529	1.222	5.692	21.071	6.10914066	2.989447	-0.07370099	0.967372722	Fine Silt	Poorly Sorted
P11	31.8382	67.838	0.324	1.32	6.728	22.58	6.90680221	2.9726748	-0.13807341	0.983404189	Fine Silt	Poorly Sorted
P11	32.4127	67.396	0.192	1.337	6.501	21.944	6.77951671	2.9270357	-0.12262368	0.987364218	Fine Silt	Poorly Sorted
P11	43.4694	56.212	0.319	1.06	4.642	18.209	5.07723865	2.9760202	-0.03094853	1.007436162	Fine Silt	Poorly Sorted
P11	34.1887	65.424	0.388	1.254	6.163	22.01	6.48223224	3.0006259	-0.10230947	0.994540475	Fine Silt	Poorly Sorted
P11	34.2619	65.336	0.402	1.215	6.225	22.878	6.51959084	3.0751566	-0.10375825	0.987207275	Fine Silt	Poorly Sorted
P11	35.5763	64.066	0.358	1.192	5.889	21.838	6.24253756	3.0398755	-0.08882705	0.995803318	Fine Silt	Poorly Sorted
P11	34.674	64.622	0.704	1.134	6.387	25.304	6.65464944	3.2800724	-0.10323983	0.948774429	Fine Silt	Poorly Sorted
P11	36.7438	62.805	0.452	1.19	5.666	21.503	6.07916082	3.0298631	-0.07030445	0.998434528	Fine Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
P11	34.9805	64.167	0.853	1.21	5.994	22.029	6.31898439	3.0386432	-0.09151152	1.007256217	Fine Silt	Poorly Sorted
P11	36.7728	62.793	0.435	1.11	5.783	22.722	6.11278937	3.167982	-0.08423147	0.977949801	Fine Silt	Poorly Sorted
P11	39.7777	59.823	0.399	1.14	5.171	20.689	5.67146901	3.0356552	-0.03692131	0.999463151	Fine Silt	Poorly Sorted
P11	35.0952	64.585	0.319	1.295	5.811	19.168	6.13045457	2.8199217	-0.10505027	1.021058677	Fine Silt	Poorly Sorted
P11	37.88	60.789	1.331	1.177	5.43	19.924	5.79568936	2.9693867	-0.06850945	1.022008921	Fine Silt	Poorly Sorted
OD2	30.8918	69.057	0.051	1.5	6.784	20.622	7.01588744	2.7573652	-0.14880968	0.970331725	Fine Silt	Poorly Sorted
OD2	29.6972	70.227	0.076	1.546	7.154	21.748	7.35667615	2.7811193	-0.15717148	0.959882744	Fine Silt	Poorly Sorted
OD2	30.9592	68.983	0.057	1.471	6.88	21.375	7.09614594	2.8135288	-0.14974165	0.958915938	Fine Silt	Poorly Sorted
OD2	30.4433	69.494	0.063	1.486	7.066	22.727	7.33142862	2.8693352	-0.1412031	0.953326929	Fine Silt	Poorly Sorted
OD2	31.0428	68.898	0.059	1.451	6.901	22.434	7.17734383	2.8766253	-0.13598578	0.956016164	Fine Silt	Poorly Sorted
OD2	31.6713	68.221	0.108	1.412	6.758	22.038	7.02178157	2.8839145	-0.13571857	0.958626492	Fine Silt	Poorly Sorted
OD2	30.8718	68.978	0.15	1.444	6.933	22.262	7.16929786	2.8721944	-0.14330026	0.96331151	Fine Silt	Poorly Sorted
OD2	30.0386	69.832	0.13	1.482	7.216	23.946	7.51112782	2.9276902	-0.13500339	0.953527458	Fine Silt	Poorly Sorted
OD2	27.6315	72.348	0.02	1.6	7.801	22.861	7.86405441	2.7999164	-0.18980295	0.966382494	Medium Silt	Poorly Sorted
OD2	30.8701	68.915	0.215	1.463	6.773	20.987	7.00673802	2.7962337	-0.14585095	0.983062621	Fine Silt	Poorly Sorted
OD2	31.2092	68.727	0.064	1.453	6.68	20.423	6.89912963	2.774241	-0.14966761	0.982969883	Fine Silt	Poorly Sorted
OD2	26.5398	73.449	0.012	1.703	7.68	20.775	7.74033456	2.6391384	-0.20272319	1.003729334	Fine Silt	Poorly Sorted
OD2	30.6449	69.307	0.048	1.475	6.774	20.473	6.98343235	2.7602215	-0.1545322	0.987654642	Fine Silt	Poorly Sorted
OD2	33.1556	66.744	0.101	1.35	6.23	19.147	6.43592648	2.7743365	-0.14599921	0.992979442	Fine Silt	Poorly Sorted
OD2	31.3029	68.578	0.119	1.427	6.636	20.397	6.85234731	2.7875002	-0.14971623	0.99216025	Fine Silt	Poorly Sorted
OD2	30.9913	68.824	0.184	1.467	6.589	19.766	6.81384169	2.7275643	-0.1499716	1.007089315	Fine Silt	Poorly Sorted
OD2	28.6587	71.341	0	1.542	7.378	22.506	7.56928462	2.8139821	-0.16524957	0.977518201	Fine Silt	Poorly Sorted
OD2	32.8886	67.014	0.098	1.402	6.19	18.776	6.44226522	2.7185683	-0.13807826	1.003131829	Fine Silt	Poorly Sorted
OD2	29.4429	70.468	0.089	1.522	6.932	20.347	7.12781725	2.7203119	-0.16416767	1.010514357	Fine Silt	Poorly Sorted
OD2	32.2103	67.631	0.159	1.43	6.257	18.819	6.51540768	2.7016826	-0.13874031	1.020619949	Fine Silt	Poorly Sorted
OD2	30.7295	69.031	0.239	1.497	6.533	19.464	6.79651159	2.6911018	-0.14338942	1.02404341	Fine Silt	Poorly Sorted
OD2	31.2493	68.571	0.18	1.453	6.47	19.387	6.70551253	2.7141819	-0.14653374	1.02017294	Fine Silt	Poorly Sorted
OD2	31.1938	68.632	0.174	1.472	6.48	19.565	6.74616735	2.7122482	-0.1402637	1.016850253	Fine Silt	Poorly Sorted
OD2	31.0477	68.807	0.146	1.451	6.531	19.904	6.77897687	2.7426822	-0.14233745	1.023167248	Fine Silt	Poorly Sorted
OD2	32.2707	67.521	0.208	1.358	6.317	19.305	6.50870696	2.7729269	-0.14814554	1.02498793	Fine Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
OD2	31.6534	68.1	0.247	1.392	6.462	20.043	6.68354964	2.7891076	-0.14246012	1.021918516	Fine Silt	Poorly Sorted
OD2	29.5795	70.261	0.16	1.512	6.855	20.45	7.0831916	2.7306525	-0.15430817	1.022203162	Fine Silt	Poorly Sorted
OD2	28.3104	71.575	0.115	1.582	7.107	20.606	7.31355192	2.6973608	-0.1659505	1.028105744	Fine Silt	Poorly Sorted
OD2	27.6403	72.313	0.047	1.625	7.254	20.397	7.42407029	2.6595501	-0.17871392	1.022730131	Fine Silt	Poorly Sorted
OD2	29.2425	70.447	0.31	1.547	6.828	19.987	7.06562454	2.685079	-0.15466359	1.034973381	Fine Silt	Poorly Sorted
OD2	31.7622	68.028	0.209	1.432	6.335	19.465	6.61380378	2.7336328	-0.13214144	1.033843342	Fine Silt	Poorly Sorted
OD2	31.5882	68.165	0.247	1.423	6.418	19.792	6.67315332	2.755974	-0.13655596	1.026763201	Fine Silt	Poorly Sorted
OD2	29.4411	70.31	0.249	1.535	6.8	20.239	7.05893344	2.7063682	-0.14766951	1.036291027	Fine Silt	Poorly Sorted
OD2	31.0742	68.779	0.147	1.474	6.449	19.196	6.70771978	2.6906128	-0.14420995	1.028454294	Fine Silt	Poorly Sorted
OD2	29.6353	70.221	0.144	1.539	6.682	19.285	6.92504175	2.6532516	-0.15588986	1.039888848	Fine Silt	Poorly Sorted
OD2	27.618	72.18	0.202	1.665	7.089	20.199	7.35724591	2.6300311	-0.15742557	1.045794722	Fine Silt	Poorly Sorted
OD2	27.6851	72.099	0.216	1.639	7.147	20.43	7.38486206	2.654832	-0.16325092	1.038570978	Fine Silt	Poorly Sorted
OD2	28.7438	71.153	0.103	1.576	6.965	20.282	7.20534481	2.6848693	-0.15901332	1.028495233	Fine Silt	Poorly Sorted
OD2	31.6578	68.25	0.092	1.427	6.368	19.164	6.60915194	2.7166347	-0.14464805	1.023388448	Fine Silt	Poorly Sorted
OD2	31.8412	68.018	0.14	1.424	6.335	19.277	6.59138572	2.7267675	-0.1385347	1.025366285	Fine Silt	Poorly Sorted
OD2	33.954	65.798	0.248	1.321	5.99	18.856	6.24832816	2.7764718	-0.12801613	1.019259264	Fine Silt	Poorly Sorted
OD2	31.599	68.291	0.11	1.422	6.389	19.178	6.62063506	2.7215741	-0.14786715	1.024806675	Fine Silt	Poorly Sorted
OD2	30.8279	69.034	0.139	1.451	6.5	19.008	6.70703652	2.6926939	-0.15802531	1.034689425	Fine Silt	Poorly Sorted
OD2	29.9985	69.931	0.071	1.516	6.603	19.033	6.84263746	2.6525464	-0.15676434	1.039224076	Fine Silt	Poorly Sorted
OD2	29.0452	70.85	0.105	1.559	6.839	19.516	7.05249391	2.6512793	-0.16546095	1.033541013	Fine Silt	Poorly Sorted
OD2	30.1345	69.839	0.027	1.511	6.565	18.24	6.74637622	2.6125237	-0.17271471	1.032824235	Fine Silt	Poorly Sorted
OD2	32.9612	66.891	0.148	1.357	6.115	18.326	6.32339232	2.7191126	-0.14654936	1.028893459	Fine Silt	Poorly Sorted
OD2	32.7559	67.119	0.125	1.387	6.118	18.185	6.34937297	2.6906269	-0.14448013	1.030186135	Fine Silt	Poorly Sorted
OD2	32.1701	67.83	0	1.374	6.403	19.716	6.60702364	2.7826173	-0.14823987	1.001699463	Fine Silt	Poorly Sorted
OD2	30.0255	69.838	0.136	1.48	6.714	19.369	6.87797803	2.6919443	-0.16921541	1.025591743	Fine Silt	Poorly Sorted
OD2	28.7463	71.148	0.105	1.558	6.995	19.379	7.11541946	2.6452049	-0.18682314	1.019651832	Fine Silt	Poorly Sorted
OD2	29.8174	69.952	0.23	1.472	6.722	19.751	6.90800181	2.7172292	-0.16084633	1.046479581	Fine Silt	Poorly Sorted
OD2	28.3323	71.535	0.133	1.596	6.897	18.922	7.08224305	2.5990489	-0.17813778	1.048157089	Fine Silt	Poorly Sorted
OD2	28.4398	71.39	0.17	1.571	6.983	19.463	7.14063163	2.6400115	-0.18025684	1.035490095	Fine Silt	Poorly Sorted
OD2	31.3905	68.452	0.158	1.418	6.448	18.973	6.62753793	2.712501	-0.1596928	1.020994886	Fine Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
OD2	32.3139	67.47	0.216	1.403	6.233	18.834	6.47703265	2.7167612	-0.14019026	1.025988645	Fine Silt	Poorly Sorted
OD2	31.8742	67.875	0.251	1.37	6.419	19.534	6.59490332	2.7759755	-0.15265133	1.019735223	Fine Silt	Poorly Sorted
OD2	30.0357	69.822	0.143	1.43	6.823	20.134	6.94584614	2.7643318	-0.17251415	1.023982243	Fine Silt	Poorly Sorted
OD2	29.1533	70.658	0.189	1.512	6.945	19.975	7.09990963	2.7024292	-0.17471205	1.022748426	Fine Silt	Poorly Sorted
OD2	28.7692	71.163	0.068	1.554	6.966	19.54	7.11417586	2.6549194	-0.18033411	1.025762158	Fine Silt	Poorly Sorted
OD2	26.6382	73.068	0.294	1.627	7.682	21.969	7.78681383	2.7322298	-0.18837278	1.022222461	Fine Silt	Poorly Sorted
OD2	27.8905	72.11	0	1.587	7.26	19.774	7.33260158	2.6493542	-0.20164172	1.014035789	Fine Silt	Poorly Sorted
OD2	31.3068	68.235	0.458	1.383	6.707	21.777	6.9339779	2.8874864	-0.13671203	1.000851982	Fine Silt	Poorly Sorted
OD2	32.9552	66.851	0.194	1.329	6.225	19.11	6.39981705	2.7839849	-0.14882589	1.012317446	Fine Silt	Poorly Sorted
OD2	31.8089	67.951	0.24	1.386	6.421	19.741	6.63183872	2.7756446	-0.14525219	1.018956117	Fine Silt	Poorly Sorted
OD2	30.2641	69.576	0.16	1.468	6.712	19.467	6.8734784	2.7059629	-0.16977359	1.01665014	Fine Silt	Poorly Sorted
OD2	29.3153	70.608	0.076	1.437	7.161	21.069	7.2115845	2.807362	-0.18837319	1.001201828	Fine Silt	Poorly Sorted
OD2	29.8163	70.066	0.118	1.477	6.83	20.001	6.99800062	2.7277874	-0.16874521	1.01843622	Fine Silt	Poorly Sorted
OD2	27.4151	72.562	0.023	1.622	7.308	20.265	7.44102781	2.6538887	-0.1881823	1.026839828	Fine Silt	Poorly Sorted
OD2	28.7225	71.137	0.141	1.525	7.112	20.264	7.2291254	2.7114773	-0.18467059	1.015213103	Fine Silt	Poorly Sorted
OD2	31.4992	68.29	0.211	1.408	6.477	19.238	6.65384169	2.7338698	-0.15974589	1.011976051	Fine Silt	Poorly Sorted
OD2	32.7367	67.137	0.127	1.334	6.318	19.976	6.52689527	2.8259791	-0.14075201	1.002878338	Fine Silt	Poorly Sorted
OD2	30.3569	69.56	0.083	1.415	6.895	21.038	7.03742168	2.8234157	-0.16566851	0.998358851	Fine Silt	Poorly Sorted
OD2	29.8051	69.989	0.206	1.439	7	20.434	7.07033097	2.775246	-0.18483612	0.998305818	Fine Silt	Poorly Sorted
OD2	27.9556	71.964	0.081	1.565	7.356	21.259	7.48569891	2.7384548	-0.18165884	1.012391214	Fine Silt	Poorly Sorted
OD2	27.3566	72.612	0.031	1.589	7.477	21.055	7.56079462	2.7123073	-0.19360862	1.018129993	Fine Silt	Poorly Sorted
OD2	28.9311	71.004	0.065	1.512	7.052	19.63	7.12537474	2.6844323	-0.19544555	1.012611645	Fine Silt	Poorly Sorted
OD2	29.1768	70.823	0	1.52	6.993	19.424	7.0842613	2.671207	-0.19332585	1.006474579	Fine Silt	Poorly Sorted
OD2	27.2454	72.755	0	1.639	7.373	19.85	7.45145583	2.6238313	-0.20273283	1.017244887	Fine Silt	Poorly Sorted
OD2	30.0379	69.949	0.013	1.449	6.808	19.209	6.8795257	2.7028718	-0.19011245	1.011274216	Fine Silt	Poorly Sorted
OD2	33.0907	66.855	0.054	1.353	6.176	18.603	6.36991587	2.7401094	-0.15002902	1.006097245	Fine Silt	Poorly Sorted
OD2	28.3935	71.372	0.235	1.556	7.315	21.389	7.45121253	2.7529822	-0.1768137	0.999556471	Fine Silt	Poorly Sorted
OD2	26.2331	73.767	0	1.684	7.913	22.016	7.96697228	2.7062227	-0.20241545	0.996371248	Medium Silt	Poorly Sorted
OD3	26.6586	73.299	0.043	1.655	8.243	23.866	8.21488423	2.8135398	-0.20207358	0.956347115	Medium Silt	Poorly Sorted
OD3	25.2795	74.665	0.056	1.725	8.865	25.454	8.74760563	2.8406626	-0.21645978	0.952974781	Medium Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
OD3	27.234	72.73	0.036	1.643	7.91	23.219	7.98762392	2.7917592	-0.1860599	0.963573083	Medium Silt	Poorly Sorted
OD3	27.808	72.115	0.077	1.568	7.931	24.716	8.04480011	2.9027663	-0.17396673	0.952737415	Medium Silt	Poorly Sorted
OD3	27.4555	72.177	0.368	1.617	7.737	22.175	7.77991993	2.7563402	-0.19323353	0.979524194	Fine Silt	Poorly Sorted
OD3	28.4082	70.2	1.392	1.564	7.322	22.806	7.55692042	2.8267271	-0.14496375	1.01886383	Fine Silt	Poorly Sorted
OD3	27.8516	70.685	1.463	1.581	7.498	23.582	7.74062423	2.8498353	-0.14507834	1.017361668	Fine Silt	Poorly Sorted
OD3	26.7032	72.735	0.562	1.656	7.786	22.368	7.88284666	2.7410613	-0.18598054	1.002668982	Medium Silt	Poorly Sorted
OD3	27.3112	71.067	1.622	1.636	7.44	22.338	7.66930923	2.7605624	-0.15138508	1.039811587	Fine Silt	Poorly Sorted
OD3	25.5187	71.785	2.696	1.714	8.332	28.143	8.67191664	2.9790004	-0.12066997	1.031824134	Medium Silt	Poorly Sorted
OD3	27.1238	68.223	4.653	1.535	8.055	30.303	8.38133176	3.2749484	-0.07462669	1.113138284	Medium Silt	Poorly Sorted
OD3	26.4852	69.218	4.296	1.662	7.779	28.014	8.25134618	3.0786176	-0.061356	1.136193231	Medium Silt	Poorly Sorted
OD3	26.5754	70.606	2.818	1.699	7.68	26.842	8.17861905	2.951023	-0.08142161	1.083418979	Medium Silt	Poorly Sorted
OD3	30.8564	68.286	0.857	1.497	6.441	19.01	6.71476576	2.6716086	-0.14149299	1.042500549	Fine Silt	Poorly Sorted
OD3	29.9195	69.368	0.712	1.566	6.554	19.462	6.89834475	2.65657	-0.13125196	1.056767299	Fine Silt	Poorly Sorted
OD3	27.7064	71.211	1.083	1.657	7.171	22.567	7.58035241	2.7599011	-0.11834953	1.057759782	Fine Silt	Poorly Sorted
OD3	27.5496	71.637	0.813	1.647	7.269	23.437	7.70498099	2.8011849	-0.11593164	1.050728722	Fine Silt	Poorly Sorted
OD3	27.9901	70.965	1.045	1.662	6.971	20.895	7.34166951	2.6777367	-0.12838605	1.069390651	Fine Silt	Poorly Sorted
OD3	29.7148	69.83	0.455	1.607	6.479	18.816	6.84071356	2.5992021	-0.12944124	1.071849337	Fine Silt	Poorly Sorted
OD3	27.3441	71.488	1.168	1.702	7.115	21.133	7.48793514	2.6685611	-0.13200905	1.068520662	Fine Silt	Poorly Sorted
OD3	29.4839	70.239	0.277	1.605	6.559	19.046	6.91186628	2.6099738	-0.1352479	1.063000053	Fine Silt	Poorly Sorted
OD3	28.8416	70.574	0.584	1.645	6.742	19.598	7.09040855	2.6202682	-0.13640831	1.054970277	Fine Silt	Poorly Sorted
OD3	29.6066	69.46	0.933	1.601	6.567	19.555	6.94103747	2.6468526	-0.12268776	1.071189234	Fine Silt	Poorly Sorted
OD3	28.9774	69.094	1.928	1.572	6.907	23.159	7.3690177	2.8486392	-0.0914327	1.079725141	Fine Silt	Poorly Sorted
OD3	28.8646	70.045	1.09	1.643	6.73	20.841	7.17336927	2.6882059	-0.10579849	1.077282347	Fine Silt	Poorly Sorted
OD3	28.7509	68.678	2.571	1.589	6.996	26.791	7.6535265	3.0051384	-0.04158888	1.110299074	Fine Silt	Poorly Sorted
OD3	30.3443	68.674	0.982	1.564	6.471	20.343	6.90372484	2.7075816	-0.10215387	1.070491795	Fine Silt	Poorly Sorted
OD3	31.1501	67.696	1.154	1.528	6.33	20.331	6.77764141	2.7317313	-0.09173666	1.073930526	Fine Silt	Poorly Sorted
OD3	32.121	67.207	0.672	1.515	6.106	19.755	6.59425245	2.7067528	-0.08123865	1.073094663	Fine Silt	Poorly Sorted
OD3	31.4781	67.618	0.904	1.521	6.226	20.185	6.70379387	2.7254601	-0.08471081	1.083309727	Fine Silt	Poorly Sorted
OD3	29.6942	68.912	1.394	1.564	6.627	21.535	7.08469017	2.7702605	-0.093382	1.087642894	Fine Silt	Poorly Sorted
OD3	29.1769	69.714	1.109	1.574	6.824	21.908	7.24780911	2.7783783	-0.10826345	1.062643175	Fine Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
OD3	27.6712	65.073	7.255	1.475	8.188	46.389	9.15843301	3.7891157	0.01221232	1.107861986	Medium Silt	Poorly Sorted
OD3	28.7891	69.886	1.325	1.601	6.908	22.471	7.36467497	2.791944	-0.10230489	1.065991121	Fine Silt	Poorly Sorted
OD3	29.1298	69.468	1.403	1.571	6.731	20.834	7.11000609	2.7289644	-0.1178763	1.085464426	Fine Silt	Poorly Sorted
OD3	29.0751	69.927	0.998	1.626	6.548	18.818	6.90693613	2.5910125	-0.132062	1.092656731	Fine Silt	Poorly Sorted
OD3	29.0922	69.427	1.48	1.61	6.717	21.802	7.20290991	2.7557994	-0.0897954	1.090216368	Fine Silt	Poorly Sorted
OD3	32.2197	66.282	1.499	1.425	6.304	22.792	6.8311719	2.9206081	-0.06485542	1.059804997	Fine Silt	Poorly Sorted
OD3	30.7703	68.717	0.513	1.592	6.238	18.844	6.68987374	2.6113935	-0.10239869	1.082013004	Fine Silt	Poorly Sorted
OD3	27.1498	70.723	2.127	1.76	7.069	22.56	7.5987605	2.7225298	-0.0829916	1.1073922	Fine Silt	Poorly Sorted
OD3	29.7646	68.091	2.144	1.521	6.761	23.777	7.27248357	2.9090388	-0.07513885	1.086807063	Fine Silt	Poorly Sorted
OD3	27.7105	71.327	0.963	1.706	6.933	21.236	7.39691595	2.6723504	-0.10929943	1.086955153	Fine Silt	Poorly Sorted
OD3	27.9341	70.027	2.039	1.659	7.073	23.785	7.6002247	2.8259983	-0.08265408	1.087893311	Fine Silt	Poorly Sorted
OD3	29.5874	68.135	2.277	1.555	6.735	23.137	7.24242492	2.8638709	-0.07483198	1.094827895	Fine Silt	Poorly Sorted
OD3	27.0009	70.998	2.001	1.69	7.345	25.288	7.89773708	2.8751141	-0.07911928	1.096795003	Medium Silt	Poorly Sorted
OD3	25.2951	66.895	7.81	1.611	9.019	50.782	10.0749135	3.7730274	-0.00036384	1.099705288	Medium Silt	Poorly Sorted
OD3	26.7368	68.797	4.466	1.613	7.932	34.52	8.71753557	3.3070891	-0.02735231	1.095684562	Medium Silt	Poorly Sorted
OD3	27.5186	68.676	3.805	1.543	7.761	33.094	8.44415652	3.2880537	-0.0440597	1.084071947	Medium Silt	Poorly Sorted
OD3	25.9708	71.788	2.242	1.804	7.39	23.224	7.89948279	2.7210222	-0.09920214	1.091491085	Medium Silt	Poorly Sorted
OD3	23.2099	75.514	1.276	1.98	8.271	25.132	8.74018821	2.7007855	-0.12633699	1.059845374	Medium Silt	Poorly Sorted
OD3	27.7299	70.465	1.805	1.625	7.335	25.072	7.81755278	2.8949201	-0.09556765	1.055083031	Medium Silt	Poorly Sorted
OD3	27.7343	68.003	4.263	1.527	7.885	34.151	8.5358303	3.3544538	-0.04331015	1.069731042	Medium Silt	Poorly Sorted
OD3	24.2238	75.073	0.703	1.9	7.921	22.731	8.26851294	2.6314437	-0.15023885	1.056469703	Medium Silt	Poorly Sorted
OD3	22.5061	75.81	1.683	1.988	8.853	27.462	9.25659774	2.7915311	-0.13700376	1.043703357	Medium Silt	Poorly Sorted
OD3	26.83	67.838	5.332	1.563	8.178	36.726	8.90300744	3.4653154	-0.02444534	1.099967921	Medium Silt	Poorly Sorted
OD3	26.83	67.838	5.332	1.563	8.178	36.726	8.90300744	3.4653154	-0.02444534	1.099967921	Medium Silt	Poorly Sorted
OD3	26.83	67.838	5.332	1.563	8.178	36.726	8.90300744	3.4653154	-0.02444534	1.099967921	Medium Silt	Poorly Sorted
OD3	26.83	67.838	5.332	1.563	8.178	36.726	8.90300744	3.4653154	-0.02444534	1.099967921	Medium Silt	Poorly Sorted
OD3	26.83	67.838	5.332	1.563	8.178	36.726	8.90300744	3.4653154	-0.02444534	1.099967921	Medium Silt	Poorly Sorted
OD3	26.83	67.838	5.332	1.563	8.178	36.726	8.90300744	3.4653154	-0.02444534	1.099967921	Medium Silt	Poorly Sorted
OD3	26.83	67.838	5.332	1.563	8.178	36.726	8.90300744	3.4653154	-0.02444534	1.099967921	Medium Silt	Poorly Sorted
OD3	26.83	67.838	5.332	1.563	8.178	36.726	8.90300744	3.4653154	-0.02444534	1.099967921	Medium Silt	Poorly Sorted
OD3	24.4088	72.839	2.752	1.78	8.515	28.339	8.87241362	2.946586	-0.12103716	1.057859941	Medium Silt	Poorly Sorted

Segment	Clay (%)	Silt (%)	Sand (%)	d (0.1)	d (0.5)	d (0.9)	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting
OD3	27.2887	68.746	3.965	1.402	8.703	33.395	8.76327274	3.4217944	-0.12812069	1.015375458	Medium Silt	Poorly Sorted
OD3	26.9479	70.695	2.358	1.561	7.992	27.385	8.2553218	3.0385626	-0.12852574	1.035778404	Medium Silt	Poorly Sorted
OD3	26.3658	70.296	3.339	1.551	8.603	29.957	8.68259105	3.1655871	-0.13864082	1.023878198	Medium Silt	Poorly Sorted
OD3	24.9843	72.474	2.542	1.668	8.952	28.982	8.98102024	3.0326555	-0.16583483	1.014592334	Medium Silt	Poorly Sorted
OD3	24.3232	71.93	3.747	1.571	10.955	35.279	10.135962	3.359807	-0.23050177	0.981167502	Medium Silt	Poorly Sorted
OD3	25.8034	69.099	5.098	1.528	9.804	34.949	9.47684488	3.491167	-0.14691667	1.051736941	Medium Silt	Poorly Sorted
OD3	24.1932	71.247	4.56	1.59	10.939	35.665	10.1928665	3.4061046	-0.2130613	1.013183518	Medium Silt	Poorly Sorted
OD3	24.2589	73.556	2.185	1.771	9.22	27.165	9.06437901	2.9039362	-0.20104606	1.003715262	Medium Silt	Poorly Sorted
OD3	30.9391	67.297	1.764	1.32	7.435	26.941	7.58826578	3.2028884	-0.13485221	0.954761493	Fine Silt	Poorly Sorted
OD3	23.0954	74.096	2.809	1.706	10.982	33.475	10.2895265	3.1861737	-0.24167276	0.991921621	Medium Silt	Poorly Sorted
OD3	25.9641	72.869	1.167	1.629	8.873	26.507	8.68036623	2.9545037	-0.2110292	0.967406282	Medium Silt	Poorly Sorted
OD3	27.9533	71.335	0.712	1.545	8.048	24.856	8.03369381	2.9333556	-0.18455236	0.960059674	Medium Silt	Poorly Sorted
OD3	26.0015	73.085	0.913	1.594	9.357	28.425	9.01634825	3.0551312	-0.22480223	0.93572015	Medium Silt	Poorly Sorted