EPSC 460: Independent reading course

Sediments as sources for paleo sea level change during MIS 5 to MIS 3: A review

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INTRODUCTION

Global relative mean sea level (GMSL) since the last glacial maximum (LGM) has been relatively well constrained. With this information, multiple numerical models have been created in the attempt to accurately project future sea levels in response to climate forcing and solid earth changes. This endeavour is of particular recent importance due to IPCC global emission scenarios that could lead to sea level rise up to 0.3 m in certain places across the globe towards the end of the century (Golledge et al. 2019). While further research on climate forcing is imperative to the improvement in current GMSL models, solid earth changes remain elusive and of great importance to the accuracy of models. Enormous complexity arises in models when solid earth changes are involved. When speaking about the earth and its GMSL, it would be much more simple to refer to sea level as eustatic - sea level would be equally distributed across a non-rotating globe. However, as the Earth is an actual rotating body, factors such as ocean and body tides, self-gravitation, obliquity forcing, and glacial isostatic adjustment (GIA) play a role in determining the non-uniform distribution of past and current sea levels. Tracking these processes far into the Pleistocene, as well as limited paleo sea level data, causes for discrepancy in GMSL values given from numerical model runs. This is largely in part due to the episodic nature of glaciations. Controlled by the Milankovitch cycles, the Earth's episodic ~100 ky glaciations have been occurring since the beginning of the Pleistocene ~2.5 Ma. Accompanying these cycles are alternating periods of warm and cool paleo climates separated into marine isotope stages (MIS) (see Figure 1). Throughout this period, glaciations have not occurred at the same frequency nor at the same magnitudes and thus, neither have their sea levels (Levy et al. 2019).

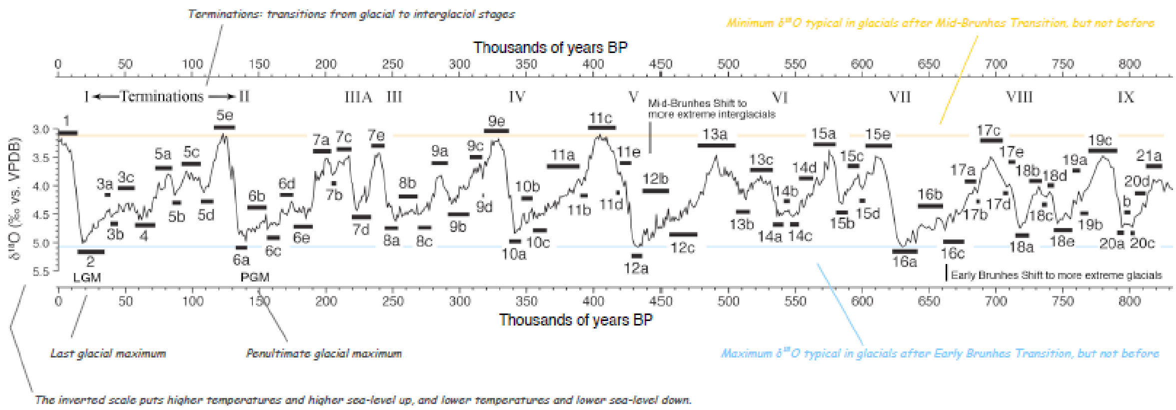

Figure 1: Marine isotope stages outlining the temporally episodic nature of glaciations through the analysis of δ^{18}O ratios since 1Ma. Figure retrieved from: Railsback et al. (2015)

Despite persisting large errors, various studies have attempted to narrow the gap and better constrain GMSL prior to the LGM. As suggested by an influential study by Raymo et al. (2011), sediment loading from deglaciation periods may provide a new piece of the puzzle. There exists the possibility that glacial sediment redistribution can perturb Earth's gravity field with a signal strong enough to attenuate the accuracy of models, as well as provide paleo sea level markers for glaciation events prior to the LGM. Therefore, the focus of this review will be to cover the current sediment redistribution applications in models as well as the use of sediments as paleo sea level markers during the Pleistocene from MIS 5-3 (~125-45 ka).

PALEO SEA LEVEL MARKERS

What constrains sea level in global models is the fine tuning of models to data. Since the LGM, the availability of observable evidence, along with GIA data, give relatively consistent results and are therefore conducive to a well agreed upon GMSL (see Figure 2). One of the primary paleo sea level markers are coral microatolls. These coral species grow laterally in shallow sea waters, as their exposure to air is toxic. By estimating coral group size and applying traditional carbon dating techniques (see ***Sediments as sea level markers: Dating techniques***), the timelines for coral growth can also mark the timelines and magnitudes of sea level rise since the LGM.

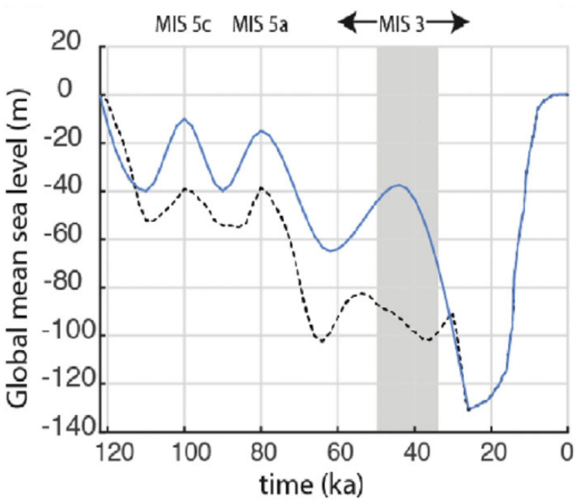

Figure 2: retrieved from Pico et al. (2016), this figure represents two independent model runs of global sea level models ICE-5G and ICE-PC2. While both models are ice coverage history models both fined tuned to GIA data, they have differing ice geometries. This leads to significant departures of GMSL from MIS 5 to MIS 3 from models ICE-5G (blue) and ICE-PC2 (dotted black).

Theoretically, as traditional radiocarbon dating can extend up to 40-50 ka, corals could conceivably be dated prior to the LGM as early as MIS 3. However, most conventional coral records that would have existed during MIS 3 were erased with the drop in sea levels during the last glaciation period leading up to the LGM (Pico et al. 2016). The timeline prior to the LGM is when large uncertainties and disagreements in sea level values occur, primarily during the Pleistocene between MIS 5 and MIS 3. For example, during MIS 3, predicted GMSL relative to present by models ICE-5G and ICE-PC2 are approximately -90m and -40 m respectively (Pico et al. 2016) (see Figure 2).

Therefore, additional paleo sea level records are required to accurately model GMSL prior to the LGM. Fortunately, these paleo sea level markers exist, as deglaciation leaves geological traces in many forms. These features include glacial features such as moraines, tills, and eskers in addition to non-glacial deposits including marine and lacustrine successions (Pico et al. 2016). The latter two are of particular relevance as new dating techniques require sediment core samples from these once glacial lakes and river deltas (Pico et. al 2016). These samples can be useful for analyses because they are relatively well preserved. With formation in very low temperatures, glacial deposits undergo very little chemical weathering and thus, maintain their stratified soil profiles useful for analyses over MIS length timescales (Young 2017; Colgan et al. 2015). However, these soil profiles can only be used as useful tellers of glacial extent as physical breakdown of glacial deposits are very high if located in areas undergoing glaciation or deglaciation (Young 2017). For example, soil profiles containing lacustrine can indicate the presence or lack thereof of ice sheets. Lacustrine sediments with textures high in silt, low in gravel, and a lack of extra sedimentary features can be featuresque of a sediment facies that was affected by rainout and thus, can locate an area without any ice sheet above it during the previous glaciation period (Colgan et al. 2015).

SEDIMENT LOADING MODEL

While the idea of sediment redistribution from deglaciation has been an acknowledged topic of discussion in the GIA community, it has not been well-rehearsed in model incorporation. It was Raymo et al. (2011) who highlighted the need for this process in self-consistent gravitational sea level models. Following suite, Dalca et al. (2013) were the first to propose a generalized theory for sediment redistribution incorporation into existing models. Their theory is reliant on data local to the deposit site where global values of sea level change are averaged relative to the local sea level change. The following review will outline the key components to their proposed theory.

The general understanding of sediments is that they are not as thick as ice sheets. While that may seem obvious, it has implications on how the theory treats sediments. Ice sheets, being thick, have the ability to displace entire ocean water columns that migrate shorelines. In contrast, the theory treats sediments as not thick enough to displace entire water columns and therefore, not as the roots of shoreline migration (Dalca et al. 2013). Thus, the primary focus of the theory did not have the added complexity of accounting for shoreline geometry as did models proposed by Mitrovica & Milne (2003) and Kendall et al. (2005). Thus, the generalized equation for sea level (sea level **SL** defined here as the height of the sea-surface equipotential relative to the solid surface) is as follows.

$$SL = G - (R + I + H) \tag{1}$$

Here, **R** is the height of the solid surface, **G** is the height of the sea-surface equipotential, **I** is the thickness of ice (either land or marine based), and **H** is the sediment thickness (see Figure 3 for conceptual representation). However, water displaced by sediments induce loading effects, hence the need for the model to take into consideration gravitationally self-consistent ocean loading (see Dalca et al. (2013) for details regarding the model).

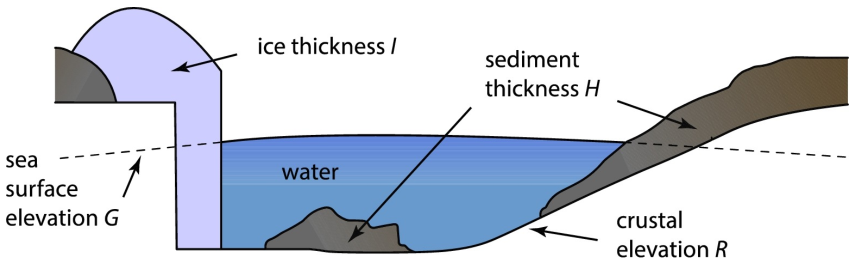

Figure 3: Conceptual sediment distribution model. Retrieved from: Ferrier et al. (2015)

To summarize, this generalized theory accounts for sediment influence in already existing components of the latest gravitationally self-consistent sea level model (see Mitrovica & Milne (2003); Kendall et al. (2005)). This theory presents topography and ocean thickness as the primary components perturbed by sediment redistribution (Dalca et al.2013). However, the theory requires the feeding of post glacial history of sediment loading (erosion and deposition rates). This means that any uncertainty already associated with ice history would be added upon by the uncertainties of post glacial erosion and deposition, both of which are data that are difficult to constrain throughout the Pleistocene (Dalca et al. 2013).

Applications of sediment redistribution theory

Based on the previously mentioned sea level theory, when modelling the GMSL of the Pleistocene in relation to sediment erosion and deposition, areas of high erosion and de-positions rates are preferred. These areas will have the largest available source of erosion and deposition data. Recent applications of the theory have studied river deltas, as outflows from rivers into marine based environments are where erosion and deposition rates are greatest at present but, in the Pleistocene as well. Sampling sediment cores from these areas provides insight into MIS 5-3 sediment redistribution. This section will comprise of two MIS 5-3 relative sea level (RSL) estimates from the Mississippi and Indus deltas using the sediment redistribution theory.

The first case study, by Dalca et al. (2013), modelled a one time pulse of sediment out from the Mississippi delta into the Gulf of Mexico (see Figure 4).

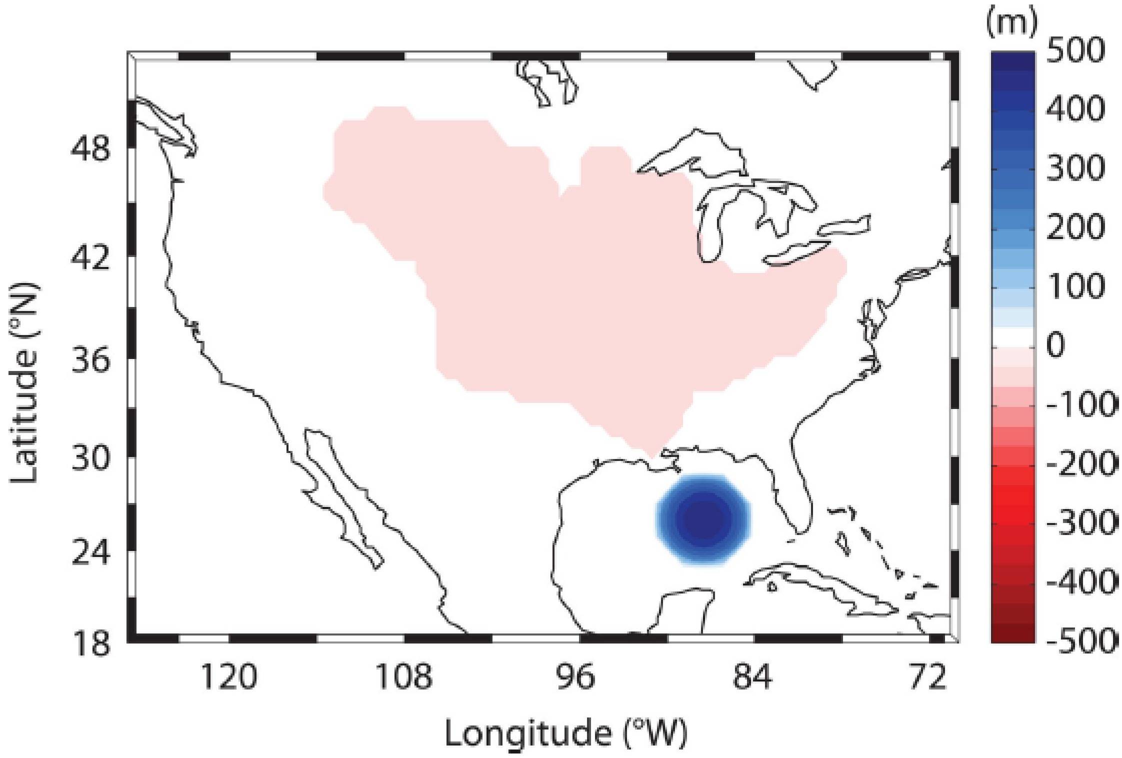

Figure 4: Retrieved from Dalca et al. (2013), this figure illustrates a map of the study site. In addition, it shows the input sediment parameters with the associated sediment erosion amount (in pink), and the deposition amount (in blue). The model treats the sediment deposition as having a uniform thickness and density.

They found that the instantaneous response to a one time pulsation of a uniform sediment deposition, with a fixed thickness and density, is elastic in nature. The instantaneous RSL changes had maximum amplitudes of 20 m (Dalca et al. 2013) with the timing of the pulsation being ~100 ka. They then tracked the the RSL signal over 100 ky. At 100 ky post sediment pulsation, they concluded that the RSL response is similar to ice loading effects on RSL (see

Figure 5).

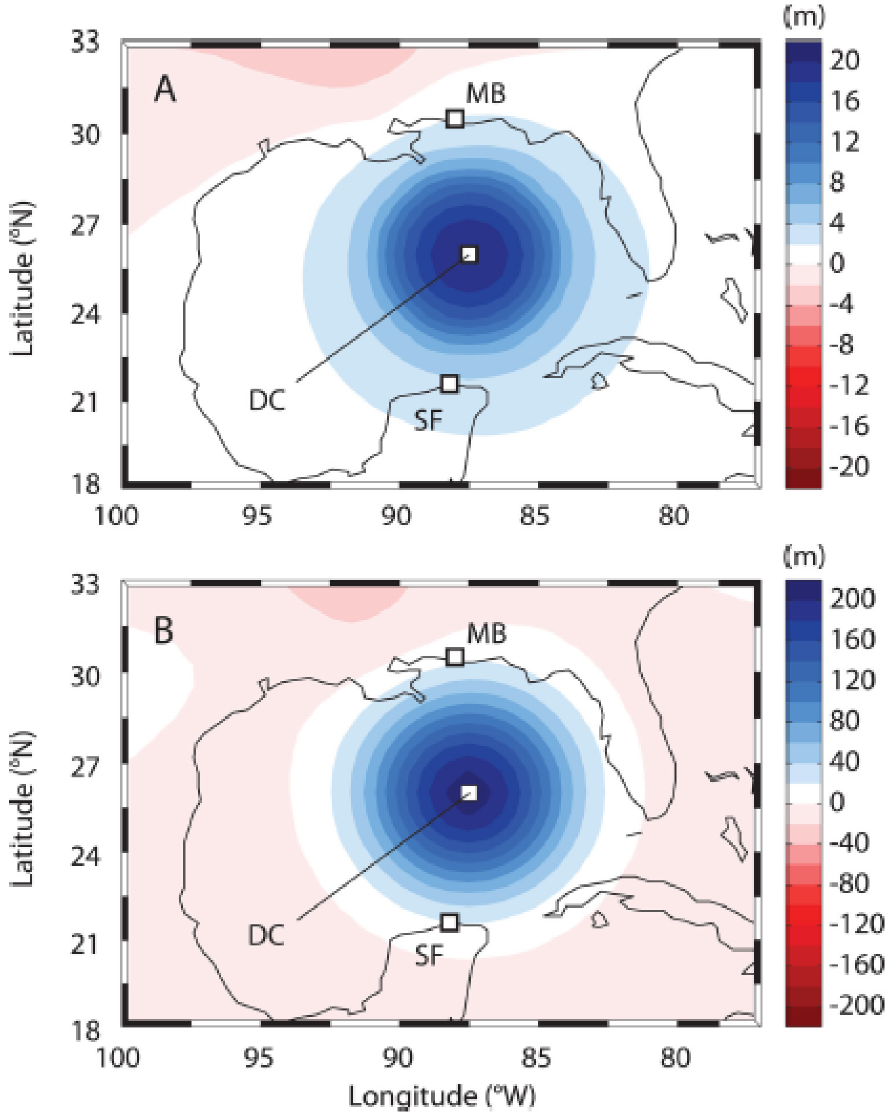

Figure 5: RSL response from sediment pulsation outlined in Figure 4. DC, MB, and SF represent reference locations in the study, unimportant for the purpose of this figure. (A) Instantaneous elastic response to sediment load with maximum amplitudes occurring at the deposit center. (B) 100 ky visco-elastic response to sediment load. Retrieved from: Dalca et al. (2013)

As previously mentioned, sediment erosion and deposition rates during the Pleistocene are not well constrained. The main issue is a well defined chronology of said rates. For example, a case study by Ferrier et al. (2015) conveyed some of the uncertainties in their continental erosion and marine deposition rates. The most important of which was the time frames over which they were taken from. Here, published erosion and deposition rate data were averaged, in some cases, over several years and others over thousands of years (Ferrier et al. 2015). While uncertainties remained large, a general RSL change could still be illustrated with only the published data previously mentioned and published sediment densities (see Figure 6).

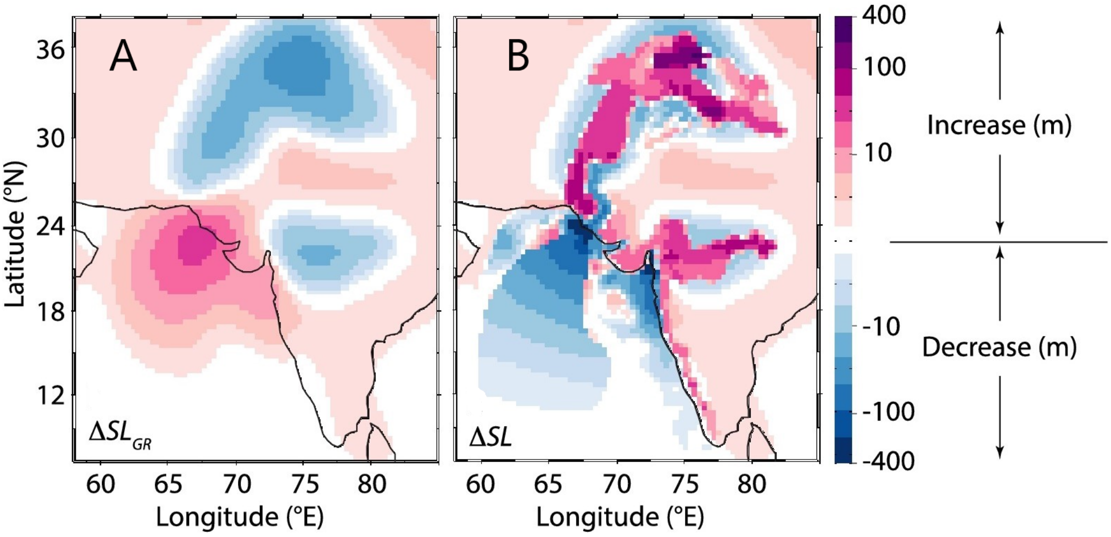

Figure 6: Modified from Ferrier et al. (2015), this figure illustrates RSL changes (marked by ΔSL) at the Indus delta and surrounding delta plains. These changes are occurring from MIS 5 to present with (A) omitted solid surface changes due to sediment redistribution (ΔSL_{GR}), and (B) with solid surface changes accounted for (ΔSL).

The multiplication of the latter parameters is all that was needed to calculate equivalent mass loading, which was then used in self-consistent gravitational sea level models to estimate ocean loading due to sediments (Ferrier et al. 2015).

Sediments also provide means of *a priori* markers of sea level. While it is difficult to obtain full chronological sequences of sea level rise and fall during glacial cycles from sediment cores, sea level can be inferred from paleo shorelines and ice volumes during glaciation or deglaciation periods given qualitative assessments of these cores (Pico et al. 2016; Rovere et al. 2016). GMSL can also be obtained by topographical changes in the paleo record. For example, during MIS 5a (80ka) and at present, the elevations of the Mississippi delta in between latitudes 30-36N were extremely similar, provided an error of +/- 10m (Pico et al. 2016).

Sediments as sea level markers: Dating techniques

From a modelling perspective, sea level 100 ky prior to the LGM is dependent on constrained erosion rates at river deltas. However, more accurately reconstructing GMSL during this period (see Figure 2) might be reliant on varied geological evidence. In the context of the more observation based approach, rather than a modelling one, the chronological sequencing of geological evidence is of critical importance. By extension, so are the dating methods used. This section will outline some dating techniques currently used to constrain the chronological sequences of geological evidence, mainly sediments.

1 RADIOCARBON DATING

One of the more reliant form of dating is Carbon-14/radiocarbon dating. Within the context of sediments, this dating technique is applied to organisms trapped within the layers of sediments, referred to as index fossils (Skinner & Porter 1989). Present in the tissues of these organisms, radiocarbon decays at a constant rate overtime, allowing for the date at which the organism died to be traced back given a residual amount of radiocarbon. The extent of this form of dating can only extend back as far as 40-50 ka, with most sea level related sediment samples dating as far back as ~25 ka (see Figure 7).

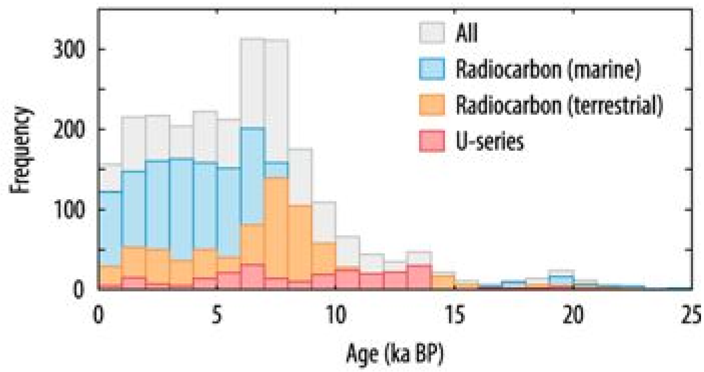

Figure 7: Frequency of coral fossil samples used for GMSL reconstruction by U-series dating, terrestrial and marine radiocarbon dating over 25 ky. Figure retrieved from: Hibbert et al. (2018)

The extremities of radio carbon dating coincide with MIS 3 (Pico et al. 2016; Hibbert et al. 2018). As mentioned in the ***Paleo sea level markers*** section, radiocarbon dating limits work well for constraining GMSL after the LGM but, does not prove as useful for MIS 5 to MIS 3. In addition, the amount of index fossils in sediments are significantly less than those exposed since the LGM. Therefore, different dating techniques in regards to sediments are essential.

2 Optically-Stimulated Luminescence

The second dating technique that will be mentioned is Optically-Stimulated Luminescence (OSL). Sediments undergo transportation and burial by means of wind, ice, and water, and thus are exposed to sunlight before being buried. OSL essentially measures the age at which quartz grains were last exposed to sunlight. The crystal lattice of quartz allows for the parent nucleus's electrons to excite due to iodizing radiation (Aitken 1998). The latter process then gives off a luminescence signal that can be tracked through geologic timescales.

The age of the samples can be calculated using the following formula (Murray & Wintle 2000):

$$Age(ky) = \frac{EquivalentDose(Gy)}{DoseRate(\frac{Gy}{ky})} \tag{2}$$

where the Equivalent Dose is the measured natural luminescence of the sample and the Dose Rate is the exponential fit for data being treated with known amounts of radiation (for details, see Murray & Wintle (2000)). Quartz is abundant in marine sediments and thus, OSL dating is of particular use during MIS 5 to MIS 3 as OSL ages can be determined to around 100-350000 years ago, if done properly (Aitken 1998).

3 Cosmogenic Nuclides

When atmospheric molecules are hit by high energy particles (i.e. protons), nuclear reactions are produced, which in turn, send out secondary high-energy (cosmic) rays. Some of these rays will hit the Earth's surface and produce cosmogenic nuclides. Due to analytical limitations, cosmogenic nuclides ^{10}Be and ^{26}Al are primarily tracked in quartz grains trapped in sediments to determine individual sample ages (von Blankenburg 2005). With respective half-lives of 1.5 & 0.7 My (von Blankenburg 2005), the ages of samples can be calculated using the same decay laws as used for radiocarbon dating. Just as for OSL dating, quartz grains are chosen for ages of sediments due to quartz's simple chemistry, resistance to chemical weathering, abundance of ^{10}Be and ^{26}Al, as well as their abundant presence in sediments themselves (von Blankenburg 2005).

In relation to constraining sea level, cosmogenic nuclide dating can be used for constraining erosion and deposition rates, as well as denundation rates (von Blankenburg 2005). This will improve the time resolution of these values at river deltas, needed for modelling approaches of paleo sea level (Dalca et al. 2013; Ferrier et al. 2015; Wolstencroft et al. 2014).

SEDIMENTS AS SEA LEVEL MARKERS: INFERRING SEA LEVEL FROM SEDIMENTS

An integral step in inferring GMSL during glaciation periods is the determination of ice sheet volume. One way to achieve this is to determine where ice sheets were non existent during different glaciation periods. Geological sampling is thus constricted to areas where paleo ice sheets would not have extended to. For this reason, river deltas and their associated sediment samples can be used. River deltas at mid latitudes are not typically geological features that exist under ice sheets, and are connected directly to oceans. Therefore, the sediments found in river deltas can help to constrain paleo-shorelines, from which relative and eustatic sea levels (ESL) can be inferred.

The steps required to reconstruct the paleo-shorelines along river deltas using primarily sediment are the dating and profiling of sediment cores. Much like soil sampling, sediment core profiling is done by segregating different sections of the core by texture (traditionally sandy, silty, or loamy) and chemical composition (i.e. clay compositions that may contract more easily in response to water forcing). Liu et al. (2010) performed a study that exemplifies sediment core profiling and sea level inferences in the Chinese Yellow river delta (see Figure 8).

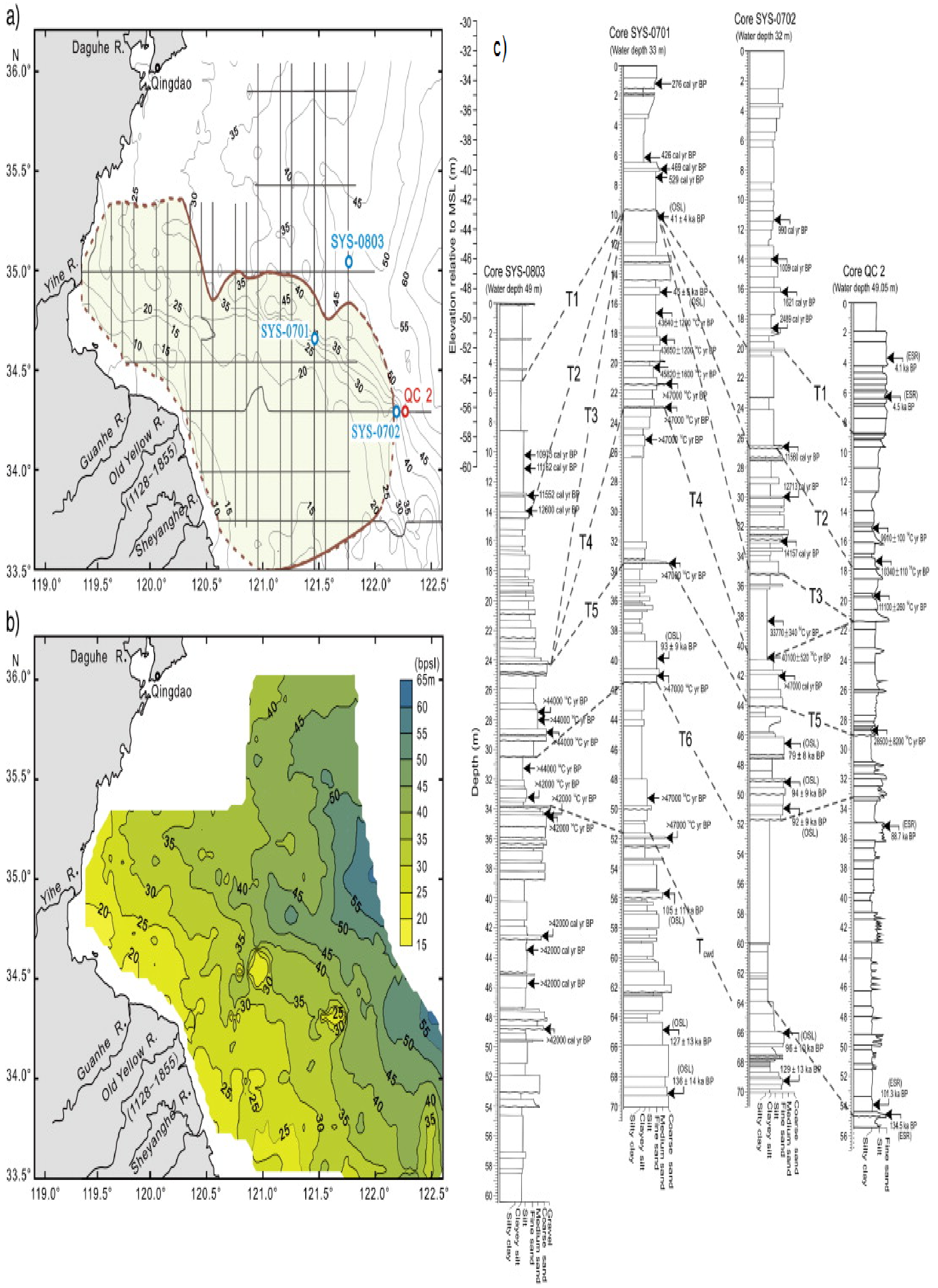

Figure 8: Adapted from Liu et al. (2010), this figure shows (a) sediment core locations, (b) stratigraphic inferences of mean sediment depth during study period (MIS 3), relative to 2010 sea level (bpsl), and (c) sediment core profiles of (a), all in the Yellow sea delta, China. This figure aims to demonstrate the complexity of the process and results of extracting information from any given sediment core, not necessarily the values themselves.

We begin with inferred shoreline migrations from river deltas. To reconstruct paleo river delta regions and their associated shorelines necessary for paleo RSL of that region, a series of steps is carried out. Essentially, when using sediments as sea level indicators, we wish to identify which sediments pertain to different sections of the paleo shoreline (see Figure 9).

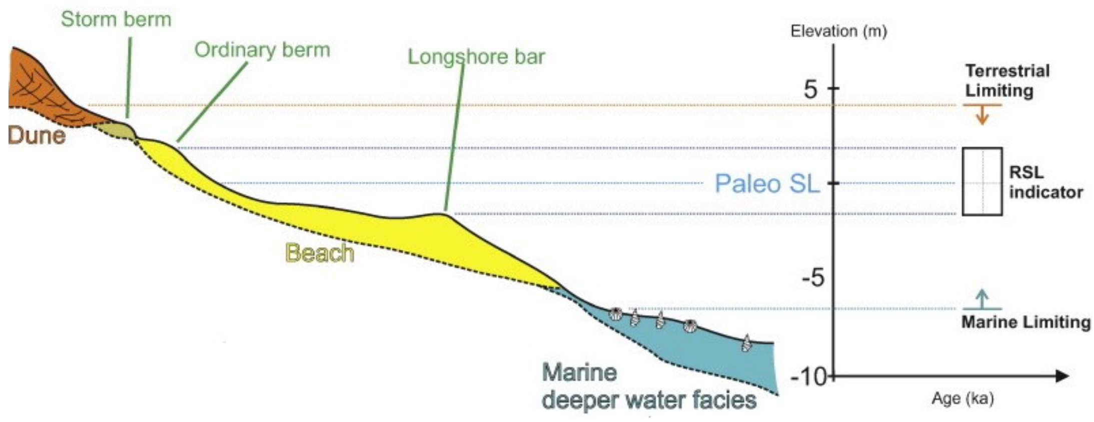

Figure 9: A typical schematic shoreline that any sediment facies, used as a RSL indicator, aims to recreate. Assumed here is that current and wave action have not reworked the sediments and distorted facies below the shoreline. Figure modified from: Rovere et al. (2016).

The first step in associating sediments with their respective paleo shoreline sections is segregating sediment facies based on texture, chemical composition, micro fauna present, etc. Secondly, facies are dated primarily using techniques outlined in ***Sediments as sea level markers: Dating***. Next, as sedimentation occurs over geological timescales, effects such as glacio-hydro-isostatic rebound needs to be taken into effect before RSL and ESL can be inferred.

In a sediment core, sediment facies are mixed together interchangeably through a number of processes over time. If the end goal is to know which facies corresponded to a paleo beach/delta barrier (see Figure 9), then the succession of the facies can be used to reconstruct the paleo environment (i.e. the stratigraphy of the sediments). Inner shelf facies are normally the facies farthest away from the beach region represented in these sediment cores. They can be separated into deeper and shallower sections. Deeper inner shelves tend to be classified as wave dominated and can be identified due to the presence of marine fauna, as well as bedding typical of storm surges (i.e. hummocky cross-bedding). More shallow inner shelves normally contain silty-sand textures and a lack of shelled organisms. Alos characteristic of these facies is evidence of tides (Daidu et al 2013). On the other side of beach/delta barriers (on land) are estuarine environments where freshwater from out flowing rivers first comes into contact with sea water. These facies can be interpreted through a number of properties. Large silt percentages and layers of fine sand are some key characteristics. The presence of organic material (i.e. in the forms of wood and plant fragments) can also imply an estuarine environment as organic matter would be most abundant in areas pertaining to land. In addition, as the assumed conditions of estuaries are brackish, then the presence of brackish fauna such as bleached carbonate shells (Yokoyama et al. 2000) can indicate that said facies originated in an estuarine environment. The bleached carbonate shells are a result of corrosive waters (fresh water meets sea water). Given the location of the former forms of sediment facies, beach/delta barriers can be identified as those who appear above or below the formerly mentioned profiles (see Figure 9;10). Typical in these sections are the presence of quartz grains as well as preserved sandy textures (Simms et al 2009). In addition, these facies' proximities to interpreted estuarine facies can be seen in the regular burrowing of muddy units within the facies as well as it being directly below estuarine sediments (see Figure 10).

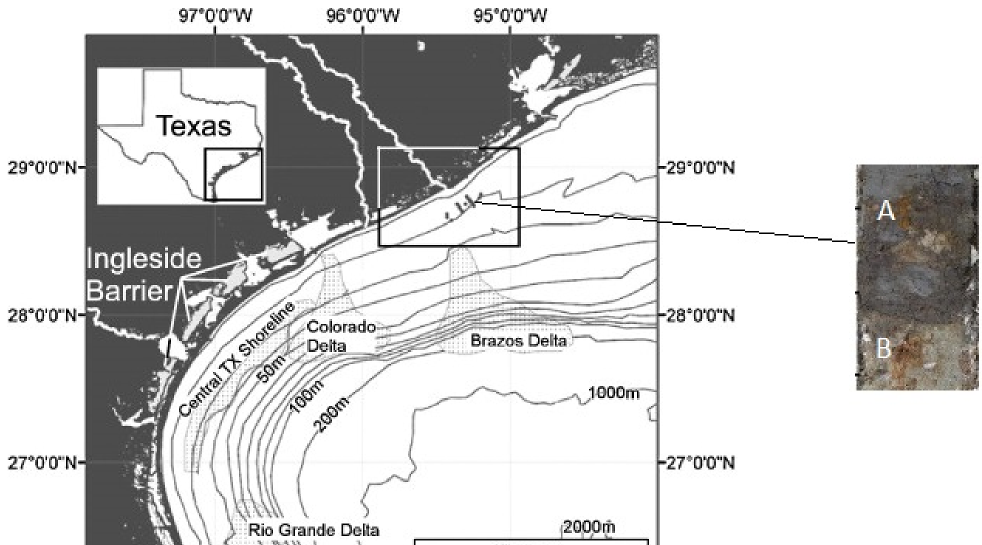

Figure 10: Sediment facies taken from the Gulf of Mexico at a depth of ~18.9m. (A) is the estuarine facies marked by the dark grey clayey silt as well as the green/brownish blotches (most likely plant fragment ans other assorted organic material). (B) is the beach facies with clear, untampered grey sand with burrows of brown (mud from estuarine facies). Figure adapted from: Simms et al. (2009)

Following the study done by Simms et al. (2009), we see what an example sea level would be following this form of analysis. If the beach facies were taken from a current depth of ~18.9m and were dated back to ~91ka (MIS 5) and assuming that beaches form ~1-2m above sea level, then the RSL along the paleo-coastline of the Gulf of Mexico at MIS 5 is ~-21m at present without correcting for subsidence effects. Now, using historical subsidence rates in the Gulf of Mexico of ~0.01$\frac{cm}{yr}$ (Simms et al. 2009), the RSL becomes ~-11m. This value represents an upper limit to GMSL during MIS 5, concurrent with modelled GMSLs of during that time (Pico et al. 2016).

Unfortunately, due to the non-uniform way that sediments RSL indicator studies are conducted, uncertainty can still discredit RSL values and their inferred global eustatic signals. Therefore, Rovere et al. (2016) propose a general approach to asses RSL once the indicator is found. The sample is dated appropriately, its depth is indicated accurately, and then the RSL must be calculated in reference to the water level of the corresponding paleo age.

$$RWL = \frac{U}{L} \tag{3}$$

Here, **RWL** represent the reference water level of the indicator with **U** being the upper depth of the sediment facies and **L** being the lower depth of the facies. RSL can then be calculated through this **RWL** and the elevation of the sediment facies in question at present (marked by **E**).

$$RSL = E - RWL \tag{4}$$

From there, the eustatic signal **ESL** can be calculated with a simple equation:

$$ESL = RSL - (GIA + PD) \tag{5}$$

where **GIA** is the amount of uplift or subsidence associated with GIA, and **PD** is the amount of uplift/subsidence associated with the post-deposition of sediments onto the sediment facies in question (Rovere et al. 2016). Both of the former values are produced from various modelling practices. In addition, error must be calculated following each value determination. It is also important to note that this method can be applied to other RSL indicators during MIS 5-3, including RSL indicators from areas of low modern erosion and deposition rates.

Just as knowing whether or not an ice sheet existed in a geographical location can constrain ice sheet volume, knowing the conditions in which paleo sediments resided during MIS 5-3 can be sufficient enough to infer relative sea level during this time. A prime example of this is studying sediment facies in areas of that were once areas of high erosion and deposition rates during MIS 5-3 but, have since seen a change in landscape (possibly due to tectonic uplift). Here, previous physical environments home to sediments can be broken down into segments: open marine (OM), shallow marine (SM), marginal marine (MM), and brackish conditions (BC) (Yokoyama et al. 2000). OM conditions normally occur at depths greater than 10m, as indicated by normal salinity found in sediment facies (Yokoyama et al. 2000). Also included are remnants of micro marine life such as pteropods. To determine water depth at the age of the sediment facies (see ***Sediments as sea level markers: Dating*** for dating techniques) present water depths and their associated geobiological signatures are used as analogues. For example, OM sediments are analogous to 20m water depths today, and thus mark the elevation of the facies at its respective age (Yokoyama et al. 2000). Moving up through the water column we turn to SM sediments that contain shallow dwelling foraminifera that are usually well preserved. These conditions are analogous to 10m water depths today (Yokoyama et al. 2000). Analogous to 5m water depths today (Yokoyama et al. 2000), are MM sediments that can be accurantely dated throughout MIS 5-3 due to the abundance of quartz grains, common for areas of marine deposition. The final sediment type, BC, is difficult to relate to sea level given the shallow depths of these sediments and thus, their exposure to tides. A key marking feature of BC sediments is bleached carbonate shells scattered within the facies which indicates, at the time of deposit, that they were exposed to corrosive waters, most likely as a result of increased marine deposition from outflows of fresh water (Yokoyama et al. 2000). Even though the methodologies for qualitatively inferring sea level re similar, studying sediment facies from low erosion and depositional areas (i.e. the Australian Outback) represent a lower percentage of studies used for constraining MIS 5-3 GMSL. This is mainly attributed to the fact that MIS 5-3 depths are assumed due to a sample's resemblance to conditions today. Therefore, qualitative assessments of river delta and bay sediments are more relevant in the current literature.

The downside to quantifying sea level using a more geologic data-based approach is large associated uncertainty. Due to tectonic rejuvenation, isostatic effects, and even sediment compaction, sediments can be displaced and buried rather easily, erasing an accurate record as it were (Pico et al. 2017; Liangtao et al. 2017). These assessments of sediment cores also neglect the possibility of suspended sediment flux, rather sediment is assumed to settle as soon as it fluxes from river deltas. Therefore, evaluation of sediments through their individual facies is more of a qualitative approach than quantitative. However, qualitative sea level change recorded in paleo-sediments can be applied through various sedimentary structures that do not necessary pertain to river deltas, unlike current modelling approaches (Rovere et al. 2015). A future aim would be to establish a network of sampling sites that cover the globe in order to infer consistent ESL signals throughout the Pleistocene.

CONCLUSION

The aim of this review was to provide a means to recognizing sediment contributions to sea level change during MIS 5-3. The effect of sediments on paleo sea level can be seen with the physical deposition of sediments along paleo shorelines or can be conceptualized through the physics of sea level change, by means of sediment redistribution and compaction. However, despite large advancements in the field of paleo sea level change, large uncertainties still persist. Therefore, models and geological records require more constrained data in order to accurately infer the paleo sea level throughout the Pleistocene, especially during MIS 5-3. Sediments may provide a means of constraining some of the information necessary for this task. In a modelling approach, paleo sediments, and their deformation of the solid Earth, can result in large departures of sea surface heights over 100ky timescales. Shoreline positions during MIS 5-3 can also be determined at sites where sediments are well preserved. These sediments can be dated and can indicate what part of the paleo shoreline that they pertain to. From there, their elevations, along with documented solid Earth changes, give estimates of RSL, necessary for inferring ESL. Global sea level models, that are fine tuned to geological data, can then benefit from these new parameter constraints. It is important to note that these improved dating techniques and stratigraphic sequences of various marine sediment facies only mark a small fraction of the paleo sea level information that can be extracted from sediments, as well as a small fraction of paleo sea level markers availible pertaining to MIS 5-3. However, new possibilities arise for more accurately determining paleo sea level change over 100ky timescales when we account for the porous mediums within sediments. For example, they can store water within the pore spaces and that water can accumulate to great amounts, depending on the lifetime of the sediment deposits. If we consider that since MIS 5, 145 ky have passed, we can imagine there to be a significant buildup of stored marine water within marine sediments porous enough to trap said water. Future studies involving sediments and their linkage to paleo sea levels will need to account for all roles that sediments may play in global sea level change.

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