IGCP Project 639
"Sea Level Change from Minutes to Millennia"

Second project meeting 17-23rd September 2017
Durban/St Lucia, South Africa

Dedicated to IGCP Project Leaders Professor Arthur L. Bloom and Professor Paolo A. Pirazzoli

Programme and information booklet
Greetings

Sea-level changes over timescales from minutes to millennia are of great concern to coastal communities. Long-term changes in sea level due to the solid earth’s response to glaciation and tectonics are the background rate upon which the hazard from anthropogenic sea-level change and extreme inundation from tsunamis and storms must be superimposed. Short-term measurements from instrumental and historical records provide short glimpses at the hazard posed by sea-level change over varying temporal scales but must be placed within the long-term context that only geological and archaeological records provide.

This project will provide a platform for the development of integrated records of sea-level change and coastal hazards obtained from instrumental, historical, archaeological, and geological records. This project will place a particular focus on integrating disparate records in growth regions for science, namely in Africa, South America, and the Middle East, expanding upon previous coastal (495, 588) and delta projects (475) that focused for the most part on Europe and Asia. Further, this project expands upon the research theme of project 588 that focused on the impacts of humans on coastal landscapes. This project will result in a coastal hazard toolkit that can be applied by those most at risk from future coastal inundation.

We are delighted to welcome you all to the second meeting of IGCP project 639. It is with great pleasure that we welcome you to South Africa and the African continent, a key focus area for the IGCP project 639. We anticipate that this meeting will build upon our successful first meeting in Oman and will ensure the continued success of the project until its completion in 2020. We hope to see you at many more meetings over the coming years and invite you to participate within the project as leaders of scientific and regional working groups under our banner.

This year has been a sad one for IGCP sea-level projects with the deaths of two former project leaders, Professor Arthur L. Bloom and Professor Paolo A. Pirazzoli. The impacts of both Professor Bloom and Professor Pirazzoli are immeasurable for both sea-level science in general and for IGCP sea-level projects they led and participated in. We will take a moment to remember them during the meeting.

Regards,

Simon, Gösta, Fengling, and Alar
General information

The east coast of South Africa is often described as South Africa’s warmest place to be. With its moderate climate, vibrant multi-culturalism and low cost of living, it has been steadily growing as a preferred destination for international visitors. A two-hour drive from the Indian Ocean to the Drakensberg Mountains, the KwaZulu-Natal province is rich in attractions for everyone. Spring is characteristically warm, with temperatures averaging from 20-28 °C during the day. Though the area is currently in a drought cycle, the climate can be wet in September. Expect the weather to be changeable during the conference and field trips, so please come prepared for sun, wind and rain. Sunscreen and a light raincoat are advised.

As with many places around the world, safety can be variable. However, being aware of your situation and surroundings, especially in a small town like St Lucia, reduces the risk of crime significantly. Delegates are advised not to carry valuables openly when walking around on their own. These can be safely stored with the hotel reception. The town itself is relatively quiet and safe. Walking between attractions and places is encouraged.

Travel information

You are reminded to furnish us with your travel details as soon as possible. Transfers from the airport have been arranged, but need to be carefully planned according to delegate flight schedules etc.

Health issues

All participants should check that their health insurance is valid for South Africa. Additional travel health insurance covering medically necessary transportation back home is advisable. The quality of medical care situation in South Africa is however excellent.

There are no mandatory vaccinations for South Africa, though we advise participants to check their general vaccination status. The area rests just south of the known malarial range and is classified as low-risk. Recent malaria outbreaks are very rare. However, please consult your travel doctor if you feel concerned and wish to take prophylactics.

South Africa is known for its dangerous wildlife. Venomous animals such as snakes, spiders and scorpions exist and are sometimes encountered. Please take extra care when you are in the field. However, dangerous confrontations or bites are extremely rare.

Please be aware that hippopotami occasionally roam the town streets, so be cautious when walking, especially at night. https://www.youtube.com/watch?v=CNE6pL6gRXo

Under no circumstances should delegates swim in the St Lucia estuary or adjoining beaches. The area has a prominent crocodile population and the risks are very high. Swimming during field trips is encouraged, but only in the ocean to the north of the town, and where specified by the meeting leader.
What to bring
Each participant should bring sturdy hiking boots, and water bottles for the field trip. Proper sun protection, including a hat and sun screen is highly recommended. If available, hiking sandals are a good addition to hiking boots. Temperatures at night can reach down to 18°C, so light but warm clothing for evenings and nights is advised.

A daypack for sun-protection, water, camera and other personal items should be brought by the participants.

ATMs accepting credit and debit cards are widely available. Foreign currencies can be exchanged at the airport, the rough exchange rate is ~ 13 Rand to the US Dollar.

Travel Support
If you have received travel support, you will need to supply Simon Engelhart with all your receipts (Flight, Registration, and Hotel) before you leave South Africa so he can process reimbursements promptly on his return to Rhode Island.
Procedures during the conference

Transfer from airport
Transfers from the airport have been arranged for each delegate flying in to Durban. For details relating to timing of the transfers and your flights in and out of Durban, please contact Sotiris Spetsiotis info@1stzulusafaris.co.za. Sotiris is arranging the transport and can answer most of your questions.

Transfer to St Lucia
The participants will be picked up at their accommodation on the morning of the 17th and transferred to St Lucia. We aim to depart by no later than 9:00.

Location
The sessions will take place in the Braza Restaurant in St Lucia, adjacent to the accommodation. https://www.tripadvisor.co.za/Restaurant_Review-g312636-d2227635-Reviews-Braza-St_Lucia_KwaZulu_Natal.html

The accommodation is held in two principal places. In Durban, delegates will overnight at the Holiday Inn Express the night of the 16th http://www.hiexhotels.co.za/holiday-inn-express/hotels/durban---umhlanga/accommodation.php.

In St Lucia, accommodation for the remainder of the basic package is at the Lake St Lucia Villas and neighbouring property, adjoining the conference venue.

Participants will return to Durban at the conclusion of the conference or their chosen package excursions and spend their final night at the Holiday Inn Express.

Food and refreshments
All meals will be supplied during the conference times from the 17th onwards, though there are also many other options if delegates wish to eat elsewhere (but on their own account). For the night of the 16th, the Butcher Block restaurant in the hotel is highly recommended and good value. http://www.butcherblock.co.za/.

We will provide a specific list of mealtimes and venues closer to the meeting. Please let Andy Green (greena1@ukzn.ac.za) know of any specific meal preferences/dietary requirements as soon as possible.

Posters and Presentations
We will provide a laptop with Powerpoint connected to a projector for the presentations. Please provide your presentations on a USB Stick in a PowerPoint compatible format on the first day of the conference.

Posters will be hung on partition walls and poster boards at the venue. Maximum poster size is A1 in portrait orientation.

Field trip
The field trips will comprise day trips into the iSimangaliso wetland park, to examine various facets of the coastal geomorphology and sedimentology. [https://isimangaliso.com/](https://isimangaliso.com/)

The field trip is full board, including food, and drinks. Lunch will be picnic-style in the field. Please take note that we will be in an area with several large species of game (e.g. elephant, rhino, hippo and buffalo), so delegates are cautioned not to stray too far from the main group.

Roads are all in good condition but we will be required to use gravel roads during the field trip and so be prepared for an occasionally bumpy and dusty ride. Participants will be required to do several short walks from the bus to the outcrops and stops during the field trip. Usually the paths to the outcrops are unpaved and cross-country. The walks are not extreme, but a healthy cardiovascular system is required.
## Conference timetable

### 18th September

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
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<tbody>
<tr>
<td>08:45</td>
<td>Registration</td>
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<tr>
<td>09:00</td>
<td>Khan and Engelhart HOLSEA</td>
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<tr>
<td>10:30</td>
<td>Tea Break</td>
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<tr>
<td>10:50</td>
<td>Khan and Engelhart HOLSEA</td>
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<tr>
<td>12:30</td>
<td>Lunch</td>
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<tr>
<td>13:45</td>
<td>Jessica Pilarczyk Foraminifera from coastal environments as indicators of paleostorms and tsunamis</td>
</tr>
<tr>
<td>14:30</td>
<td>Colin Woodroffe Micro-atolls and reconstructing sea level</td>
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<tr>
<td>15:15</td>
<td>Tea Break</td>
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<tr>
<td>15:30</td>
<td>Andy Green Difficulties in reconstructing sea level on high-energy highstand coasts</td>
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<tr>
<td>16:15</td>
<td>Simon Engelhart IGCP Project 639 – History and Goals</td>
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<tr>
<td>17:00</td>
<td>Informal Discussion and “refreshments”</td>
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</tbody>
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### 19th September

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
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<tbody>
<tr>
<td>08:30</td>
<td>Matthew Brain <strong>Keynote:</strong> Sediment compaction: a key driver of relative sea-level and coastal change</td>
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<tr>
<td>Time</td>
<td>Speaker</td>
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<tr>
<td>09:05</td>
<td>Claude Hillaire-Marcel</td>
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<tr>
<td>09:30</td>
<td>Michaela Falkenroth</td>
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<tr>
<td>09:55</td>
<td>Merle Muru</td>
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<td>10:20</td>
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<tr>
<td>10:40</td>
<td>Daria Nikitina</td>
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<tr>
<td>11:05</td>
<td>Peter Parham</td>
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<tr>
<td>11:40</td>
<td>Rachel Stearns</td>
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<tr>
<td>12:00</td>
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<tr>
<td>13:15</td>
<td>Joseph Kelley</td>
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<tr>
<td>13:50</td>
<td>Timothy Shaw</td>
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<tr>
<td>14:15</td>
<td>Andrew Cooper</td>
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</tbody>
</table>
14:40  Nicole Khan  6000-year records of relative sea-level change from south Florida

15:05  Break

15:25  Byron Halavik  Late Holocene sea-level changes in Narragansett Bay, Rhode Island (USA)

15:50  Alice Kelley  Disappearing Shell Middens: Ground-Penetrating Radar Assessment of Cultural and Paleoenvironmental Archives and Sea-Level Rise

16:15  Susane Lindauer  Sea level recorded in shells from Gulf of Oman and Arabian Gulf

16:30  Bijan Saha  Records of Late Quaternary sea level rise and coastal inundation along east coast of India, Bay of Bengal—some observations

17:00  Evening entertainments
<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker</th>
<th>Topic</th>
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<tbody>
<tr>
<td>08:30</td>
<td>Gloria Lopez</td>
<td><strong>Keynote:</strong> Beyond dating paleo-records: luminescence as a new sedimentological proxy for the marine extreme events identification and characterization tool kit</td>
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<tr>
<td>09:05</td>
<td>Taneisha Edwards</td>
<td>Evidence of Neotectonics on a microtidal beach in Jamaica, West Indies</td>
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<tr>
<td>09:30</td>
<td>Constance Chua Ting</td>
<td>Tsunami Damage Estimation for Coastal Infrastructure in Macau Based on Damage Fragility Curves Derived from the 2011 Great Eastern Japan Tsunami</td>
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<tr>
<td>09:55</td>
<td>Noelynna Ramos</td>
<td>Preliminary analysis of coastal sediments in Zamboanga del Sur, Philippines: Could they be related to the 1976 Mw8.1 Moro Gulf earthquake and tsunami?</td>
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<tr>
<td>10:20</td>
<td></td>
<td>Tea Break</td>
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<tr>
<td>10:50</td>
<td>Athi Mfikili</td>
<td>Evidence of late-Holocene tsunami deposits in estuaries along the South African coast</td>
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<tr>
<td>11:15</td>
<td>Louise O’Boyle</td>
<td>Monitoring of sea level variations for studies of coastal boulder transport on the Aran Islands, Ireland</td>
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<tr>
<td>11:40</td>
<td>Jessica Pilarczyk</td>
<td><strong>Keynote:</strong> Paleoseismic evidence of earthquakes and tsunamis along the southern part of the Japan Trench</td>
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<tr>
<td>12:15</td>
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<td>Lunch</td>
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<tr>
<td>13:30</td>
<td>Fengling Yu</td>
<td>Quantitative Research on the Sediment Processes in Small Estuaries—A Case Study of Jiulong River Estuary, southern China</td>
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<tr>
<td>Time</td>
<td>Speaker</td>
<td>Topic</td>
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<tr>
<td>13:55</td>
<td>Peter Vos</td>
<td>Tidal-facies transitions as sea-level index points from archaeological terp sites in the coastal area of the province of Friesland (northern Netherlands)</td>
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<tr>
<td>14:20</td>
<td>Kerrylee Rogers</td>
<td>Sea-level change and mangrove shorelines: from monitoring to millennia</td>
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<tr>
<td>14:45</td>
<td></td>
<td>“Refreshment” Break</td>
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<tr>
<td>15:00 till 17:00</td>
<td></td>
<td>Poster Reception</td>
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Nicole Khan (Asian School of the Environment, Nanyang Technological University), Simon Engelhart (Department of Geosciences, University of Rhode Island)

HOLSEA workshop

Determining the rates, mechanisms and geographic variability of sea-level change is a priority science question for the next decade of ocean research. To address these research priorities, the HOLocene SEA-level variability (HOLSEA) working group is developing the first standardized global synthesis of Holocene relative sea-level data to: (1) estimate the magnitudes and rates of global mean sea-level change during the Holocene; and (2) identify trends in spatial variability and decipher the processes responsible for geographic differences in relative sea-level change.

Here we present the preliminary efforts of the working group to compile the database, which includes sea-level index points and limiting data from a range of different indicators across seven continents from the Last Glacial Maximum to present. We describe the composition of the global database, identify gaps in data availability, present a framework for systematic analyses of relative sea-level data, and highlight our effort to create an online platform to access the data. These data will be made available in a special issue of Quaternary Science Reviews and archived on NOAA’s National Centers for Environmental Information (NCEI) in early 2018. We also invite researchers who collect or model Holocene sea-level data to participate. Long-term, this effort will enhance predictions of 21st century sea-level rise, and provide a vital contribution to the assessment of natural hazards with respect to sea-level rise and coastal response.

Jessica Pilarczyk (Division of Marine Science, University of Southern Mississippi)

Foraminifera from coastal environments as indicators of paleostorms and tsunamis

Coastal risk assessment requires datasets on centennial and millennial timescales in order to capture the variability and multiple occurrences of the largest, but infrequent, events. Coastal sediments from low-energy depositional environments archive geologic evidence of storms and tsunamis, making it possible to assess patterns of intensity and recurrence over sufficiently long timescales. Many of the best reconstructions of these events are derived from foraminiferal assemblages because they indicate the transport of marine sediment into an otherwise terrestrial setting. Foraminifera-based reconstructions of storms and tsunamis are enhanced by including information concerning the taphonomic (or surface) condition of
individual foraminifera because it provides important information about sediment provenance and transport that cannot be obtained from the taxonomic assemblages alone. This workshop will explore how a combined taxonomic and taphonomic approach (unaltered, fragmented, corraded tests) is beneficial when documenting storm deposits from Vanuatu and the Philippines, as well as tsunami deposits from Japan, Oman and Indonesia. Storm deposits from Vanuatu and the Philippines could not be discriminated from underlying sediments using only their taxonomic assemblages. Foraminifera contained within the storm deposits and underlying beach sediments were nearly identical as they were sourced from the same location, but by different processes. However, their taphonomic assemblages were distinct. Sediments deposited by both storms contained 80-100% unaltered foraminifera, while sandy sediments from the underlying layers were 90-100% corraded. Similarly, sediments deposited by tsunamis in Japan, Oman, and Indonesia contain relatively high abundances of unaltered foraminifera because the tsunami waves scoured marine sediment from protected subtidal and offshore locations. The combined use of taxonomy and taphonomy identified a mixed source for the 2011 Tohoku tsunami deposit, where corraded foraminifera were sourced from the beach and dunes and minor abundances of unaltered foraminifera were sourced from the offshore. Based on these examples, it can be argued that taphonomy strengthens paleoecological interpretations and will be useful to studies that aim to document paleo-overwash deposits using microfossils.

Andy Green (Geological Sciences, University of KwaZulu-Natal)

Difficulties in reconstructing sea level on high-energy highstand coasts

Sea-level change around southern Africa (southern Namibia, South Africa, southern Mozambique) since the last glacial termination has been quantified using a variety of indicators. Records vary in resolution, with a dearth of salt marshes and an overall poor preservation potential for microfossil based records. Those records that do exist generally agree with global records of major marine transgression associated with Termination I. Detailed Holocene records present as yet unresolved discrepancies with Global Isostatic Adjustment (GIA) model predictions for far-field sites. An extensive database of coastal sites on the more temperate west coast of South Africa enables a robust sea-level curve to be constructed for 9 cal. ka BP. This includes a Holocene highstand of +2-4 m between 7 and 6.5 cal ka BP and several oscillations of < 1 m amplitude around present-day sea level. Offshore data provide age control on seismic stratigraphic units consistent with the proposed Termination I eustatic sea-level rise. On the subtropical east coast, fewer indicator points are available for the mid to Late Holocene (post 7 cal. ka BP) compared to the west. This is because of the steep beach gradients, steep shelf setting, high-wave energy and subtropical weathering. Those available span up to 13 cal. ka BP and mostly include submerged indicators, though vertically stacked beachrock sequences have recently been identified as good archives if the sedimentary architectures and facies are carefully interrogated. Existing data suggests a sea-level curve similar to that of the west coast, but with a time lag between the two. The east coast data are however insufficient to accurately constrain the magnitude and timing of the peak highstand. Chronological and geomorphological evidence are
consistent with several alternating periods of slow and rapid sea-level change, linked to meltwater pulses (MWPs).

19th September, Day 1

Matthew Brain (Department of Geography, Durham University)

Sediment compaction: a key driver of relative sea-level and coastal change

Compaction describes a range of syn- and post-depositional processes that reduce the volume of sediments deposited in low-lying coastal areas, causing land-level lowering and a distortion of stratigraphic sequences. Compaction affects our reconstructions and understanding of historic sea levels, influences how relative sea level changes in the future and can act as a catalyst for rapid, widespread changes in coastal geomorphology.

In this talk, I will firstly provide an overview of our understanding of the causes and effects of compaction, considering findings from key palaeoenvironmental and stratigraphic studies, sea-level reconstructions and recent observational data. Such data have revealed that rates of compaction are variable both spatially and temporally but importantly can be greater than current and projected increases in absolute sea level. Secondly, I will consider how compaction influences our interpretations of reconstructions of relative sea-level change obtained from compaction-prone coastal stratigraphies. Without correction, compaction affects the accuracy of estimates of long-term rates and spatial patterns of glacio-isostatic adjustment and can affect our understanding of the sensitivity of global sea level to past and projected temperature changes. Thirdly, I will consider our ability to project rates of compaction-induced coastal subsidence into the future. Importantly, this depends on accurate assessment of causal compaction processes and the spatial and temporal timescales over which they operate. Finally, I will assess whether our understanding of compaction processes in coastal sediments is complete, focusing in particular on the difficulties associated with modelling time-dependent processes such as biodegradation and creep.

Claude Hillaire-Marcel (Geotop, Université du Québec à Montréal)

Short-lived and nuclear fallout isotope monitoring of recent sea level change and extreme event recordings in coastal sediments

Whereas, geochemical tracers (e.g., $^{13}$C in organic matter; Lamb et al., 2006) can be used for the documenting of recent/on-going anthropogenically or naturally induced sea-level changes in coastal sediments, the precise dating of such recent changes remains challenging, even when using well established dating methods (e.g., $^{210}$Pb and nuclear fallout isotope
Several effects may indeed blur the sedimentological imprint of such changes; notably they include benthic mixing and extreme events, and strongly depend upon sedimentation rates. Here we illustrate the use of several isotopic systems to decipher such effects on marine sedimentary records based on examples from the Arctic Ocean, the Gulf of St. Lawrence and coastal areas from the Pacific and Atlantic coastlines of Mexico. In order to make a full use of such approaches, care must be taken when coring to avoid artifacts (compaction, stretching...). In a similar fashion, precise measurements of standard sedimentological properties must be secured (water content, density, grain size, mineralogy). To avoid potentially misleading interpolations, sediment sampling for isotopic measurements should be made continuously, at most at 1 cm intervals, possibly a lesser interval in very low sedimentation rate sequences. In the lab, we combine several geochronological methods depending on the sedimentological setting and major processes involved: $^{14}$C, $^{210}$Pb,$^{226}$Ra, $^{137}$Cs or $^{239}$Pu as well as common lead abundances and isotopic compositions, and isotopes from the U and Th-decay series, in particular the short-lived isotopes $^{228}$Ra, $^{228}$Th, $^{210}$Po. This is in order to zoom down through time scales and better constrain time-dependent processes. The most critical indication for pristine recordings is usually illustrated by specific behaviors of $^{210}$Pb and nuclear fallout isotopes. However, focusing on yearly or seasonal processes with $^{228}$Ra, $^{228}$Th, $^{210}$Po might reveal small departures from steady state sedimentation, as well as the occurrence of recent sedimentological rate changes (<30 yrs). These isotopes are also particularly useful in documenting exceptional events (erosion, resuspension, flood events linked to storminess or seismic activity) at the same time scale. Based on the above examples, it is concluded that sedimentary records may indeed be used for the documenting of on-going global changes, but that a combination of time-dependent tracers should be considered to secure reliable reconstructions.

**Michaela Falkenroth (Steinmann Institut, University Bonn)**

**Beach evolution along the coastline of Oman using facies analysis and petrography on uplifted beach rock deposits (Northern Indian Ocean)**

Evidentially, analyses of beach rock deposits are useful in the reconstruction of regional sea level changes and hold the potential of complementing present coral-based reconstructions. Their sedimentological features allow detection of the exact water depth during their formation in contrast to corals, which have a wide vertical living range. Furthermore, they can be used to test coral-based records, or, due to their higher abundance, establish records where no coral markers are available. Despite the potential of reconstructing facies variations preserved in beach rock deposits and the need for such reconstructions in order to confirm beach rock based sea level data, detailed sedimentological facies analysis of beach rocks have received little attention. Any paleo-beach rock location above or below present sea-level can be interpreted as evidence for eustatic, isostatic or neotectonic movements. The aim of the ongoing project in Oman is to quantify the uplift rates of the area and the time frame of its occurrence in order to reconstruct coastal evolution.
The study area is located on the north-eastern coastline of Oman. This coastal section shows geomorphological evidence of neotectonic activity and presents us with a unique setting for the investigation of beach rock deposits: six raised marine terraces, showing erosional remnants of paleo beaches along their former shoreline angle. The terraces are cut into Palaeocene to Early Eocene limestone and marl formations and usually consist of a wave-cut platform unconformably overlain by a few meters of Quaternary terrace deposits, including beach rocks. However on the upper, and therefore older, terrace levels only lag deposits in form of beach rocks could be documented. The arid climate of the region in combination with a history of uplift caused multiple wadis to cut these sediments and left several meters of beach rock profiles in sheltered places.

Nineteen outcrops on three terrace levels were mapped, surveyed, logged and sampled. The investigation focusses on sedimentology, ichnology, and petrology to understand paleoenvironment and conditions at the time of beach rock formation as well as post-depositional changes. With regard to this analysis of the sedimentological and ichnological features allows us to identify lateral facies relationships, energy level, sediment entry, and beach morphology. Thin section-based petrographic microscopy helps to recognise the depositional environment in terms of water chemistry, cementation cycles and mineralogy.

The results show that all beach rocks in the area classify as calcarenites or calcirudites. Their sedimentological features have been assigned to a variety of depositional environments, including high energy-wave-controlled gravel pockets on rocky coastlines or sandy backshores influenced by terrestrial mass flow events. Calcarenite beds with a bioturbation index of 4 and higher are commonly occurring. Major sediment components are extralasts, which show signs of reworking, as well as peloids and fossils, whereas Quartz, Pyroxene, and Olivine grains are secondary. This causes limitations in terms of dating approaches by optical stimulated luminescence (OSL) due to the scarcity of Quartz and Feldspar minerals. Furthermore, in the majority of the samples, over half of the grains have been leached. The oldest beach rocks even show complete porosity inversion. In all samples multiple stages of cementation can be observed, the cement is calcitic or aragonitic and occurs as isopachus or irregular crust cement, passive cement, meniscus cement, or microstalagtites.

Merle Muru (Institute of Ecology and Earth Sciences, University of Tartu)

Relative sea-level change and Stone Age coastal settlement in Estonia, eastern Baltic Sea

Many prehistoric settlement sites that show evidence of coastal habitation have been found in the eastern Baltic Sea region. In Estonia, these sites are presently located inland and at different altitudes because of varying glacial isostatic land uplift. In the early phases of cultural development, hunter-gatherer populations in this region were faced with alternating transgressions and regressions of the shoreline due to competition between hinterland uplift and eustatic sea-level rise. The focus of this study is on GIS modelling and the compilation of multidisciplinary data as methods for studying Holocene shoreline change and coastal landscape evolution in relation to the history of Stone Age human occupation. Results are
presented for three case studies: Narva-Luga Klint Bay, the coastal lowland in NE Estonia and NW Russia; the city centre of Tallinn, the capital of Estonia; and Ruhnu Island in the middle of the Gulf of Riga. For each study area, a shore displacement curve was compiled on the basis of radiocarbon dated sediment stratigraphies or luminescence dated sequences of coastal formations. Elevation data from different sources (airborne LiDAR, topographic maps, on site measurements) were used for creating digital terrain models (DTM). Shore displacement curves and relict coastal landform data were used for interpolation of former sea level surfaces in both time and space. Luminescence ages of coastal formations were used for delineation of former beach zones on the high-resolution DTM. Palaeo-land surfaces were modelled by subtracting the paleo-water surfaces from the present terrain surfaces. The effects of later deposition (i.e. younger peat accumulations, younger cultural layers) were removed based on geological maps of Quaternary cover, field measurements and geomorphological analysis of topography. GIS-based palaeo-geographical reconstructions were generated for any time slice relevant for the landscape changes and developments of Stone Age settlement patterns.

The studies showed that, besides the determination of the locations of former shorelines, GIS-based palaeo-geographical reconstructions can uncover unnoticed features of past coastal landscapes and make it possible to describe the locations of prehistoric settlements and therefore clarify the reasons behind the choice of these sites by Stone Age hunter-gatherers. The results of the palaeo-geographical studies help to determine the period of Stone Age coastal occupation in the eastern Baltic Sea region. In the study areas, the start of the coastal habitation at about 7.2 cal. ka BP largely coincides with the Litorina Sea transgression maximum, while the disappearance of the settlements from the sea shores at about 4.7 cal. ka BP was induced by the shift in subsistence strategy towards farming.

Daria Nikitina (Department of Earth and Space Sciences, West Chester University of Pennsylvania)

Reconstructing relative sea level in the White Sea, Russia using distribution of foraminifera, diatoms and sediment geochemistry

We investigated the utility of foraminifera, diatoms and bulk-sediment geochemistry ($\delta^{13}$C and parameters measured by RockEval pyrolysis) as sea-level indicators in Eurasian sub-Arctic salt marshes. At three salt marshes in Dvina Bay (White Sea, Russia), we collected surface sediment samples along transects sequentially crossing sub-tidal, tidal-flat, salt-marsh and Taiga forest environments. Foraminifera formed bipartite assemblages, where elevations below mean high higher water (MHHW) were dominated by Miliammina spp. and elevations between MHHW and the highest occurrence of foraminifera were dominated by Jadammina macrescens and Balticammina pseudomacrescens. Both assemblages existed on all three transects and we conclude that foraminifera are sea-level indicators in Eurasian sub-Arctic salt marshes. Five, high-diversity groups of diatoms were identified and they displayed geographic variability among the study sites (<15 km apart). RockEval pyrolysis and $\delta^{13}$C measurements recognized two groups (clastic-dominated environments below MHHW
and organic-rich environments above MHHW). Since one group included sub-tidal elevations and the other supra-tidal elevations, we conclude that the measured geochemical parameters do not meet the criteria for being stand-alone sea-level indicators. Core JT2012 captured a regressive sediment sequence of clastic, tidal-flat sediment overlain by salt-marsh organic silt and freshwater peat. The salt-marsh sediment accumulated at 2804 ± 52 years BP years before present and preserved foraminifera (*J. macrescens* and *B. pseudomacrescens*) with a high degree of analogy to modern assemblages indicating that relative sea level was 2.60 ± 0.47 m above present at this time, which is broadly consistent with predictions from the Earth-ice model ICE6G-C VM5a and our interpretation of the sedimentary sequences preserved beneath freshwater peatlands in the study area. Diatoms confirm that marine influence decreased through time, but the lack of analogy between modern and core assemblages limits their utility as sea-level indicators in this setting. Recovery of additional sediment cores that include sections of salt-marsh sediment offer an opportunity to increase the number and resolution of RSL reconstructions from the Eurasian sub-Arctic.

Peter Parham (Earth Observatory of Singapore, Nanyang Technological University)

Rock encrusting oysters as palaeo-sea-level indicators, southeast Asia

Rock-encrusting oysters (*Saccostrea cucullata*) are important sea-level indicators for Peninsular Malaysia and Malaysian Borneo. Fossil rock-encrusting oysters are preserved on crystalline igneous and erosion-resistant sedimentary rocks, especially limestone. They are found in clefts or between boulders where they are protected from the leaching effects of rain and runoff. To reconstruct former sea level, we measure the difference in elevation between living and fossil rock-encrusting oysters at the same locality. However, the indicative meaning of rock-encrusting oysters is unknown. The indicative meaning of a sea-level indicator describes the vertical relationship between the local environment in which it accumulated and a contemporaneous reference water level.

We surveyed rock-encrusting oysters from over 65 locations along the Peninsular Malaysia and Malaysian Borneo coasts. Living rock-encrusting oysters in this area are confined to the intertidal zone between mean low water and mean high water spring tide. Tidal ranges vary from 1.5 to 4 m with vertical distribution of oysters increasing with tidal range. The upper limit of living oysters is also influenced by wave exposure and microhabitat. Rock-encrusting oysters are typically concentrated within a 60 cm zone near the upper limit of their vertical distribution between mean sea level and mean high water spring tide. Along vertical faces, the upper limit of this zone terminates to form a distinct, largely horizontal line (often a shelf) that corresponds closely with mean high water. Along sloping faces and in clefts, the upper limit is up to 20 cm higher.
We use rock-encrusting oysters to illustrate that relative sea-level was above present during the mid to late Holocene. Preliminary results from 19 sites show relative sea level was between 1.1 +0.5, -0.1 m and 4 +0.5, -0.2 m from 6212 to 2335 cal yr BP.

Rachel Stearns (Department of Geosciences, University of Rhode Island)

A High-Resolution Reconstruction of Late-Holocene Relative Sea Level in Rhode Island, USA

Studies on the US Atlantic and Gulf coasts have utilized salt-marsh peats and the macro- and microfossils preserved within them to reconstruct high-resolution records of relative sea level (RSL). To expand our knowledge on RSL trends beyond the Common Era from high-resolution continuous-core records in New England, we reconstructed RSL change in Rhode Island. Rhode Island marshes contain deep and continuous salt-marsh peats (>3 m), experience microtides (0.9-1.4 m), and avoid the paleo tidal range changes that may contaminate RSL reconstructions within Long Island Sound. We conducted preliminary coring at over 10 salt-marsh sites within Narragansett Bay and found the thickest continuous salt-marsh peat sequences at Fox Hill Marsh on Conanicut Island where we recovered a ~3.4 m core. Foraminiferal assemblages were enumerated from the core at 3 cm intervals and trends in δ13C were assessed at 5 cm resolution. We obtained 30 AMS 14C dates and historical chronological markers of known age (e.g. 137Cs, Pb, Pb isotopes, Hg, and Ambrosia pollen) were used to develop the chronology, spanning ~3,300 years with an average resolution of ±50 years for a 1 cm slice. The effects of compaction (mechanical compression) were assessed by both collecting basal peat samples and using a decompaction model.

We employed our fossil salt-marsh foraminifera and bulk sediment δ13C to estimate paleomarsh elevation using a Bayesian transfer function trained by a previously-published regional modern foraminiferal dataset. We combined our RSL reconstruction with local tide gauge measurements from Newport, Rhode Island (1931 CE to present) and used an Errors-in-Variables Integrated Gaussian Process (EIV-IGP) model to estimate past rates of RSL change and sea-level change after removal of the contribution from Glacial Isostatic Adjustment (GIA) of 0.9 mm/yr. RSL rose from -3.9 m at ~1250 BCE reaching -0.4 m at 1850 CE (1 mm/yr). Our reconstruction shows multiple oscillations of accelerating and decelerating RSL superimposed on this overall rising trend. Our data captures three sea-level falls from ~500 BCE to ~0 CE, ~500 CE to ~900 CE, and ~1450 CE to ~1700 CE. Contemporary instrumental observations made by the Newport tide gauge (1931-present) record RSL rising almost 3 times faster than background rates (2.74 ± 0.17 mm/yr). Our reconstruction is in agreement with prior reconstructions from the US Atlantic coast showing evidence for sea-level changes that may be related to the Medieval Climate Anomaly (MCA) and Little Ice Age (LIA). Further work is required to identify whether oscillations in RSL prior to the MCA are related to other periods of climate variability or reflect local-scale processes at Fox Hill Marsh.
The Gulf of Maine, USA “Family” of Sea Level Curves: Lowstand and Slowstand

Observations on changes in sea level in the Gulf of Maine were first published in the early 19th Century. All early work focused on higher-than-present coastal landforms (shorelines, deltas), but by the middle 20th Century salt marshes were investigated from Cape Cod, USA to Nova Scotia, Canada. Salt marsh records over the late Holocene allow more precise measurements of rates of sea-level rise, and are strongly impacted by regional isostatic adjustment. The lowest rates are found to the west (Maine coast), more distal to the former ice margin, where uplift of the land is still occurring. This is further manifest in contemporary tide gauge records with rates highest in the northeast and southeast and lower rates along the present coast of Maine, where consistent sea-level rise rates apply for more than 200 km along the former ice margin.

Evidence for the lowstand of sea level was discovered in the middle 1970’s off central Maine with the application of geophysical and coring techniques. Widespread seismic-geomorphic evidence for a lowstand is manifest in shorelines and deltas graded to approximately -48 m off the Merrimack River in Massachusetts and -60 m off the Kennebec River in Maine. Calibrated radiocarbon dates place the timing of the lowstand at about 11,500 and 12,500, respectively. However, these dates are from shells that were not in life position, nor bear a close relationship to a tidal datum. Off Nova Scotia, a lowstand was tentatively dated to approximately 12,000 B.P. Unpublished work from the region between the Merrimack and Kennebec paleodeltas, off the Saco River, measured a lowstand by dating in situ, articulated Mya fossils that intriguingly date between those from the Kennebec and Merrimack paleodeltas.

In the 1990’s a “slowstand”, or period of time during which sea level rose very slowly, was discerned off the Maine and Nova Scotia coasts. Though unexpected, this interval became well documented with numerous dates falling between 11,000 and 8,000 BP from the many estuarine deposits that accumulated but were not later eroded. New cores from the SW part of the Gulf of Maine on the inner shelf seaward of the Merrimack and Saco Rivers, now further document a slowstand temporally indistinguishable from the interval in the north.

The slowstand consists of a sea-level rise of less than 5 m over 3000 years (< 1.6 mm/yr) and is bracketed by periods of much more rapid rise (> 4 mm/yr). Although unpredicted by models and not intuitively expected, it is now a defining feature of the regional Gulf of Maine sea-level record. Its simultaneity across a region where isostatic adjustment has led to differing times/depths of high and low stands of sea level suggests that a local effect, like continental levering (hydroisostasy) may underlie its creation.
Detecting sub-century sea-level changes from salt-marsh environments in the Mediterranean

Late Holocene relative sea-level (RSL) records from the Mediterranean have been reconstructed using archeological, geomorphological and sedimentological sea-level indicators. However, the accuracy and precision of these sea-level indicators often restricts their capacity to document spatially variable RSL changes that reflect the interplay between eustatic, glacio-hydro-isostatic and tectonic processes on a variety of temporal scales.

Here, we produce new high-resolution reconstructions of RSL from salt-marsh environments along the central Adriatic coast of Croatia. We constrained changes in RSL, vertically, by contemporary foraminiferal distributions from sites where analyzed cores were recovered, and temporally, by radiometric analyses to provide sub-century resolution within a Bayesian age-depth framework. We modelled changes in RSL using an Errors-In-Variables-Integrated-Gaussian-Process (EIV-IGP) model showing ~ 0.28 m RSL rise since the early 18th century. Rates of RSL change from the salt-marsh reconstructions increase from 0.7 mm/yr at 1735 CE to 1.2 mm/yr at 2009 CE and are concurrent with nearby tide-gauge measurements for the 20th century. Our results underline the ability of salt-marsh sediments to provide high-resolution records of RSL change extending beyond the instrumental period, a first in the Mediterranean region.

We combined our salt-marsh records with tide-gauge measurements and standardized local published sea-level index points (n = 21) to reconstruct the late Holocene sea-level history for the central Adriatic region. RSL rose from -1.47 m at 715 BCE to -0.16 m at 1900 CE. The background rate of rise is 0.55 mm/yr, which we attribute to glacial isostatic adjustment. Application of the EIV-IGP model to the composite dataset reveals sea-level trends similar to global reconstructions (Kopp et al., 2016) in response to climate events that encompasses the Common Era. We show current rates of sea-level rise are unprecedented in ~ 2700 years for the central Adriatic region.

Seismic stratigraphy and evolution of Santa Catarina Island and Florianopolis Bay in the context of Late Quaternary sea level change and neotectonics

Florianopolis Bay is a shallow, coastal embayment sheltered from South Atlantic oceanic wave processes by Santa Catarina Island. Shallow seismic stratigraphic investigations reveal that the Bay was a shallow tidal embayment in the last interglacial (MIS 5) during which, up to 40 m of sandy sediments accumulated. These record a transition from open water through bayhead delta sands to tidal sandwaves and tidal flats.
Following valley incision during the Last Glacial Maximum, wave ravinement accompanied sea-level rise until a sea level of approximately -50 m was reached. At this level, a prominent erosional notch and cliff was formed on the ocean shoreline, reflecting a significant period of sea-level stability. This was the focus for deposition of a major shoreline complex adjacent to an emergent coastal plain. The wide sandy beaches and broad dune systems were ultimately cemented as beachrock and aeolianite, respectively. Continued Holocene sea-level rise created a ravinement surface on which modern seabed sediments accumulated. These thicken northward and form a shelf clinoform wedge. Reflooding of Florianopolis Bay in the mid Holocene was accompanied by ravinement of the sandy sediments and deposition of up to 5 m of Holocene silts and clays. At least two periods of seismic activity (one late Pleistocene, one Holocene) are recorded in nearshore sediments by widespread soft-sediment deformation structures, faulting and fluid-escape pipes terminating in pockmarks. These are centred around Tijucas Bay although faulting is present at least as far as Pinheira (60 km distant).

Nicole Khan (Asian School of the Environment, Nanyang Technological University)

6000-year records of relative sea-level change from south Florida

Paleo-sea-level records are important for determining the contribution of local- to regional-scale drivers to projections of future relative sea-level (RSL) change. We produced RSL histories spanning the last ~6000 years from two sites where the relative contributions of drivers of RSL change are poorly known in the lower (Snipe Key) and upper (Swan Key) Florida Keys, USA. We reconstructed paleo-mangrove elevations using foraminifera preserved in cores of mangrove peat that were dated primarily using radiocarbon. At Snipe Key, RSL rose by ~5.1 m during the past ~5900 years compared to ~6.8 m at Swan Key during the past ~6000 years. Rates of RSL rise were highest (1-2 mm/yr) from 6000 to 4000 years ago and slowed to 0-1 mm/yr during the last four millennia. The spatial difference between the sites, which are separated by ~160 km, is opposite from the pattern expected from differential GIA, which would cause Holocene RSL rise to be greater at Swan Key than at Snipe Key. We explore the influence of additional local- to regional-scale processes that may have driven differences in RSL between the two study sites, as well as other regional RSL records, including non-stationary tides, sediment compaction, regional variations in hydroclimate, and the dynamic response of the Florida Current and Gulf Stream to climatic-induced changes to Atlantic Meridional Overturning Circulation (AMOC) and an associated weakening/strengthening of the Gulf Stream.
Late Holocene sea-level changes in Narragansett Bay, Rhode Island (USA)

Late Holocene sea-level reconstructions are of importance because they provide context for comparisons of long-term relative sea-level (RSL) with recent, accelerated rates of RSL rise during the last ~150 years. These reconstructions also provide the necessary data to tune parameters governing models of glacial-isostatic adjustment (GIA), and in turn allow for the better assessment of the many simultaneous contributors to RSL changes, particularly at the regional and local scales. To address a significant spatial gap in sea level records along the east coast of North America, we produced the first RSL reconstructions in Rhode Island, USA which utilize basal salt-marsh peats to minimize the effects of compaction. We sought to quantify and compare RSL changes to other regional reconstructions, and to test whether RSL varied between study sites due to spatially variable GIA.

We sampled salt marsh basal peats from four Rhode Island salt marshes: Fox Hill; Touisset; Osamequin; and Nag Pond, spanning a transect from south to north in Narragansett Bay. We reconstructed paleomarsh elevations using a multi-proxy approach that investigated salt-marsh foraminifera, in-situ plant macrofossils, and bulk sediment δ¹³C. We established sample chronology using accelerated mass spectrometry (AMS) radiocarbon dating of identifiable in-situ plant macrofossils. We have produced 18 new sea-level index points for Rhode Island. At Fox Hill, 12 sea-level index points demonstrate that RSL rose from -3.87 ± 0.24 m at 3,140 ± 69 cal yrs BP, whereas at Touisset, six sea-level index points demonstrate that salt marshes developed later with RSL rising from -1.65 ± 0.22 m at 1,246 ± 56 cal yrs BP. Comparison of RSL records from Fox Hill and Touisset demonstrates that, within error, they record similar RSL histories with late Holocene rates of rise of ~1 mm/yr. When compared with modern rates at the Newport tide gauge (2.73 mm/yr; 1931 CE-present) the data reveals a nearly three-fold increase in RSL rise. Our preliminary results suggest minimal variability in late Holocene RSL across Rhode Island.

Disappearing Shell Middens: Ground-Penetrating Radar Assessment of Cultural and Paleoenvironmental Archives and Sea-Level Rise

Current investigations on the coast of Maine, USA are a case study of the application of ground-penetrating radar (GPR) as a rapid, noninvasive technique for quantifying shell midden extent and stratigraphy in the face of sea-level rise. This is a time-critical issue in this region, as virtually all of Maine’s over 2000 shell middens, representing 5,000 years of cultural and environmental history, are experiencing coastal erosion. Most exhibit fresh, wave-cut faces, and some have completely disappeared within the last two decades. The
application of this geophysical technique is being developed as part of a monitoring and rescue strategy for Maine’s coastal cultural resources.

While focused on the coast of Maine, this work has wider applications. Aboriginal shell middens are located on many of the world’s coasts. While varying greatly in age, size and details of composition, shell middens have several characteristics in common. These include a human-generated accumulation of mollusk shells often combined with artifacts and additional faunal material from mammals, fish, reptiles, and birds. In all cases, these features record local marine-focused subsistence strategies and cultural practices. In regions with acidic soils, where only stone and calcined bone are preserved, shell middens provide a unique cultural and paleo-environmental archive. The chemical buffering effect of carbonate shell decomposition in the middens enhances preservation of organic subsistence and cultural remains. The analysis of mollusk shells or associated fish otoliths can provide site seasonality data, as can the analysis of other faunal remains. Stable isotope analyses of shells have been used as indicators of paleo-temperature and local hydrology, with great potential for more information from detailed isotopic/chemical investigations of shells and associated midden sediment or soil layers. Non-mollusk faunal remains also represent a biased, but singular sampling of species diversity, population, and individual animal size range for pre-historic periods in many locations.

As these sites disappear, a valuable cultural and paleo-environmental archive is lost. GPR can be used to rapidly and noninvasively quantify shell midden size and stratigraphy, assess site integrity, to assist in excavation decisions, and/or monitoring plans.

Susanne Lindauer (Curt-Engelhorn-Zentrum Archaeometry, Klaus-Tschira-Archeometry-Centre)

Sea level recorded in shells from Gulf of Oman and Arabian Gulf

We report species-specific reservoir effects for shells found at excavations along the Arabian Gulf and the Gulf of Oman. Part of the data was reported at the last meeting of the IGCP 639 project and since then we have extended our research along both coasts. For one site we are able to monitor changes in reservoir effects for two shell species (Terebralia palustris and Anadara uropigimelana) due to a changing sea level during ancient times. For other sites, two along the coast of the Arabian Gulf and three sites along the Gulf of Oman, we are able to derive reservoir effects during one time frame. The data on the shells of Anadara spp., Terebralia spp., Marcia spp. and a few specimens of Hexaplex spp. allowed us to derive climatic conditions of the estuaries of the periods of interest. With these new data we are now able to derive a reliable reservoir effect for Terebralia spp. and Marcia spp. for the Arabian Gulf during the Iron Age. This new report represents another step towards a detailed understanding of coastal development, ocean circulation patterns and changing sea levels along these coasts from Neolithic until Iron Age.
Records of Late Quaternary sea level rise and coastal inundation along east coast of India, Bay of Bengal-some observations

The Bay of Bengal and adjoining eastern coast of India is prone to marine geohazards like cyclones, storms, subsidence due to compaction, slope failures in the deltaic areas, submarine erosion, subsidence due to neotectonism and tsunami (though rare). Coastal erosion, extreme waves and unusually high tides causing inundation are common. The major part of the east coast of India comprises low-lying deltaic and estuarine environments with wide coastal plains. Parts of the southern sector of the east coast comprise high and low rocky promontories and cliffs consisting of charnockite, khondalite, granite gneiss and schist with emplacement of basic dykes.

The signatures of rising sea levels above the present sea level (from +2 to +3 m, up to +6m during the Late Holocene) are preserved in the form of raised marine terrace, sea cliffs, natural bridges, and wave cut benches/notches/sea caves in the Precambrian rocks of the southern part of the east coast of India.

Recent studies in the inner shelf off the Ganga delta picked up signatures of submarine erosion of the sea bed. Around Sagar Island, which lies in the southern part of Ganga delta, underwater sea bed slope failures from one meter isobath are recorded, followed by slumping, resulting in the ingress of the sea. The western bank of Pitt’s Creek has moved by about 400m westward, and having a steeper slope near the mouth, is currently being attacked by bottom friction due to the northward divergence of littoral currents moving from the west. Major changes in the coastline configuration of the Ganga delta happened during catastrophic events which resulted in coastal inundation.

In the northern Andhra Pradesh coast, near Baruva, the mid-Holocene transgression coincided with the neotectonic uplift of the southern part of the coast along a lineament and led to the evolution of a barrier-lagoon coast. The rapidly transgressing shoreline on the western side of the Vasistha Godavari River mouth was due to subsidence along neotectonically exploited fault-lines. Submergence of coastal forests along Palk Bay in recent times is due to relative vertical movements along E-W lineaments (Vaz et al, 2006). The overall geomorphology of the Dhanushkodi coast has changed and the southern part of the erstwhile Dhanushkodi township subsided in 1948 AD and is now submerged.
Gloria Lopez (CENIEH, Luminescence Dating Laboratory)

Beyond dating paleo-records: luminescence as a new sedimentological proxy for the marine extreme events identification and characterization tool kit

Luminescence Dating is based on the ability of certain minerals to emit light in response to external stimulation as a result of ionised radiation trapped in the form of electrical charges within the crystal lattice of specific mineral grains. The amount of luminescence signal within a grain can be analyzed by means of optical (light) stimulation using both Optically Stimulated Luminescence (OSL) and Thermo-Luminescence (TL) on pure separates of quartz or feldspar grains, or by Pulsed Photon-Stimulated Luminescence (PPSL) on a poly-mineral fraction of the bulk, untreated sediment sample.

The uniqueness of OSL, as a chronological method, relies on its capacity to determine the last time a mineral grain was effectively exposed to sunlight, just prior to its final burial. Hence, luminescence (in the form of OSL, PPSL and even TL) is intrinsically related to both transport and depositional processes during a particular event. The type and degree of chaos of such processes (and potentially their duration) can be reflected in the homogeneity (or lack thereof) of the optical signal resetting process (zeroing), evidenced in the normality and modality of the distribution of the luminescence signal (in the form of Equivalent Dose – $DE$ – or Photon Count values). The former can be defined as the degree of over-dispersion, variance or skewness of a sample, whilst the latter as the number of value populations within the distribution. Eventually, these could be defined as luminescence signal patterns exclusive to specific transport/depositional conditions, hence specific sedimentary environments/deposits.

Marine-derived extreme events such as severe storms and tsunamis occur Worldwide, independent of lithological setting. The success of the luminescence methods depends on the quality and sensitivity of the mineral grain analyzed. The longer the mineral grain is recycled along its source-to-sink path, the more sensitive it becomes to zeroing, hence the better it is at re-building its luminescence signal over time. This process increases its luminescence quality, therefore its potential as an analytical proxy. However, the original source of the mineral may derail its quality development (e.g. glacially-derived sediments and metamorphic quartz are known to be problematic). Therefore, the importance of knowing the source of the quartz/feldspars forming these palaeo-tsunami and palaeo-storm deposits, in order to better elucidate the quality and potential geographical extension of this new extreme event proxy, is essential.

This investigation slowly began in 2008 analyzing modern and palaeo-sediments, of both hurricane, tsunami and severe storm origin, as well as normal marine condition analogues found along some coasts of USA, Japan, Mexico and Israel (from both nearshore terrestrial and underwater settings). The collection of extreme event sediments has slowly grown, incorporating some samples from Greece, Kenya, Chile, and Ecuador. The research is still on-
going and in need of more known extreme event specimens, young and old, to further calibrate the accuracy and reliability of this novel proxy and analytical approach.

**Taneisha Edwards (Department of Geography and Geology, the University of the West Indies)**

**Evidence of Neotectonics on a microtidal beach in Jamaica, West Indies**

Past sea-level fluctuations have commonly been modelled from oxygen isotope data and calibrated using past sea-level indicators (e.g., coastal peat deposits, raised coral reefs).

Recent ICPP sea-level variability and reconstruction studies are related to temperature change and they are important for predicting and understanding the response of the coastlines globally to global warming. Yet it is well known that coastlines may also be affected by positive or negative tectonics, which will affect the accuracy of these models. Granulometric features of beachrocks and unconsolidated sediments (from the subsurface) of the modern beach are being investigated from Grant’s Pen (St. Thomas, Jamaica) to reconstruct the palaeo-environmental conditions at the time of cementation and compare these to the present. At this site two sea-level notches are present, one cut in raised beachrock and one cut in a limestone cliff behind the beach on which the beachrock is present. Particle size analysis based on statistics suggests that during the time period of beachrock formation (recently), depositional conditions differed from those presently. The data also suggest that different processes were occurring along the same coastline as angular clasts of limestone are preserved in some beachrock while none are present in the modern beach sediments or adjacent beachrocks. These findings indicate that the angular clasts resulted from rock falls from the limestone cliffs and were incorporated rapidly within the beachrock. Furthermore the textural maturity at the time of cementation of the beachrock is lower (coarser sediments) compared to the present with higher textural maturity (finer sediments). The higher sea-level notch is cut in the White Limestone and the lower (active) sea-level notch is cut in raised beachrock that contains the angular limestone clasts. The higher notch cannot be ascribed to higher sea-levels, and is here interpreted to be due to neotectonics, consistent with uplift of maybe 40 m for the Late Pleistocene Falmouth Formation (100 k yr B.P.) at the site. The angular clasts may also have been formed by cliff collapse due to neotectonics. Carbon dating of aragonite shells in the beachrock should help us to constrain this neotectonic activity but it is expected to be recent, and younger than the beachrock.
Constance Ting Chua (Earth Observatory of Singapore, Nanyang Technological University)

Tsunami Damage Estimation for Coastal Infrastructure in Macau Based on Damage Fragility Curves Derived from the 2011 Great Eastern Japan Tsunami

Recent studies indicate that heterogeneous fault slip along the Manila Trench is capable of generating large tsunami waves which can severely affect many of the coastal cities in the South China Sea basin. To date, damage estimations for tsunami events have primarily been focused on assessing building damage, and the risk to critical infrastructure such as ports to tsunami impacts is still poorly understood. Tsunami damage fragility curves are commonly used to quantify tsunami damage to buildings. Here we present a case study on potential damage to coastal infrastructure in Macau. We develop tsunami damage fragility curves for various port industries, based on observations from the 2011 Great Eastern Japan tsunami. We present a detailed synthesis of damage through spatial analysis based on satellite imagery and photograph interpretations in the framework of Geographical Information System (GIS). The fragility curves are then applied to the ports of Macau, which have been chosen as our first training site for the South China Sea. We estimate the likely damage to port structures in Macau in a Manila Trench earthquake-related tsunami, where a number of scenarios will be considered.

Noelynna Ramos (National Institute of Geological Sciences, University of the Philippines, Quezon City, Philippines)

Preliminary analysis of coastal sediments in Zamboanga del Sur, Philippines: Could they be related to the 1976 Mw8.1 Moro Gulf earthquake and tsunami?

This study highlights our initial and preliminary data on the coastal sediments of Pagadian City and nearby coastlines in relation to the 1976 Mw8.1 Moro Gulf earthquake and tsunami in southern Mindanao Island, Philippines. The Moro Gulf tsunamigenic earthquake remains to be the most damaging recent earthquake in the country, having devastated the coastal provinces of Maguindanao, Zamboanga del Sur, Lanao del Sur, and Pagadian City. The earthquake occurred on 17 August 1976 (1211H PHT) beneath Moro Gulf and was reported to have been generated along a shallow NW-SE trending fault of the Cotabato Trench. In this study, we conducted coastal surveys and initial surface drilling along the coasts of Pagadian City and nearby municipalities to investigate the potential overwash sediments of the 1976 tsunami event. Coastal sediments were sampled from lagoonal and mangrove swamp environments, wherein 1-m-long auger cores and geoslicer samples were extracted to examine the characteristics of background sediments and potential event deposits. Sediments are generally composed of lithic volcanic fragments with grain sizes of 3.00 to 2.00 φ, with thin to thick occurrences of clay to peaty silt layers. Their possible association to the Moro Gulf tsunami has yet to be constrained with further sedimentological and radiometric analyses. These initial data hope to provide baseline information on the occurrence and
characteristics of sediments along tsunami prone coastal zones in western Mindanao Island, Philippines.

Athi Mfikili (South African Environmental Observation Network)

Evidence of late-Holocene tsunami deposits in estuaries along the South African coast

Tsunamis are ocean waves generated by underwater disturbances of the seafloor or by surface impacts, triggered mostly by earthquakes and less commonly, by landslides, volcanic eruptions, and meteorite impacts. The strong wave surge during a tsunami event entrains marine sediment from the seafloor and deposits it onshore. Estuaries, tidal marshes and wetlands located behind low coastal barriers host a record of tsunami deposits, where they are often covered by peat or mud and thus preserved as part of a stratigraphic sequence. These deposits can be dated to provide their age, which could be used to estimate the relative magnitude of near- and far-field tsunamis and to determine the frequency and magnitude of tsunami inundation.

Although South Africa is not demarcated as a global site of high tsunami risk, the Indian Ocean Tsunami on 26 December 2004, as well as recent studies, have revealed that the coastline is susceptible to tsunami events generated in the subduction zones of the Indian Ocean. Based on numerical models, the bathymetry and orientation of Algoa Bay along the southeast coast of South Africa are key elements that could amplify the effects of tsunami waves, especially in the western sector of the bay and inside the two ports. However, to date, these models have not yet been validated by geological sampling for historical tsunami deposits. Unpublished field data on the intertidal areas of the Swartkops Estuary in Algoa Bay revealed a layer of marine sand and shell deposits up to 2 m in depth, which is believed to have been deposited during a Late-Holocene tsunami event along this coastline. In this study, we propose to investigate evidence of Late-Holocene tsunami deposits in selected estuaries and bays along the coast of South Africa. The outcomes of this study will improve our knowledge on tsunamis that can be used to improve risk assessment and to establish appropriate environmental set-back lines along the South African coastline.

Louise O’Boyle (School of Natural and Built Environment, Queen’s University Belfast)

Monitoring of sea level variations for studies of coastal boulder transport on the Aran Islands, Ireland

Recent evidence from winter 2013/14 has shown that storm waves are responsible for transporting boulders on the Aran Islands and at other locations in Galway Bay, Ireland. Transportation of boulders and megagravel with masses greater than 50t, and at least one block of mass exceeding 500t, has been recorded at elevations of up to 25m above the high
water mark. Boulder transport on this scale would not have been predicted based on the existing wave records and tidal predictions. During this period of observation, the greatest significant wave height recorded west of the Aran Islands was 13.6m (on 26th January 2014). This measurement was obtained from the M6 weather buoy located over 300km from the study location.

In order to improve understanding of the nearshore wave climate in this energetic environment, and to further our understanding of boulder transport in this area, a field measurement campaign is ongoing to measure waves incident on the Aran Islands. Instrumentation during the winter of 2016/17 included the deployment of 3 intertidal DHI Sense pressure sensors sampling continuously at 10Hz, coupled with a tide gauge and atmospheric pressure sensor on Inishmann. These data are also correlated with wave measurements offshore.

These data will further our understanding of nearshore wave transformation processes and contribute to the development of wave propagation models for prediction of storm wave impacts on our coastlines.

Jessica Pilarczyk (Division of Marine Science, University of Southern Mississippi)

Paleoseismic evidence of earthquakes and tsunamis along the southern part of the Japan Trench

The northern part of the Japan Trench has frequently generated tsunamigenic earthquakes up to ~M 8.0. In contrast, the middle and southern parts of the Japan Trench were considered relatively inactive until the 2011 Tohoku-oki (M 9.0) event generated one of the largest tsunamis in recorded history. Geologic evidence from the Sendai plain revealed an event in CE 869 that could have forecast the severity of the Tohoku-oki tsunami in 2011. Seismic models indicate that the Tohoku-oki earthquake may have transferred stress southwards down the fault to the potentially locked southern part of the Japan Trench. This transfer of stress towards a locked section of the trench could produce an earthquake in the near future that would be comparable in magnitude to the Tohoku-oki event.

Reconstructing the history of individual great earthquakes and accompanying tsunamis using geological records from the coastal zone adjacent to the southern part of the Japan Trench provides an assessment of the seismic hazard for metropolitan areas in east-central Japan. We have found two anomalous marine sand layers intercalated with muddy peat, which can be traced 3.8 km inland and 5.5 km along the present Kujukuri coastline approximately 50 km east of Tokyo. Both sand layers have features consistent with tsunami deposits, such as a distinct erosional base, ripup clasts, normal grading, mud drape, and marine foraminifera. Results of radiocarbon dating constrain the age of the upper sand to 337 - 299 cal. yrs. BP, which likely corresponds to the only known southern Japan Trench rupture ever recorded, the Empo tsunami of CE 1677. The age of the lower sand is 979 – 903 cal. yrs. BP; marking an event for which there is no historical documentation at present. Preliminary tsunami simulation models indicate that a middle trench (Tohoku-style) rupture is not responsible for
significant inundation of the Kujukuri coastline and would not have been capable of depositing either sand layer. Similarly, published simulation models of the Empo earthquake do not produce sufficient inundation to explain the occurrence of either sand, indicating that the historical Empo event may have been larger (i.e., in slip area and magnitude) than previously thought.

Fengling Yu (Xiamen University)

Quantitative Research on the Sediment Processes in Small Estuaries—A Case Study of Jiulong River Estuary, southern China

Estuary-deltas are typical land-ocean interaction zones, the marine and terrigenous material from which is an important part of the global material cycle. Understanding the transport process of estuarine material is an important link for understanding global material circulation. However, existing studies mainly focus on the distribution law of marine and terrigenous material in large estuaries, resulting in limited research on estuary sedimentary models and their quantitative research. Compared with large estuaries, small estuaries have uniform provenances, smaller accommodation spaces and less tributaries, which facilitates quantitative research with high space-time resolutions.

Taking a small estuary, Jiulong River estuary (JRE) in Fujian Province as an example, this study aims to develop a sediment transport model with the four stages of sedimentary process: horizontal transport, vertical settlement, deposition and resuspension. This aim was explored through three steps: Firstly, organic carbon isotopes were employed as contrastive tracer indices of suspended particles. Secondly, by using multi-station fixed-point synchronous observations, we collected particulate sediment from the four stages, and the transport processes during the four stages were observed. Finally, the sedimentary mechanism of the JRE was quantitatively analyzed by the existing ROMS model.

Results show that in the JRE, the turbidity maximum zone plays an important part in filtering the terrigenous particulate organic matter, with large amount of terrestrial sediment trapped in the upper estuary. Results also show that resuspension is the main reason for the high concentration of terrigenous sediment in the estuary. The results of this project are expected to provide an important theoretical basis for the sedimentary process study of small estuaries, and can be further used in large estuary studies, thus offering important scientific bases for further study on the role of estuarine material in the global material circulation.
Peter Vos (Deltares)

Tidal-facies transitions as sea-level index points from archaeological terp sites in the coastal area of the province of Friesland (northern Netherlands)

Dwelling mounds or terps were raised in the salt-marsh region of the northern Netherlands from the middle of the first millennium BC up to the late Middle Ages when salt-marsh areas were diked in. People lived and worked safely in the prehistoric times on these high and dry artificial platforms.

Since the excavations in the terp of Wijnaldum-Tijitsma (1991-1993) geological research has been part of nearly all archaeological terp excavations in the province of Friesland. The cooperation has proved beneficial to both parties. For archaeologists, geology is indispensable for understanding the developments in palaeo-landscape, and the relationship between human inhabitants and the surrounding landscape. For geologists, the archaeological sites in this area offer the opportunity to acquire detailed data of the natural sedimentary sequence below and next to the artificial terp layers.

The acquisition of palaeo sea-level data was subsidiary to the palaeoenvironmental research in the archaeological excavation pits. The dated transitions between the intertidal and supratidal deposits are palaeo mean high water level (MHW) index points (age / depth data). Therefore they can be used as proxies in sea level studies. The palaeo-MHW was estimated to lie about 20 cm above the base of the salt-marsh facies and a range of 2-10 cm was applied as the compaction correction of the sandy tidal-channel subsurface. The sedimentary boundary between the intertidal- and supratidal deposits can be easily distinguished. The intertidal flat deposits consist of very fine clayey sands which are almost homogeneous (no layering) due to strong bioturbation by marine organisms. The salt-marsh deposits consist of clays with a varying number of thin and crinkly sand or silt layers. The top of the intertidal deposits was radiocarbon dated by marine shells (mainly Scrobiculalia plana) which were exposed in excavation pits. A sea-level curve from 3.5 ka was compiled from 12 terp sites in the province of Friesland. The MHW curve and the relation between the palaeo-MHW and mean sea level (MSL) will be discussed in the presentation. It is worth noting that the observed changes in palaeo-MHW level should not only be attributed to MSL change, but also to changes in the geometry of local tidal systems. For instance, at present MHW near the mainland coast is 20 cm higher than in the main tidal inlet. To fully separate sea-level rise from these morpho-dynamic MHW effects, the bathymetry of the past tidal system also needs to be palaeogeographically assessed.
Kerrylee Rogers (School of Earth and Environmental Sciences, University of Wollongong)

Sea-level change and mangrove shorelines: from monitoring to millennia

On low-energy tropical and subtropical shorelines, mangrove forests occur within the upper part of the intertidal. Although not as readily preserved as coral reefs, mangrove sediments provide a paleoecological record of past sea levels. The accumulation of sediments beneath mangroves, whether autochthonous organic or allochthonous minerogenic, is a function of accommodation space. We present a framework for viewing the response of mangrove shorelines to sea-level change at millennial timescale, based on an adaptation of the concepts of keep-up, catch-up and give-up that have been so successfully adopted in relation to coral reefs. We use this framework to revisit the discussion about whether coastal wetlands are able to keep up with sea-level rise. We show that, when studying coastal wetlands such as mangroves and salt marshes, it is necessary to understand the processes by which sediments accrete and substrate elevation changes. Short-term observations indicate that sediment accretion and substrate adjustment vary in complex ways within a wetland unrelated to changes in mean sea level. However, most coastal wetlands are restricted to the upper portion of the tidal frame, such that their longer-term trajectory does appear to track sea level. At millennial timescales, it has been shown that there is considerable geographical variation in the pattern of relative sea-level change, and as a consequence there are important contrasts in the stratigraphy of coastal deposits which have resulted in substantial differences in the long-term capacity of coastal wetlands in different parts of the world to sequester carbon. Observed, and anticipated, sea-level rise, now and into the future, can be considered to similarly result in different capacities to store carbon in the substrates below mangroves, and associated wetland systems, providing challenges as to how to model the potential carbon pools and incorporate coastal wetlands into broader initiatives that aim to mitigate the effects of climate change.
Matsinhe Celso de Carvalho (Tongji University)

Tidal fluvial systems of the Selune Estuary, France

Tidal-fluvial systems have been extensively studied in the past decades. The spatio-temporal variation of sedimentary textures, structures, geochemical contents and their interrelationship from macrotidal systems are of academic interest, and the spatio-temporal variation can be extensive with changes in tidal flow condition, river discharge and topography. In this paper, the sedimentary and geochemical characteristics of modern deposits are investigated in detail at the Selune estuary in the Mont Saint Michel Bay (France). Tidal bore is one of the most important factors to control sediment distribution and channel evolution. Time-series satellite images and sediment cores are therefore collected from the bore-affect estuarine reach to study the impact of tidal-bore and associated activities on the channel morphology and depositional facies. Carbonate contents, grain-size parameters and hydraulic components are then calculated through some mathematical functions. Geochemical contents are analyzed by using XRF core scanner to get relatively elemental concentration (e.g., Ca, Ti). Well-developed tidal rhythmites can be found, with some structural characteristics at the intertidal flat showing a gradient of bedding thickness comprising thick massive sand, relatively high carbonate content with high ratio of Ca/Ti and coarser particles, to well-developed tidal rhythmites at upper intertidal flat. Most sedimentary characteristics observed from the Selune bore affected reach are comparable with those in the middle Qiantang estuary fostering the world’s largest tidal bore, except for the former highly abundant with carbonate contents from marine source.

Anne Griffis (Division of Marine Science, University of Southern Mississippi)

Lagoon sediments document a 3000-year-record of overwash events impacting northeastern Oman

Countries boarding the Arabian Sea are susceptible to inundation from tsunamis due to their close proximity to the Makran Subduction Zone (MSZ). However, the historical accounts of tsunamis affecting these coastlines are spatially and temporally limited. Examining the sediments deposited by prehistoric tsunamis provides a means for bridging this gap and extending the timeframe of events to include centennial to millennial timescales, capturing the long-term spatial and temporal variations associated with MSZ earthquakes and tsunamis. Recent geological and archaeological investigations along the Omani coastline have revealed additional historic and prehistoric tsunamis, including the most recent event in 1945.

On November 28, 1945 an 8.1 Mw earthquake originating from the MSZ generated a tsunami that inundated coastlines encompassing the Arabian Sea with wave heights reaching up to 13 m. At Sur, a small fishing village located on the northeastern coastline of Oman, the
tsunami deposited a laterally continuous shell-rich layer within 12 km² lagoon. This shell layer contained distinctive taphonomic assemblages of foraminifera and bivalves. Below the 1945 shelly deposit at Sur Lagoon, seven anomalous sand layers were found preserved within finegrained lagoonal sediment. These layers of medium to coarse sands range in thickness from 10 to 35 cm and are separated by sandy-mud sediment. Extensive grain size analysis indicates each of the anomalous sand layers are followed by an abrupt return to lagoonal mud. Many of the sand layers have features consistent with the 1945 tsunami deposit such as fining upward sequences, a sharp basal contact, and marine foraminifera species (e.g., *Amphistegina sp.*, *Ammonia inflata*, planktics). In contrast, the surrounding lagoon deposits are generally massive, finer in grain size, and contain foraminiferal species typically found within shallow quiescent coastal environments (e.g., *Ammonia tepida*, *Elphidium gerthi*, miliolids). We have attributed these seven marine sand layers to tsunami overwash deposition. Preliminary radiocarbon dating of articulated bivalve shells establish a late Holocene age range for the tsunami sand layers. Not including the 1945 deposit, tsunami-related sediments more recent than 1390 cal yBP are not present within the lagoon. Ongoing analyses will constrain the timing of each of the seven overwash layers and will assess relative magnitudes of the events that deposited them.

**Greta Janigian (Department of Geosciences, University of Rhode Island)**

A stratigraphic and microfossil record of coseismic land-level changes and tsunami deposits from Old Harbor, central Kodiak Island, Alaska

The Alaska-Aleutian subduction zone has produced multiple great megathrust earthquakes in recent history. Almost the entire subduction zone interface ruptured in the 20th century with earthquakes greater than M8.0 in 1965, 1964, 1957, 1946, and 1938. The largest of these was the M9.2 1964 Great Alaska earthquake. Our study site, Old Harbor on Kodiak Island, is near the western end of the 1964 rupture zone. Old Harbor was severely damaged both by subsidence and a tsunami with a run-up of 7.3 m above Mean Sea Level. Thirty four of 35 residences were destroyed. Coastal subsidence was estimated by Plafker and Kachadoorian (1966) at 0.6-0.9 m and may include a component of compaction of the coastal sediments. Old Harbor may lie within the rupture area of an earthquake in 1788 that was reported 15 km to the southwest at Three Saints Bay.

To reconstruct the paleoseismic history of Old Harbor, we undertook exploratory coring at two coastal sites, Big Creek and Bear Terrace, both 1 km northeast of Old Harbor. We chose the longest core from Big Creek for analysis. Six sand layers occur in this core (BC.15.02). The uppermost sand deposit probably records the 1964 tsunami, the most recent large tsunami to inundate Old Harbor. This sand layer lies 5 cm above a layer of pumice from the 1912 eruption of Mount Katmai, which is located ~150 km northwest of Old Harbor. Three of the sand layers (including the 1964) are associated with site submergence. Computerized tomography (CT) scans and X-rays were taken of the cores to determine density changes throughout the cores. Diatom and grain-size analyses will be used to determine the source of each sand and evaluate degree of land level change associated with sand deposition. Radiocarbon dating and radiometric marker (Cs-137 and Pb-210) analyses will aid in
estimating ages of sand deposition. We will compare our age results to established chronologies from nearby study sites at Sitkinak to the southwest and Kodiak to the northeast. Where sand beds from our cores are not associated with land-level changes and/or do not correlate with historic or paleoseismic records, we will investigate whether diatom assemblages support the alternative depositional mechanisms, which are storms or floods.

Anandasabari Karthikeyan (Geodynamics Unit, Jawaharlal Nehru Centre for Advanced Scientific Research)

Holocene records of high energy events in the Geological Record: Sedimentary deposits from Cauvery Delta Coast, SE Coast of India.

The Cauvery Basin is one of the important sedimentary basins of southern India and provides information on geological processes since the Cretaceous. Most of the studies in the basin have been carried out on the sediments of Cretaceous age, with less emphasis on the Quaternary period with marine high energy events. In the present study, we present the sedimentological and micro fauna assemblages from a 150 cm long trench in the Kameshwaram village, Nagapattinam District, South East Coast of India, in order to reconstruct previous high energy coastal inundations. OSL and Carbon dating of sandy sediments from the Cauvery Basin provide the first proxy-record of high energy marine events from the region over the mid Holocene. The dating of the event layer indicates an age of 6 kyrs (6545 BC), material beneath the layer was dated at 8 kyrs. A combination of sedimentological parameters of grain size, sorting, geochemical analyses (XRF) of Fe, Mn, Ti, Cr, Cu, Ni, Sr, Zr and foraminifer species like Ammonia beccarii, Ammonia dentate and Asterorotalia trispinosa were identified. The sediment layers have thinning-up sequences start from the bottom of the layer at 150 cm to 130 cm, and include shell debris and rip-up clasts. In addition, characteristic increases in elemental content in the bottom units of Zr, Ti, Ca is evident, an indicator of a high-energy depositional event (often associated with an increase in Ti (2.08 % to 16.016 %) and Sr (116 ppm to 275 ppm)). Ca on the other hand suggests a marine influence and Fe, Mn, Cr, Ni values show lower concentration indicating marine incursion. Based on the multiproxy evidences, we conclude that this could be a major high energy marine incursion during the mid Holocene period in this region, one which is being studied in detail in other parts of the coastal region of SE India.
Thomas Kosciuch (Division of Marine Science, University of Southern Mississippi)

Sedimentological and micropaleontological characteristics of the 2015 Hurricane Joaquin deposit: implications for long-term records of storms and tsunamis impacting the Caribbean

Late Holocene relative sea-level (RSL) histories provide important context for understanding past, present, and future sea-level changes. However, there is a significant gap in RSL records in Rhode Island, USA. To address this, we will reconstruct RSL along the coast of Narragansett Bay, Rhode Island where numerous salt marshes offer suitable environments for sea-level research. We will produce a compaction-free record by utilizing the basal peat approach. By using foraminifera as sea-level indicators, and in-situ plant rhizomes for radiocarbon dating, our record will have centennial-scale age errors and decimeter-scale vertical errors. A collection of laterally- and vertically-ordered basal peat samples have been sampled from several marshes. Basal peat recovered ~3.5m below the modern marsh surface holds the potential for reconstructions extending back ~3000 years. This study will determine the rate of late Holocene RSL rise in Rhode Island and will help determine if glacial isostatic adjustment varies within the state. Additionally by comparing this basal peat sea-level reconstruction with an ongoing single core reconstruction at a shared study site, the role of sediment compaction in local reconstructions will be determined. This study will add new sea-level index points to the east coast of the United States sea-level database and provide important insights for the refinement of Earth-Ice and climate models.

Makan A. Karegar (School of Geosciences, University of South Florida)

Nuisance Flooding and Relative Sea-Level Rise: the Importance of Present-Day Land Motion along the Atlantic Coast of North America

The Atlantic Coast of North America is experiencing spatially variable, long-term vertical motion due to glacial isostatic adjustment (GIA). Most of this margin is increasingly affected by nuisance flooding which causes inundation of many low-lying areas. High-quality records of late Holocene relative sea-level (RSL) rise are now available, allowing separation of long-term GIA-induced displacement from modern vertical displacement measured by GPS. We compare geological records of late Holocene RSL to present-day vertical rates from GPS. For many coastal areas we found no significant difference between these independent data. Exceptions occur in areas of recent excessive groundwater extraction where the present-day subsidence rates are approximately double the long-term geologic rates.

While sea-level rise is a global issue, the goal of this work is to heighten awareness of the problem of human-induced land motion and its relationship to nuisance flooding. We assess the frequency and location of nuisance flooding along the eastern seaboard of North America, and compare these to a wide range of datasets. We show that groundwater-induced subsidence is a contributing factor for certain regions that are currently affected by increasing rate of nuisance flooding. Our analysis and results are based on a range of datasets that cover different time scales (e.g., GPS, tide gauges, GRACE, hydrological models,
Holocene RSL rise rates and GIA models). Our results have implications for flood susceptibility, forecasting and mitigation, including better management practices for extraction of groundwater from coastal aquifers. It is also important to recognize that areas currently experiencing nuisance flooding are “canaries in the coal mine” for many other coastal areas that are increasingly susceptible to both nuisance and catastrophic flooding as sea-level rise accelerates.

Kathrine Maxwell (National Institute of Geological Sciences, College of Science, University of the Philippines)

Long-term deformation and relative sea level changes in northwest Luzon, Philippines deduced from emerged coral platforms

We studied raised coral sequences in Badoc Island, Badoc, and Currimao, northwest Luzon, Philippines to understand long-term deformation and relative sea level changes during the Late Quaternary. In the three localities, we identified three to possibly four Holocene terrace platforms that are generally well preserved and with varying heights and widths. Three terrace steps are recognized in Currimao with the lowest step (TI) measured 3.3 to 3.7 m above mean sea level (amsl), TII measured 6.1 to 6.8 m amsl, and TIII at about 8.4 to 9.2 m amsl. Two to three terrace platforms are observed in Badoc and measured from the lowest to highest at 2.1 to 3.6 m, 3.8 m, and 6 to 9.1 m amsl. Three to possibly four terraces are recognized in Badoc Island with the highest terrace inferred to rise up to ~7 m amsl. We observed variably elevated terraces around the island with TI measured at 1.9 to 3 m and 2.3 to 3.7 m amsl along the east and west coasts, respectively, TII measured 3 to 3.8 m amsl, TIII measured 4.2 to 5.3 m amsl, and a possible TIV measured ~7 m amsl. Corals about ~7000 to 6000 years BP are collected on top of the lower terrace steps in the three localities and could possibly represent the mid-Holocene marine transgression. Meanwhile corals samples in Badoc Island yielded two sets of Late Holocene coral ages: 2,726.84 ± 13 years BP and 945.10 ± 5 to 903.14 ± 4 years BP. It is suggested that an episode of RSL rise during the mid-Holocene was recorded in an attached coral yielding an age of 2,726.84 ± 13 years BP, however, available data is limited and further studies should be done to further constrain this period. The very young samples dated at 945.10 ± 5 to 903.14 ± 4 years BP possibly represent extreme wave events that could have emplaced these corals on top of the 4.9 m amsl terrace surface. Whether the young corals were transported by a tsunami or a strong typhoon, their occurrence on top of a ~5 m-high terrace highlights the importance of understanding coastal hazards along northwest Luzon, Philippines and the South China Sea region.
Replicability of coseismic subsidence estimates using foraminifera from Humboldt Bay, northern California

Microfossils, primarily foraminifera and diatoms, have been used to reconstruct the amount of coseismic coastal subsidence during past megathrust earthquakes. With a sufficient density of estimates we can constrain geophysical models of megathrust rupture. Comparisons of foraminiferal-based estimates in tidal-marsh cores 10-20 m apart demonstrate estimates are reproducible. However, little work has investigated the reproducibility of such estimates over distances of 1-5 km in tidal marshes of the same estuarine system. Here we investigate four abrupt peat-to-mud (coseismic subsidence) contacts along a 6-km transect at three sites (Jacoby Creek, McDaniel Creek and Mad River) in northern Humboldt Bay, California (~44.8°N, -124.2°W).

We derived quantitative reconstructions of relative sea-level rise across each contact by applying a transfer function to fossil foraminiferal assemblages. The validated transfer function uses a modern foraminiferal dataset (174 samples) from six coastal sites in Oregon. To assess the replicability of our coseismic subsidence estimates, we analyzed 3-5 different core sections across each peat-to-mud contact. For the 250 cal yr BP earthquake (AD 1700), we obtained estimates of 0.63, 0.39, 0.32, 0.29, and 0.22 m (average of 0.37±0.32 m at ±2 SD). For an earthquake ca. 870 cal yr BP, we obtained estimates of 0.5, 0.39, 0.37, 0.30, and 0.09 m (average of 0.33±0.30 m). For an earthquake ca. 1,125 cal yr BP, we obtained estimates of 0.52, 0.40, and 0.36 m (average of 0.43±0.16 m). For an earthquake ca. 1,600 cal yr BP earthquake, only minimums subsidence estimates could be determined (≥0.74, ≥0.55, ≥0.48, and ≥0.39 m) because the contact formed above the upper limit of foraminiferal habitation. The results highlight that there is variability in subsidence estimates derived from different locations in the estuarine system. The variability in subsidence estimates (ranging from 0.16 to 0.41m for four contacts) lies within the 1σ error of the transfer function reconstructions (±0.25 m at Humboldt Bay). When using fossil foraminifera to reconstruct subsidence with transfer functions, we recommend replicate reconstructions for each contact per estuary.

Siddharth Prizomwala (Active Tectonics Group, Institute of Seismological Research)

Late Pleistocene-Holocene sea level fluctuations inferred from the fluvial sequences along the western coast of India

Sea level fluctuations during the Holocene period have long been a topic of debate. Based on geochemistry, sedimentology and optical dating we examine two fluvial sequences near the coastline of western India as a potential archive for sea-level changes. We report on estuarine successions from Kharod river, Kachchh and the lower most segment of Shetrunji River, Saurashtra. The oldest units in the sequences dates back to 13 ka, when the sea level was speculated to be much lower than present. The geochemical data of the deposits suggest
strong monsoonal conditions prevailed during the early Holocene with much lower sea levels from those of the present day. This was followed by sea-level rise between 6 ka to 3 ka, illustrated by the geochemical and sedimentological signatures. The extent of the transgression, was estimated based on the landward extent of these sedimentary signatures, together with archeological evidence. It is estimated at being least 2 m higher than present day level. Based on geochemistry, sedimentology, and archeological findings, we reconstruct three stages of sea level occupation viz, a lower than present level during the Early Holocene period, higher levels during the Middle Holocene, and attainment of present day like conditions during the Late Holocene period. The findings were also consistent with the climate history of the western Indian region during the Holocene.

**Jennifer Walker (Department of Marine and Coastal Sciences, Rutgers University)**

Testing a new multi-proxy presence/absence method to produce a mid Holocene relative sea-level record in New Jersey

Most high resolution relative sea-level (RSL) records for the U.S. Atlantic coast using salt-marsh microfossils as a proxy only extend through the Common Era, which limits our understanding of driving mechanisms of RSL change and how sea-level is influenced by changing climate. Records beyond the Common Era are limited by the depth of continuous sequences of salt-marsh peat, which is suitable for high resolution reconstructions, as well as contamination of the RSL record by local processes such as sediment compaction.

We devise a new Multi-Proxy Presence/Absence Method (MP²AM) to develop a mid Holocene RSL record. We extract a series of 1 m basal salt-marsh sediment cores that overlap along an elevational gradient. We analyze each core for a combination of three sea-level indicators: foraminifera, testate amoebae, and stable carbon isotope geochemistry. To reconstruct RSL, this multi-proxy approach uses presence/absence of foraminifera and testate amoebae to determine the locations of the highest occurrence of foraminifera and the lowest occurrence of testate amoebae in each basal core. We use stable carbon isotope geochemistry to determine the C3/C4 vegetation boundary in each basal core. We develop age depth models for each 1 m sediment core using a series of radiocarbon dates. The RSL record from each 1 m individual short basal cores are combined to create a “stack,” or in effect, one long core of salt-marsh material. This method removes the issue of compaction in order to create a continuous mid Holocene RSL record for southern NJ to address temporal changes and to identify periods of climate and sea-level variability.

We aim to reconstruct the mid Holocene RSL record from Edwin B. Forsythe National Wildlife Refuge in southern NJ where Kemp et al. (2013) previously completed a 2500 year RSL record using a foraminifera-based transfer function approach. We have completed a stratigraphic survey from 16 cores. We have identified a basal peat along a uniform elevational gradient above an incompressible basal sand contact. Preliminary radiocarbon dates suggest the basal salt-marsh sequence is at least 4246-4408 cal yrs BP.
**Mengyuan Wang (Department of Earth Sciences, The University of Hong Kong)**

**New MIS5 sea-level records from the southeast coast of China**

Over the past decade, late Pleistocene marine deposits have been found in many sites along the southeastern coast of China. Most previous studies on this marine unit provide radiocarbon ages between 1.8 ka and 44 ka, showing a time span from marine isotope stage 3 (MIS 3) to MIS 2. However, recent records suggest that this marine unit should be a deposit of MIS 5. This presentation reports high-resolution sea surface temperature (SST) changes for the MIS5 period reconstructed from the Hainan Island (18°16′N), Pearl River delta (22°16′N) and the Fujian coast (25°55′N), supported by optically stimulated luminescence (OSL) dating analyses. Other data from this unit include the abundance of long-chain alkenones, sediment grain-sizes, foraminifera abundances and sediment color indices that reveal changes of environmental conditions during the deposition. Whilst the sea surface temperature record helps confirm the timing of the deposition, other data provide details for inference of the water depth or palaeo-sea-level height. Specifically, a high-resolution UK′37-SST record indicates the unit was deposited during the peak period of the Eemian interglacial (i.e. MIS5e). Secondly, the reconstructed water depth implies a higher-than-present palaeo-sea-level during this time period, after the tectonic component is included in the estimates. Finally, a decreasing trend of SST from approximately 29°C to 26.5°C during MIS5e is consistent with the changes in sediment grain size, suggesting a correlation between the cooling trend of SST and the gradual lowering of sea level.

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**Jinpeng Zhao (State Key Laboratory of Marine Geology, Tongji University)**

**Suspended sediment transport in Xinghua bay**

Xinghua Bay is located in the central coastal region of Fujian Province and the west side of the Taiwan Strait (119°06′28.26″~119°30′56.82″E, 25°15′49.56″~25°36′01.03″N). A cruise was carried out in March (2016) to survey the hydrodynamic setting of the Nanri waterway (119°24′33.42″E, 25°16′39.50″N) in Xinghua Bay, obtaining 26-hour continuous observational data regarding sediment transport in winter and the environmental characteristics in Xinghua bay. An Ocean Seven 304Plus CTD Probe, Optical Backscatter Sensor and Flow-Quest ADCP 600 kHz were used to collect temperature-salinity and current profile data, respectively. Based on the water and sediment data measured in the Xinghua bay by use of the mechanism decomposition method, the characteristics of the suspended sediment transport in the Xinghua bay have been illustrated highlighting the mechanisms of the advection, tidal pumping effects, vertical circulation and shear diffusion for sediment transport. The analyses show that offshore-sediment moves toward the inner of the bay along the Nanri channels under the action of tide. The advection and tidal pumping effects are the primary factors for the suspended sediment transport, the shear diffusion and the vertical circulation also play an important role in suspended sediment transport. The sediment transport under tidal pumping effect is dominated by the correlation between the
suspended sediment and the tidal current, which is less than the sediment transport caused by the advection and more than the sediment transport caused by vertical circulation and shear diffusion.

**Bastian Schneider (Steinmann Institut, University Bonn)**

**Quaternary elevated marine shorelines in north-eastern Oman**

The coastal geomorphology of Northeastern Oman indicates dynamic landscape evolution during the Quaternary associated with differential crustal movement. The area is characterised by a staircase of raised terraces with elevations of up to 450 m. We aim to quantify the vertical crustal movement in order to understand the tectonic geomorphology, neotectonics and related earthquake activity.

Terrace formation took place during the Quaternary. Bioerosion and abrasion produced wave-cut platforms within Upper Cretaceous to Eocene limestone formations during times of global eustatic sea-level highstands. Serpentinised peridotites of the Semail ophiolite underlie the limestone formations.

We mapped the terraces over a coast parallel distance of 60 km and identified at least twelve terrace levels aided by ground-based differential GPS measurements and a high-resolution digital elevation model. The uppermost terraces are erosional, whereas the lower ones are depositional in style. Mollusc and coral remains as well as beachrock are encountered on the terrace surfaces. The formations are dissected by a NW-SE trending fault. The precise levelling of the shoreline angles revealed a tilting of the terraces towards the north.

Individual terrace levels were sampled for two independent dating approaches. Optically stimulated luminescence dating was performed on delta deposits covering the lower terrace levels; surface exposure dating based on cosmogenic nuclide (10Be and 36Cl) was performed on samples collected on higher levels as well. Our dating results indicate that the terraces formed within the last million years. The oldest dated terrace level revealed ages correlated to MIS 15 and the lowest terrace level is correlated to MIS 5. Every warm phase in between is represented by a sea-level highstand and expressed as an individual terrace level within the coastal morphology. The highest recorded terrace is attributed to MIS 25.

Various models have been put forward trying to explain the neotectonic deformation pattern. These include forebulge development in association with subduction processes. Compressional tectonics dominate with continent-continent collision and along-strike transition to ocean-continent conversion forming the Makran Subduction Zone along the Arabian-Eurasian Plate boundary. We conclude that local components associated with the serpentinization of underlying Cretaceous peridotites have to be taken into account as this process also triggers an isostatic response.
Field trip

**Sunday, 17th September – Coastal morphology, long-term coastal changes**

Check out of hotels in Durban, pick-up and departure to St Lucia. Arrive St Lucia.

Preliminary field trip. The St Lucia estuary and the Narrows, Sunday afternoon.

Location: -28.370102°S; 32.410122°E

The Narrows (Fig. 1) form the current connection to Lake St Lucia, Africa’s largest estuarine system. In the 1950’s the Mfolozi River which also entered the estuary, was diverted to a separate mouth to the south, at Maphelane, altering the hydrology of the estuary and lake irrevocably. Despite these anthropogenic interventions, a substantial hippopotamus (*Hippopotamus amphibious*) and crocodile (*Crocodylus niloticus*) population exists. The area is fringed by extensive mangrove stands of mostly the white (*Avicennia marina*) and red (*Rhizophora mucronata*) varieties, within which countless hippo pathways have been sculpted by these bioengineers.

**Thursday, 21st September – Beachrocks and boulder deposits, the coastal lakes of KwaZulu-Natal**

Stop 1: Mission Rocks

Location: -28.278134°S; 32.485720°E

One of the few laterally persistent rocky shorelines in the area, Mission Rocks hosts a variety of interesting beachrock and aeolianite exposures. The shore platform mainly consists of aeolianites of the Isipingo Fm, considered to be MIS5e in age. A last glacial maximum inlet for the adjoining Lake St Lucia crossed the area, marking the northern terminus of the rocky outcrop (Fig. 2). Superimposed on the platform are thin and variable outcrops of beachrock, representative of deposition in environments that range from the littoral to swash zone. Trough-cross bedded to tabular bedded medium sandstones, and seaward dipping, planar stratified medium sandstones and conglomerates are the most common (Fig. 3).

Mantling the shore platform are a number of large slabs of beachrock that have been deposited as a perched, laterally continuous, seaward-imbricated boulder beach (Fig. 4). Clasts range in size from cobbles, up to boulders with long axes exceeding 5 m in length. Impact marks, chip-structures and pressure solution contacts can be found, indicating recent movement and the periodic deposition of new clasts to the beach. Given the tectonic stability of the area, a storm origin for the blocks is considered appropriate.
Figure 1. General locality of the conference and field trip surrounds.
Figure 2. Lake St Lucia, with underlying incised valley networks superimposed.

Figure 3. Trough cross bedded upper shoreface beachrock facies. Photo courtesy Dr. B. Mauz.

Lunch
Figure 4. Imbricated slabs of beachrock and aeolianite mantling a raised shore platform at Mission Rocks. Note the boulder-swept seaward edge of the platform.

Stop 2: Mfabeni Pan and Lake St Lucia

Location: -28.156385°S; 32.519241°E

Mfabeni Pan (Fig. 3) is one of the oldest known peatlands in southern Africa, spanning ~ 50 ka of continuous deposition. The upper 1 m of the peat spans the entire Holocene period and, where undisturbed by animal movements, allows for a reconstruction of the hydroclimate for the last 11.5 cal. ka.

The adjoining Lake St Lucia system forms an important component to the regional groundwater aquifer of the area. Fluctuating lake levels, initially driven by sea-level variations, then later by El Niño cycles, provide important clues as to the response of the coastal zone to climatic and sea-level drivers. The system appears to have formed in the Pliocene, when the hinterland was uplifted and several rivers incised the original bedrock-hosted incised valley. These have later been exploited by successively younger stages of the palaeo-drainage, the most recent of which were the last glacial maximum fluvial systems which exhumed almost all the older infill and cut several inlets to the north, at Leven Point, and to the south, at Mission Rocks. The infilling of these LGM aged channels reveals a stepped rise in sea level since the LGM. Both inlets closed ~ 7-6 cal. ka BP, marked by a change to tranquil estuarine-lake style deposition. Major oceanic flood incursions, coeval with an increasingly stormy period as documented in the shelf records, occurred ~ 4.55 cal. ka BP.

The stopover looks out over the Catalina Bay area. This area was used as a base by the Catalina bombers of 262 Squadron during WWII, whose mandate it was to patrol the waters between Durban and southern Madagascar for U-boat activity. Parts of the beachrock from Mission Rocks were used to construct the jetties in the area. The area is now known for an
abundant hippo community, a member of whom was imaged in the seismic reflection profile in figure 5.

Figure 5. Seismic profile through the hippopotamus community of Catalina Bay. LGM-aged channels were a bonus image. Soiled underwear not shown.

Friday, 22nd October – Raised coral terraces and Tertiary aged sea level movements

Stop 1: False Bay

Location: -27.970283°S; 32.382223°E

A sequence of vertically stacked shoreline facies exposed by unprecedented water level lowering in Lake St Lucia, South Africa, shows multiple occupation of the same shoreline (5-6m amsl) (Fig. 6) on at least eight occasions since the late Cretaceous. The sequence involves a basal wave-cut surface that is the outcrop of a regional unconformity cut into Upper Cretaceous siltstone, with occasional borings representing a hardground (Facies 1). This is succeeded by a limestone unit indicative of sedimentation in a region of low terrigenous input quite different to today. This commences with a 10cm-thick unit comprising corals and giant clams that colonised the hardground as a shallow reef (Facies 2). The reef has an erosional upper surface that is overlain by a 30-50cm thick coquina (Facies 3) with characteristic sand-lined branching burrows, representing a coarse clastic beach unit of Miocene/Pliocene age. This unit has in turn been colonised by patchy development of a coral reef representing a renewed phase of reef development (Facies 4). The reef and the underlying Facies 3 have been wave-planed and eroded to form an erosional rocky shoreline with small potholes on a shore platform. The potholes are encrusted with barnacles and oysters to form a distinctive unit (Facies 5). The oysters and barnacles are encrusted with red algae suggesting a slight subsequent rise in sea level which is also associated with the formation of an erosional notch and a higher level shore platform with several small erosional gullies (Facies 6). These gullies are in turn encrusted by thick accumulations of serpulid worm tubes (Facies 7) into which two subsequent notches have been cut by wave action.
Figure 6. Sand lined burrow in coral-rubble beach facies (left). Wave-planed rock platform comprising coquina with scattered coralline encrustings.

**Next IGCP 639 meetings**

The next IGCP Project 639 "Sea Level Change from Minutes to Millennia" meeting will be hosted in 2018 in Italy (likely in early to mid September) with the meeting traveling from Apulia to Sicily for fieldtrips. The meeting will be hosted by Giuseppe Mastronuzzi and Massimo Moretti. More details, including the exact dates will follow shortly. For more information on the 2018 meeting, please feel free to talk to any of the project leaders in South Africa.

IGCP Project 639 will be sponsoring sessions over the coming year at the AGU and EGU Annual Meetings, as well as the 24th Biennial conference of CERF. If you wish to host a session under the IGCP Project 639 banner, please contact one of the project leaders.

**Organizers and contact persons**

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