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

First project meeting 9-14 November 2016
Muscat, Oman

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 first meeting of IGCP project 639. It is with great pleasure that we welcome you to Oman and the Middle East, a key focus area for the IGCP project 639. We anticipate that this meeting will provide the building blocks that 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.

Regards,

Simon, Gösta, Fengling, and Alar
General information

Oman is a beautiful, culturally rich, and safe country. English is widely spoken. Temperatures in November vary from 10°C at night to over 30°C during the day. The climate is arid and rain is very rare with an average annual precipitation of only 100mm. Expect the weather to be hot and dry during the conference and field trips.

As a visitor to Oman, participants should be aware of local laws and customs and behave accordingly. Respectful behavior towards Omani traditions, society, religion and the Sultan are required. Shorts, strapless tops, tight clothing and showing cleavage should be avoided. Headscarves are not required for women (apart from if you plan on entering mosques). It is strictly forbidden to export any kinds of rocks, minerals or fossils.

Travel information

Your passport must be valid for at least six months after your arrival into Oman, otherwise immigration will be refused at the airport! Please check if your country is eligible for visa on arrival or if you need to pre-arrange a visa. If you need a visa to be arranged and you haven’t contacted us yet, please do so as soon as possible or you may not be able to enter Oman.

Participants who contacted us to obtain a pre-arranged visa can pick it up at the designated counter in the airport. Please pay the visa fee at the conference. Participants eligible for a visa on arrival can purchase it at the Travelex Foreign Exchange counter at the airport. Oman Rial (OMR), common foreign currencies (such as US-Dollar, Euro, and GBP) and major credit cards are accepted. The best value is to use OMR, the exchange rates for foreign currencies can vary from the general exchange rate.

There are two options for a tourist visa:

a) Single-entry, valid for 10 days, 5 OMR (about 13 US-$), non-extendable
b) Single-entry, valid for 4 weeks, 20 OMR (about 52 US-$), extendable up to 8 weeks for additional 20 OMR

Most participants should be fine with the first option.

Passport and invoice need to be presented at the immigration counter to get your visa stamped into your passport.

We can arrange hotel transportation from the airport but this is likely to involve significant waiting and driving between the different hotels. We there highly recommend taking a taxi from the airport to your accommodation. If you wish to arrange a transfer, please contact Bastian.

Health issues

All participants should check that their health insurance is valid for Oman. Additional travel health insurance covering medically necessary transportation back home is advisable. The quality of medical care situation in Oman is good.
There are no mandatory vaccinations for Oman. We advise participants to check their general vaccination status (such as Hepatitis A, Tetanus).

Venomous animals such as snakes, spiders and scorpions exist in Oman and are sometimes encountered. Please take extra care when you are in the field. However dangerous confrontations or bites are extremely rare.

**What to bring**

Each participant should bring a sleeping bag, a camping mat, sturdy hiking boots, and water bottles for the field trip. Proper sun protection including a hat and sun screen is highly recommended due to the scorching sun. If available, hiking sandals are a good addition to hiking boots. Flip-Flops are any other water-resistant light shoes are recommended, as we might enter a lagoon. Temperatures at night can reach down to 10°C, so 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. Our field camp at Fins is located close to the shore and provides opportunities to swim.

Alcohol is not sold freely in Oman. For non-muslims, the permitted amount of spirits (2 liters) or beer (24 cans) can be purchased cheaply at the Duty-Free-Shop right after the immigration at the Muscat Airport. Do not buy more than your allowance as it will be confiscated. Carrying alcohol openly in public is banned, so duty free purchases should be packed in your luggage.

ATMs accepting credit and debit cards are widely available in Muscat but rather limited in rural areas.

Foreign currencies can be exchanged at the airport.

**Travel Support**

If you have received travel support, you will need to supply Simon Engelhart with all your receipts (Flight and Hotel) before you leave Oman so he can process reimbursements.
**Procedures during the conference**

**Transfer**
The participants will be picked up at the accommodation in the morning and transferred to the conference venue at GUtech University. Transfer time between the hotel and the venue will be between 30 and 60 minutes, depending on the exact location of the hotel. For a detailed schedule, please refer to the conference timetable below. Accordingly, a bus will return the participants to the accommodation after the sessions in the evening.

**Location**
The sessions will take place in room 101 in GUtech University.

**Food and refreshments**
We will supply coffee, tea and snacks during the conference. GUtech University hosts several convenience stores and restaurants where a variety of food and beverages can be purchased.

**Posters and Presentations**
We will provide a laptop 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 180cm (6 feet) wide by 120cm (4 feet) tall.

**Wi-Fi Access**
GUtech University provides a wireless network which can be used by the participants.

SSID: GUtech
Password: gutech@123

**Conference Dinner**
A recommended (but optional) conference dinner will be hold at the rooftop of Eastin Residences on Thursday November 10th and can be booked for 5 OMR at the venue. The Eastin does not provide alcohol, but participants are welcome to bring their own.

**Field trip**
We will provide a tent including a field bed for each participant. Please bring your own sleeping bag and preferably a camping mattress for an extra isolation. It is possible to sleep under the stars which is recommendable due to the great sky at night. Our field camp also includes tables and camping chairs for all participants. We will supply cups, plates and cutlery.

The field trip is full board, including food and soft drinks. Lunch will be in picnic-style in the field. Breakfast and dinner will be cooked freshly in our camp on an open fire. Food is generally simple, according to the limited local possibilities in rural areas. We will also offer halal and vegetarian dishes.
There are no designated toilets in the field camp. Nearby natural shelters such as rocks or bushes provide privacy. Fresh water for hygienic use is provided, however limited due to the climate. Simple showers will be possible with the use of canisters. Swimming in the sea (and wadis) is possible.

Roads are generally 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 a short walk 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, especially due to the expected high temperatures and intense sunshine.

**Conference transfer schedule:**

**Wednesday, 9th November**
- Holiday Inn: 08:00
- Peninsula: 08:15
- Eastin Residences: 08:30

**Thursday, 10th November**
- Holiday Inn: 07:30
- Peninsula: 07:45
- Eastin Residences: 08:00

**Friday, 11th November**
- Holiday Inn: 07:30
- Peninsula: 07:45
- Eastin Residences: 08:00

**Saturday, 12th November (departure to field trip)**
- Holiday Inn: 08:30
- Peninsula: 08:45
- Eastin Residences: 09:00
## Conference timetable

### 9th November

<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker(s)</th>
<th>Title</th>
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<tbody>
<tr>
<td>09:00</td>
<td>Registration</td>
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<tr>
<td>10:00</td>
<td>Hoffmann and Schneider</td>
<td>GPR and LiDAR demonstration</td>
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<tr>
<td>12:00</td>
<td>Lunch</td>
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<tr>
<td>13:00</td>
<td>Adam Switzer</td>
<td>Differentiating storm and tsunami deposits in the geological record: insights from recent work in tropical Asia</td>
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<tr>
<td>13:45</td>
<td>Gösta Hoffmann</td>
<td>Extreme wave event deposits along the coastline of Oman</td>
</tr>
<tr>
<td>14:30</td>
<td>Robert Weiss</td>
<td>The TSUFLIND-EnKF Model: Inversion of Tsunami Flow Condition with Quantified Uncertainty</td>
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<tr>
<td>15:15</td>
<td>Break</td>
<td></td>
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<tr>
<td>15:30</td>
<td>Tina Dura</td>
<td>The application of diatoms in paleogeodesy and paleotsunami research</td>
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<tr>
<td>16:15</td>
<td>Simon Engelhart</td>
<td>Land-level changes and tsunami deposits along the Alaska-Aleutian subduction zone</td>
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<tr>
<td>17:00</td>
<td>Informal Discussion</td>
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<tr>
<td>Time</td>
<td>Speaker</td>
<td>Presentation Title</td>
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<tr>
<td>08:50</td>
<td>Welcome by Professor</td>
<td>Welcome by Professor Michael Modigell, Rector of GUtech</td>
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<tr>
<td></td>
<td>Simon Engelhart</td>
<td>Introduction and information on IGCP 639</td>
</tr>
<tr>
<td>09:30</td>
<td>Ben Horton</td>
<td><strong>Keynote:</strong> The importance of sea level research</td>
</tr>
<tr>
<td>10:05</td>
<td>Budruddin Faruque</td>
<td>Episodes of stillstands during the transgressive phase of the last glacio-eustatic cycle, east coast of India</td>
</tr>
<tr>
<td>10:30</td>
<td>Break</td>
<td></td>
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<tr>
<td>10:50</td>
<td>Martin Seeliger</td>
<td>Sea-level curve for the Bay of Elaia (W-Turkey) based on archaeological and microfaunal sea-level indicators</td>
</tr>
<tr>
<td>11:15</td>
<td>Juan Gonzalez</td>
<td>Advances in constructing a compaction-free sea-level chronology for the Caribbean coast</td>
</tr>
<tr>
<td>11:40</td>
<td>Peter Vos</td>
<td>Backgrounds of the prehistoric ingressions in the seaport area of Rotterdam (Rhine-Meuse estuary, the Netherlands)</td>
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<tr>
<td>12:05</td>
<td>Lunch</td>
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<tr>
<td>13:00</td>
<td>Andrew Cooper</td>
<td><strong>Keynote:</strong> Beachrock breakdown and preservation potential under sea level rise</td>
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<tr>
<td>Time</td>
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<tr>
<td>13:35</td>
<td>Alar Rosentau</td>
<td>Sea-level change and Stone Age coastal settlements in the Baltic Sea region</td>
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<tr>
<td>14:00</td>
<td>Sascha Schneiderwind</td>
<td>Visualizing Holocene gradual and rapid relative sea-level change by tidal notch modelling</td>
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<tr>
<td>14:25</td>
<td>Tomasz Boski</td>
<td>North-Eastern Brazilian sea-level curve of the last 10 ka</td>
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<tr>
<td>14:50</td>
<td>Break</td>
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<tr>
<td>15:15</td>
<td>Lauren Pretorius</td>
<td>Boulder accumulation styles in an embayed coastal setting, Morgan Bay, South Africa</td>
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<tr>
<td>15:40</td>
<td>Kosmas Pavlopoulos</td>
<td>Using multi-proxy methods to reconstruct the late Pleistocene and Holocene coastal dynamics in the Quriyat-Fins region (Sultanate of Oman)</td>
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<tr>
<td>16:05</td>
<td>Bastian Schneider</td>
<td>Terrestrial laser scanning as a tool for process modelling in coastal geomorphology</td>
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<tr>
<td>16:30</td>
<td>Susanne Lindauer</td>
<td>Comparing the local marine reservoir effect at Kalba (Oman Sea) and Umm-al-Qwain (Arabian Gulf) as a mirror for sea level change</td>
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<tr>
<td>17:00</td>
<td>Evening entertainments</td>
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<tr>
<td>Time</td>
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<tr>
<td>09:00</td>
<td>Tina Dura</td>
<td>Keynote: The role of Holocene relative sea-level change in preserving records of subduction zone earthquakes</td>
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<tr>
<td>09:35</td>
<td>Miklos Kazmer</td>
<td>Features of rapid uplift observed on Holocene tropical rock coasts - are these seismic markers?</td>
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<tr>
<td>10:00</td>
<td>Kathrine Maxwell</td>
<td>Raised coral platforms in Bohol Island, central Philippines as records of paleo-sea levels and coseismic uplift in the Late Quaternary</td>
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<tr>
<td>10:25</td>
<td>Break</td>
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<tr>
<td>10:45</td>
<td>Jason Padgett</td>
<td>Changes in fossil foraminiferal faunas suggest variable subsidence during great Cascadia earthquakes at Humboldt Bay, California</td>
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<tr>
<td>11:10</td>
<td>Noelynna Ramos</td>
<td>Holocene deformation across West Luzon, Philippines, constrained from 230Th-dated emergent coral terraces</td>
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<tr>
<td>11:35</td>
<td>Jessica Pilarczyk</td>
<td>Paleotsunami records from arid environments: an example from Sur Lagoon, Oman</td>
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<tr>
<td>12:00</td>
<td>Lunch</td>
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<tr>
<td>13:00</td>
<td>Siddharth Prizomwala</td>
<td>Traces of AD 1008 Strait of Hormuz generated tsunami along the Kachchh coast, Western India?</td>
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</tbody>
</table>
13:25  Anandasabari Karthikeyan  A study of 2013 Phailin cyclone deposits and 2004 tsunami preservation from the east coast of India

13:50  Thomas Kosciuch  Assessing provenance of the 2015 Tropical Cyclone Pam sediments from Vanuatu using foraminifera

14:15  Daria Nikitina  New Jersey (USA) wetlands resilience to sea level rise and storm impacts in the past, present and future

14:40  Break

15:00 till 17:00  Poster Reception
Adam Switzer (Asian School of the Environment, Nanyang University, Singapore)

**Differentiating storm and tsunami deposits in the geological record: insights from recent work in tropical Asia**

A definitive universal methodology for distinguishing storms and tsunamis in the geological record continues to allude the paleo-storm and tsunami community. In fact, recent events such as the ‘tsunami-like’ storm surge associated with Typhoon Haiyan in 2013 have done more to confound the issue then resolve it. Here, I present a synthesis of recent work in Asia including studies of the 2013 Haiyan deposits in the Philippines and comparative studies of deposits from the 2004 Indian Ocean tsunami and recent cyclones from India and Thailand. I will conclude by introducing our recent work on the geomicrobiological signatures of storm and tsunami inundation that potentially provides a true quantum leap in the level and diversity of data for investigating the difference between coastal flooding from storms and tsunamis.

Gösta Hoffmann (Steinmann Institute, University of Bonn, Germany)

**Extreme wave event deposits along the coastline of Oman**

Deposits along the coast of Oman, northern Arabian Sea, reveal sedimentological and archaeological evidence of past strong inundation events and are interpreted as remnants of tsunamis that were triggered by earthquakes in the Makran subduction zone. According to radiocarbon and luminescence dating, the record covers the last 7600 years and several tsunami events are identified, in particular one that occurred around 1000 years ago. The spatial distribution of deposits related to this event indicates a more energetic impact than was observed during the 1945 tsunami, which was triggered by an MW 8.1 earthquake in the eastern Makran subduction zone. Numerical tsunami models suggest that in order to produce the observed distribution of tsunami deposits, either the western segment or the entire subduction zone must have ruptured. This implies that the western segment is currently locked. Based on the dating results, there is weak evidence of return periods in
Robert Weiss (Department of Geosciences, Virginia Tech, USA)

TSUFLIND-EnKF Model: Inversion of Tsunami Flow Condition with Quantified Uncertainty

For tsunami events in geologic and historic past, deposits often are the only physical evidence. The characteristics of the causative events are encrypted in the deposits. Decrypting the information about the causative events will result into a better understanding of tsunami hazard impacts in coastal areas and, therefore, positively impact tsunami hazard and risk assessments. Numerical modeling can help to retrieve the quantitative information about tsunamis from their deposits: Inversion techniques need to be employed, which are comprised of data, a forward model and augmentation steps. The augmentation step is important because it helps to restart the forward model based on measured data. The inversion process is iterative and converges to a condition that produces a minimal error between the results of the forward model and the measured data. Furthermore, if the augmentation step is stochastic and not deterministic, the inversion results are provided in a distribution and allow us to estimate the uncertainty of the model results as well as to study how the uncertainty propagates through the model framework from the different sources.

In here, will present TSUFLIND-EnKF, the first tsunami inversion model. Other models have been put forward, but they are not inversion models in a strict sense, with the consequences that any study involving a range of initial conditions is a study of the sensitivity, but not uncertainty and uncertainty propagation. TSUFLIND-EnKF is based on TSUFLIND, extended by the Ensemble Kalman Filter (EnKF) technique, and it can be employed to invert different tsunami characteristics, such as bottom shear velocity and overland flow depth, separately or jointly.

We present the results for tsunami deposits created by 2006 Java and 2004 Sumatra tsunamis, and also show the results of a parameter study. The results from the real tsunami deposits show that the TSUFLIND-EnKF is able to invert meaningful results and is ready to be field tested with paleo-tsunami deposits. The most important result from the parameter study is that the error associated with the inversion results depends on the sample as well, and is limited by the source of the largest error. For example, it does not make sense to employ high-precision numerical models if the data contains a large amount of error due to sloppy sampling, or a numerical tool that suffers from too many simplifying assumptions if the data is perfect. Based on this, the results from the parameter study can also help to create collection strategies of tsunami deposits that can minimize errors, which perhaps is the most important outcome because it narrows to gap between those whose work is mostly field and laboratory focused and those working on theoretical considerations.
The application of diatoms in paleogeodesy and paleotsunami research

Earthquake and tsunami records on centennial and millennial temporal scales are necessary to understanding long-term subduction zone behavior and the occurrences of large, but infrequent events. Microfossils, such as diatoms, incorporated into coastal stratigraphy provide some of the most detailed reconstructions of the history of earthquakes and tsunamis. We explore qualitative and quantitative techniques that employ the relation between diatoms and salinity, tidal elevation, and life form to: (1) reconstruct records of vertical land-level change associated with large earthquakes; and (2) identify anomalous sand and silt beds deposited by tsunamis. A global database shows that diatoms have been successfully employed in the reconstruction of earthquake and tsunami histories in Chile, the Indian Ocean, Japan, New Zealand, the North Sea, the Pacific Northwest of North America, and the South Pacific. We use case studies from some of these locations to highlight advancements in the field and new capabilities that diatoms have enabled. In Alaska and Chile, diatoms have documented both uplift and subsidence at proposed segment boundaries, expanding our knowledge of the variability of slip in megathrust ruptures. In tsunami studies in Alaska and Chile, allochthonous marine and brackish diatoms along with high fragmentation of diatom valves within sand deposits signaled repeated, high-energy marine incursions into coastal lowlands. To conclude, we provide an example of a marsh monitoring experiment along the Cascadia subduction zone to emphasize the importance of studying the modern diatom response to changing environmental conditions to refine estimates of coseismic deformation.

Simon Engelhart (Department of Geosciences, University of Rhode Island, USA)

Land-level changes and tsunami deposits along the Alaska-Aleutian subduction zone

Recent great earthquakes and tsunamis in Sumatra, Chile, and Japan underscore the importance of understanding subduction zone rupture patterns and recurrence intervals. The 50 states in the USA are home to two subduction zones, the Cascadia subduction zone from northern California to British Columbia, Canada, and the Alaska-Aleutian subduction zone that encompasses the Aleutian Island chain in the west to the Gulf of Alaska in the east. These two subduction zones vary in the level of knowledge that we have on rupture timings, magnitude, and extent. The entire Cascadia subduction zone ruptured in AD 1700, and three decades of research has led to a general understanding of the timing of past earthquakes.

In contrast to Cascadia, little is known about the rupture history of the Alaska-Aleutian subduction zone, with the exception of sites within the 1964 rupture area. The Alaska-Aleutian subduction zone is the source of frequent great earthquakes and accompanying destructive tsunamis (e.g., 1946, 1957, 1964, 1965). GPS identifies sections that are highly
coupled in the interseismic interval but it is unknown how accumulated strain will be released in future ruptures, because GPS instrumentation only spans a fraction of the earthquake cycle. For example, historical evidence suggests the 1788 earthquake may have propagated through a 600-km-long swath of the Alaska-Aleutian subduction zone from Sanak Island to Kodiak, although portions of this area are currently identified as creeping by GPS. Paleoseismology studies are the only way to test the persistence of creeping patches and rupture boundaries through time.

In this presentation, I will present data compiled from paleoseismology studies undertaken during the last seven years in Alaska, identify how they have improved our understanding of past rupture and megathrust behavior, identify areas where further progress might be made using the paleoseismic record, and share some of the broadly applicable lessons we have learnt from working in the region.

**10th November, Day 1**

Ben Horton (Department of Marine and Coastal Science, Rutgers University, USA)

The importance of sea-level research

200 million people worldwide live in coastal regions less than 5 meters above sea level. By the end of the 21st century, this figure is estimated to increase to 500 million. These low-lying coastal regions are vulnerable to changes in sea level brought about by climate change, storms or earthquakes. But the historic and instrumental record is too short to fully understand the climate relationships and capture the occurrence of the rare, but most destructive events. The coastal sedimentary record provides a long-term and robust paleo perspective on the rates, magnitudes and spatial variability of sea-level rise and the frequency (recurrence interval) and magnitude of destructive events.

Reconstructions of paleo sea level are important for identifying the meltwater contributions, constraining parameters in Earth-Ice models, and estimating past and present rates of spatially variable sea-level change associated glacial isostatic adjustment, sediment compaction and tidal range variability. Sea-level reconstructions capture multiple phases of climate and sea-level behavior for model calibration and provide a pre-anthropogenic background against which to compare recent trends. Pre-historic earthquakes (Mw>8.0) are often associated with abrupt and cyclical patterns of vertical land-motion that are manifest in coastal sedimentary archives as abrupt changes in relative sea level. Geologic evidence of paleo-earthquakes elucidates characteristic and repeated pattern of land-level movements associated with the earthquake-deformation cycle. Tsunamis and storms leave behind anomalous and characteristic sediment that is incorporated into the coastal sedimentary record often as evidence of a high-energy event affecting a low-energy, depositional
environment. Records of tsunamis developed from the sedimentary deposits they leave behind improve understanding of tsunami processes and frequency by expanding the age range of events available for study. Reconstructions of paleo storms may reveal spatial and temporal variability of tropical cyclone activity and provided insight into their relationship with global climatic changes.

Budruddin Faruque (Geological Survey of India)

Episodes of stillstands during the transgressive phase of the last glacio-eustatic cycle, east coast of India

The transgressive phases, subsequent to Last Glacial Maximum, have left imprints of episodes of cooling on the shelf off northern part of Andhra Pradesh coast. The 50 km wide continental shelf has its shelf break at depths of 180m to 230m. The gentle gradient 1:277 of the shelf is interrupted by a series of shore-parallel elevated ridge deposits off Rattikonda-Gangavaram shelf, which were revealed by shallow seismic records in water depths ranging from 30m to 122m. Skeletal, peloidal, ooid packstones, oolitic and skeletal grainstones, coral debris with microfaunal and shell fragment assemblages were recovered from the ridge deposits, collected using gravity corer, vibro corer and grab sampler.

The ridges I and II, located at 122m and 108m water depths, are made up of grainstones composed of coarse carbonate and silica sand, bioclasts of small bivalves and coralline debris often cemented together with calcareous matrix. The ridge-I is prominent in its uniform morphology and consistency in its crest relief, in all the seismic transects. The ridges in the shallower part of the shelf are composed predominantly of relatively coarser terrigenous silicate sands and heavy minerals derived from the Eastern Ghats Super Group rocks exposed in the hinterland coastal tract. The deepest ridge complex in the outer-shelf found between 122m and 84m water depth extends laterally for 230 km, sub-parallel to the present shoreline. The 122m ridge is masked under deltaic sediments in the shelf off some of the major rivers like Mahanadi, Rushikulya, Vamsadhara, Godavari and Krishna. The ridge however, is traceable for distance beyond 230km. The distal part of the midshelf within water depths of 80m and 130m has a number of ridges, pinnacles and terraces with carbonate sands and coral reefal debris. Ooids within a zone of 90 to 120m water depth, form a substantial component of sandy sediment. The deposits along the -122m ridge are dominated by coral debris and bear a relief of 17m on the seaward flank. Sediments recovered from the outer shelf ridges are coral debris, carbonate sands, oolitic grainstones, and shell fragments. The skeletal remains of biota, like lamellibranch, foraminifera, and ostracod belong to marine fauna characteristic of shallow water habitat. Similarly the silicate sand grains and their granulometric studies corroborate a shallow water, surf zone and high energy environment of deposition. The ridges are interpreted to be palaeoshorelines evolved during the sea level transgression. Evolution of these geomorphic features with terrigenous, chemogenic and biogenic materials are attributed to stillstands during rapid changes in the rate of the deglacial sea level rise, following the Last Glacial Maxima.

The bioclastic carbonate sediments from ridge-I at water depths of 122m have yielded calibrated radiocarbon ages of 21,120 yrs BP and 13,820 yrs BP from two different locations.
of the ridge, 108m ridge-II was dated 11,980 yrs BP, ridge-III at 76m gave an age of 9850 yrs, ridge IV from 63m bore an age of 8820 yrs, and ridge-V at 30m evolved 7290 yrs BP. The beach rocks from the present beach 2m above the high tide level from near Rameswaram in the east coast of India, far away from the Gangavaram - Rattikonda sector, were dated 5650 and 6110 yrs BP. The sea level rise which began with the post LGM deglaciation reached present sea level around 5ka B.P. The ridge at 108m with a date 11980 yrs BP is being correlated with Younger Dryas cold phase, though with a caution, since it does not have a proliferating presence in the tropical shelves.

**Martin Seeliger (Institute of Geography, University of Cologne, Germany)**

**A sea-level curve for the Bay of Elaia (W Turkey) based on archaeological and microfaunal sea-level indicators**

During Hellenistic and Roman times, Elaia, the harbour city of ancient Pergamon, was an important place of trade and traffic at the western coast of Asia Minor. Intense military and mercantile activities are documented by literary sources and archaeological evidence.

For the first time, a reliable regional sea-level curve (RSL-curve) for a continental site on the Turkish Aegean coast has been established with a new methodology to define sea-level index points. The microfossil composition in connection to the transgressive contact acts as a useful new sea-level indicator and should be further tested at other sites. Its strengths are the exclusion of compaction and that only corings which include the transgressive contact are needed. Additionally, the remains of the breakwater of the closed harbour basin was used as a second valuable sea-level indicator.

The curve is in good agreement with other curves from the adjacent Aegean region which do not show a mid-Holocene peak and present similar slopes. In addition, most of the curves are below Lambeck’s modelled one; for Elaia an overall offset of around -0.7 m can be stated.

The main reason for the negative offset is in the subsidence of the Bergama- and Zeytindağ grabens wherefrom the Bay of Elaia is a part.
Juan Gonzales (School of Earth, Environmental and Marine Sciences, The University of Texas Rio Grande Valley, USA)

Advances in constructing a compaction-free sea-level chronology for the Caribbean coast of Colombia, a far-field site in South America

The initial results from an ongoing effort to construct the first Holocene relative sea-level chronology for Caribbean South America in Colombia, a far-field setting, are summarized. Farfield paleo-sea-level data are useful to infer the eustatic component of relative sea level (RSL) change and to constrain the extent of glacial isostatic adjustment-induced sea level change. Northernmost Caribbean South America is located in a far-field setting, however, Holocene paleo-sea-level records for this large geographic area are lacking. The study area, an infilled coastal lagoon with an area of ~25 km2, bounded on the ocean side by a 200 m wide sandbar, is well suited for paleo-sea-level studies, it is located on the tectonically stable Caribbean coast of Colombia, it has a microtidal range of ~0.5 m and contains a thick and continuous peat deposit. Peat accretion is still ongoing on the seaward 1/3 of the lagoon and is dominated by the salt tolerant golden leather fern, Acrostichum aureum. On the landward portion of the lagoon the peat was truncated and sealed by a 2 to 3-meter-thick clay deposit, and sits on a compacted sandy substrate. The new record uses basal peat to track sea level, thus ruling out the role of compaction of Holocene strata. At present the new RSL record isse. Chronologic control was obtained from radiocarbon dating of botanic remains extracted from the peat. The fact that at tectonically stable far-field locations, the RSL signal is commonly characterized by a mid-Holocene high-stand needs to be reconciled with the new curve which does indicate a sea level high-stand.

Peter Vos (Research institute Deltares, The Netherlands)

Backgrounds of the prehistoric ingressions in the seaport area of Rotterdam (Rhine-Meuse estuary, the Netherlands)

For the Atlas Westland, which will be published in November of this year, a multidisciplinary geological, archaeological and historical research has been carried out in order to document the landscape history of the Westland-Delfland region north of the Nieuwe Waterweg (waterway connection to the Port of Rotterdam). For the publication, nine new regional paleo-geographical maps were reconstructed for the period between 1200 BC and 2000 AD.

The geological map and LIDAR images of the region supplied the necessary information about of existence of dune, tidal channel and peat deposits in the subsurface. With the help of geoarcheological data from excavation pits (‘key sites’ in the reconstruction) and historical
sources, the ages of the different deposits were determined. On the basis of this time framework the palaeogeographical maps could be reconstructed.

In order to understand the meaning of the geometrical features, visible on the LiDAR maps, two geological profiles were compiled. These profiles were based on new field data (see picture below). It appears that prehistoric tidal channels broke into the paleo-peat lakes which were formed in between the higher oligotrophic peat domes, present at the northern side of the former mouth of the Rhine-Meuse estuary. This sea ingression in the paleo-peat lakes took place around 250 BC during exceptionally high floods. These high floods were the result of a combined effect of storm floods and extremely large river discharges from the rivers Rhine and Meuse. Proof of exceptionally high floods around 250 BC are found in the archaeological ‘key site’ Vergulde Hand West where at that time - during extremely high water - large blocks of peat tore loose from the subsurface and became buoyant (‘peat islands’, with human settlements on it!).

In the presentation the new palaeogeographical maps of the region are shown and the backgrounds of the coastal evolution of the Westland-Delfland area further discussed.

Andrew Cooper (School of Environmental Sciences, University of Ulster, Coleraine, North Ireland)

Beachrock breakdown and preservation potential under sea level rise

The contemporary geomorphology of extensive beachrock outcrop in NE Brazil affords insights into the post-formation processes and the preservation potential of beachrock in the geological record. The outcrop comprises a 1.5-2 m-thick core of trough-cross-bedded beachrock. This is broken into large joint-bounded blocks that gradually move by undermining and settling. This creates micro-cliffs, gullies and irregularities in the surface elevation of the outcrop. The overlying beachrock units exhibit horizontal bedding that is exploited by wave action and breaks into tabular blocks that are transported landwards by large waves. These blocks occur in distinctive assemblages including: isolated megaclasts (up to 40 tons); ridge-top berms with landward- and seaward-dipping clasts; and subaqueous and subaerial washover fans. The isolated megaclasts often occur against microcliffs in the trough cross-bedded core. They exhibit fitted textures and pressure-solution at clast-bedrock contacts, pointing to emplacement during extreme wave conditions (Hs = ca. 12m) followed by rocking and shaking by subsequent sub-transport threshold waves. The beachrock clasts in the berm and overwash units are thinner (typically 0.3-0.5 m c-axis) and have a and b axes of 1-3 m. These often exhibit recent fractures, impact marks and breakages indicating periodic contemporary transport. Several fresh quarried slots also prove active exploitation of the beachrock surface. Accumulations of small beachrock clasts (<0.5 m) are preserved in joints and within the berm. Localised cementation of accumulations of these fine clasts on the surface of the beachrock outcrop indicates periods of berm stability (allowing cementation) alternating with berm destruction (that removes the formerly
protective clasts). Waves competent to transport the platy berm and overwash-sized clasts (3–5 m) have been recorded in the historical wave record and the geomorphology and clast surface textures point to ongoing clast transport on a regular (semi-annual) basis.

Although surface karstification is evident in places, physical erosion is dominant over chemical weathering as a denudational process of beachrock. Wave erosion, entrainment and transport of horizontally or low-angle bedded beachrock facies creates a distinctive facies assemblage of eroded beachrock clasts akin to those of sand and gravel beaches (berm, overwash fans). The thicker trough cross-bedded unit is, however, resistant to wave-transport and is therefore most likely to be preserved in the geological record; contemporary beachrock outcrop at several adjacent sites is composed almost entirely of the trough-cross-bedded unit and lacks any visible beachrock clasts. This suggests the beachrock clast units (particularly those of the berm) to be ephemeral at geological timescales, although the washover unit may be preserved.

**Alar Rosentau (Department of Geology, University of Tartu, Estonia)**

*Sea-level change and Stone Age coastal settlements in the Baltic Sea region*

In the early phases of cultural development, Mesolithic and Neolithic human populations in the Baltic region experienced times of significant marine transgressions and regressions owing to the melting of the continental ice sheet and glacial isostatic land uplift. Geological–archaeological studies in the southern Baltic Sea area have revealed a number of Mesolithic and Neolithic traces of human occupation off from the Danish and German coasts as a result of Holocene sea-level rise. Prehistoric coastal sites in the northern Baltic Sea areas have, however, been uplifted and are located successively at different altitudes as a result of glacial rebound. In transitional areas, prehistoric man experienced transgressions and regressions of the shifting coastline owing to competition between glacial rebound and sea level rise. In current presentation I will demonstrate how archaeological data together with geological record can provide information about relative sea level changes and palaeoshoreline locations in the Baltic Sea region. Interdisciplinary approach in sea-level research is important to improve our understanding on the ongoing interplay between sea-level rise and glacial rebound for better relative sea level predictions of the future Baltic Sea.
Visualizing Holocene gradual and rapid relative sea-level change by tidal notch modelling

Palaeoseismological studies in coastal areas use the relative sea-level as a regional reference datum and focus on the identification of fossil palaeoshorelines which might have been rapidly displaced from paleo-sea-level due to coseismic slip. In particular, in the microtidal Mediterranean Sea tidal notches have been used to infer Holocene paleo-sea-level positions at decimeter confidence. These erosional sea-level indicators pose distinct and obvious ecological and morphological cliff face topographies ranging from a few centimeters up to several meters deep. Notches form at sea-level within the tidal range by continuous physical, chemical and biological erosion. Assuming erosion rates between 0.2-1.0 mm/yr, time periods of several decades to hundreds of years either in stable conditions or with balanced contributions of eustasy, isostasy and tectonics are required to form these distinct sea-level markers.

Conceptual models comparing local sea-level curves with associated regional uplift estimates conclude that the highest elevation tidal notch on uplifting coasts dates to ~6,000 years BP in the Mediterranean. At that time the rate of eustatic sea-level rise decreased to ~1 mm/yr and reached gravitational equilibrium with the continental lithosphere. Since the Mid-Holocene slow relative sea-level changes caused gradual changes of the erosional base at emerging coastlines. However, in seismically active regions, rapid displacements occur due to coseismic uplift of the coastlines that may not have exceeded the tidal range. As a consequence of both slow (eustatic) and rapid (coseismic) variations in the position of the erosional base, notch shape modification occurs. When both rapid and slow processes interplay distinguishing between notch widening and new notch development is challenging. It has to be expected, that the time period for notch formation might be short and the resulting indentation is only of minor scale, and that massive overprinting and degradation of older features has occurred since 6,000 years BP.

In order to visualize the development of notch sequences incorporating eustatic and isostatic balances, erosion rates, coseismic uplift, and cliff steepness, we developed a numerical model that simulates the migration of the erosional base through the Holocene. Well dated features can operate as inputs in order to verify the interpreted results or to indicate missed events due to notch degradation.

The results show how slow and rapid sea-level change bias the modern cliff face, and highlights that the present-day notch sequence from top descending to sea-level is not inevitably of decreasing age. Furthermore, the initiation of notch formation is not necessarily linked to the date of a certain seismic event. Especially in extensional tectonic settings where coseismic uplift is low and coastal morphological marks are not as distinct, knowledge about coastal evolution is beneficial for palaeoseismological research.
NE Brazilian sea-level curve of the last 10 ka

The studies of Bezerra et al. (2003), Caldas et al. (2006) and Vieira et al. (2007) carried out in the state of Rio Grande do Norte (NE Brazil), enabled reconstruction of the variation of the mean sea level (MSL) for the last 7000 years i.e. after the last pulse of postglacial transgression. In order to get an insight into the history of SL in the period antecedent the Mid-Holocene stabilization/highstand, we drilled several boreholes in the mangroves of Potengi-Jundiai Estuary, Natal. The ca 18 km long estuary is situated within the Cretaceous Potiguar Basin and underlain directly by Neogene Barreiras Formation and Pleistocene fluviatile sediments. Holocene sediments, which infilled the paleovalley during the most recent post-glacial transgression attain several tens of meters in thickness. Estuarine fill deposits are covered in ~ 70% by mangrove vegetation, which developed in the intertidal zone of the main channel, 170 m average width and a depth between 8 and 10 m. Samples from manual and mechanical boreholes were analyzed in terms of foraminifera content, texture, mineralogy, organic matter and 14C age. The benthic foraminifera assemblages, in the Mid-Holocene to contemporaneous part of sedimentary column are dominated by calcareous species: *Ammonia tepida, Elphidium excavatum, Elphidium poeyamn, Partarotalia spp, Elphidium sp, Haynesina germanica*, indicating free influx of ocean water and negligible fluvial discharge. Only in the deepest part (-22 to -30m) of IG8 / IG9 boreholes the environment presented himself as more confined, yet always of intertidal character with salinity close to ocean waters. Dating of vegetal organic matter remnants, permitted to reconstruct the history of the RSL in the period between 10 – 7 ka cal BP and integrate the new data with previous SL reconstructions, which embraced the last 7 kyrs. The central part of the estuary experienced the period of mangrove forest stability between 9.7 to 8.9 ka cal BP which could accompany the rising of the sea-level with a rate of ca 10mm/yr. The massive influx of sand from the shelf led to the accretion of flood tidal delta and interrupted the period of thriving vegetation in the central part of estuary, for about 1 millennium. The dates of the plant remains indicate the existence of extensive *Rhisophora* and *Avicennia* forest there 8300 years cal. AP (Boski et al., 2015) positioned in extensive plains of the sheltered inner estuary and at depths between 6 and 7 m in relation to current NMM. It is very likely that the discussed record embraces also the last meltwater pulse between ca 8.1 to 7.5 ka cal BP which displaced the mangrove forests to the upper lying safehavens.
Lauren Pretorius (Geological Sciences, School of Agriculture, Earth and Environmental Sciences, University of KwaZulu-Natal, South Africa)

Boulder accumulation styles in an embayed coastal setting, Morgan Bay, South Africa

This paper documents the occurrence of boulder beaches and ridges within an embayed coastline at Morgan Bay, in the Eastern Cape of South Africa. Two boulder settings were examined, an embayed mixed cobble and boulder beach and a headland boulder ridge. The boulder ridge appears to be the product of an unusually high magnitude event (post 1060 BP) that resulted in the stranding of the ridge at > +6 m elevation. The boulder source was the raised shore platform immediately seaward of this ridge. These boulders are angular and form an interlocked and armoured deposit that formed in a limited accommodation setting. Occasional well rounded boulders occur seaward of the ridge on the raised shore platform and are sourced from a gully in the intertidal zone. The close agreement between platform joint spacing and boulder size is suggestive of minimal reworking. In comparison, the shore platform-hosted boulder beach rests in the swell shadow of the headland, shows greater clast size variation and both alongshore and cross-shore grading. Material here is sourced from the lower intertidal shore platform.

Numerical modelling of the transporting wave heights and velocities show that the largest boulders required extreme wave heights (19.14 m) and velocities to emplace them. These values exceed the contemporary swell regime for the area. The calculated transport envelopes showed that, under the modelled velocity conditions, the expected mechanisms of transport embayment-wide would be lifting and/or saltation in either a sub-aerial or joint bounded scenario. Within the boulder beach, boulders would have been transported as per the calculated envelopes, especially when the wave approach direction is favourable during storm swell approach. The raised shore platform boulder ridge would be unlikely to move in either of these scenarios due to the limited accommodation space and interlocked nature of the clasts. It appears this ridge was deposited by a single event of extreme magnitude, the scale of which has not been experienced since. This study emphasises the importance of setting within embayed coastal compartments when examining the storm response of mixed rocky and boulder beach coastlines.

Kosmas Pavlopoulos (Paris-Sorbonne University Abu Dhabi, United Arab Emirates)

Using multi-proxy methods to reconstruct the late Pleistocene and Holocene coastal dynamics in the Quriyat-Fins region (Sultanate of Oman)

The coastal area between Quriyat and Fins (Sultanate of Oman) has been affected since the late Pleistocene by several processes and extreme events that implied various timescales, ranging from the millennia (uplifting and post glacial sea level rise) to the instant
(storm/tsunamis), and various morphogenetic response (fluvial sedimentation-flash floods, marine erosional and depositional processes...). Attempting a reconstruction of the relative sea-level changes along this coastline is challenging regarding the large panel of phenomena that impacts in different ways this area.

The geomorphologic survey, with the contribution of the geoarchaeological records, done in the frame of the MEDEE (Mer, Desert, Environnement) program, implemented since 2013 under the direction of Eric Fouache and supported by the French Ministry of Foreign Affairs, aims to obtain new geomorphological and palaeoenvironmental data together with archaeological data in order to reconstruct the evolution of the geography and the links between humans and nature in the area between Sur and Quriyat.

This presentation focuses on the multi-proxy methods developed in three areas (Fins/mouth of the wadi Ra’s Ash Shajar, Daghmar/Dibab and Quriyat): (i) geomorphological mapping including sea level markers (as marine terraces, notches and beachrocks) using a semi-automatic approach based at GIS database, (ii) microscopic analyses of beachrock, (iii) faunal and micro faunal analyses of core samples of a Quriyat coastal plain, (iv) dating’s of marine deposits in uplifted terraces by $^{14}$C AMS method, (v) dating’s of marine shells in samples sediments of the coring in Quriyat alluvial plain and (vi) ERT geophysical profiles to connect the cores lithostratigraphy in Quriyat.

The preliminary results testified the heterogeneous evolution of this coastline, divided into different tectonic blocks, with various uplift rates and tectonic cinematics. Uplift and sedimentary infilling in tectonic basins confirm a swift transformation of the coastline since MIS 3 (at least +/- 40 000 BP), until the mid-late Holocene.

Bastian Schneider (Steinmann Institute, University of Bonn, Germany)

Terrestrial Laser Scanner (TLS) as a tool for the reconstruction of extreme wave event characteristics

The Northern Indian Ocean and the east coast of Oman was and is exposed to various extreme wave inundation events in the past. A profound understanding of return periods and magnitudes of past events is essential for adopted land-use planning and risk mitigation measures for the authorities of Oman and neighboring countries. Two relevant hazards, tsunamis and storm surges triggered by tropical cyclones, are known but rarely instrumentally recorded. Various sediment deposits along the coast are the only remnants of those past events.

A detailed investigation of those deposits, in this case mainly blocks and boulder trains, hints on parameters such as wave height or inundation distance which then can be used for modeling inundation scenarios superimposed on the modern infrastructure. We are investigating the 3D-distribution of the tsunami sediments along the coastline through a
high-precision survey of the block and boulder deposits using a Faro Focus 3D X330 TLS. A TLS is capable of recording high-detail and colored point clouds, which allow detailed measurements and proved to be a powerful tool in geosciences.

Relevant parameters are size, shape, volume, masses of the boulders as well as their relative arrangement. Those parameters, in combination with dating results, serve as a base for return period and magnitude estimations and can hint on the initial hazard. Furthermore the TLS data can be used to distinguish between the various lithologies of the boulders using a multi-scale supervised classification. Moreover, the distribution of the boulders relative to their origin hints on the flow direction of the waves.

Susanne Lindauer (Curt-Engelhorn-Zentrum Archaeometry, Mannheim, Germany)

Comparing the Local Marine Reservoir Effect at Kalba (Oman Sea) and Umm al-Qwain (Arabian Gulf) as a Mirror for Sea Level Change

The Oman Sea, being part of the Indian Ocean, is characterized by wind-induced upwelling. The upwelling causes carbon that remained in the deep sea for centuries to ascend to the surface. Therefore marine organisms show a shift in radiocarbon age towards higher ages. This shift from an atmospheric radiocarbon measurement is described by the reservoir effect. Arabian Gulf and Oman Sea are linked via the Straits of Hormuz which allows the water of the Oman Sea to enter and exit the Arabian Gulf. However, mixing with continental river discharge from the north into the Arabian Gulf will modify the reservoir effect compared to the Oman Sea. Knowledge of the reservoir effect is fundamental for accurate dating of archeological sites on the Arabian Peninsula.

We chose two sites with archaeological finds, one at each Gulf area. Kalba is an in the Northern part of the Oman Sea (Fig. 1). Khor Kalba, an important nature reserve and mangrove swamp (dating from the Arabian Neolithic period until recent times), is presently surrounded by a large sabkha area. Umm al-Qwain at the Arabian Gulf is a well-known archaeological site close to a mangrove swamp with settlement starting from the Neolithic until today. As both sites show similar age ranges we are able to compare the data as well as the resulting reservoir effects. Moreover, $^{14}$C ages from stratified archeological deposits are also influenced by the estuarine mangrove environments which provided food and wood to the Neolithic people. In order to further understand the UAE reservoir effect between Neolithic and Bronze Age, new $^{14}$C data from the specimen *Anadara uropigimelana* and *Terebralia palustris*, and charcoal/ash layers found at both sites are presented.

The results show differences between both Gulf areas but also over time which needs to be explained by sea level changes and other oceanic events.
Tina Dura (Department of Marine and Coastal Science, Rutgers University, USA)

The role of Holocene relative sea-level change in preserving records of subduction zone earthquakes

Eustasy and glacio- and hydro-isostatic adjustment are the main drivers of regional variability of Holocene relative sea-level (RSL) records. These regional variations in Holocene RSL influence the preservation of coastal wetland stratigraphic records of prehistoric earthquakes along subduction zone coasts. The length and completeness of prehistoric earthquake records is intrinsically linked to the accommodation space provided by gradually rising (<3 mm/yr) Holocene RSL. In near field regions that were located beneath northern hemisphere ice sheets (e.g., western Vancouver Island), RSL fall from a mid-Holocene highstand has limited prehistoric earthquake records to the last 1 ka. In intermediate field regions (e.g., southern Washington and central Oregon), gradual RSL rise over the last ~7 ka has preserved widespread records of prehistoric earthquakes. In far-field regions (e.g., Sumatra, Chile, and Japan), fragmentary stratigraphic evidence of prehistoric earthquakes has been preserved only during periods of gradual RSL rise prior to a mid-Holocene highstand, or during the last 1-3 ka, when RSL was within 2 m of modern sea level, and thus within the tidal frame.

Miklos Kazmer (Department of Palaeontology, Eötvös University, Budapest, Hungary)

Features of rapid uplift observed on Holocene tropical rock coasts - are these seismic markers?

While low, sedimentary coasts provide excellent records of subsidence, rock coasts are at their best recording uplift. Bioerosion of grazing and boring organisms and bioconstruction of encrusting organisms (fixed biological indicators) preserved on a variety of hard substrates are sea-level markers of variable trustworthiness. Ecological requirements of organisms (food, exposure, predation, competition) determine their zonal distribution relative to sea level. Instead of mechanically applying their elevation to reconstruct past sea levels, it is advised to exercise caution, considering variable width of fossil zones, telescoping of zones in supratidal pools, widening of zones with increasing exposure to wave attack, and increasing elevation of zones in rock crevices and caves.

Searching for horizontal zones, and especially for zone boundaries of considerable horizontal extent (as opposed to singular occurrences of fossils) helps to elucidate this problem. The narrower a zone, the better sea-level marker it is. Distinct narrow zones of oysters in the
supratidal indicate stasis in the oyster zone, interrupted by repeated uplift. Distinct zonal boundaries, and misplaced zones in general mark rapid uplift, left intact by bioerosion or spray dissolution above mean sea level. Marine notches are considered ubiquitous sea-level markers, formed between high and low tide. The maximum concavity (vertex) is usually attributed to mean sea level. However, notches created by various bioeroders have different cross-section, e.g. vertex at floor level. Abrasion notches are formed higher than bioerosion notches, displaying a characteristic inclination parallel with the beach surface. Overprinting bioerosion by abrasion further complicates matters. Broken notch outline, either in floor or roof, is a definite marker of sudden displacement. Elevation of the floor provides a first assessment of sudden uplift dimension. However, steps in the notch floor tend to amalgamate, suggesting improbable uplift in a single seismic event. Therefore each step records at least one, possibly several earthquakes.

Terraces are routinely used for assessing seismic uplift. However, a protocol is needed to describe the form assumed as wave-cut terrace and the sediment overlying it. Additionally, potential redeposition of terrace sediments by high-energy events is to be considered. Rubble, in general, gives younger ages than the formation of the terrace. Age of bioclasts in rubble can be thousands of years older than that of the emplacing event. Rubble can be deposited high above sea level during high-energy events (storm waves/waterspout/tsunami). Adjacent coastal sites can display displacement in opposite direction simultaneously. Therefore each study site must pass a thorough assessment whether the displacement history can be extended along the coast. Examples illustrating these points are taken from the coasts of South and Southeast Asia and the Western Pacific.

Katherine Maxwell (National Institute of Geological Sciences, University of the Philippines, Quezon City, Philippines)

Raised coral platforms in Bohol Island, central Philippines as records of paleo-sea levels and coseismic uplift in the Late Quaternary

We studied the emergent Late Quaternary sea level indicators in southwest Bohol Island to assess their implications for long-term deformation in central Philippines. The island has been the subject of previous studies which generally focused on paleo-sea levels and vertical stability. Uplift rates have also been estimated from the age and elevations of raised Late Pleistocene to mid-Holocene notches and terraces. On 15 October 2013, an Mw7.2 earthquake shook the island and resulted to severe ground shaking, ground rupture, and karst collapses. This large magnitude earthquake was reportedly related to the movement of the previously unmapped NE-striking North Bohol Fault. Coseismic uplift was noted along the southwestern coast of the island, where a broad modern coral reef platform was raised by as much as 2 meters. Using the vertical displacement of 1.5 m to 2.9 m along the fault rupture and coastal deformation measurements from emerged sea level indicators, we infer an approximate delineation of the North Bohol Fault from northeast (Inabanga) to southwest
(east of Sandingan Island, Calape). Meanwhile, new 230Th-dated fossil corals collected on the uplifted platform reveal young ages (~20 to 40 years), thereby providing us a recent example of young corals attached onto an older (i.e., Late Pleistocene) regressive terrace. This study further demonstrates how calculated uplift rates may vary based on the dating of attached corals or eroded corals on a regressive reef.

Jason Padgett (Department of Geosciences, University of Rhode Island, Kingston, USA)

Changes in fossil foraminiferal faunas suggest variable subsidence during great Cascadia earthquakes at Humboldt Bay, California

Four abrupt peat-to-mud contacts at three sites (Jacoby Creek, McDaniel Creek and Mad River) in northern Humboldt Bay, California (~44.8°N, -124.2°W) record subsidence during past megathrust earthquakes at the southern Cascadia subduction zone. Maximum and minimum radiocarbon ages on plant macrofossils from above and below laterally extensive (>5 km) contacts confirm regional synchronicity of subsidence. The shallowest contact has radiocarbon ages consistent with much previous research at Cascadia, which infers that the contact dates from 250 cal yr BP (AD 1700) earthquake. Using Bchron and OxCal software, we model ages for the three older contacts: ~870, ~1,125 and ~1600 cal yr BP. Changes in fossil foraminiferal assemblages across each contact reveal sudden relative sea-level (RSL) rise with lasting submergence. To estimate subsidence during each earthquake, we reconstructed RSL rise across the contacts using fossil foraminiferal assemblages and a transfer function derived from a new Oregon modern foraminiferal dataset. For each earthquake, coseismic subsidence estimates at the three investigated sites agree within error terms, and so we average estimates for each contact: 5 estimates for 250 cal yr BP average to 0.38±0.24 m; 5 estimates for ~870 cal yr BP average to 0.33±0.24 m; 3 estimates for 1,125 cal yr BP average to 0.44±0.24 m; and 4 estimates for the oldest buried soil, 1,600 cal yr BP, average to ≥0.53±0.24 m. Our data highlight variability of preserved stratigraphy related to each individual earthquake and further suggest that subsidence may have varied over the past four earthquake cycles at southern Cascadia.
Noelynna Ramos (National Institute of Geological Sciences, University of the Philippines, Quezon City, Philippines)

Holocene deformation across West Luzon, Philippines constrained from $^{230}$Th-dated emergent coral terraces

We study raised geomorphic features such as emergent coral terraces in west Luzon Island, Philippines to understand the long term deformation of the island related to the seismotectonic activities along the Manila subduction zone and associated upper plate structures. Emerged coral terraces in Ilocos Norte, Ilocos Sur, La Union, Batangas, and Occidental Mindoro are generally well-preserved exhibiting a step-like topography with recognizable meter-scale terrace risers and paleo-shoreline angle. We recognized variable elevations of terrace steps across west Luzon Island: Burgos and Badoc, Ilocos Norte (2 to 3 m above mean sea level (amsl)), Santa Maria and San Esteban, Ilocos Sur (1.2 to 1.4 m amsl), Bacnotan and San Fernando, La Union (1.2 to 3.6 m amsl), Calatagan, Batangas (1.3 to 2.4 m amsl), and Lubang and Cabra, Occidental Mindoro (1 to 5 m amsl). Based on $^{230}$Th-dating of fossil coral samples taken on terrace surfaces, we infer that the older (~7.5 ka to ~6 ka) fossil corals are related to the mid-Holocene marine transgression. We also found younger attached corals (~1 ka) that could either represent the age of the terrace surface prior to emergence or coral debris emplaced by a strong wave event. Different factors may be attributed to the emergence of the coral terraces which include regional sea level changes and possibly accumulated uplift from aseismic and seismic processes along the Manila Trench and nearby faults. We further examine the varied uplift patterns of the raised Holocene coral terraces to provide us additional constraints on the role of local tectonic structures across the Manila Trench fore arc.

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

Paleotsunami records from arid environments: an example from Sur Lagoon, Oman

The seismically active Makran Subduction Zone (MSZ), located in the northern Arabian Sea, has previously generated tsunamigenic-earthquakes that have impacted the coastlines of Iran, Pakistan, India, and Oman. The historical record of tsunamis impacting this region is limited to only a few accounts spanning the last 2000 years; resulting in uncertainty over the recurrence interval and possible magnitudes of earthquakes originating from the MSZ. Coastlines of the Arabian Sea may contain sedimentary evidence of past tsunamis that have occurred over the last several millennia, however, these coastlines are predominantly arid and few tsunami indicators are developed for these settings. In arid environments, where physical weathering due to wind exposure is common, settings conducive to the preservation of tsunami deposits are generally limited low-energy marginal marine environments such as lagoons. These environments can be problematic for identifying tsunami deposition due to
the lack of contrast between the marine-influenced tsunami deposit and the surrounding marginal marine sediment. In this study, we developed a suite of paleontological proxies that were used to document an anomalous shell bed in Sur Lagoon, Oman, inferred to be from the most recent Makran tsunami in 1945. The 1945 tsunami deposit consists of a coarse shell-rich layer with distinctive taphonomic and stratigraphic characteristics that extends laterally throughout the 12 km² lagoon. Our findings indicate that the combination of foraminifera and mollusk taphonomic analysis can be used to delineate the 1945 tsunami deposit from normal background sedimentation in an arid intertidal environment. Within the inferred tsunami deposit, high abundances of angular shell fragments, articulated bivalves (out of life position), and calcified fossil foraminifera support an offshore provenance. This suite of paleontological proxies holds potential for detecting older events at Sur Lagoon as well as arid environments elsewhere.

Siddharth Prizomwala (Earthquake and Environmental Geology, Institute of Seismological Research, Raisan, India)

Traces of AD 1008 Strait of Hormuz generated tsunami along the Kachchh coast, Western India?

It was reported that an earthquake in AD 1008 along the Strait of Hormuz, generated waves which led to sinking of several ships and the sea inundated the land. However this is also contested by several workers. Nevertheless if a tsunami wave was generated it was likely to travel eastwards and with high probability would have inundated Kachchh coast. The inundation would depend on amplitude of the wave near the coast which may as well vary keeping in mind the macrotidal nature of the coastline; with higher tidal amplification expected in eastern part of coast. Fortunately the coastline of Kachchh hosts several back barrier swamps and palaeomudflats which would serve as promising sites for preservation of such a likely high energy marine flooding. Hence Kachchh region by virtue of its location proves to be an excellent location for reconstructing record of past marine flooding events originating from the Makran Subduction Zone (MSZ).

We explored several shallow trenches along the Kachchh coast from Pingleshwar in the west to Bhadreshwar in the far east and encountered a sand layer at an average depth of 40 cm to 80 cm. This sand layer ($S_1$) varied in thickness from 20 cm in the west to 40 cm in the east. The sedimentological character of $S_1$ suggested that it is primarily composed of coarse sand, with no sorting, however the basal part of this sand layer is accompanied by gravel layer. The $S_1$ layer is rich in broken shells fragments and reworked foraminifers. The presence of rip-upclasts/mudballs is one of the fascinating signatures of a high energy marine wave eroding the cohesive offshore mudflats and depositing them landwards. One of the strong points which substantially differs the origin of this sand layer from storms is that the extent of $S_1$ is traced at several places up to 250 m and more from the high tide line. Other than sedimentology some geochemical studies also pointed out the origin of the $S_1$ layer to
offshore sediments of Gulf of Kachchh. Interestingly the AMS $^{14}$C ages from two sequences of Luni and Mundra bracketed this event between AD 975 to AD 1414. This gives a supportive claim to provenance of this tsunami wave that it originated from the MSZ. In absence of another major known event from this period, we link this sand layer to be originated by tsunami generated from AD 1008 earthquake in Strait of Hormuz.

Karthikeyan Anandasabari (Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore, India)

A Study of 2013 Phailin cyclone deposits and 2004 Tsunami preservation from East coast of India

The 2013 Phailin cyclone wind speed of 220 km/h it was remnant cyclonic circulation from south china; it had major impact on geomorphology and sedimentology of Odisha coast. At Rushikulya river mouth, Ganjam district, cyclone had produced washover sand sheets as described in eyewitness along the river mouth of both north and south bar. The study reveals that the washover sand sheets provides the inundation of the water level, and characteristics of sediments where storm deposit has a highly variable grain-size distribution with a marked coarsening at its landward extent, is better sorted, coarser, and has a sharp, non-erosional lower contact associated with buried vegetation and soil. Also, the thickness of cyclone deposits are about 5 cm with the distance from coast 80 m, heavy mineral percentage ranges between 9 % to 75% for entire pit and sandsheets lateral extent are about 45 m. The presence of the laminations and alternate layers of heavy minerals are indicative of the complexity of sedimentation on the coast. The 2004 Indian Tsunami has deposited a varied layer of sand sheets along the coast it depends on the coastal topography. Recognition of these deposits was clear immediately after the tsunami as the sand sheets were laid over the soil which is distinctly different due to differences in the weathering and presence of organic material of vegetation. To under the preservation potential of 2004 tsunami deposits we studied a transect profile with seven pits sediments at Thiruvengadu coast, Nagapattinam. The study reveals that presence of sand sheets of minimum of 10 cm thickness to maximum of 22 cm and starting at the distance of 300 m from HTL. There are six sedimentary layers were identified which are (a) Top sediments deposited after IOT, (b). Tsunami sand sheets (c) Silty sand (d). Erosional base and top (e) Silty sand (d) lagoonal sediments. The recent marine event of 2004 tsunami preservations and Phailin cyclone deposits which are helpful to identify the paleo tsunami sediment characteristics from east coast of India and it as a back ground model for distinguishing tsunami and cyclone.
Assessing provenance of the 2015 Tropical Cyclone Pam sediments from Vanuatu using foraminifera

The coastlines of South Pacific islands are susceptible to inundation by tropical cyclones. Recently, Tropical Cyclone (TC) Pam (Cat. 5) made landfall on Vanuatu in March 2015, impacting coastlines with storm surge with wave contributions producing high water marks up to 7 meters above sea level (m.s.l.). Predecessor events are relatively unknown and limited to only several decades. Geologic studies conducted in low-energy coastal settings provide an opportunity to expand the storm record to include longer timescales. In this study we document a rare Category 5 event that serves as an important modern analogue for future paleotempestological investigations.

We examined the foraminiferal assemblages contained within TC Pam sediments at two locations in Vanuatu: a mixed-carbonate embayment at Manuro (Efate Island) and a volcaniclastic beach at Port Resolution Bay (PRB; Tanna Island). At Manuro, the TC Pam sediments were up to 12 cm in thickness and composed of medium sand that contained abundant foraminifera and fragments of corals and mollusks. At PRB, TC Pam sediments were up to 45 cm in thickness and composed of medium sand-sized volcanioclastics. TC Pam sediments could be discriminated from underlying units by a sharp contact, an abrupt decrease in organic matter, and an increase in the concentration of foraminifer. TC Pam foraminiferal assemblages between the two sites varied in terms of taxonomy and taphonomy (surface condition of individual foraminifera). At both sites, the assemblage was dominated by intertidal and subtidal species such as Amphistegina spp. (11 to 37%), Baculogypsina sphaerulata (9 to 50%), Calcarina mayori (11 to 29%), and Pararotalia spp. (8 to 46%). However, the total concentration of these species varied (e.g., 191 to 403 foraminifera per 1 cm3 at Manuro vs. 5 to 41 at RB). The assemblage at Manuro is characterized by individuals that were unaltered (i.e., pristine; 26 to 30% of the assemblage) and abraded (52 to 60%). By contrast, sediments at RB contained fewer unaltered (0 to 25%) and more abraded (74 to 97%) foraminifera. Provenance was assessed by comparing surface foraminiferal distributions with those from TC Pam sediments. We used Partitioning Around a Medoid (PAM) cluster analysis to first document the modern surface distributions within a sheltered bay that was unaffected by TC Pam’s storm surge. PAM analysis identified 6 clusters: beach, mangrove, intertidal, subtidal, lagoon (proximal) and lagoon (distal), which are related to depth. Discrete intervals sampled from TC Pam sediments were then individually clustered.
**Daria Nikitina (Geology and Astronomy, West Chester University, Pennsylvania, USA)**

**New Jersey (USA) wetlands resilience to sea level rise and storm impacts in the past, present and future**

Due to the rapid and pervasive loss of coastal wetland ecosystems and the enumerable services they provide, recent attention has been given to understand their resilience and response to natural and anthropogenic impacts. Knowledge gaps exist particularly regarding response times of wetland ecosystems to natural factors (storms and sea-level rise) and the appropriate indices or metrics of ecosystem health to be incorporated in management practices to achieve restoration goals. Here we present results from monitoring studies and stratigraphic investigations from marshes across New Jersey, USA shoreline, from Delaware Bay to Raritan Bay (~210 km of coastline that vary in degree of urbanization and anthropogenic disturbances) that address these limitations. In the Delaware Bay, we identified a series of abrupt contacts (mud-peat couplets) in a sediment sequence spanning the past two thousand years that we interpret as resulting from erosive storm events. By dating the base of these couplets and the return to high salt marsh peat, we are able to estimate the recovery time of marshes under varying rates of sea-level rise. In marshes from Great Sound to Raritan Bay, we use microfossils (e.g., foraminifera, diatoms) as indices of ecosystem health. We monitor the response of microfossils to natural (e.g., changes in salinity or inundation frequency from sea-level rise) and anthropogenic (e.g., nutrient loading) influences. We also apply quantitative paleoenvironmental reconstruction techniques to sediment archives to infer the relative influence of these disturbances on New Jersey wetlands over the past two thousand years. These results provide the information necessary to inform future coastal wetland restoration targets and to support development of site-specific goals in other regions.
Presented Posters

Long Wang (Estuarine and Coastal Research, East China Normal University, Shanghai, China)

Early to Middle Holocene Rapid Sea-level rise in Ningbo Plain, China

As global average temperature continue to rise, Ice sheets and glaciers accelerate melting, the uncertainty of future global sea level rise may increases. Sea-level change is closely related to evolution of Environment and human civilization in global coastal lowlands. Reconstruction of relative sea level change can provide reliable geological constrain for research on Glacial Isostatic Adjustment (GIA), recovery of ice sheet history and crustal movement. During the last decade, a few Holocene sea-level curve has been established on eastern China coast. On the basis of previous related research on the Yangtze River Delta, here we present a new high-quality early to middle Holocene sea-level curve on the Ningbo plain, southeast of Yangtze coast, east China.

Ningbo plain is a geological relative stable area, with continuous formation and preservation of Holocene marine strata. On the basis of our preliminary geological investigation, we drilled 22 Holocene boreholes within 0.3 km² on the plain. Ground altitude was measured for each core from established benchmarks using a total station. Framework of Holocene relative Sea level change was determined using precise AMS¹⁴C dated basal salt marsh peat, upper tidal flat sediments and supratidal flat sediments as sea-level index points, based on multi-proxies(dinoflagellate cysts, aquatic plants pollen, TOC/TN, δ¹³C, sedimentary facies, lithology) sample analysis process.

The results show: (1) the early to middle Holocene RSL has risen rapidly in Ningbo plain by 16m during 8.80 - 9.07 ka BP, at a long-term rate of 9.30 mm/a. This result provides a new early-mid Holocene RSL record for far-field region. (2) During 8.5-8.0 ka BP, RSL has risen by 6.27 m, with an average rate of 12.54 mm/a. During 8.5-8.3 ka and 8.3-8.0 ka BP, RSL has risen by 2.39 m, 3.88 m, at a long-term rate of 11.95 mm/a, and 12.93 mm/a, respectively. This result was lower than the records from the neighboring Yangtze River Delta, but much higher than the records from Mississippi delta and Rhine delta. We hypothesize that previous study may underestimated the amount of water input from the Laurentide Ice sheet lake or neglected other melt water sources may contribute to far-field records. Subsequently, simulation of GIA and sea-level fingerprint and comparison among different temporal-spatial geological records are required in the future to better understanding the discrepancy and mechanism of rapid sea-level rise.
Din Kakar (Department of Geology, University of Balochistan, Pakistan)

Dominant role for tsunami waves in emplacing imbricated boulders on the Sindh coast west of Karachi, Pakistan

Imbricated boulders line much of the Maripur coast 20 km west of Karachi, and about 2 km southwest of Abdul Rehman Goth. The boulders rest on a rocky coastal platform. Their mean size on the platform is in the range 2 to 8 cubic meters, and it decreases inland from there. The largest boulders are as much as 30-60 m from the fair-weather shore, and the smaller clasts extend as much as 100 meters inland from that shore. The boulder sources are 3-6 m below sea level. The flows that emplaced the boulders, inferred to be 180 degrees from the dip direction of the imbrication, is to the northeast, perpendicular to the most of the local coast. Two eyewitnesses testified that the Maripur boulders were brought ashore by the 1945 tsunami. I infer that only a tsunami has enough energy to lift these boulders from a depth of 3-10-meter-deep sea, and that storm waves have merely rearranged the clasts.

Tsunami waves have been invoked to explain additional examples of coastal boulders beside the Arabian Sea at Gujarat, India; Chahbahar, Iran; and northwest of Sur, Oman. All the boulders indicate flow away from the likely source areas of tsunamis from the Makran Subduction Zone, though also in directions consistent with storm waves. I am unaware of any evidence that storm waves have introduced these additional clasts.

Aldona Damušytė (Lithuanian Geological Survey)

Possible paleo-tsunamis footprints in the Baltic Sea south-eastern coast

The whole Eastern Baltic region, including the south-eastern coast of the Baltic Sea, for many years have been considered as an area of low seismic activity. This opinion has radically changed after a few earthquakes that occurred on the junction of XX-XXI centuries (4.7 magnitude, Osmussaar Island, Estonia, 1976; 5.0 and 5.2 magnitudes, Kaliningrad Oblast of the Russian Federation, 2004). The structures formed as a result of soil liquefaction were known in a number of localities along the whole south-eastern Baltic Sea coastal zone, whereas preliminary information about these structures possibly caused by strong earthquakes after the decay of the Last Glacial were published only a few years ago (Bitinas and Lazauskienë 2011, Bitinas 2012, Nikonov 2013). New special investigations in Latvia confirm this standpoint (Van Loon et al. 2016). Some earthquakes with the epicentres in the Baltic Sea could cause the tsunami waves which might have reached the shores of the Baltic. The tsunami waves leave obvious specific footprints in the seashore sediments: remnants of marine diatoms in freshwater sediments of coastal lagoon layers; sandy or gravel interlayers in the coastal wetland peat thickness, etc. (Morton et al. 2007). Tsunami descriptions in the neighboring Polish Baltic coast were found in the historical documents (Mörner, 2008); the results of the current special geological surveys also maintain about the possibility of such events during the recent geological past (Piotrowski et al. 2015).
Some geological peculiarities of Holocene sediments in the Lithuanian Baltic Sea coastal zone could be also attributed to the footprints of the palaeo-tsunamis. The marine diatoms species (*Trybionella acuminata*, *Campylodiscus clypeus*, *C. echenis*, *Diploneis smithii f. rhombica*, *Mastogloia smithii*, *Thalassiosira lacustris*) were identified inside the peat layers near Būtingė (Lithuanian-Latvian cross-border coastal area), as well as inside the freshwater lagoon sediments near Nida (Curonian Lagoon) that currently are laying a few meters below the present sea level. It was interpreted as salt water invasions, possibly caused by the tsunami waves. The same interpretation is possibly available for the explanation of the origin of the sand interlayer in the peat thickness in the Svenčelė bog (eastern coast of the Curonian Lagoon). According to the results of radiocarbon (\(^{14}\)C) and luminescence dating (IR-OSL), as well as pollen analysis, all the above mentioned geological events occurred not later than before 4.5 ka. Besides the palaeo-tsunamis version, the saltwater inflow with marine diatoms could be resulted by strong palaeo-storms, whereas the sand interlayer in the peat thickness could be caused by aeolian processes that occurred in the adjacent dune fields. Thus, the presented hypothesis about possible footprints of palaeo-tsunamis in the south-eastern Baltic Sea coast still are needs more solid argumentation and more detailed special investigations in future.

**Drasti Gandhi (Institute of Seismological Research, Gandhinagar, India)**

Do sheltered environments necessarily exhibit higher preservation potential for archiving extreme wave events?

Indian Ocean tsunami 2004, 2011 Tohoku tsunami and 2014 Chile tsunami have left several traces of tsunami deposits at the Indian ocean rim countries, which provoked researchers to explore the sites where little or no palaeotsunami research (i.e. extreme wave event) have been done. This is important as it would help in assessing vulnerability of coastlines and thereby mitigating its hazards. However, the major issues often faced by researchers is where to look for such palaeotsunami deposits? Simultaneously there is a lack of knowledge about the preservation potential of various coastal archives to archive palaeotsunami deposits.

Based on processes active during the propagation of a tsunami wave it is understood that the coastal geomorphology plays a vital role and has a unique response to a tsunami event. Every landform plays a different role and behaves differently during a tsunami event. For instance, some morphological settings are particularly favourable for the deposition and the preservation of tsunami deposits while some are not. These depositional environments are isolated from regular beach processes and some, by virtue of their elevation or distance from the coast accessible by high energy waves which inundate deeply in land like ~ tsunami. In light of this palaeomudflats or swales formed behind the sand dune or beach ridge ‘barrier’ would serve as an ideal place for deposition and preservation of tsunami deposits. Even the elevated beach terraces that are not reached by storms are also open to tsunamis, where tsunami may deposit large size debris.
To prove this hypothesis, firstly we studied that LANDSAT imagery and then carried out fieldwork along the Gulf of Kachchh coastline, western India. It directly faces the tsunamigenic sources like Makran Subduction Zone (MSZ) and Owen Fracture Zone in the Arabian Sea which makes it a probable site for archiving palaeotsunami deposits. We carried out trenching at the coast extending from Okha-Jamnagar in Saurashtra peninsula, as several tsunami simulation models have marked this zone as area with high influence from potential tsunami waves generated from the MSZ. This coastal segment is fringed by numerous dead coral reefs and extensive mud flats though it lacks palaeotsunami deposits. This we explain on the basis that there is absence of any kind of barrier at the above sites, hence the amount of sediment deposited during a tsunami event could also have been eroded away by its backwash. On the contrary to this we encountered sandy tsunami layers at the Luni, Mundra, Pinglehwar, Panjor Pir (near Kori creek) region of Kachchh coastline where retreating beaches formed the ridge swales or dune palaeomudflats systems. Owing to the barrier configuration against the palaeomudflat setting, these areas successfully archived geological signatures of past high energy marine flooding events. Same hypothesis can be applied to the other world coastline for identifying evidences of palaeotsunami deposits with a higher probability of success ratio.

**Byron Halavik (Department of Geosciences, University of Rhode Island, Kingston, USA)**

Compaction free late Holocene sea-level record for Rhode Island, USA

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.
Temporal variation of coastal geomorphology in Southern and Southwestern coastal zone of Sri Lanka

Southern and Southwestern coastal zone of Sri Lanka is the most productive, urbanized and highly populated coastal sector in Sri Lanka. Also it is the most dynamic coastal zone compared to other coastal regions in Sri Lanka. This coastal zone is experiencing high energetic oceanographic conditions created by the Southwest monsoon and is the main reason for such situation. Variety of coastal geomorphological features can be found within the Southwest coastal zone of Sri Lanka. These features include cliffs, islands, barrier beaches, bays, spits, lagoons, etc. This study attempts to identify the variation of shapes and sizes of these geomorphological features over the time. Both natural processes and human activities are responsible for such changes. To achieve this task, main geomorphological features extracted from historical topographic maps and aerial photographs are compared with recent satellite images and google earth images. First, geomorphological features extracted from 1956, 1974, 1984 aerial photographs and historical topographic maps were digitized and converted to georeferenced digital thematic layers. Next geomorphological features extracted from recent satellite images were also digitized and prepared a georeferenced digital thematic layer. Later by overlying these thematic layers, main changes of the geomorphological features of the study area over sixty years were compared. According to this study, it was noted that there are significant variation of some geomorphological features over the time. According to the National Aquatic and Research Agency (NARA) Sri Lanka, the sea water level around Southwest coast has increased about one meter within last three to four decades and is one of the main reason to change in geomorphological features. However, according to this study human influences are also contributes to change the geomorphology in the study area. As an example, when comparing the recent satellite images, it is very clear that the sand nourishment closer to Unawatuna beach had contributed to significant change in geomorphological features around the Unawatuna beach. According to the outcome of this research, it can be concluded that there is a significant temporal variation can be recognized in many locations along the Southwest coastal zone of Sri Lanka since last six decades due to both natural processes as well as human influences.

Effect of rise in sea water level on land degradation during last six decades in Southern coast of Sri Lanka

Along the coastline of Sri Lanka which circles about 1530 km there are many coastal geomorphological features can be identified. Of these features, majority of erosional
landforms are concentrated to Southern and Southwestern coasts while many depositional landforms can be found in Northwestern, Northern and Eastern coasts. This study has been focused to about 140 km from Kalutara to Matara along the Southern coast of Sri Lanka where there is a significant coastal erosion and land degradation has been recording compared to other coastal regions in the island. Five main geomorphological features i.e Weligama bay, Galle cliff, Coral reef at Hikkaduwa, Seenigama Island and Unawatuna beach are considered as main control locations of the study. According to the National Aquatic and Research Agency (NARA), Sri Lanka, these five location receive similar oceanographic conditions other than occasional change in local climatic and meteorological conditions. However, there is a slight variation of other conditions such as land use type, geological conditions etc. slightly vary from one location to the other.

First, with the comparison of historical maps and aerial photographs, trend of coastal erosion at these locations are demarcated. It has been noted that except the Galle cliff area, other four locations show a significant erosion during last sixty years. At some locations, the coastline has shifted towards the land more than 50 meters. Secondly, factors effecting on erosion in these locations were studied. Even though similar oceanographic conditions can be observed in these locations, there is a variation of surface materials. It was noted that two locations Unawatuna and Weligama consist of sandy beaches, Galle cliff and Seenigama locations consist of hard rocks while Hikkaduwa location mainly composed of coral reefs. Therefore, within last sixty years land at Unawatuna and Weligama has to be degrade in similar manner while Galle and Seenigama has to show similar observation. However, according to erosion trends observed in this research, there are different rates of erosion can be observed in these locations. Therefore, other influence not has been considered in the above involve to make such changes i.e sea water level rise. The topography of these locations varies. When comparing Galle cliff and Seenigama island, it is noted that Galle is located higher elevation than Seenigama and therefore, Seenigama immerge about 4m and about 1 to 2 km² land degradation can be observed during last sixty years while such observation cannot observe at Galle cliff area. Similarly more land degradation can be observed at Weligama bay compared to Unawatuna bay as it located lower elevated area than Unawatuna. Also it was noted that some coral reef exposures which could be seen at surface in 1956 aerial photographs of Survey Department of Sri Lanka at Hikkaduwa have been immerging for las sixty years and at present these coral reefs cannot see at the surface. These observations shows a significant land degradation occurred in the Southern coast of Sri Lanka within last six decades due to sea water level rise.

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

A 3000-year record of overwash events documented in coastal sediments from Sur Lagoon, Oman

Coastlines of the Arabian Sea are vulnerable to inundation by tsunamis due to their proximity to the Makran Subduction Zone (MSZ). However, the historical record of tsunamis impacting
This region is limited to only a few geographically isolated accounts spanning the last 2000 years. This fragmentary record has resulted in uncertainty over the recurrence interval and possible magnitudes of tsunamigenic-earthquakes originating from the MSZ. Examining the sediments deposited by 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 28 November 1945, a Mw 8.1 earthquake generated a tsunami that inundated coastlines surrounding the Arabian Sea with wave heights up to 13 m. At Sur Lagoon, Oman, the tsunami deposited a laterally extensive shell-rich layer that contained distinctive taphonomic assemblages of both foraminifera and bivalves. Beneath the 1945 deposit at Sur Lagoon, we found seven anomalous marine sand layers preserved in fine-grained lagoon sediment that we attribute to deposition by tsunami. These medium to coarse sand layers range in thickness from 10 to 40 cm and are intercalated with sandy-mud. Detailed grain size analysis indicates that each of the sand layers are followed by an abrupt return to lagoon mud. Many of the sands have features consistent with the 1945 tsunami deposit, such as a sharp basal contact, fining upwards sequences, and marine foraminifera (e.g., Amphistegina sp., planktics). By contrast, the underlying and overlying lagoon deposits are generally finer, massive, and contain foraminifera that are typical of shallow low-energy coastal environments (e.g., Ammonia tepida, Elphidium advenum). Preliminary radiocarbon dating of articulated bivalves establish a late Holocene age range for the tsunami sands. Other than the 1945 deposit, tsunami layers younger than 1390 cal yBP are absent. Pending analyses will constrain the timing of each of the overwash layers.

Miklos Kázmér (Department of Palaeontology, Eötvös University, Budapest, Hungary)

Archaeological evidence for modern coastal uplift at Diu, Saurashtra Peninsula, India

There is a tank hewn into coastal Pleistocene limestone near Diu city on the Saurashtra Peninsula of western India. Site survey and a review of similar structures worldwide provide evidence that this tank could have been used for holding fish or Murex snails. The approximately 5 × 5 m tank is connected to the sea by a 1-m-deep canal; today it would be impossible to use the tank, given that not even the high spring tides can fill it. It is suggested that the Diu coast was uplifted by ~0.5 m after the tank was hewn in the coastal platform. Since that time, the carved surfaces have been modified by coastal karst dissolution and have developed deep gouge marks. Uplift of the Diu coast raises the possibility of a major seismic event in Diu during the latter part of the last millennium.
Hira Lodhi (NED University of Engineering and Technology, Karachi, Pakistan)

Numerical simulation of Makran tsunamis in creeks of the Indus Delta, Pakistan

We are studying the behavior of tsunamis in tidal creeks of the Indus Delta. The study uses an open-source modeling code and historical bathymetry to simulate the 1945 Makran tsunami, which caused many fatalities in the area. The simulations are being compared with written records of those losses, which vary among newspaper reports from December 1945, and with recollections of eyewitnesses interviewed in the past five years. The modeling is beginning with Hajambro Creek and Turshian Creek, near Keti Bunder. The eventual goals include a Delta-wide assessment of risks posed by future Makran tsunamis of various sources and sizes.

The simulations made thus far, using Geoclaw, simplify the 1945 tsunami as having a purely tectonic source from the fault rupture estimated by Byrne et al (1992). The two creeks were chosen because both connect the Arabian Sea to the port of Keti Bunder. Bathymetry is available from British Admiralty charts and from modern surveys. The model output includes wave arrival times, wave heights and current speed within the two creeks. Complications include post-1945 enlargement of creeks attributed to sediment starvation from upstream impoundments and diversions.

The calibrations require skeptical synthesis of written and oral accounts of the 1945 tsunami in the Indus Delta. Most of the writings obtained thus far come from newspapers that were published in Bombay and Karachi, and which were allied with various factions in the run-up to independence and partition. The accounts published include loss estimates in the thousands, later reiterated in tsunami catalogs that were attributed to representatives of the Indian National Congress and were contested by British colonial authorities. In the Keti Bunder taluka, the tsunami reportedly took lives in Hajamro (Hajambro), Chhan, Tulsian and Khorban villages.

Ilham Bouimetarhan (MARUM, University of Bremen, Germany)

Tracking deglacial sea-level variations in the Indian Ocean through changes in tropical saltmarsh ecosystems and mangrove dynamics.

The marine pollen record off the Rufiji River, Tanzania (Indian Ocean) provides new information on the deglacial sea-level changes associated to high-latitude climate variation in the Northern Hemisphere. Our new palynological results indicate a directional succession of three pollen families, between ~19 to 14.8 kyr BP, in the following order: Poaceae, Cyperaceae and Amaranthaceae, followed by an increase in mangrove around 14.8 kyr BP. Although they inhabit a wide range of environments, their development in this sequence in addition to the following expansion of mangrove would be related to past sea level changes. The comparison of our high-resolution pollen record with general sea-level reconstructions...
shows that when sea level was ~80-120 m lower relative to today, the exposed shelf allowed the grass (Poaceae) and sedges (Cyperaceae) to expand. During the subsequent sea-level rise, only pioneer species from the Amaranthaceae tolerating highly saline environments with a permanent tidal influence and having high colonizing abilities could expand under these stressful conditions. Rapid sea-level rise characterizes the onset of the North Atlantic Bolling/Allerod warm event when mangrove forests expanded considerably in the Rufiji delta around 14.8 kyr BP. These results add to the scarce knowledge on the East African coastal vegetation, a major biodiversity hotspot in the area. They have a great ecological significance, as much as they deal with intertidal ecosystems that are poorly documented on longer timescales and provide independent information on past sea-level changes that complements the almost exclusively marine body of evidence. Therefore, intertidal tropical ecosystems may provide clues to a better understanding of the potential for sea-level rise as an alternative mechanism for abrupt perturbations of the ocean-land-atmosphere system under future climate change.

Ghazala Naeem (Resilience Group, Islamabad, Pakistan)

Promoting survival of the next Makran tsunami in the Indus Delta, Pakistan

Coastal communities of Pakistan, especially small fishing villages dotted in Makran and Indus Delta regions, are extremely vulnerable to potential threat of tsunamis generated from Makran Subduction Zone which can allow only less than half an hour time of reaction. Even the same hazard i.e. 1945 Makran tsunami, could be much more devastating if happened today in the region. Many of these small settlements ranging population of less than 50 households to a maximum of 800, lack basic communication infrastructure like roads, telephone, electricity, internet, etc., making a tsunami early warning, even if detected timely, impossible to reach out these target areas timely.

In order, to study the Gaps and Capacities of Pakistan's Coastal Hazard Early warning System, Oxfam GB Pakistan has taken an initiative of supporting a short study to understand the gravity of the ground situation.

A recent study underway in the Indus Delta is intended to assess the risk from future Makran tsunamis by means of modeling that is calibrated to effects of the 1945 tsunami. The modeling is being done at NED University, Karachi, with focus on Hajambro Creek and Turshian Creek, near the port of Keti Bunder. The model results will be used to guide tsunami preparedness measures that would include rapid dissemination of official warnings and deployment of emergency responders. The effort will be guided, as well, by the results of the Oxfam GB (2016) and UNDP (2010) studies, particularly regarding socio-economic conditions, built environment, communication infrastructure, topography and location (distance from sea & nearest city, height from sea level, access through roads/boats, availability of evacuation site), and further accounts from eyewitnesses to the 1945 tsunami (in addition to those at http://itic.ioc-
The findings include possible impediments to dissemination of the official tsunami warnings, in total of 14 communities of Makran and Indus Delta Creeks including Keti Bander. The efficient promulgation of official warnings will likely require careful advance work with television and radio broadcasters. When many of those settlements are informal and even not listed on the local government database, land use management is extremely important. In addition to technological solutions, self response training for observing natural warning of tsunami, evacuation on high grounds, rescue, etc. are extremely important for making these communities self reliant.

Adam Switzer (Asian School of the Environment, Nanyang University, Singapore)

Sedimentary record of ‘tsunami like’ overwash: Typhoon Haiyan in the central, Philippines

In November 2013, Typhoon Haiyan caused a 5-8 m ‘tsunami like’ storm surge left washover sediments up to 1.5 km inland that provide a modern example for reconstructing pre-historical events in tropical settings. We mapped the thickness and extent of the deposits and documented the textural and compositional variations overwash sand sheet in three contrasting coastal environments, the siliciclastic coast of Tanauan, the mixed carbonate-siliciclastic coast of Basey and the open carbonate coast of Hernani. Each transect extends from the shore to the landward limit of the Haiyan deposit. Sediment samples were taken using a gouge auger or by excavating shallow trenches. Grainsize analysis, organic and carbonate content were determined by standard techniques. Microfauna including foraminifera and testate amoebae were sieved and counted. On the mixed siliciclastic-carbonate coast of Basey, the Haiyan sediment is beige, poorly-sorted, silt to fine sand. Here the thickest deposit was 8 cm and is found close to the shore. The thickness at Basey varies irregularly from 1 to 4 cm, away from shore and the deposit displays systematic landward trends of fining grainsize and decreasing carbonate content. In contrast, on the silicilastic coast of Tanauan, the typhoon Haiyan sediment is predominantly gray, moderately- to well-sorted, fine to coarse sand. The thickness varies greatly with topography and ranges from 5 to 20 cm with little internal stratification. The thickest accumulations were found in mangrove stands and shallow ponds between 200 to 400 m from the shore. In both locations the microfossil signature of the Haiyan deposit is characterised by the predominance of nearshore and subtidal benthic, and planktic foraminifera suggesting mixed provenance, including a contribution of sediment sourced from deeper environments. Low numbers of freshwater testate amoebae and brackish agglutinated foraminifera are also present in the Haiyan deposit, indicating some scouring of terrestrial environments. On the open carbonate coast that was affected by a wave-dominated setup surge, the overwash sediments include two distinct assemblages: carbonate boulders now occupying the reef flat surface, and a sand sheet that blanketed the coastal plain up to ~300 m inland. On the open coast, inverse modeling of flow velocity derived from boulder dimensions, sediment thickness, and grainsize distributions indicates that the storm surge travelled across the wide reef flat and inundated the coast at flow velocities exceeding 4 ms⁻¹. The Haiyan deposits share many
characteristics of tsunami deposits. Notably, although storm surge conditions at the 3 sites were similar significant differences in sediment grainsize, composition and sorting exist. This variability is attributed to local factors including variations in bathymetry and sedimentology of the nearshore environment. These findings underscore the importance of studying local variability and of comparing storm and tsunami deposits from similar settings.
Field trip

Most of the following outcrop descriptions are obtained from Hoffmann, G., Meschede, M., Zacke, A., & Al Kindi, M. (2016): “Field Guide to the Geology of Northeastern Oman”.

Saturday, 12th November – Coastal morphology, long-term coastal changes

Check out of hotels in Muscat, pick-up and departure

Stop 1: Seeb - Archeology and agriculture in an arid setting: The Batinah Coastal Plain

Location: UTM 40 Q 624612 2616785 / N 23°39'26" 58°13'18"

The site at Seeb consists of 2.5 m of poorly sorted fine to medium sand, with incorporated shells, rock and coral debris, together with fish and mammal bones (Fig. 3C). Most of the shells are bivalves such as Cypraeidae, Strombidae and Conidae together with Turritellidae and Potamididae, in particular Terebralia palustris. Of the five radiocarbon ages on non-marine material, the lowest is treated as an outlier, but the others are around 1000 cal. yr BP. Anthropogenic remains comprise various types of pottery sherd. Silty intraclasts are documented at the base of the profile interpreted as erosional remnants of mud bricks. The archaeological finds are related to daily life including pottery, cooking pots and jar fragments. Turquoise-blue alkaline glazed pottery and white opaque-glazed ware bowls both date to the 8th to 9th century, and were imported from Iran and Iraq, respectively. Most abundant is sgraffiato decoration ware which dates to the 10th and 11th century.

Stop 2: Qurum National Park: Mangrove swamps and settlement history

Stop 3: Viewpoint Wadi al Kabir: Ophiolite obduction and coastal development

Location: UTM 40 Q 660197 2606808 / N 23°33'49” E 58°34’10”

This stop is located on a mountain overlooking Wadi al Kabir, located some 200 m below. The Arabic word “kabir” means large. The wadi follows a major fault which strikes NW-SE and separates Triassic dolomites of the Mahil formation from peridoditic rocks of the Samail Ophiolite sequence. There is an ongoing discussion whether or not the fault is active, as the coastal configuration in this area indicates on-going subsidence (Hoffmann et al. 2013). The Triassic sequence is thrust onto Cretaceous sediments of the Muti formation which
represents the top of the autochthonous unit of the Arabian plate margin. The ultramafic rocks across the fault, view towards NE) are mostly composed of dark harzburgite with some layers of lighter dunite. They form a rugged relief and are unconformably overlain by paraautochthonous Eocene strata (yellow marl). The contact between the Cretaceous igneous rocks of the ophiolite sequence and the Eocene marls is developed as a nonconformity. The landscape characteristics are subject to change with ongoing land clearance in the area. The valley floors are widened to accommodate more commercial buildings.

Lunch

Stop 4: Bimmah sinkhole: Karst morphology and terrace formation

Location: UTM 40 Q 712322 2548990 / N 23°02′09″ E 59°04′19″

The Arabic name “Hawiyat Najm” refers to a local legend and translates to “meteorite impact crater”. However, the sink hole represents a collapsed cave in a karstified area and formed due to chemical dissolution of carbonate rocks. Karstification describes the process of limestone dissolution by meteoric water.

The sinkhole, or doline, is situated within an elevated abrasion platform of Eocene limestone. It has a slightly oval shape with a diameter of 65 m at the widest point and 50 m at the narrowest. It has a depth of about 25 m. The water in the sink hole is a mixture of salty sea water and groundwater. The hydraulic contact between salty sea water and groundwater contributes to the erosional effect and plays an important role in karstification in this area. The Eocene limestone is overlain by a 5 m thick layer of terrestrial gravel resulting from the abrasion of the limestone plat- form. This indicates sea-level changes caused at this location mainly by tectonic uplift. There are steps leading down into the sinkhole, where it is possible to swim in the water.
Stop 5: Fins: Raised marine terraces

Location: UTM 40 Q 727400 2535610 / N 22°54'47“ E 59°13'02”

Exposures along the wadi reveal an angular unconformity between the lower Eocene limestone which dips by 25° towards the sea and the horizontally bedded Quaternary cover. The latter compromises of beachrock deposits and limestone made up of coralline algae. The cover sediments become dominated by fluvial gravel further towards the highway. In-situ remains of the gastropod *Pleuroploca trapezium* can be found. These indicate an intertidal setting. The surface of the Quaternary cover sediments is littered with flintstone flakes, remnants of a Neolithic flint workshop.

Panoramic view of the different terrace levels (view from Fins towards west).

Stop 6: Fayah: Fossil coral reef

Location: UTM 40 Q 739122 2517902 / N 22°45'05” E 59°19’43”

The coastal area between Quriyat and Sur is currently uplifting as indicated by a flight of raised coastal terraces. The terraces are cut in the Eocene limestone. Whereas the upper terraces are erosional, the lower one is depositional. This outcrop offers the unique possibility to study the recent coastal evolution. We have to assume that the rocks are of Quaternary age. However, they are not dated as yet. The outcrop is located at the mouth of a wadi cutting through the terraces. An intercalation of marine and terrestrial deposits is exposed in a cliff section.

The surface of the terrace was mined for gravel when the highway was constructed from 2005 to 2008. The walk along the gravel beach leads to the base of a coastal cliff which is 9–12 m high. The outcrop shows an impressive succession of coral-reef units and conglomerates. The fossil Quaternary coral-reefs are very well exposed in life position at the wave-cut cliff.
Fossil Quaternary coral-reef at a cliff south of Tiwi capped by a conglomerate.

The basal unit is a 3-m thick coral-reef with some coral colonies measuring 1.2 m in length. A silty matrix is observable between the coral colonies. Clastic sediment input must have been quite high as the corals show a branching – rather than a plate-like growth pattern. The latter would be more common for *Porites* sp. as observed here. Irregular branching trace fossils, possibly belonging to the ichnogeneric *Ophiomorpha nodosa* are common within this unit. The trace fossil *Ophiomorpha nodosa* is produced by burrowing endobenthic shrimps lining their cavity walls with fecal balls.

The basal unit is capped by a massive and grain-supported conglomerate of 1 to 5 m thick and a maximum grain size in the range of 1 m. This unit is overlain by a 3m thick silt layer with individual coral reefs containing abundant *Thalassinooides* trace fossils. The uppermost part of the visible profile is a grain-supported conglomerate again of several meters thickness. A thin layer of well-rounded pebbles with abundant shells makes up the surface of the terrace. Most of it is, however, has been mined and is no longer available.

The alternating marine (coral reef) and terrestrial (conglomerates) layers indicate the interplay of eustatic and neotectonic processes. The global (eustatic) sea level shows considerable variations throughout the Quaternary. Regressional phases are characterized by a seaward shift of the coastline whereas transgressions result in the landward shift.

**Overnight: Field camp on the beach in Fins**
Stop 7: Ras al Hadd: Early Bronze Age site HD-6

Location: UTM 40 Q 788690 2490588 / N 22°29′50″ E 59°48′21″

The coastal area of Ras al Hadd is very rich in archaeological remains dating from the 3rd millennium BC and later (Cleuziou & Tosi 2007c, Hannss 1998). The archaeological site HD-6 was discovered in 1986 and has been subject to archaeological investigations from 1996 to the present (Azzara 2009, Cartwright & Glover 2002, Hilbert & Azzara 2011). The site covers a circular area of approximately 10,000 m² and is elevated by a couple of decimeters above the surrounding landscape. The mount appears to have been densely settled and three main periods of occupation have been identified.

View into the excavation of HD-6 (February 2013). The foundations of the houses made up of clay bricks as well as the stone wall in the back are visible. For scale, the girl’s height is 0.85 m.

The main phase is represented by sand and mud brick structures, and marks the very beginning of the Early Bronze Age. The absolute age for this period is given as 3100–2700 BC. A total number of fourteen buildings surrounded by a stone wall were dug out. The walls of the adobe structures were made up of standardised mudbricks of 55 x 32 x 8 cm which were joined by 1–2 cm layer of mortar. Smoothed clay was used for the floors, and square tiles of 35 x 35 cm have also been taken note of. The houses have 3 to 6 rooms where the individual rooms are rectangular and rather small, only a few square meters each. Archaeological evidence suggest a comparatively large population of around 150–200 inhabitants occupying the site over several centuries, however probably only seasonally during the winter months. The function of the rooms is not unambiguously clear. They were
probably used as storage facilities or for the manufacture of domestic supplies and ornamental goods. Fireplaces are common inside and outside the buildings.

The economy was dominated by fishing as evidenced by numerous fishing related artefacts such as ropes, nets, net sinkers and copper fishing hooks. The fishing gear was sophisticated so that even large prey such as dolphins was caught. Cold hammering of metal objects appears to have been a common activity. There is lack of evidence, e.g., slag deposits, that copper was smelted on site; it therefore had to have been imported from elsewhere. The copper was used for pins, knives, chisels, and many other small tools. There are plenty of remains indicating the manufacturing of beads.

There is sedimentological evidence that the site was inundated by an extreme-wave event around 2500 ± 200 BC (Hoffmann et al. 2015). The causative process is either storm or tsunami. The interpretation as tsunami inundation is favored as no overwash deposits were observed in the last 2 cyclone events, in 2007 and 2010 respectively.

**Stop 8: As Silah: Coastal environments and humans**

**Location:** UTM 40 Q 781495 2450172 / N 22°08'02" E 59°43'44"

The outcrop is located directly at the coast, forming a cliff approximately 5 m high. The sequence is composed of conglomerates, sandy as well as silty layers of inferred Quaternary age. These deposits were laid down in a near shore coastal environment. They most probably represent beach deposits that formed during the last interglacial period (Eemian Interglacial, Marine Isotope Stage 5e). The Quaternary rocks discordantly overlie a series of vertically inclined layers of shelf sediments with alternating reddish radiolarian mudstones and grey pelagic limestone which belong to the Triassic Sal Formation of the Batain basin (Peters et al. 2001).

Carbonate shells of up to 30 cm in length are abundant in the upper layers of the Quaternary sequence (Figs. 93 and 94). The round, elongated tube-like and locular shells are remnants of oysters (*Crassostrea gryphoides*). They are preserved with one valve only, indicating that they accumulated along the paleo-beach and were not pre-served in-situ.

**Lunch**

**Stop 9: Al Ashkara: Shell middens**

**Location:** UTM 40 Q 777651 2445323 / N 22°05'26" E 59°41'27"

The coastline is dotted with these shell middens. The more than 50 sites that are known between Ras al Jinz in the north and Asylah in the South, provide evidence for prehistoric subsistence economies (Biagi 1994a, Berger et al. 2013). The middens appear as circular
structures which may be up to several meters high and tens of meters in diameter. The material found in the shell middens comprises shells of various edible species including oysters and other bivalves as well as gastropods. Especially the gastropod shells (e.g. *Terebralia palustris*) are fragmented, indicating the mechanical opening of the shell to access the soft part of the animal for consumption. Besides the dominating shells, remains of bones, fishes and crabs are common. Fishing equipment such as net sinkers, mother-of-pearl shellhooks and line-weights are documented as are many types of stone tools (Berger et. al. 2013). There is no evidence for agriculture, and herding activities were only marginal.

The material in the middens was accumulated by Neolithic fisher communities that lived in the coastal environment from the 6th to the 4th millennium BCE. The material indicates that lagoon and mangrove environments were exploited. This in turn allows the conclusion to be drawn that the climate must have been wetter than today. The shell middens are protected archaeological sites. Hence disturbances, collection of material, etc. should be avoided.

Stop 10: Paleoclimatology – where the sand desert meets the sea

Location: UTM 40 Q 703310 2341913 / N 21°10’02” E 58°57’29”

Exposed along the beach section are aeolianites, weakly cemented dune deposits which according to Gardner (1988) underlie the entire Wahiba sands. The cliff reaches more than 10 m in height locally. The most striking features are the bedding structures which can best be observed in the early morning hours when they are nicely illuminated by the rising sun. Large scale cross bedding structures with decimeter to meter thick tabular planar cross beds made up of curved laminae represent the slip face of the former dune. Climbing ripple lamination as well as trough cross-beds are also common.

Aeolianites with cross-bedding at the coastline south of Al Ashkharah.

Overnight: Field camp on the beach in Fins
Stop 11: Fins: Fine grained deposits

Location: UTM 40 Q 725493 2540004 / N 22°57’10” E 59°11’57”

Fine grained, predominantly sandy ridges were examined in several locations along the coastline around Fins. The beach ridges north of Fins are up to 3.3 m high, and an incorporated shell layer is situated at 2.5 m above MHW. The most common shell in this layer belongs to *Pinctada radiata*, a species that lives attached to hard substrata. The shells are often articulated and the mean shell size is ~6 cm. The presence of well-preserved colonies of the worm snail *Thylacodes variabilis* which lives cemented to hard surfaces is noteworthy. These species construct delicate, irregular shaped shells, susceptible to damage when exposed to repeated wave action, which makes storm-related transport unlikely. Furthermore, coral fragments, barnacles, pebbles, cobbles and small boulders of up to 50 cm in diameter are incorporated in these layers. The ridge is discontinuous but can be followed for several kilometers along the coast. Radiocarbon-dating of four articulated shells of *Pinctada radiata* obtained depositional ages younger than ca. 1500 cal. yr BP. Whereas OSL dating indicate depositional ages older than 2700 years in the lower part of the section, the sample underlying the shell layer has an age of 1010±310 years.

Stop 12: Fins: Block and boulder deposits

Location: UTM 40 Q 729217 2530530 / N 22°52’01” E 59°14’03”

The car park is located within a small gravel pit where material for construction purposes was mined. The remaining material on the eastern or seaward side of the pit allows an insight into the stratigraphy of shore-parallel coastal ridges. The ridges consist of reworked beach material, mainly sand with floating boulders and gravel with bivalves like oysters and *Tridacna* sp., scaphopods, gastropods and coral fragments. The marine faunal remains testify to a near-shore origin. Also *Lithophaga* sp. borings in limestone pebbles support this assumption. The entire de-posit apparently has an inverse grading, as the largest boulders are found on the top of it. However, the sedimentary sequence shows internal fining-up cycles. One boulder (c. 1.0 x 1.0 x 0.8 m) with attached oysters was found 80 m from the cliff edge and 8 m above mean sea-level. This may reflect the maximum transport distance for boulders.

A short walk towards the cliff involves a climb over the boulder ridges onto the cliff platform. This platform is made up of Eocene limestone. Remnants of lithified beach deposits in the form of beach rock cover the limestone in places. The platform formed by a combination of wave action and bioerosion (cf. Taboroši & Kázmér 2013). Uplift of the crust then resulted in emergence of the platform as a terrace well above present high tide level. The terrace surface is barren; there are no deposits except for some isolated blocks, several meters in diameter.
The angular boulders at (UTM 40 Q 729217 2530530 / N 22°52′01″ E 59°14′03″) are made up of Eocene limestone and the largest one has dimensions of 7 x 6 x 1.5 m and a mass of 120 tons. The blocks rest on the lithified beach rock and hence must have been moved against gravity. They were quarried at the cliff edge.

The largest tsunami block found along the coastline has a mass of 120 tons

A rounded limestone boulder can be observed 250 m further north (UTM 40 Q 729203 2530788 / N 22°52′09″ E 59°14′02″). The rounding as well as the presence of sessile marine organisms, e.g. oysters, bryozoans, Lithophaga, indicate an intertidal origin of this boulder.

It is concluded that the fine grained material which makes up the coast parallel ridges as well as the blocks and boulders were deposited during tsunami events. The most likely source for the tsunami is the Makran Subduction Zone which defines the northern limit of the Arabian Plate. The last significant earthquake (M 8.1) that resulted in a tsunami occurred on 27 November 1945. However, the wave impact along the Omani coast was comparatively small (Hoffmann et al. 2013b). The deposits along this coastal section are indicative that larger events than 1945 can be expected.

Stop 13: Tiwi graveyard: Block and boulder deposits

Lunch
Stop 14: Sur: Lagoonal fine grained deposits and shell beds

Location: UTM 40 Q 757779 2496002 / N 22°33’04” E 59°30’24”

The city of Sur stretches along the coast and covers the area between Wadi Raisah and an irregular shaped lagoon of about 3.5 km by 2.5 km. The old city center is located on a peninsula stretching into the lagoon. Sheltered from the open sea yet still influenced by tides, mangroves flourish here. They cluster in the area of two wadi outlets which terminate into the south-western part of the lagoon. Mangroves, here of the species Avicennia marina (family Avicenniaceae, Black Mangroves; Pickering & Patzelt 2008), serve an important ecological function as they provide shelter for water birds in general but also for migrating birds and small forms of marine life (Pickering & Patzelt 2008). The scrub-like trees with gnarled trunks reach up to eight meters in height. Mangroves are adapted to the intertidal zone and are therefore able to tolerate a wide range of salinities. Obvious are the so-called pneumatophores, which stick vertically out of the ground. As the typical roots are covered by waterlogged soil, these aerial roots allow the plants to absorb oxygen. Mangroves are vulnerable in Oman as their distribution is limited to only small areas along the coast.

Overview of the lagoon of Sur with its mangrove forest.

Several lagoons, especially along the rocky coast east of Muscat were destroyed for construction projects. A successful reforestation project has been undertaken by the Ministry of Environment and Climate Affairs and Sultan Qaboos University in the lagoon of Ras al Hadd.

Overnight: Field camp on the beach in Fins
Tuesday, 15th November – Farewell

Departure to Muscat airport in the morning

Stop 15 (Optional): Hike through Wadi Shab and departure to Muscat airport in the evening

Location: UTM 40 Q 730496 2527460 / N 22°50’21” E 59°14’46”

Wadi Shab is one of Oman’s major tourist attractions and is mentioned in every guide-book. It certainly warrants a visit as it truly is one of the most beautiful wadis in the country. The impressive deeply cut canyon with its steep rock faces reaching up to 200 m is accessible only on foot. The 45 min. walk of 2 km leads to several pools and runs mainly on the wadi bed.

The canyon is cut into Eocene limestone. They appear massive-nodular, yellow to brown in colour, and were shaped by the erosional forces of water. Wadi Shab hosts a perennial stream with a changing water level, depending on precipitation. Additionally, the water is responsible for the creation of an open karst system. Due to carbonic acid weathering, caves, overhangs, and massive block falls are observable all along the walk.

Pool in the Eocene limestones of Wadi Shab.

The wadi has spectacular hanging gardens, terraces which are farmed well above the wadi’s floor. The water used for irrigation flows through falaj systems onto the fields. Most of the terraces including the soil and vegetation were destroyed by the tropical cyclone Gonu in 2007. Some date palms survived and the terraces are now being re-cultivated.
Next IGCP 639 meetings

The next IGCP Project 639 "Sea Level Change from Minutes to Millennia" meeting will be hosted in 2017 in Durban, South Africa.

More details, including the exact dates will follow shortly. For more information at the meeting, please feel free to talk to either the project leaders or Dr. Andrew Green, who will be hosting the meeting at the University of KwaZulu-Natal

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