Proof

CONTROL ID: 932512

TITLE: Arctic Submarine Slope Stability

PRESENTATION TYPE: Assigned by Committee (Oral or Poster)

CURRENT SECTION/FOCUS GROUP: Ocean Sciences (OS)

CURRENT SESSION: OS09. Submarine Landslides: Characterization, Processes and their Sedimentary Record

AUTHORS (FIRST NAME, LAST NAME): Daniel Winkelmann\textsuperscript{1}, Wolfram Geissler\textsuperscript{2}

2. Alfred Wegener Institute for Polar and Marine Science, Bremerhaven, Germany.

Title of Team:

ABSTRACT BODY: Submarine landsliding represents aside submarine earthquakes major natural hazard to coastal and sea-floor infrastructure as well as to coastal communities due to their ability to generate large-scale tsunamis with their socio-economic consequences.

The investigation of submarine landslides, their conditions and trigger mechanisms, recurrence rates and potential impact remains an important task for the evaluation of risks in coastal management and offshore industrial activities. In the light of a changing globe with warming oceans and rising sea-level accompanied by increasing human population along coasts and enhanced near- and offshore activities, slope stability issues gain more importance than ever before.

The Arctic exhibits the most rapid and drastic changes and is predicted to change even faster. Aside rising air temperatures, enhanced inflow of less cooled Atlantic water into the Arctic Ocean reduces sea-ice cover and warms the surroundings. Slope stability is challenged considering large areas of permafrost and hydrates.

The Hinlopen/Yermak Megaslide (HYM) north of Svalbard is the first and so far only reported large-scale submarine landslide in the Arctic Ocean. The HYM exhibits the highest headwalls that have been found on siliciclastic margins. With more than 10.000 square kilometer areal extent and app. 2.400 cubic kilometer of involved sedimentary material, it is one of the largest exposed submarine slides worldwide. Geometry and age put this slide in a special position in discussing submarine slope stability on glaciated continental margins. The HYM occurred 30 ka ago, when the global sea-level dropped by app. 50 m within less than one millennium due to rapid onset of global glaciation. It probably caused a tsunami with circum-Arctic impact and wave heights exceeding 130 meters. The HYM affected the slope stability field in its neighbourhood by removal of support. Post-megaslide slope instability as expressed in creeping and smaller-scaled slides are the consequence. Its geometrical configuration and timing is different from submarine slides on other glaciated continental margins. Thus, it raises the question whether slope stability within the Arctic Ocean is governed by processes specific to this environment.

The extraordinary thick slabs (up to 1600 m) that were moved translationally during sliding rise the question on the nature of the weak layers associated with this process. Especially theories involving higher pore pressure are being challenged by this observation, because either extreme pore pressures or alternative explanations (e.g. mineralogical and/or textural) can be considered.

To assess the actual submarine slope stability and failure potential in the Arctic Ocean, we propose to drill and recover weak layer material of the HYM from the adjacent intact strata by deep drilling under the framework of Integrated Ocean Drilling Program. This is the only method to recover weak layer material from the HYM, because the strata are too thick. We further propose to drill into the adjacent deforming slope to identify material properties of the layers acting as detachment and monitor the deformation.
(No Table Selected)
(No Image Selected)

Additional Details
Previously Presented Material:
Mass-transport deposits (MTDs) form a significant component of the stratigraphic record in ancient and modern deepwater basins worldwide. However, the difficulties encountered when performing direct observations of these submarine units, the limited area covered by geophysical surveys acquired by research institutions, and the often surficial nature of seafloor data collected by federal agencies represent major hurdles in understanding submarine mass-movement dynamics. Three-dimensional seismic reflectivity imaging, drawn mainly from energy exploration in deepwater regions of the world, has allowed researchers to describe the architecture of MTDs at unprecedented spatial and temporal scales. In this talk, we present observations made using thousands of square kilometers of three-dimensional seismic data acquired by the oil and gas industry in offshore Trinidad, Morocco, and the Gulf of Mexico, where MTDs are a common occurrence in the stratigraphic record. Detailed mapping of MTD architecture has allowed us to better understand the role that MTDs have in continental-margin evolution. Morphometric data obtained from the mapping of MTDs is used to model tsunamigenic waves and their potential affect of coastal areas. The effect of low permeability MTDs on reservoir and aquifer fluid behavior has important implications, enhancing the economic importance of understanding the occurrence and distribution of these deposits. The recognition of MTD processes and morphology leads to new understanding of the processes possibly active in shaping other planets. Such analogs speak to a possible deepwater origin for features on Mars previously attributed to subaerial events. As industry-quality 3D seismic data become increasingly available to academic institutions, current studies become important bell weathers for future analysis of MTDs and processes in oceans of this planet and beyond.

INDEX TERMS: [3002] MARINE GEOLOGY AND GEOPHYSICS / Continental shelf and slope processes.
CONTROL ID: 946681

TITLE: Overview of Submarine Landslides From the Charlevoix-Kamouraska/Lower St. Lawrence Estuary Seismic Zone, Eastern Canada

PRESENTATION TYPE: Assigned by Committee (Oral or Poster)

CURRENT SECTION/FOCUS GROUP: Ocean Sciences (OS)

CURRENT SESSION: OS09. Submarine Landslides: Characterization, Processes and their Sedimentary Record

AUTHORS (FIRST NAME, LAST NAME): Guillaume St-Onge\textsuperscript{1,2}, Jacques Locat\textsuperscript{3}, Patrick Lajeunesse\textsuperscript{3,4}, Cauchon-Voyer Geneviève\textsuperscript{3}, Hubert Gagné\textsuperscript{3}, Bryan Sinkunas\textsuperscript{3}, Geneviève Philibert\textsuperscript{3}, David J.W. Piper\textsuperscript{5}, Thierry Mulder\textsuperscript{6}, Claude Hillaire-Marcel\textsuperscript{7}, Joseph Stephen Stoner\textsuperscript{2}

INSTITUTIONS (ALL): 1. ISMER & GEOTOP, Rimouski, QC, Canada. 2. COAS, Corvalis, OR, United States. 3. Université Laval, Quebec, QC, Canada. 4. CEN, Quebec, QC, Canada. 5. Geological Survey of Canada-Atlantic, Dartmouth, NS, Canada. 6. Université Bordeaux 1, Talence, France. 7. UQAM & GEOTOP, Montreal, QC, Canada.

Title of Team:

ABSTRACT BODY: The Charlevoix-Kamouraska/Lower St. Lawrence Estuary seismic zone (CK/LSLE) is the most active intraplate seismic zone in Canada, where at least five earthquakes of magnitude of 6 or stronger occurred during the last 350 years. In addition, due to 1) very high sedimentation rates (as high as 30 m/ka in the St. Lawrence Estuary during deglaciation), 2) the deposition of marine clays by the Goldthwait and Laflamme postglacial Seas in the St. Lawrence Estuary and Saguenay Fjord respectively, and 3) the influence of postglacial rebound, the thick Quaternary sedimentary sequence is prone to remobilisation following strong earthquakes. Here, using recent geophysical, sedimentological and geochronological data collected during several cruises on board different research vessels, we will overview some of the Holocene and historical submarine mass wasting events recorded in the St. Lawrence Estuary and Saguenay Fjord in order to identify, characterize and date submarine landslides possibly associated with strong pre-historical and historical earthquakes. Similarly, we will also overview recent geophysical and sedimentological work conducted in lakes from the CK/LSLE seismic zone.


Additional Details

Previously Presented Material: 60 % in scientific papers
CONTROL ID: 944881
TITLE: Landsliding as the progressive growth of a slipping region: Initiating dynamic rupture propagation by local pore-pressure increase and its potential for arrest.
PRESENTATION TYPE: Assigned by Committee (Oral or Poster)
CURRENT SECTION/FOCUS GROUP: Ocean Sciences (OS)
CURRENT SESSION: OS09. Submarine Landslides: Characterization, Processes and their Sedimentary Record
AUTHORS (FIRST NAME, LAST NAME): Robert C Viesca-Falguières1, James R Rice1, 2
Title of Team:
ABSTRACT BODY: Given the low angles of continental slopes, sedimentation alone may not be sufficient to initiate failure, in which case a source of locally elevated pore pressure $p$ is a likely candidate. Heterogeneities in $p$ may arise from spatially variable sources of gas (e.g., Fleischer et al., Geo-Mar. Lett. 2001), variations in permeability, and channelized seepage, and are expected in regions affected by methane hydrates and their dissociation (e.g., Xu & Germanovich, JGR 2006). Additionally, while marine sediments are ideally considered as normally consolidated sediments (for which shear strength is expected to increase with deformation), given typical sedimentation rates on these slopes (~mm/yr or less) strength may develop due to the long lifetime of interparticle contacts. Such behavior is indicated by increased sample stiffness following long periods of fixed loads in consolidation tests (e.g., Karig & Ask, JGR 2003); as well as by the development of increasingly peaked stress-strain profiles under triaxial loading conditions for normally consolidated samples previously held under loads for increasingly long times (e.g., Bjerrum & Lo, Geotechnique 1963). Such strength would be lost upon sufficient disruption of contacts (i.e., the sediments are considered sensitive), and if weakening is sufficiently strong, localized deformation may be expected as traditionally is for overconsolidated sediments.

Consequently, we apply a fracture-mechanics model of the quasistatic growth of a thin zone of localized shear (represented as a slipping crack surface) due to a locally peaked and increasing $p$ profile of a generic nature. Strength on the slip surface weakens with slip and we find that the ruptured region may reach a limit at which the quasistatically calculated crack growth rates become unbounded, corresponding to initiation of dynamic rupture and landsliding. In some cases rupture propagation may not be indefinite, because another equilibrium crack length and slip distribution may exist at this limit which will generally be stable; then the dynamic rupture may arrest in that configuration, as also shown by Garagash & Germanovich, (2010, priv. comm.). Such arrest is predicted for sufficiently shallow (or strong) slopes, such that the prestress is near or below the residual strength. The quasi-static predictions are then generally comparable to results of elastodynamic initial-value problems.

Such modeling may have implications for a specific nucleation mechanism due to hydrate dissociation. If pressurized pore fluids exist below the hydrate stability zone as has been commonly suggested (e.g., Flemings et al., Geol. 2003; Bunz et al., EPSL 2003; Hornbach et al., Nature 2004), then shear stress is effectively elevated relative to the shear strength of this potential failure plane. Consequently, if local dissociation occurs at the base of the hydrate zone, then conditions may be met for indefinite rupture propagation. We also highlight key results from the consideration of a simple mechanism of $p$ increase
due to the obstruction of basin-scale fluid flow by permeability reductions in the localized shear zone.


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Additional Details

Previously Presented Material:

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In the historic records of off-shore mega-earthquakes along the subduction zone offshore Japan, there are a lot of witnesses about large-scale burning of flammable gas possibly ejected from sea floor. This gas was supposed to be the dissolved methane hydrates (MH), which have been found in the soundings of IODP and other oceanology projects. Since the vast distribution of the BSR in the continental margins, a lot of papers have been published which pointed out the possibilities of that gasification of those hydrates could have triggered gigantic submarine landslides. Global warming or large earthquake or magma intrusion may trigger extremely deep gigantic landslides in continental margins that which could cause catastrophic tsunami. However, recent triaxial compression tests on artificially prepared sand-MH-mixture samples revealed that they have slightly higher strength than the ones of only sands and MH's endothermal characteristics may resist against accelerating shear and large-displacement landslides as well.

While, the stress-controlled undrained ring shear apparatuses have been developed by Sassa and Fukuoka at Disaster Prevention Research Institute, Kyoto University to reproduce subaerial landslides induced by earthquakes and rainfalls. Using the apparatuses, they found localized liquefaction phenomenon along the deep saturated potential sliding surface due to excess pore pressure generation during the grain crushing induced bulk volume change. This phenomenon was named as "sliding surface liquefaction." Similar sudden large pore pressure generation was observed in pore pressure control test simulating rain-induced landslides.

In this paper, authors examined the shear behavior of the dry sand-dry ice mixture under constant normal stress and shear speed control tests using the latest ring shear apparatus. Sample was mixture of silica sands and dry-ice pellets (frozen carbon-dioxide). Those mixtures are often used for studying the mechanism of the methane hydrates in laboratories because no explosion protection facility is required. In order to prevent rapid gasification, the specimen was prepared without water. Applied total normal stress was 200 kPa and initial normal stress was maintained at about 70 kPa by slightly opening the drainage valve to vent pressured CO2 gas. When the sample was sheared at 30 cm/s, the stress path reached failure line of friction angle of about 37 degrees immediately. However, excess pore air pressure increased soon after and the stress path moved to the origin along the failure line. This means rapid shearing generates frictional heat and it accelerates the gasification of dry ice quickly. On the other hand, crushing of pellets may contribute to increase the total surface area of dry ice and to acceleration of gasification, to some extent. Authors are conducting to examine the velocity weakening characteristics of the samples and upcoming results will give more detail of the mechanism. But this sliding-surface-liquefaction in the mixture supports the possibility of similar accelerating displacement in the sand-MH mixture or boundaries between MH and sand layer induced by certain strong ground motion under sea floor.

(No Table Selected)

(No Image Selected)

Additional Details

Previously Presented Material:
TITLE: 3D Seismic Analysis of Buried Slide Deposits in the SW Vøring Basin, Mid-Norwegian Margin
PRESENTATION TYPE: Poster Requested
CURRENT SECTION/FOCUS GROUP: Ocean Sciences (OS)
CURRENT SESSION: OS09. Submarine Landslides: Characterization, Processes and their Sedimentary Record
AUTHORS (FIRST NAME, LAST NAME): Stefan Buenz1, Runar Johansen1, Jan Sverre Laberg1

ABSTRACT BODY: Sediments on the Norwegian deep water margin have failed repeatedly during the last 2.5 Ma. This region has seen some of the largest submarine mass wasting events on continental margins worldwide. Considering the increased interest of the hydrocarbon industry in deep-water areas, there is a need to better understand slide deposits, slide development and areas prone to failure. The development of the Ormen Lange gas field in the Storegga Slide headwall area has been a showcase of assessing slope stability in hydrocarbon frontier areas. This integrated project led to a better comprehension of the Late Pliocene / Pleistocene evolution of the mid-Norwegian margin and its frequent slide activity. The slide mechanism is likely related to a distinct depositional environment of the glacial-interglacial cycles. Slide deposits may constitute a major geohazard for exploration and development of seafloor and sub-seafloor resources.

Two 3-D seismic data sets from the southwestern part of the Vøring Basin on the mid-Norwegian continental margin have been used to analyze the upper part of the Naust Formation (~ 0.5 to 0.2 ma) showing a number of chaotic units interpreted as slide deposits. A seismic stratigraphy with four main units has been established (unit 1-4). The two oldest units (unit 1 and 2) are dominated by glacial debris-flow deposits formed during glacial maxima when the Fennoscandian ice sheet reached the shelf edge. Parts of unit 2 are later deformed by younger slide events. The two youngest units (unit 3 and 4) are characterized as slide material and are related to the Vigrid Slide and the Sklinnadjupet Slide. Unit 3 shows compressional structures formed by well-consolidated deposits that have been broken up and pushed on top of rather undisturbed sediments. Less consolidated deposits are deformed by compression, which resulted in the formation of folded structures. Deposits in unit 4 show that the slide can be associated with a complex flow process and the development of general shear zones that separate zones of sediments with varying degrees of deformation. Slide deposits within the different zones may have been deposited at different times or may have moved at different velocities in one mega-event. The Sklinnadjupet Slide was probably triggered just after the Vigrid Slide. The Sklinnadjupet Slide has probably developed retrogressively and filled in the upper part of the Vigrid Slide.

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Modeling tsunamis generated by submarine mass failure is not as well understood as waves generated by seismic displacements. Co-seismic deformation occurs very rapidly even in comparison with the shallow-water wave speed, allowing for a specification of the displacement of the sea surface to be set as identical to the deformation of the ocean floor, as initial conditions for computer modeling. Submarine mass failure exhibits slower speeds and water gravitationally adjusts to a new potential field while the submarine mass is failing.

Empirical formulae and computer models exist to calculate the one or two-dimensional surface waveform generated by underwater mass movements. For different empirical formulae, estimates vary over orders of magnitude for the same slide. We present the scatter from ten different empirical formulations for the leading wave amplitude for 19 different underwater landslides. Some of these formulations are based on modeling, some on analytical solutions, and some are based on experimental data. The scatter highlights that it is important to use higher order approximations of the Navier-Stokes equations to reliably and robustly compute the interaction between water surface and the deforming mass. We carry out modeling with iSALE, a hydrocode that numerically solves the compressible Navier-Stokes equations in a multi-material and multi-rheology framework, and present preliminary results for the leading wave height with varying rheologies to account for different slide materials. It appears that multi-material modeling is important in for understanding the hydrodynamics of tsunamis generated by submarine mass failures under geophysically realistic conditions.

INDEX TERMS: [3070] MARINE GEOLOGY AND GEOPHYSICS / Submarine landslides, [3045] MARINE GEOLOGY AND GEOPHYSICS / Seafloor morphology, geology, and geophysics.

(No Table Selected)
(No Image Selected)

Additional Details
Previously Presented Material:
Proof

CONTROL ID: 971374
TITLE: Slide Activity along the eastern slope of the Gela Basin (offshore Sicily): First results from expedition MSM-15/3
PRESENTATION TYPE: Assigned by Committee (Oral or Poster)
CURRENT SECTION/FOCUS GROUP: Ocean Sciences (OS)
CURRENT SESSION: OS09. Submarine Landslides: Characterization, Processes and their Sedimentary Record
AUTHORS (FIRST NAME, LAST NAME): Katrin Huhn¹, Michael Strasser¹, Tim Freudenthal¹, Federica Foglini², Fabio Trincardi², Daniel Minisini²,³
INSTITUTIONS (ALL): 1. MARUM, Bremen, Germany.
2. ISMAR-CNR, Bologna, Italy.
3. Shell International Exploration and Production, Houston, TX, United States.
Title of Team: MSM15/3 working group
ABSTRACT BODY: Submarine slides occur at all sediment bearing margins worldwide (Camerlenghi et al., 2009; Masson et al., 2006). Although numerous studies have dealt with mapping and monitoring of submarine landslide as well as investigations of trigger mechanisms and sediment failure processes, many open questions persist why a given slope fails whereas adjacent remains stable. Besides large slide events, smaller scaled mid-size slides became recently of particular importance because especially these local slides enable investigation of physical and kinematical processes during failure and to test a wide range of different trigger mechanisms.

Hence, during the research expedition MSM15/3 we drilled two distinct landslides in the Gela Basin offshore south of Sicily (Italy) utilizing the MARUM sea floor drill rig (MeBo). These so-called ‘Twin Slides’ have previously been identified in water depth between 200 – 800m on the basis of side-scan sonar, Chirp seismics, swath bathymetry and shallow core data. Besides, these landslides are described as multiple failures likely controlled by specific stratigraphic surfaces acting as glide planes (Minisini et al., 2007; Minisini and Trincardi, 2009). Nevertheless, failure planes are located in depth inaccessible by conventional coring and we therefore lack groundtruthing of the geophysical data. Therefore, MeBo was deployed to drill e.g. critical subsurface intervals. A systematic MeBo drilling transect from the undisturbed slope apron to the depositional area of these landslide masses recovers up to 55 meter long cores, including the failure planes and stacked mass transport deposits in the proximal and distal areas, respectively. Sedimentological, geochemical, geophysical and geotechnical analysis of these core materials will enable (1) an age dating and estimation of the recurrence rate of mid-sized slide events and (2) a sediment physical characterization to gain a deeper insight into kinematics and physical processes during failure as well as to test a number of hypothesis regarding the trigger mechanisms, such as the weakness of clayey deposits, the liquefaction potential of the interbedded non-cohesive sand and/or ash layers, and the building up of high pore pressures due to high accumulation rates.

References

(No Table Selected)
(No Image Selected)

Additional Details
Previously Presented Material: 0% presented or published
CONTROL ID: 971047
TITLE: Subsurface Seismic Record of Sediment Failures in the Neogene of Deepwater West Africa: Causal Mechanisms and Characteristics
PRESENTATION TYPE: Poster Requested
CURRENT SECTION/FOCUS GROUP: Ocean Sciences (OS)
CURRENT SESSION: OS09. Submarine Landslides: Characterization, Processes and their Sedimentary Record
AUTHORS (FIRST NAME, LAST NAME): Ayodeji P Oluboyo¹, ², Daniyar Zhunussov¹, Mads Huuse¹, Rob Gawthorpe³
2. PGS-Reservoir, Weybridge, United Kingdom.
Title of Team:
ABSTRACT BODY:

Catastrophic sediment failures in deepwater margins are initiated by a wide range of triggering mechanisms including but not limited to; sea-level fluctuations, earthquakes, rapid sediment overburdening, progressive slope failures and gas hydrate destabilization. Three-dimensional seismic interpretation of a 1,400 km² 3D volume from the Neogene stratigraphic record of the Lower Congo Basin (LCB) demonstrates the existence of two major types of sediment failures within an elongate salt bound mini-basin (c. 15 km by 60 km). These slope instabilities are distinguished on the basis of their size, origin, geometries and deformational structures.

Within the Middle Miocene, a regionally extensive, frontally emergent mass transport deposit occurs, and is a part of a much larger, regionally prevalent sediment failure deposit within the LCB. This deposit covers an area of ~ 750 km² with an average thickness of ~ 60 m and a volume of 45 km³, with its lateral extent delimited by the salt diapirs which bound the mini-basin. Seismically, it exhibits chaotic, discontinuous, low amplitude semi-transparent facies with an erosive basal scour surface and an irregular upper bounding surface.

The second type of sediment failure is a Pliocene aged, detached MTC with a short run out distance c. 10km. The slump is areally constrained to the flank of the western bounding salt-cored fold, with a preserved scarp along the fold crest. This deposit is frontally confined, with an average thickness of ~250 m and covers an area ~ 100 km² (4 km by 26 km). It is defined by a high amplitude reflection at the base, with a series of syndepositional thrusts detaching off this surface at the terminal end of the deposit. Compressional structures are also seismically resolvable in strata adjacent to the distal end of the MTC. The presence of pressure ridges along the top bounding surface, coupled with the differential compaction of the slump deposits and mounded topography relative to local bathymetry affects the locus of post failure sedimentation from the Pliocene till present day.

We propose the triggering mechanism for these sediment failures to include an interplay between regional climatic factors, eustatic sea level fluctuations, increased erosion and subsequent high sedimentation rates due to tectonic uplift of the West African margin during the Middle Miocene and oversteepening of salt cored folds in the Pliocene due to compression.


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Additional Details
Previously Presented Material:
The response of submarine slopes to seismic or storm loading has become an important element in the risk assessment for offshore structures and local tsunami hazard. Evaluation of submarine slope stability requires characterization of soil behavior and relies on the selection of appropriate parameter values. Although the traditional simple shear device has been used to investigate cyclic loading effects on marine clay, it does not allow for complex loading conditions which often contribute to the failure on submarine slopes.

Understanding the interaction between the initial shear stress, the slope angle, and the multi-directional shaking due to earthquakes or storm loading is an important aspect to understanding the failure mechanisms of submarine slope failures. The initial static driving force on the slope is combined with the dynamic loading by storms and earthquakes to create complex loading paths. Therefore, the ability to apply complex stress or strain paths is important to fully study the shear response of marine clays on submarine slopes.

A new multi-directional simple shear device developed at Texas A&M University allows loading along three independent axes, two perpendicular horizontal directions to allow any stress or strain paths in the horizontal plane, and a third in the vertical direction. This device is used to investigate the response of Gulf of Mexico marine deposits to different loading conditions. To study the effect of slope angle on the shear response of the soil, samples are subjected to a shear stress during consolidation, $K_0$ consolidation. One-dimensional monotonic and cyclic shearing of $K_0$ consolidated specimens is used to simulate level ground conditions, whereas sloping surfaces were simulated using $K_0$ consolidation for both monotonic and cyclic tests. The effects of shearing rate on the soil response are investigated using strain controlled tests at varying frequencies.

INDEX TERMS: [3070] MARINE GEOLOGY AND GEOPHYSICS / Submarine landslides.
Recent studies suggest that tsunami risk along the SW coast of Sumatra could be due to co-seismic slip along a backthrust at the NE Margin of the Mentawai Island and associated landslides (Singh et al., 2010). Using a combination of high-resolution seismic reflection and bathymetry data, they observed deposits of large submarine landslides at the NE margin of Mentawai Island and suggest that the high wave that occurred in 1797 might have been enhanced by landslides, producing a large localised tsunami. Until now most of the work devoted to tsunami hazard assessment in the area of Sumatra Island focussed on megaearthquakes earthquakes generated tsunamis. Therefore, estimating the run up heights due to submarine landslides is essential for risk mitigation along the SW coast of Sumatra.

A series of numerical scenarios are performed here to simulate potential submarine landslides and generated tsunamis in the area of Sumatra Island. The height and velocity of the water wave and the impact zones are calculated using a new numerical model solving the depth-averaged shallow water equations with high order finite volume methods. This model corresponds to the 2D extension of the model developed by Fernández-Nieto et al., 2008. The fluidized mass is modeled using a generalization of the Savage-Hutter model [Savage and Hutter, 1989] by including the role of buoyancy and fluid into the thin-layer equations with a Coulomb-type friction law. Our model takes into account the coupling between the fluid and the landslides and incorporates the rigorous description of topography effects that play a key role in the dynamics of landslides. We study the magnitude of variation of the wave expected depending on the location and volume released. These results show that landslide generated tsunamis have to be taken into account for risk assessment in the area of Sumatra Island.


(No Table Selected)
The northern Ligurian Margin is characterized by a steep and narrow continental-slope, high-sediment supply delivered through small mountain-supplied rivers and a recurrent seismic activity favouring the destabilization of sediments. The recent history of this area is marked by several major earthquakes (M~6) and three historical tsunamis (1564, 1818, and 1887 AD).

The morphology of the northern Ligurian Margin and the distribution of submarine failures on the continental slope have been studied using a large dataset including new multibeam bathymetric data (EM300), high resolution Chirp profiles and 24- and 72-channels seismic-reflection profiles collected during the MALISAR1-2 surveys (2006 and 2007) in order to discuss their triggering mechanisms. More than four hundred and fifty submarine failures of various morphology and sizes have been identified along the whole northern margin of the Ligurian Basin. Two zones, East and West, were discriminated along this margin with respect to the continental-slope morphology and the type of sedimentation/erosion processes. The greatest number of large-scale scars incising the quaternary deposits up to 100 to 400 m depth below the seafloor and testifying of large mass-wasting events are preferentially located in the western area (between the cities of Nice, France, and Imperia, Italy), whereas smaller scars are distributed homogeneously on the whole margin.

Several types of failures are pointed out along the northern Ligurian Margin:
1. small-scale scars are located at the transition between the shelf and the continental slope where they contribute to the progressive erosion of the shelf which is located, in some areas, only a few hundreds of meters off the coastline or along the walls of canyons. Such type of failures represents about 60 % of the studied scars. This large number of scars affecting quaternary deposits suggests a high frequency of failures that does not allow the preservation of over-consolidated deposits on the continental slope;
2. large-scale amphitheatre-like scarps such as the "Cirque Marcel" are located at the base of the continental slope and possibly related to the seismic activity of a neighbouring fault;
3. the upper part of interfluvces is sometimes incised by very vast scars cutting only superficial sediments. This type of instabilities is mainly represented in the eastern part of the basin and could have been triggered by earthquakes as well as by indirect effects of the last sea-level fluctuations.

The morphological analysis of the continental slope and the study of the spatial distribution and the main features of the submarine failures help identify the main triggering mechanisms and the factors controlling the failure's occurrence. Because of the increasing number of inhabitants settled along the Mediterranean Coast, the improvement of geohazard assessment concerning seafloor instabilities is also a relevant societal target.
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Additional Details
Previously Presented Material:
Landslides can trigger tsunamis with locally high amplitudes and runup, which can cause devastating effects in the near field region. The events of 1958 Lituya Bay, 1998 Papua New Guinea and 2006 Java tsunamis are reminders of the hazards associated with impulse waves. Tsunamis generated by granular landslides were studied in the three dimensional NEES tsunami wave basin (TWB) at Oregon State University (OSU) based on the generalized Froude similarity. A novel pneumatic landslide generator was deployed to simulate landslides with varying geometry and kinematics. Granular materials were used to model deformable landslides. Measurement techniques such as particle image velocimetry (PIV), multiple above and underwater video cameras, multiple acoustic transducer arrays (MTA), as well as resistance wave and runup gauges were applied. Tsunami wave generation and propagation is studied off a hill slope, in fjords and around curved headlands. The wave generation was characterized by an extremely unsteady three phase flow consisting of the slide granulate, water and air entrained into the flow. Landslide deformation is quantified and the slide kinematics with reference to slide surface velocity distribution and slide front velocity is obtained. Empirical equations for predicting the wave amplitude, period and wavelength are obtained. The generated waves depend on determined non-dimensional landslide and water body parameters such as the slide Froude number and relative slide shape at impact, among others. Attenuation functions of the leading wave crest amplitude, the lateral wave runup on the hill slope, the wave length and the time period were obtained to describe the wave behavior in the near field and to quantify the wave amplitude decay away from the landslide source. The measured wave celerity of the leading wave corresponds well to the solitary wave speed while the trailing waves are considerably slower in propagation. The individual waves in the wave train span from shallow to deep water depth regime. The energy conversion between landslide and waves is lower compared with 2D and solid block landslides due to radial spread of unidirectional landslide energy by the wave front. The slide characteristics measured in the experiment provide the landslide source for numerical landslide tsunami modeling. The measured landslide and tsunami data serve the validation and advancement of 3-dimensional numerical landslide tsunami and prediction models.

**INDEX TERMS:** [4564] OCEANOGRAPHY: PHYSICAL / Tsunamis and storm surges, [3070] MARINE GEOLOGY AND GEOPHYSICS / Submarine landslides.

(No Table Selected)
Landslide impact and tsunami generation (Photo credit: Devin K. Daniels)

Additional Details
Previously Presented Material:

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Abstract Body: The Plio-Pleistocene sedimentary sequence of the Pescara Basin (Central Adriatic Basin, Italy) has been investigated through the analysis of commercial 3D seismic reflection data. It consists of a complex of progradational and aggradational large scale eastward-dipping clinoforms (200 ms - 500 ms high).

Conventional seismic facies interpretation, combined with seismic geomorphology techniques, and rollover trajectories analysis have permitted to recognize two large scale mass-transport deposits (MTDs) of different age, buried within the slope clinoforms succession of the Pescara Basin. The two MTDs (named MTD1 and MTD2) affect the entire clinoform surface, from the shelf-break to the basin floor.

The older deposit (MTD1), buried at around 800 ms below the present day seafloor, is the largest, with a failed area of around 90 km², and is associated with a descending rollover point trajectory. The evacuated main headwall of MTD1 is roughly spoon-shaped, and is around 10 km wide and fairly smooth and linear. It also indentents the shelf-break. The basal shear surface of MTD1 has a ridge and through morphology, with small internal headwalls, that could be indicative of a retrogressive mechanism of failure. Steep lateral ramps of the basal shear surface abut against the undeformed slope sediments in strike profiles. In the accumulation area, at the toe of the slope, the slumped material overruns the former seabed. In some portions of the MTD1, frontal ramps connect with the basal shear surface resulting in a partially emergent landslide. The geometry of the landslide can act a lateral seal of unfailed units both along the sidewalls and along the frontal region of the landslide.

MTD2 (buried at around 650 m), covers an area of around 57 km², and is associated with a high-angle positive roll over trajectory. The evacuation area is smaller and shallower, with an arcuate headwall scar around 5 km wide, that affects also the continental shelf-break. MTD2 appears characterized by sectors with different internal deformation: a blocky area, that is scattered mainly to the south, and a northern sector, where the seismic facies analysis suggest the presence of completely remoulded deposits likely corresponding with debrites.

It has been observed that, especially in the case of MTD1, the topography created by the irregularities of the MTDs form stratigraphic traps through the ponding of sand-prone sediment gravity currents, resulting in discrete packages of possible sand-rich material. In addition, since the headwall scars of both the MTDs indent the shelf-break, it is possible that shelf-margin progradational successions have been mobilized and incorporated in the extensive chaotic bodies, bringing coarse grained material to the base of the slope. A comparison of the two buried MTDs, with modern landslide exposed at the seafloor in the southern Adriatic basin, permits to link the interpretation of seafloor mapping and VHR seismic profiles of modern
mass-transport complexes with industry-standard geophysical data.

**INDEX TERMS:** [3070] MARINE GEOLOGY AND GEOPHYSICS / Submarine landslides, [3002] MARINE GEOLOGY AND GEOPHYSICS / Continental shelf and slope processes. 
(No Table Selected) 
(No Image Selected) 

**Additional Details**

**Previously Presented Material:**

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The 1908 Messina Tsunami: the most likely sources from marine data

ABSTRACT BODY: Dangerous, if not devastating, tsunamis can be sourced from submarine mass failures. Research over the past decade has resulted in an improved recognition of this hazard. Numerous anomalous tsunamis may have a submarine landslide component, and these are identified by runups that, to some degree, are too large in relation to their proposed earthquake source. They include Sanriku, 1896, Messina, 1908, Puerto Rico 1918, Indian Ocean, 1945, Alaska, 1946 and Flores Island, 1982. Re-evaluation of these events, most notably using improved sea bed mapping technologies, has improved our understanding of their source, but not always with a proven result. Thus we are still challenged in our ability to differentiate historical tsunamis that may be sourced from either earthquakes or submarine landslides. Qualification of tsunami sources is critical if we are to validate submarine landslides as an important hazard.

The 1908 Messina tsunami is one such enigmatic event, but (for its time) unique in that there is a remarkable catalogue of tsunami inundation and runup data that provides a control on the actual tsunami source(s). The centenary of the 1908 Messina earthquake and tsunami has come and gone, yet over 100 years after this event took place, no complete model of the tsunami source mechanism(s) has yet been produced. Previous analyses of the 1908 tsunami have looked at a wide variety of earthquake rupture mechanisms, and several possible mass failure events. Whereas progress has been made in understanding the event, there still remains some doubt as to the validity of the geological interpretations and, therefore, subsequent tsunami modeling results.

Using marine geology data, notably multibeam bathymetry, we present a new unified model of the tsunami and its sources, providing a complete simulation of the event (Watts and Tappin, 2010). The earthquake rupture mechanism is by faulting along stepovers in the Messina Strait. Individual fault segments have NNW-SSE trending strike, and rupture proceeds from south to north trending NNE-SSW along the Messina Strait. These two facts explain the different seismic wave analyses and fault orientations proposed by various researchers. An ab initio mechanical model of fault segments reproduces both seismic inversion solutions and sea floor topography. We also examine several mass failures and discriminate between older events and those that probably contributed to the tsunami. We provide a thorough and rigorous examination of their precise locations, dimensions, displacements, and deformations. We reproduce mass failure motion with a state of the art mechanical model.

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Additional Details
Previously Presented Material: 30% AGU 2008

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Mass wasting processes on continental margins have strong relevance both for geohazards of coastal areas and for the emplacement and monitoring of offshore infrastructures. The seabed dynamics of the Ionian Calabrian Margin (ICM) are currently being examined in the context of the project MAGIC (Marine Geohazard along the Italian Coasts). The objective of this project is the definition of elements that may constitute geological risk for coastal areas. The ICM is a tectonically-active margin, the structures of which reflect two main processes: frontal compression and fore-arc extension during the SE advance of the Calabrian accretionary prism since the late Miocene; and a rapid uplift (up to 1mm/yr) of onshore and shallow shelf areas since the mid-Pleistocene. These processes are reflected in different tectonic settings at seabed, which is characterized by a narrow continental shelf above a slope of irregular morphology in water depths of 150–2000 m. In the north, a broad slope is dominated by ridges and intervening basins that are the morphological expression of the southern Apennine fold-and-thrust belt; in the south, the continental slope descends steeply towards the deep-water Crotone and Spartivento fore-arc basins.

The overall objective of this study is to map major features of mass wasting on the slopes of the ICM, investigate possible triggering mechanisms and consider the geohazards these features may represent for coastal areas. The study is based on an integrated analysis of multibeam morpho-bathymetric data and subbottom profiles, which together allow the recognition of four main types of mass wasting phenomena along the slopes of the ICM:

1) mass transport complexes (MTCs) within intra-slope basins – these are identified in the northern area, within the piggy-back basins: seabed imagery show the slopes of all the seabed ridges to be marked by headwall scarps recording widespread failure, while Chirp profiles show the adjacent basins to contain unstratified bodies indicative of debris flows buried beneath stratified sediments; multiple debris flows in several basins indicate one or more past episodes of failure that may be linked to activity on the faults bounding the structural highs.

2) slope slide scars – these are identified in two locations along the relatively steep southern Calabrian slope; the slide scars record several episodes of failure, linked to deposits within the deep-water basins that are yet to be identified.

3) possible gravity sliding – in one area of the southern Calabrian slope, elongate seabed features oriented subparallel to contours are observed, associated with diapiric structures that have been linked to Messinian
salt observed on seismic profiles (Rossi & Sartori 1981); we suggest that the elongate seabed features may record a form of downslope sediment sliding above salt, resulting in features analogous to the cobblestone topography of the outer Calabrian Arc; 4) canyon headwalls – in the upper parts of all canyons, numerous headwall scarps are consistent with retrogressive activity of the canyons.

INDEX TERMS: [3002] MARINE GEOLOGY AND GEOPHYSICS / Continental shelf and slope processes.

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(No Image Selected)

Additional Details
Previously Presented Material:
Lake Mjøsa is Norway's largest lake (117 km long, area: 365 km², greatest depth 468 m). It lies in a depression formed by glacial over-deepening of the southward extension of the Gudbrandsdalen glacial valley. It is therefore characterized by typical glacial “U-shaped” cross sections. In the study area it almost annually covered by winter ice.

The present study arose from pipeline breakages near the city of Gjøvik that ROV inspections demonstrated were caused by subaqueous mass movements.

The purpose of the study was suggest new pipeline routes based on slope stability evaluations from morphological analyses supplemented by simple geotechnical testing of core samples.

Data consisted of a multibeam bathymetric survey of the study area, a grid of sub-bottom profiler lines (SES 2000) and 9 gravity cores.

The morphological analysis of the multibeam data revealed that lake bed has slopes between ~15° and ~35° from the coastline and into the central deep (~250 m in the study area). Numerous flow paths were identified as were areas offshore from river mouths with clear evidence of downslope mass transport. Several slide scarps from 1 to 3 m were also discovered.

Slope stability analyses reveal safety factors close to 1 for the steepest gradients. The submarine slides are therefore thought to have been caused by density currents of cold water formed during winter. This dense water flowed downslope along the flow paths and is believed to erosively undercut the soft seafloor sediments which thereby lost their downslope support.

New pipeline corridors were drawn to avoid such scenarios.


(No Table Selected)
(No Image Selected)
TITLE: Evidence for seismic strengthening and climate influence in creation of an anomalously large slope failure, Aleutian-Yakutat margin, Gulf of Alaska

PRESENTATION TYPE: Assigned by Committee (Oral or Poster)

CURRENT SECTION/FOCUS GROUP: Ocean Sciences (OS)

CURRENT SESSION: OS09. Submarine Landslides: Characterization, Processes and their Sedimentary Record

AUTHORS (FIRST NAME, LAST NAME): Robert Reece1, Sean P S Gulick1, Gail Lynn Christeson1

INSTITUTIONS (ALL): 1. University of Texas Institute for Geophysics, Austin, TX, United States.

ABSTRACT BODY: Recent seismic studies reveal an isolated, anomalously thick mass-transport deposit (MTD) with an unusually short runout in the Gulf of Alaska. The MTD is located on the Aleutian margin proximal to the deformation front for Yakutat terrane subduction. The MTD geometry, size and location on a convergent margin lend support to recent studies suggesting seismic strengthening and infrequent sediment failure on tectonically active margins. Study of this MTD may provide insight into the magnitude and scope of triggers required for events of this type, including the influence of climate and sea level change. The previously uninterpreted MTD is buried in the Surveyor Fan off the Kayak Trough slope in the Gulf of Alaska, and we refer to it as the Surveyor MTD. The MTD is buried beneath at least 1 km of sediment in water depths of 3.5 to 4.5 km in the Surveyor Fan. Preliminary calculations suggest this MTD is the largest by volume globally with an area of 7,950 km², minimum thickness of 500 m, and volume of 4,470-6,705 km³. The deposit consists of debris flow with large rafted blocks 5-10 km in length that traveled as far as 50 km from the base of the slope. These blocks are present in the full vertical extent of the MTD, suggesting that the deposit represents one event at these locations, instead of several layered events. Distinct from other large MTDs, the Surveyor MTD has a short runout at ~80 km, and remains thick over a large area.

Due to Yakutat terrane and Pacific plate subduction zones, great earthquakes are expected in the Gulf of Alaska every few 100 years, yet no other MTDs are observed. The lack of additional MTDs, the large volume, and short runout distance all suggest high sediment strength of the MTD source material, which may be the result of seismic strengthening. Possible factors involved in overcoming the high shear stress to mobilize the high strength material are a significant increase in sediment flux and larger oscillations in sea level and glacial extent caused by the mid-Pleistocene transition since ~1 Ma. The combined effects of these processes may even be necessary prerequisites for a Surveyor MTD magnitude failure based on the lack of other MTDs associated with historical great earthquakes on this margin.


Additional Details
Previously Presented Material: Preliminary observations on physical characterization of this MTD were presented as a poster in October 2009 at the Submarine Mass Movements and Their Consequences International Symposium in Austin, Texas, USA.
Identification and dating of a submarine landslide in the western Argentine Basin - an interdisciplinary approach

Gravity core GeoB13804-1 was retrieved during the RV Meteor cruise M78/3a (May/June 2009) in an area of a submarine landslide, on top of which no drape could be detected by high-resolution geophysical data. Non-steady state conditions of the pore water system are evidenced by distinct gradient changes of the sulfate, phosphate, and alkalinity profiles at ~2.4 m depth below the sediment-water interface - the depth at which an erosive contact was identified during the sedimentological core examination. Shear strength analysis show the sediments to be less consolidated above the interface at 2.4 m than below. The data indicates that we recovered a recent MTD in our core. Integrating geochemical profiles and diffusion-based transport models we simulated the re-equilibration of the SO$_4^{2-}$ profile after deposition of the slide mass and determined a maximum age of 20-50 yrs for the MTD. A likely candidate for triggering the observed recent landslide was a local magnitude 5.2 earthquake that occurred in 1988. In order to test this hypothesis, we performed probabilistic slope stability back-analysis of the observed landslide structure. Results reveal that the initiation of the slope failure indeed required additional ground accelerations and that the 1988 earthquake is a reasonable trigger if likely additional weakening processes, e.g. excess pore pressure, preconditioned the slope towards failure. Our multidisciplinary approach provides the means to more accurately recognize and date recent slope failures in the Argentine Basin and other slope environments.
(No Table Selected)
(No Image Selected)

Additional Details
Previously Presented Material:
Several types of mass failures are observed along the Owen ridge (NW Indian ocean) using multibeam bathymetry, acoustic imagery and sediment echosounder. The Owen ridge is associated with the Owen fracture zone, a 800 km-long active fault system which accommodates the strike-slip motion between the Arabia and India plates. Mass failures mobilize a pelagic cover and display a large variety of features along the three parts of the Owen ridge, from cohesive to desintegrative flows. We present a complete morphometric analysis of submarine landslides, and provide a synthetic map of the different types of sediment destabilization along the ridge. Spectacular instability scars, which could have removed up to 45 km$^3$ of material, were evidenced on the southern part of the ridge. Such volumes are unexpected in a sedimentary environment dominated by slow pelagic sedimentation rate. The spatial variation of failure morphology seems to be strongly related to the topography of the basement. The detailed re-analysis of seismic lines collected during the ODP Leg 117 reveals the recurrence and the sporadic repartition of mass wasting events along the southern fragment of the ridge since its uplift in the early Miocene. Earthquakes are more frequent than slides along the southern ridge, excluding seismicity as a unique triggering process. We propose that mass wasting frequency is mainly constrained by the slow pelagic sedimentation rates.

INDEX TERMS: [3070] MARINE GEOLOGY AND GEOPHYSICS / Submarine landslides.
Additional Details

Previously Presented Material: Submitted to EPSL, as "Owen Fracture Zone, the Arabia-India plate boundary unveiled"
Submitted to Marine geology, as "MASS WASTING PROCESSES AND GIANT LANDSLIDES ALONG THE OWEN FRACTURE ZONE (NORTHWEST INDIAN OCEAN)"
CONTROL ID: 964112

TITLE: Slow-motion gravitational collapse on the flanks of a rapidly subsiding transform basin: the Marmara Sea, Turkey

PRESENTATION TYPE: Assigned by Committee (Oral or Poster)

CURRENT SECTION/FOCUS GROUP: Ocean Sciences (OS)

CURRENT SESSION: OS09. Submarine Landslides: Characterization, Processes and their Sedimentary Record

AUTHORS (FIRST NAME, LAST NAME): Donna J Shillington1, Leonardo Seeber1, Christopher C Sorlien2, Michael S Steckler1, Hulya Kurt3, Günay Çifçi4, Caner Imren3, Derman Dondurur4, Savas Gürçay4, Duygu Timur4, Emin Demirbag3

2. Earth Research Institute, University of California, Santa Barbara, Fairbanks, Japan.
3. Istanbul Technical University, Istanbul, Turkey.
4. Dokuz Eylül Üniversitesi, Izmir, Turkey.

Title of Team:

ABSTRACT BODY: High-resolution multi-channel seismic (MCS) data acquired during the Turkish American MArmara Multichannel project (TAMAM) in 2008 and 2010 and swath bathymetry data reveal extensive ‘wave’ fields throughout the Marmara Sea, a 150-km-long trough comprising several active transform basins along the North Anatolian Fault. The origin of similar ‘waves’ globally remains controversial; competing models ascribe them to sedimentary processes, tectonic shortening or gravitational collapse. Likewise, previous work based on older datasets in Marmara concluded that features here are folds formed by tectonic shortening or sediment waves formed by the interaction of bottom currents with seafloor topography. Determining their origin is essential to understand the tectonic and sedimentary evolution of the Marmara Sea.

‘Waves’ in the Marmara Sea exhibit many of the classic features of sedimentary waves (upslope migration, syndepositional development, thicker beds on upslope flanks of waves), but cannot have a purely depositional origin. The consistent parallelism between the crests of the ‘waves’ and bathymetric contours over a wide-range of orientations, the progressive steepening of the flanks downward from the sea floor, and their formation on steeper slopes (~3-10°) than those usually associated with sediment waves (<1°) argue for folding associated with gravitational downslope movement as a dominant process in their formation; we thus term them ‘gravitational folds’. Folds have typical wavelengths of ~0.5-1 km, but MCS profiles indicate that wavelengths commonly change through time. Fold amplitudes also vary with depth, from ~20 m near the seafloor to a much as ~100-200 m at depth. Stratigraphic growth on the upslope flanks of folds indicates that they are syndepositional features that form slowly. Using our age model, which is based on a series of lowstand deltas, it appears that deformation is occurring over time periods of at least 0.5 m.y. Thus folds do not represent geologically instantaneous events, like submarine landslides previously identified in this region that are thought to be triggered by earthquakes. Movement and deformation is probably modulated by compaction-related feedbacks between deposition, slope, and fluid escape. Stratigraphic growth on the upslope sides of folds also indicates that topography created by folding modulates deposition, such that sedimentary processes also contribute to their development. Structures indicative of gravitational collapse are observed in our data nearly everywhere in the basin with slopes of ~3-10°; this implies that...
slopes less than 3° are too flat to drive this process, while slopes >10° are composed of highly competent rocks that are too strong to creep.

The temporal and spatial evolution of the gravitational folds is clearly related to the evolution of slopes in the basin by vertical and lateral tectonic deformation. Fields of gravity folds, therefore, are powerful markers for reconstructing the tectonic history of basins.


(No Table Selected)

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**Additional Details**

**Previously Presented Material:**
ABSTRACT BODY: Breaching is a type of slope failure that can deliver sand from the continental shelf into the deeper sea. The slow erosion rate and near vertical failure angle of breaching is connected with the evolution of pore pressure in the sediments. We study this connection by creating breaching in a flume while monitoring the pore pressure in the sediment deposit. We find the pore pressure decreases in the sediment deposit as the breaching initiates, suggesting dilation in the sediment. Our measurements show that the excess pore pressure decays exponentially with distance away from the failure surface. The abnormally low pore pressures dissipate through pore water flow. We find that the spatial distribution of excess pore pressure is self-similar through time while the absolute values of excess pore pressure decrease with time. These observations suggest that the interaction between stress and pore pressure is in quasi-steady state. We couple the stress and pore pressure in a numerical model to study their interaction. In the model we relate the changes in stress with the retrogressive sediment failure. We find that the erosion rate of the retrogressive sediment failure is proportional to the coefficient of consolidation and inversely proportional to the relative dilation strength of the sediment deposit. This observation suggests that the slope failure style of breaching is controlled by the evolution of pore pressure. The results also imply that breaching can occur in any type of sediment that has a low coefficient of consolidation and a high dilation strength, including silts.


Additional Details
Previously Presented Material:
Abstract

Sedimentary Characteristics and Ages of Submarine Mass Movements around Puerto Rico and the Virgin Islands

Submarine landslides and earthquakes in close proximity to Puerto Rico and the Virgin Islands have the potential to trigger tsunamis, which could cause significant damage to coastal communities in the region, as was the case both in 1867 and again in 1918. Evidence of substantial failure of the carbonate platform that rims Puerto Rico and the Virgin Islands is revealed by geophysical data, yet little is known about the temporal occurrence, size, triggers, and failure processes. Gravity cores collected in 2008 and pre-existing core and seafloor samples from the Puerto Rico Trench and deep basins south of the Virgin Islands (Whiting, Vieques, and Virgin Islands basins) provide insight into the recent mass movement history of the region. In the Puerto Rico trench, a lack of coarse carbonate debris or chaotic deposition in the upper 10 m of sediment suggests that there has not been massive catastrophic collapse of the edge of the carbonate platform and underlying material within the last 30 kyr. Rather, progressive scalloping of the margin may be the primary failure process, resulting in turbidite-dominated transport. Turbidite deposits, which can be correlated across semi-enclosed basins along the southern slope and axis of the Puerto Rico trench, have calibrated radiocarbon ages between 25 and 7 ka. Cores from the Virgin Islands basin show marked variations in the stratigraphy over short distances. In the south-eastern corner of the basin, turbidite and coarse-grained intervals are common, reflecting basin-wall destabilization or shelf-derived input driven by hurricane activity. Along the northern and southern margins of the basin, homogeneous clay, almost entirely free of biogenic material, reminiscent of a unifite facies, is common in the upper 2 m of sediment. The origin and age of this clay-facies is currently unclear, although it may be the distal deposit of a mass movement which entered the eastern or western end of the basin, or it may be the only material able to bypass entrapment by small depositional sinks during destabilization of the steep basin walls.

Regionally extensive scour surfaces on continental margins and in epeiric basins develop due to two major processes: submarine landslides, mainly affecting slopes in excess of 1 degree and subglacial scour beneath ice streams draining alpine or continental ice sheets. Both types of surfaces can extend for tens to hundreds of kilometres in the dip and strike directions, with tens of metres relief across tens of kilometres long scours and ridges. Correct interpretation within a sediment system tract enlightens models of synchronous glacial, marine and climatic conditions.

We present four megaslides imaged in, and interpreted from 3D seismic volumes acquired in diverse settings:

1. On the passive margin shelf of Cameroon, large-scale, downslope-oriented striations extend 40 km from the upper slope to the deep basin area. Individual striations are 20-50 m wide, 8 km long, 5-10 ms TWT deep, and broadly arcuate. The striations present in two sets and mark the base of a chaotic-to-discontinuous, high-amplitude package with chaotic, low amplitude reflections in the unstriated area. The facies is interpreted as a zone of repeated gravity sliding during the early Pleistocene in response to tectono-climatic forcing.

2. A basal surface from the Moray Firth, UK Central North Sea, tentatively dated as Paleocene in age. It is 20 km in width, over 40 km long and displays parallel grooves measuring typically 100-1000 m wide, 10-20 km long, of sinuous form along the section imaged in the dataset and with evidence of post-slump failure along the margins of the slide zone. It is interpreted as scour caused by a single sliding event.

3. An areally extensive scoured surface measuring 45x45 km that is part of a larger Pliocene system on the Angolan margin. The basal shear surface is marked by divergent scours. The geometry and spatial location of this flow are confined by listric faults and salt-cored folds with compressional thrusts within the distal toe of deposits on the flanks of salt diapirs. The system evolved through instabilities triggered by increased Pliocene uplift of the hinterland, an increased sediment flux, and oversteepening of fold limbs.

4. Ice stream scours on the present land surface and seafloor, and in the geological record display mega-scale lineations with elongation ratios proportional to ice streaming velocity within troughs measuring several km to more than 100 km across. Individual landforms are up to a few km across and 10-100 km long with the majority of grooves observed seismically being 1-100 m wide and 1-10 km long. Depth of grooves and height of erosional remnants are 10-100 m depending on substrate erodibility. Groove sets are parallel, converging or diverging depending on lateral constraints, flow path deviation and substrate properties.
We utilise seismic geomorphologic and morphometric analyses of these basal scour surfaces to develop distinguishing characteristics which can be used as predictive tools in inferring causative mechanisms of gravity-related processes. This provides a discriminative framework for shelf-edge glacial, interglacial and aglacial sequences.


(No Table Selected)
(No Image Selected)

Additional Details
Previously Presented Material: Only one of the four case studies has been presented. We're very excited about putting the whole lot together as a poster/talk.
Proof

CONTROL ID: 959727
TITLE: Response of submarine slopes to shaking by earthquakes: Examples from Sagami and Nankai troughs, Japan
PRESENTATION TYPE: Assigned by Committee (Oral or Poster)
CURRENT SECTION/FOCUS GROUP: Ocean Sciences (OS)
CURRENT SESSION: OS09. Submarine Landslides: Characterization, Processes and their Sedimentary Record
AUTHORS (FIRST NAME, LAST NAME): Ken Ikehara¹, Juichiro Ashi²
INSTITUTIONS (ALL): 1. Geological Survey of Japan, AIST, Tsukuba, Ibaraki, Japan. 2. Atmosphere and Ocean Research Institute, University of Tokyo, Kashiwa, China, Japan.
Title of Team: 
ABSTRACT BODY: Earthquake is a triggering mechanism of submarine slope failures and turbidite deposition. Exact relationship between earthquake magnitude and occurrence of submarine slope failures and turbidite deposition, however, is not fully understood, because the relationship might be changed by many factors such as slope gradient, sediment type, sediment accumulation rate and so on. On the other hand, from the turbidite paleoseismological viewpoint, it is very important to understand how large earthquake can form thick and coarse-grained turbidite observed in deep-sea cores. The Kii-hanto-oki Earthquake, the epicenter of which located at the upper landward slope of the Nankai Trough, occurred in September, 2004. Highly turbid bottom water conditions were observed in small slope basins near the epicenter just after the Earthquake. However, the bottom water was clear in August, 2010. Thin turbidite sand layer overlaid by clear turbidite mud was obtained from a slope basin. This indicates that turbidite layer can be formed by the earthquakes with magnitude larger than 7 in this area. In the western Sagami Trough, small earthquakes with their magnitudes around 6 occurred every several years. The occurrence of turbidity currents was observed by the JAMSTEC Hatsushima-oki deep-sea observatory in 1997 and 2006. Undisturbed surface sediment samples obtained near the observatory in 2005, however, did not contain clear turbidite beds. This indicates that the earthquake with magnitude around 6 has a potential to create turbidity currents at the slope, but does not have a potential to form turbidite at the foot of slope. Recurrence of clear turbidites found in deep-sea cores near the observatory might be an evidence of recurrence of earthquakes larger than magnitude 6 in this area.

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(No Image Selected)

Additional Details
Previously Presented Material: 30% at 2009 AGU Fall meeting
Continental margins are commonly interested by mass movements caused by gravitational instability, usually triggered by sediment erosion and seismic shaking. Such events can involve considerable masses of sediments and rocks, that can reach high velocities due to the slope steepness and provoke huge tsunamis, even if their source is located in deep water and far from the coast. The continuous advances in bathymetric techniques allowed a detailed characterization of continental margin morphologies also in deep environments, thus unveiling mass failure features related to past events and improving the geohazard assessment of those areas most prone to sediment instability. An example of a huge mass failure in a seismically active area is the North Gorringe landslide. This landslide is located along the north-eastern flank of the Gorringe Bank, west of the Portuguese coasts in the Atlantic Ocean, where the convergent boundary between the European and African Plates occurs. Bathymetric data revealed the existence of a well defined headwall, 7 km large, at 2900 m sea depth, and of a depositional zone with massive rock blocks and debris avalanche material. The deposits cover a sub-horizontal area (average slope 1.5°) of almost 280 km² at a depth of about 5100 m, for a maximum run-out of 27 km and a drop of 2200 m. The interpretation of multichannel seismic profiles and the reconstruction through bathymetric data lead us to estimate the volume of the mass failure to be around 70-80 km³.

In order to assess the consequence of such event on the Iberian coasts, a scenario involving the North Gorringe landslide has been set up and explored by means of numerical simulation codes that study separately the slide dynamics and the tsunami generation and propagation. After reconstructing the initial slide geometry and position, the Lagrangian code UBO-BLOCK2, assuming the mass as partitioned into a matrix of interacting constant volume blocks, was applied to compute the time evolution of the slide and the space-time history of the tsunamigenic impulses. The tsunami simulations were performed by means of the Eulerian code UBO-TSUE based on finite elements computational schemes, that solves non-linear shallow-water equations.

What was found is that the North Gorringe avalanche, although located far from the coast (at least 150 km from Portugal) and in deep water (depth from 3 to 5 km) is potentially able to generate considerable waves, probably more than 10 m high, impacting the coasts of Portugal, Spain and North Africa, in relatively short travel time (from 30 to 60 minutes). Furthermore, this study shows that in order to assess tsunami hazard and the related risk it is quite important not to underestimate submarine mass movements as possible tsunami sources, since they can produce large-impact tsunamis comparable or greater than the one...
generated by the more typical earthquake sources.

INDEX TERMS: [3070] MARINE GEOLOGY AND GEOPHYSICS / Submarine landslides.

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CONTROL ID: 958587
TITLE: Recurrent Pleistocene Mega-Failures in the Norway Basin, NE Atlantic Margin
PRESENTATION TYPE: Poster Requested
CURRENT SECTION/FOCUS GROUP: Ocean Sciences (OS)
CURRENT SESSION: OS09. Submarine Landslides: Characterization, Processes and their Sedimentary Record
AUTHORS (FIRST NAME, LAST NAME): Berit Oline Hjelstuen1, Elin Andreassen1, 2, Haflidi Hafldason1
2. Statoil ASA, Stavanger, Norway.
Title of Team:
ABSTRACT BODY: The Late Neogene history of the NE Atlantic continental margin is characterized by numerous mass failures, showing large variation in scales and in their triggering processes. A high number of the mapped failures have occurred along the continental slope off Norway. Here we report on three large buried sediment debrites within the Early- and Mid-Pleistocene sediment sequence deposited in the Norway Basin; a deep-water basin located in water depths >2000 m. The buried slide debrites have been identified as acoustic chaotic units within high-quality multi-channel seismic lines. The slide units, termed Norway Basin Slides I-III (NBSI-III) reach a maximum thickness of between 450-700 m, and each failure have affected an area between c. 60 000 – 85 000 km². The two oldest slide events, NBSI and NBSII, mobilized a sediment volume larger than 23 600 km³. The age constrains for the identified slide debrites are uncertain, but we infer that NBSI was initiated between 2.5 Ma and 1.7 Ma, and that the NBSII and NBSIII failures occurred in the 1.1-0.5 Ma time period. The NBSI-III slide debrites have approximate the same volumes and area distributions as mapped slide debrites in the Lofoten Basin, which have been considered the largest buried slide debrites observed so far. During the past c. 2.5 Ma, the Northern Hemisphere Glaciations have resulted in rapid deposition of a thick cover of dense deposits over a softer substratum. Together with high depositional rates, this setting promoted instable conditions favourable for releasing mega-slides.
INDEX TERMS: [3022] MARINE GEOLOGY AND GEOPHYSICS / Marine sediments: processes and transport.
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(No Image Selected)

Additional Details
Previously Presented Material: 0%
A large number of recent submarine landslides on the Eastern Australian continental slope were investigated during voyages aboard the RV Southern Surveyor in 2006 and 2008. Preliminary sedimentological analysis, geotechnical and radiocarbon data resulting from the examination of twelve gravity cores recovered from upper-slope slides showed that at least three of the twelve cores penetrated large, geologically-recent, submarine landslide failures. The failure surfaces lay within slide scars at distances of between 60 cm and 200 cm beneath the present-day seabed. Sediment present on the upper slope comprises mixtures of calcareous and terrigenous sand and mud. Distinct differences in physical properties (bulk unit density, water content, grain-size distribution) were recorded across the slide-plane boundaries.

Slope stability modelling using classical soil mechanics techniques and measured sediment shear-strengths indicates that the slopes should be stable. However, the ubiquity of slides on this margin indicates that their occurrence is a relatively common event and that submarine-sliding should be considered to be a normal characteristic of this continental margin. While this presents something of an interpretational paradox, it nevertheless indicates that an unidentified mechanism acts to reduce the shear resistance of these sediments to very low values which enables the slope failures to occur.

Preliminary bulk dates confirm Boyd et al's (2009) conclusion based on sedimentation rates, that some of the landslide masses were mobilised during the most recent glacial-interglacial cycle. Penecontemporaneous dates recorded for separate but adjacent slides are consistent with the slides being triggered by a single event such as an earthquake.


Additional Details

Previously Presented Material: 20% background information on the study area; presented at a conference in 2009 by Boyd.
Bathymetric data from the Northern Cascadia margin offshore Vancouver Island reveal several submarine landslide features on the seaward slopes of frontal ridges. The slides occur just landward of the deformation front of the subducting Juan de Fuca and Explorer plates. Possible trigger mechanisms for the slope failures include earthquakes, pore pressure changes induced by sea-level changes, and the dissociation of gas hydrates. Evidence of gas hydrate has been found beneath the frontal ridges. A bottom simulating reflection (BSR) has been identified in regional seismic data and logging data showed gas hydrate indicators including sonic velocity and high electrical resistivity. The influence of gas hydrate formation and dissociation on slope stability is of special interest since previous studies showed coincident depths of BSRs and failure planes.

We investigate two slope failure events in detail using numerical modeling techniques such as finite and discrete element modeling. Hybrid techniques provide a means to model processes ranging from grain-scale interactions up to movements of the sliding body by addressing both the continuous and discontinuous aspects of the problem. These include the internal forces, the evaluation of material failure criterion, deformation, and interaction forces. Furthermore, tensile failure and crack propagation, for example caused by gas hydrate or by the gradual breakdown of the slope material, can be characterized. Particle flow using different shapes and properties can be simulated. By examining the effect of local sea-level changes, glacial rebound, and gas hydrate formation or dissociation on stresses and fluid pressures, the work involves modeling the failure conditions associated with a decrease in shear strength, an increase in pore pressure, and the possible development or re-opening of cracks.

Beyond describing the trigger mechanism, we also have interest in reconstructing the dynamics of the slide events to explain their different morphologies (e.g., blocky or smooth) observed in the bathymetric data. The results of this study have potential to contribute to the assessment of local tsunami hazard by evaluating the present state of slope stability and by estimating the impact of the dynamic slope failure events on the movements of the water body.

Additional Details
Previously Presented Material:
Proof

CONTROL ID: 950200

TITLE: Large submarine landslide discovered on the outer shelf and slope of the Great Barrier Reef: a local mechanism capable of generating tsunamis along the northeast Australian coastline

PRESENTATION TYPE: Assigned by Committee (Oral or Poster)

CURRENT SECTION/FOCUS GROUP: Ocean Sciences (OS)

CURRENT SESSION: OS09. Submarine Landslides: Characterization, Processes and their Sedimentary Record

AUTHORS (FIRST NAME, LAST NAME): Nicholas George1, 2, Jody M Webster3, Robin J Beaman4, Elizabeth A Abbey3, Peter J Davies3

INSTITUTIONS (ALL): 1. Netsurvey, Banbury, Oxfordshire, United Kingdom.
2. School of Earth and Environmental Sciences, James Cook University, Townsville, QLD, Australia.
3. School of Geosciences, University of Sydney, Sydney, NSW, Australia.
4. School of Earth and Environmental Sciences, James Cook University, Cairns, QLD, Australia.

Title of Team:

ABSTRACT BODY: We have discovered a large, submarine landslide on the shelf edge of the central Great Barrier Reef, Australia, 10 km from the modern reef. Due to the large size and shallow emplacement depth of the “Viper” slide deposit, it has significantly influenced the geomorphology of the continental shelf and upper slope, allowed the mass movement of large volumes of coral reef limestones and unconsolidated sediments from the shelf edge to the upper slope and likely caused a tsunami capable of reaching the Australian coastline. In this presentation we analyse high-resolution multibeam, seismic and dredge data collected on the RV Southern Survey (SS07), investigate the nature of the slide scar and deposit and discuss the origin and tsunamigenic potential of this event.

The Great Barrier Reef (GBR), a World Heritage Area, has been the focus of a wide body of research aiming to understand the development of this unique, diverse and large coral reef system. This study is the first to document a landslide on the shelf edge of the GBR. Submarine landslides have been known to dramatically change ocean topography, destroy underwater infrastructure and cause devastating tsunamis. The systematic study of this landslide has allowed detailed classification of surface and subsurface features to gain an understanding of the mechanics and volume of the mass movement. In addition, samples taken from the slide were classified and dated.

The results, revealed a debris avalanche on the shelf edge, 7 kms wide and 6 kms from head to toe, at depths between 70 and 230 m. Three adjacent, successive, landslides occurred almost simultaneously creating a total movement of 5.9x10^5 m^3 of material. Limestone rock and coral reef structures from the shelf edge were transported and deposited onto the finer sediment of the upper slope. A progression of larger blocks of sizes up to 16,300 m^2 and 17 m high, to fine sediment the farther away from the escarpments is apparent. Dating of coraline algal-dominated limestones dredged from 163 m below present sea level from the center and top of the landslide debris showed that the landslide occurred at least 15,000 years ago. The shape of the landslide deposit, the distribution of debris as well as the distance the slide traveled suggest a submarine event that would have happened at an earlier date during a sea level high stand. No other mass movement has occurred in the area since.

Calculations using the Ward and Day (2003) formula based on the deposit thickness and area suggest that the landslide would have created a tsunami with a run up of 1 m on the northeast Australian coastline. Therefore, in addition to the more regional subduction-driven tsunamis generated in the Pacific (e.g., 2007 Solomon Islands event) our discovery highlights an important new local mechanism – the catastrophic
collapse of the GBR shelf edge – that can (1) drastically alter the morphology of the margin and (2) generate tsunamis capable of impacting the coastline.


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Additional Details
Previously Presented Material:
A large number of submarine landslides were identified on the continental slope on the Eastern Australian margin during voyages aboard the RV Southern Surveyor in 2008. Preliminary sedimentological analysis as well as geotechnical and biostratigraphic data determined for mid-slope dredge samples are reported. The dredge samples are normally-consolidated, calcareous sandy-muds of Neogene age and were recovered from submarine scarps located on the mid-continental slope. These scarps probably represent submarine landslide failure surfaces.

Slope stability modelling using classical soil mechanics techniques and measured sediment shear-strengths indicates that the slopes should be stable; however, the ubiquity of mid-slope slides on this margin indicates that their occurrence is relatively common and that submarine-sliding should probably be considered to be a normal characteristic of the margin as suggested by Boyd et al (2010). While this presents something of an interpretational paradox, it nevertheless indicates that an, as yet, unidentified mechanism acts to reduce the shear resistance of these sediments to very low values which enables the slope failures to occur.

It is suspected that the expansion of the Antarctic Icesheet in Mid-Miocene time and the consequent large-scale production of cold, equator-ward migrating, bottom water has caused significant erosion and removal of material from mid-slope and lower slope of the Australian continental margin in the Tasman Sea since the Mid-Miocene. Such a process would help to explain the exposure of hard Palaeozoic basement rocks along much of the southern part of the Eastern Australian continental margin. It is also suspected that erosion due to equator-ward moving bottom water effectively and progressively removed material from the toe of the continental slope sediment wedge. This rendered the slope sediments that were deposited throughout the Tertiary more susceptible to mass failure than would have otherwise been the case.


INDEX TERMS: [3070] MARINE GEOLOGY AND GEOPHYSICS / Submarine landslides.
Additional Details

Previously Presented Material: 20% background information on the study area; presented at a conference in 2009 by Boyd.
Submarine tsunamigenic landslides at Stromboli Volcano: characterization and estimation of recurrence time

AUTHORS (FIRST NAME, LAST NAME): Daniele Casalbore¹, Francesco Latino Chiocci²,¹, Claudia Romagnoli³, Alessandro Bosman¹

INSTITUTIONS (ALL): 1. igag, cnr, Rome, Italy.
2. University La Sapienza, Dipartimento Scienze della terra, Rome, Italy.

ABSTRACT BODY: Seafloor mapping and morphometric analysis of landslide scars can provide useful insights for marine geo-hazard assessment, as demonstrated by several studies performed on different geological settings. The availability of high-resolution multibeam bathymetry and long-range side scan sonar data on the submarine portions of Stromboli Volcano allow us to map and characterize the main mass-wasting features that affect, on the whole, about the 90% of its submarine extension. In particular, two main kinds of tsunamigenic landslides have been recognized and analyzed. Large-scale sector collapses (Fig. 1) are catastrophic events that mobilize 1-2 cubic kilometers of material, generating huge tsunami waves that may affect Stromboli and propagate in surrounding areas; related hazard is not very high, as they show recurrence periods of some (or more) thousand years. Conversely, medium-scale landslides are more hazardous, as they occur at higher frequency with respect to the previous events, i.e. from some hundreds up to few tens of years. These events are, however, able to generate local but severe tsunamis when occurring in shallow water, as demonstrated by the recent 2002 tsunamigenic landslides that struck the Stromboli coasts with waves up to 10 m-high.

The aim of this contribution is thus to evidence the main predisposing factors, the possible recurrence time and the size of potentially induced tsunami for the different recognized landslides according to the available geologic constraints and historical tsunami report.

Fig. 1 3D images of Eastern (a) and Northwestern (b) flank of Stromboli Volcano (vertical exaggeration 2x). Note the presence of scars in the upper part of the flank and debris avalanche deposits (i.e., megablocks) in the lower part. SdF: Sciara del Fuoco, Stromboli Cy: Stromboli Canyon

**Additional Details**

**Previously Presented Material:** 20% International Conference on Seafloor Mapping for geohazard assessment. 11-13 May 2009, Forio d'Ischia (Italy)
Most Mediterranean prodeltas show undulated sediment features on the foresets of their Holocene wedges. These features have been described all along the Mediterranean for the last 30 years and interpreted as either soft sediment deformation and incipient landsliding, and more recently, as sediment transport structures. We perform a review and detailed analysis of these undulated sediment features using ultrahigh-resolution seismic and bathymetric data as well as geotechnical information and hydrodynamic time series and hydrographic transects. In this study we show that the characteristics of the sediment undulations (configuration of the reflections down section and between adjacent undulations and overall morphologic characteristics) are incompatible with a genesis by sediment deformation alone and do not show evidence of sediment deformation in most cases. Various processes in the benthic boundary layer can be invoked to explain the variety of features observed in the numerous areas displaying sediment undulations.


(No Table Selected)
Additional Details

Previously Presented Material: