Application of the concept of maximum resilience to pelagic and mesopelagic food webs leads to predictions about system behavior that are in remarkable agreement with observations. The predictions underscore the role of temperature as a regulator of community behavior.

OS22D-08 1745h

Clues to Coral Reef Ecosystem Health: Spectral Analysis Coupled with Radiative Transfer Modeling

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Coral reefs are among the world's most productive and biologically rich ecosystems and are some of the oldest ecosystems on Earth. Coralline structures protect coastlines from storms, maintain high diversity of marine life, and provide nurseries for marine species. Coral reefs play a role in carbon cycling through high rates of organic carbon metabolism and calcification. Coral reefs provide fisheries habitat that are the sole protein source for humans on remote islands. Reefs respond immediately to environmental change and therefore are considered "canaries" of the oceans. However, the world's reefs are in peril: they have shrunk 10-50% from their historical extent due to climate change and anthropogenic activity. An important contribution to coral reef research is improved spectral distinction of reef species' health where anthropogenic activity and climate change impacts are high. Relatively little is known concerning the spectral properties of coral or how coral structures reflect and transmit light. New insights into optical processes of corals under stressed conditions can lead to improved interpretation of airborne and satellite data and forecasting of immediate or long-term impacts of events such as bleaching and disease in coral. We are investigating the spatial and spectral resolution required to detect remotely changes in reef health by coupling spectral analysis of in situ spectra and airborne spectral data with a new radiative transfer model called CorMOD2. Challenges include light attenuation by the water column, atmospheric scattering, and scattering caused by the coral themselves that confound the spectral signal. In CorMOD2, input coral reflectance measurements produce modeled absorption through an inversion at each visible wavelength. The first model development phase of CorMOD2 imposes a scattering baseline that is constant regardless of coral condition, and further specifies that coral is optically thick. Evolution of CorMOD2 is towards a coral-specific radiative transfer model that includes coral biochemical concentrations, specific absorptivities of coral components, and transmission measurements from coral surfaces.

URL: http://geo.arc.nasa.gov/sge/coral-health/

OS31A MCC: 3000 Wednesday 0800h

Identifying Submarine Landslide Time of Failure II *(joint with T)*

Presiding: **D R Tappin,** British Geological Survey**; P Watts,** Applied Fluids Engineering, Inc.

OS31A-01 0800h INVITED

Dating of Submarine Landslides and Their Tsunami Deposits Using Hawaii as an Example

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There have been several approaches to dating the initiation of submarine landslides and the tsunamis they inevitably produce. In Hawaii, the timing of flank failures of major volcanoes has been estimated by radiometric and paleomagnetic dating of the youngest shield-building flows and dikes, the apex ages of the volcanoes, which can also be constrained by the oldest flows of post-collapse volcanism. More precise age estimates can be obtained by direct dating of the landslide. These approaches include paleomagnetic and U-series stratigraphic dating of the overlying pelagic sediment cover upon and in front of the landslide, the latter method producing minimum ages of last landslide turbidite emplacement, e.g., the ca. 120 ka Alika phase 2 event. Elevated, detached landslide blocks make the best targets for such dating because it is assumed that smaller post-emplacement turbidites will not reach their summits. Catastrophic events such as the 1.0 Ma Wailau giant landslide have, however, been dated by turbidite deposition upon large, elevated blocks of the nearby 1.8 Ma Nuuanu giant landslide. Other direct methods for older events include use of thickness of ferromanganese crusts collected from steep, exposed rock scarps and cosmogenic Be-10 or U-series radiometric determination of the few mm/Ma rate of accumulation. In subtropical areas such as Hawaii, coral clast-bearing, elevated marine deposits on the southeastern islands have been identified as deposits from giant tsunamis. Among the key evidence are the great age and paleo-elevations of the coral clasts found in situ. Since modern coral clasts are relatively young, a few thousand years old or less, older analogs swept from the presently submerged reefs offshore can reliably date tsunamigenic depositional events within the late Quaternary using U-series methods. The age of the tsunami will date within these limits (and the analytical precisions) to the youngest in situ coral clast that was entrained by the waves. U-series dates approximately coeval with the Alika 2 giant landslide suggest a youngest 100 ka tsunami emplacement age from 100-137 ka corals collected on Lanai and Hawaii; likewise, older deposits on Molokai and Lanai suggest a 200 ka tsunami emplacement age from corals that range 200-258 ka in age, but interpretative care must be taken as open-system behavior upon weathering may produce apparently younger dates. Other promising methods for dating these deposits include cosmogenic Cl-36 exposure ages of cements and Cl-36 and He-3 exposure ages of the entrained volcanic rocks. Younger events can be dated by the above methods using C-14 or unsupported Pb-210.

OS31A-02 0815h

Ages of Potentially Tsunamigenic Landslides in Southern California

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The innermost basin slopes of the Southern California Borderland contain numerous large-scale submarine landslides. Many of these are of sufficient size to have generated tsunamis when they occurred, assuming that the imaged deposits represent a single failure and that their motion was rapid. We have obtained high resolution subbottom profiles of five well-defined slope failures. These failures are located off the Palos Verdes Peninsula, within Santa Monica Bay, and within the Santa Barbara Channel. A landslide motion and tsunami generation model for one of the landslides shows that it likely generated a tsunami with a source height of at least 8 m. For four of the failures, ages were determined by identifying acoustic reflectors in the vicinity of the failed masses that either clearly postdate or predate the landslide events. The ages of the reflectors are determined by using seismic-reflection profiles to correlate with dated sections at ODP sites or by directly dating the slide masses with piston cores. In the case of the most recent failure in the Santa Barbara Channel, post-failure sediment deposited on the scar of the landslide was sampled completely with a gravity corer, and the age was estimated based on a representative sedimentation rate. Our assessment shows that three of the four older landslides are approximately 10,000 years old and that the Palos Verdes event was about 7,500 years ago. However, the most recent failure may be as young as 200 years. Such a landslide might have generated a tsunami such as was observed by early Spanish settlers during the 1812 earthquake.

OS31A-03 0830h INVITED

Dating one Slide Event of the Complex Compound Goleta Submarine Landslide, Santa Barbara Basin, California, USA

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Dating of submarine sediment slumps and slides is fraught with problems, especially those taking place during the past several thousand years. However, we need to develop accurate dating techniques so as to improve our ability to assess the periodicity of, and the actual risk from, these events. The large (130 km2) Goleta landslide located off Coal Oil Point near the town of Goleta, California measures 14.6-km long, extends from 90 m to nearly 574 m below sea level, and is 10.5 km wide. The slide is complex, and includes both buried slump blocks and mudflows, with a surface expression of three distinct segments of failures. Each segment is composed of a distinct head scarp, down-dropped head block, and a slide debris lobe. We estimate that at least 1.75 km3 of surface material represents the most recent displaced events of this slide. Dating of the more recent failures of this slide has been speculative and based on modeling and estimated sediment cover on one of the head scars. The most recent event is thought to be the cause of the reported tsunami of 1812. However, sophisticated dating of the slide has yet to be done. Recent interpretation of newly acquired seismic reflection profiles indicates that the head slump block of the eastern segment of the slide dammed sediment behind it after it came to rest at the base of the head scarp. We calculated that about 64 m of sediment was dammed behind the block, based on a measured two-way travel time through the sediment pond of 0.075 sec. and an assumed velocity of 1680 m/sec. Using a sedimentation rate of 1.73 m/Ka to 2.5 m/Ka, the range of sedimentation rates determined by other investigators for the mid- to lower shelf areas of the western Santa Barbara Basin, the time required for deposition would be 37-25.6 Ka. Therefore, if the sedimentation rates are correct and that the ponded sediment represent nothing but normal sedimentation devoid of sloughing or debris flows down the slope, the maximum age of when the block came to rest in its present position would be 37-25.6 Ka. However, given the tectonic dynamics of the area and the instability of the slope in this part of the Santa Barbara Basin, the likelihood of deposits derived from mass movement filling the depression behind the slump block is high, thus suggesting a possible younger age for the failure.

OS31A-04 0845h

T waves from the 1998 Papua New Guinea earthquake and its aftershocks: Timing the tsunamigenic slump

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T waves recorded at hydrophone and seismic stations following the Papua New Guinea earthquake of 17 July 1998 and its aftershocks show that a small event at 09:02 GMT featured source properties incompatible with an elastic dislocation of appropriate body-wave magnitude (m sub b = 4.4). These include an exceptional duration (47 s at the Wake Island hydrophone station WK31), a spectrum rich in high frequencies (7 to 12 Hz), and a generally low spectral amplitude. These characteristics can be explained by the model of an underwater slump, accelerating from a standstill and eventually slowing down. The relocation of the 09:02 event is compatible with its location within an amphitheater inside which shipboard cruises in 1998 and 1999 documented the presence of a 4-km**3 geologically fresh slump. We propose that the slump took place at 09:02 on 17 July 1998, i.e., 13 minutes after the mainshock, and that it generated the locally catastrophic tsunami, whose properties (amplitude and distribution of run-up; timing) could not be explained by a dislocation model.

OS31A-05 0900h INVITED

Determining the Ages and Origins of Earthquake Triggered Submarine Landslides

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We have been determining the ages of turbid flows from submarine landslides to establish a paleoseismic record for the Cascadia margin and the Northern San Andreas Fault. This involves multiple approaches to both test the turbidites for earthquake origin, and to develop the time series of events. In our work, we are focusing on the Holocene record, because prior to the Holocene, lowered sea-level resulted in a very different sediment distribution system, essentially defeating many of the mechanisms that allow the earthquake record to accumulate in abyssal channels during high sea-level stands. To establish earthquake origin, we test for synchronous triggering using simple relative dating techniques, and for wide geographic correlation. The basis for this is that of all the possible triggers for turbid flows, only earthquakes are capable of triggering widespread failure of many canyon systems simultaneously. To test for synchroneity, we look for channel confluences and examine the deposits both above and below the confluence. If the record is entirely of earthquake origin, the total number of events above any given datum will be the same above and below the confluence. Because of the high velocity of turbid flows, merging at the confluence must take place within hours, or deposits from separate tributaries will be recorded as multiple events. Looking more closely, we find that separate mineralogies from such tributaries are observed to merge and form a bi-modal amalgamated turbidite down stream. To look for wide geographic correlation, we use physical properties such as density, magnetics, and color reflectance to attempt to establish a regional correlation. To establish the paleoseismic history, once having determined the origin of the events, we determine AMS 14C ages from planktonic forams deposited in the hemipelagic sediments that underlie each turbidite sequence. Our rationale is to collect samples from the youngest hemipelagic interval between events to date the overlying event. Though there may be some erosion of this interval, thus biasing events to slightly older ages, we use more distal cores, which are less likely to have basal erosion for primary dating, and inspect the bases visually for evidence of erosion. Dating the lower hemipelagic sediment between events can be problematic due to the difficulty in positively identifying the boundary between the turbidite tail and the overlying hemipelagic sediment. Current work shows that reservoir corrections applied to these ages can vary temporally and spatially, emphasizing the need for independent datums for best results.

OS31A-06 0915h INVITED

Tsunami landslide source models as a tool for analyzing complex case studies

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In tsunami generation, coseismic displacement sources can essentially be considered as having negligible duration (i.e., of a few to a few dozen seconds), as compared to characteristic times of tsunami propagation (i.e., period of at least several minutes). By contrast, submarine landslides, when they occur in or near very deep water areas, may last for a much longer time and thus produce tsunami sources of significant duration as compared to tsunami period. In analyzing data from landslide tsunami case studies, and in particular wave data, it is therefore very important to be able to understand the full history of both landslide and tsunami generation, in order to accurately estimate landslide time of failure based on such data. Recent three-dimensional (3D) hydrodynamic models developed to simulate tsunami generation by complex landslide scenarios offer such possibilities. Using these models, together with field data, the authors were able to identify both likely types and times of failure in specific case studies, in order to reproduce at best the observations in both the near and far field. To obtain far field results, the modeled 3D tsunami source is used as initial condition in a two-dimensional long wave propagation model. The cases of Skagway, PNG, and Unimak 1946 will be specifically discussed.

URL: http://www.oce.uri.edu/∼grilli

OS31A-07 0930h

Use of Vesicomyid Clams as Proxies for Ageing Submarine Landslide Events

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Age dating of submarine landslides and other geologic events that produce tsunamis is desirable, but difficult. Estimation of the time of failure" for submarine slides may be possible using proxies for age, including estimates of the time of colonization of animals on landslide scars or associated features. For submarine landslides in methane-rich strata, chemosynthetic biological communities (CBCs) will likely colonize the site, and establish a baseline' for estimating the age of the slumping event. Vesicomyid clams are conspicuous members of methane seep environments (CBCs) worldwide, and are the dominant megafauna inhabiting eastern Pacific seep communities. Although several geological settings, including subduction zones, mud volcanoes, submarine landslide scars, and submarine canyon settings are associated with the presence of CBCs, the principal geological processes that regulate their distribution remain unresolved. Nevertheless, vesicomyid clams commonly colonize sites of recent erosion or slope failure events on continental margins, where access to sulfide-rich fluids is possible. CBCs in Monterey Bay include a fairly high diversity of vesicomyid clams (10+ species), which are somewhat segregated by geochemical conditions, water depth, and perhaps other factors. Seep sites with highest sulfide (>10.0 mM) and methane (>2.0 mM) concentrations in pore waters are dominated by *Calyptogena kilmeri*, while *C. pacifica* is the principal species at sites with low sulfide (∼0.1 mM) and methane (∼0.0 mM) levels. Time-lapse observations suggest that variation in sulfide levels may stimulate clam movement. These two species cohabit individual seeps but exhibit very different sulfide physiologies and growth rates. *C. kilmeri* is well-adapted to higher sulfide tolerance, which may enable high rates of production by bacterial symbionts, high carbon intake, and high rates of growth compared to *C. pacifica*. Growth rates of *C. kilmeri*, calculated from tagged individuals, was ∼10 mm/y, with individuals reaching an maximum size of ∼120 mm in approximately 10 y. In contrast, although the sulfide physiology of *C. pacifica* is more efficient in some ways than *C. kilmeri*, it is restricted to low sulfide microhabitats (<1.5 mM), and exhibits very low rates of growth. All *C. pacifica* tagged grew less than 1 mm/y, indicating a period of 50-75 y, or more, to attain asymptotic size near 65 mm. The density and size structure of populations of *C. kilmeri* and *C. pacifica*, as well as other CBC organisms may be useful in constraining the timing of slumping events associated with tsunamis. While knowledge of the growth rates and size versus age relationships of vesicomyid species enhance their value in aging submarine slope failure events, the observed wide differences in growth rates among species also complicates interpretation of the colonization history following landslide events.

URL: http://www.mbari.org/benthic/coldseeps.htm

OS31A-08 0945h

The Betsiamites-Outardes (Quebec) Submarine Mass Movements and Their Potential for Tsunami Generation

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The Betsiamites Outardes area has been the locus of a team effort to investigate the connection between submarine features indicative of large mass movements and the presence of a coastal slide scar involving about 800 millions cubic metres of raised marine deposits along the North Shore of the St. Lawrence River, about 300 km east of Québec city.. Although the signature of the coastal slide is quite clear, the underwater morphology, revealed by a multibeam survey, indicated the presence of a complex system of flow features imbricated into a channel landform most likely related to the relic Betsiamites River submarine channel system. Holocene deposits related to the high-stand delta have also been eroded leaving, in places, significant escarpment of nearly 100m. In addition there are clear bedrock related features forming the major boundary between the shelf, less than 100m deep, and the deeper part in the middle of the St. Lawrence Estuary at a depth of about 400m. Just in front of the sub-aerial slide, lies, in the central and deep part of the St. Lawrence, a very extensive feature with a more or less regular elevation of about 10m above the surrounding sea floor and covering an area of about 130 square kilometers. The initial interpretation was to consider it as the distal depositional part of the sub-aerial slide sediments. A recent detailed high resolution seismic survey indicated otherwise and rather revealed that much of it could have been pushed up, or deformed, by underlying gas pressure of an origin still to be determined, but which could be related to the surrounding bedrock structure. On the other hand, the seismic survey on the shelf confirmed the presence of extensive debris flow deposits with various signatures including compression ridges and other evidences of rapid mass movements. At the time of writing, it is not clear what is the origin of the slide and the triggering mechanism and if it could have originate from the shelf and propagate onto the coastal zone. The dating of the sub-aerial slide has been linked to the 1663 earthquake but this still awaits confirmation. Actual morphological information and the seismic survey indicate that the slide was very large and that it developed into a rapid mass movements with a high potential for generating a tsunami wave. This wave should have easily crossed the St. Lawrence Estuary and leave typical inundation deposits in the marshes boarding the south shore, near Rimouski.