[2]Emile Okal, Dept. of Geological Sciences Northwestern University, Evanston, IL 60208, United States

Identification of a suitably located cohesive sedimentary slump offshore off the north coast of Papua New Guinea, mathematical modelling of which provided appropriate run-ups compared with onshore measurements, might have been expected to provide compelling evidence for the source of the registered tsunami in the context of an alternative hypothesis based on a shallow dipping thrust source. However, notwithstanding the evidence, alternative slump source mechanisms, as well as those attributed to a thrust fault, are still considered by some investigators as a likely alternative. In this context we present evidence on the dating of the slump by observational, acoustic and biological methods that supports the slump source of the tsunami. The observational data from Remote and Manned Submersibles shows that seabed features, such as fissures and fractured limestone, on the surface of the slump, to be more recently deformed than outside the slump area. Fluid expulsion from the seabed was only observed from the area of the slump mass. Additionally, the seabed chemosynthetic cold water faunas, such as mussels and tubeworms, as well as bacterial mats that are intimately associated with sulphide rich sediment, are much more common on the slump surface. Their presence is interpreted to indicate active expulsion of sulphide and methane rich pore fluids. T-phase data, from an unblocked hydrophone on Wake Island, in the context of the arrival time of the tsunami from eyewitness accounts and mathematical simulation, suggest that a slump source for the tsunami to be more likely than an earthquake.

OS22A-1150 1330h POSTER

Exploration of the Humboldt Slide using Anisotropy of Magnetic Susceptibility - Comparison with the Gaviota Slide

Kurt Schwehr[1] (858-822-4879; kdschwehr@ucsd.edu)

Neal Driscoll[1] (ndriscoll@ucsd.edu)

Lisa Tauxe[1] (ltauxe@ucsd.edu)

Homa J Lee[2] (hjlee@usgs.gov)

[1]UCSD, MC-0208, La Jolla, CA 92093, United States

[2]USGS, 345 Middlefield Rod MS 999, Menlo Park, CA 94025, United States

The origin of the "so-called" Humboldt Slide has raised much controversy. Some researchers argue that it is a slide deposit, while others interpret the deposit as a depositional feature mantling an old slide scar formed by down-slope gravity flows. We adapted the standard paleomagnetic tool of Anisotropy of Magnetic Susceptibility AMS in order to detect minor post-depositional deformation $i.e.,$"$crypto-slumps$" in sedimentary successions and applied it to the Humboldt Slide controversy. Crypto-slumps are slumps that are not easily observed in outcrop or core samples. Undeformed sediments show a typical oblate fabric while even slightly deformed sediments develop a triaxial fabric. Based on examining cores from the center and top of the Humboldt Slide structure, we find no evidence for deformation. The cores from the top are in an area that is clearly free from drape and thus we can be sure that we are sampling the structure seen in chirp seismics. We recently sampled a known slide for comparison to the Humboldt Slide. We used 5 gravity cores from the USGS V1-81-SC cruise which sampled the Gaviota Slide. The Gaviota Slide in on the northern slope of the Santa Barbara Basin and is just to the west of the much larger Golita Slide. The AMS measurements from the Gaviota Slide show a clearly deformed fabric that we expect from a slide. From these analyses we found that the fabric is dominantly oblate for the Humboldt Slide while the Gaviota Slide is predominantly triaxial. Based on these results, we re-emphasize our conclusion that the Humboldt Slide is not a slide. We now know that the ridges and swales of the Humboldt Slide appear to have grown as sediment waves on an old slide scar and our chirp seismics show thickening on the upslope side of these structures and continuous reflectors across regions where others have mapped normal faults.

URL: http://schwehr.org/agufall2003

OS22A-1151 1330h POSTER

Submarine Landslides, Isostasy, and Drastic Reorganizations of Depositional Environments on the Shelf and the Slope

Mason Dykstra[1] (8058953279; dykstram@umail.ucsb.edu)

Ben Kneller[2] (8058938467; ben@crustal.ucsb.edu)

[1]Dept. of Geological Sciences, University of California Bldg. 526, Santa Barbara, CA 93106-9630, United States

[2]Institute for Crustal Studies, 1140 Girvetz Hall University of California, Santa Barbara, CA 93106-1100, United States

We present analytical evidence that large-scale submarine landslides will result in isostatic readjustment of the crust and lithosphere. Some of the possible results of this readjustment include: (1) increased seismic activity, (2) relative sea-level fall and a consequent basinward shift in facies, (3) development of sequence boundaries due to subaerial exposure of a shallow continental shelf, (4) deflection of drainage patterns and sediment pathways on land, on the shelf, and on the slope, and (5) oversteepening of the headwall region due to domal uplift of the evacuated slide scar. We demonstrate that isostatic readjustment can be increased by almost a factor of two due to the feedback effect of overlying seawater. Many of these factors are also positive feedbacks toward future mass-failure events. Considering that gas hydrates may be destabilized by mass-failure, isostatic readjustment associated with submarine landsliding may be a strong positive feedback toward climate change. Isostatic readjustment of the crust and lithosphere takes the form of uplift in the area of the evacuated slide scarp, and subsidence in the area of the mass-transport deposit (MTD). Two-dimensional mathematical modeling indicates that for a slide scarp or MTD with dimensions of 100 km wide, 100 km long, and 100 m thick, the magnitude of the primary isostatic readjustment will vary from about 21-48m, depending on the effective elastic thickness (Te) of the lithosphere (a lower Te leads to a greater isostatic response). Additionally, changes in the depth of the overlying water column act as a feedback to both the uplift and/or the subsidence. The magnitude of this factor is nearly as great as the primary isostatic response, bringing the total isostatic adjustment to approximately 39-88 m. The wavelength of the isostatic response (area affected) also depends on the Te of the lithosphere. Calculations show this to vary from 28 km for lithosphere of very low Te (2 km) to greater than 250 km for lithosphere with high Te (>38 km). Therefore, the isostatic response of the lithosphere and crust to submarine landslides is of sufficient amplitude and wavelength to significantly alter large areas of continental shelves, and is almost certainly an important but previously unrecognized mechanism for drastic reorganizations of depositional environments.

OS22B MCC: Level 2 Tuesday 1330h

Progress in Tsunami Research and Mitigation III Posters *(joint with T)*

Presiding: **E N Bernard,** NOAA Pacific Marine Environmental Laboratory**; C Synolakis,** University of Southern California

OS22B-1152 1330h POSTER

Deep-sea tsunami deposits in the Miocene Nishizaki Formation of Boso Peninsula, Central Japan

In Tae Lee[1] (82-62-670-2483; itlee63@hanmail.net)

Yujiro Ogawa[2] (81-29-853-4307; yogawa@arsia.geo.tsukuba.ac.jp)

[1]Dr Lee In Tae, Department of Oceanography, Chonnam National University, Kwangju, Cho 500-757, Korea, Republic of

[2]Dr Yujiro Ogawa, Institute of Geoscience, University of Tsukuba, Tsukuba, Iba 305-8571, Japan

Many sets of deep-sea deposits considered to be formed by return flow of tsunami were found from the middle Miocene Nishizaki Formation of Boso Peninsula, Central Japan, which is located near the convergent plate boundary at present as well as in the past, and has been frequently attacked by tsunami. The characteristics of the tsunami deposits in the Nishizaki Formation are as follows. Each set consists of 10-20 beds with parallel laminations formed under upper plane regime composed of alternated pumiceous beds in white and black colors. The white bed comprises coarse sands and pebbles with thickness of 5-10 cm. In contrast, the black bed is made of silts with thickness less than 1 cm. Among the 10-20 beds, the grain size is coarsest in the middle part of the set in general. The uppermost bed of each set shows cross-lamination formed by lower plane regime, gradually changing into finer graded bed on top. Sometimes, the lower part of the parallel laminated bed is associated with an underlying debrite or turbidite bed. Each set of these parallel-laminated beds is lenticular in shape thinning to the east in consistent with the generally eastward paleocurrent of the cross-lamination at the top. Such sedimentary characteristics are different from any event deposits reported in deep-sea but similar to the deep-sea K/T boundary deposits in the Caribbean region. Statistically, tsunami waves occur totally 12-13 times. Among them the height of 5-6th wave is known to be strongest. Interval time of each return flow is known to be 30-40 minutes, enough to settle the finer clastics at each bed top. The parallel-laminated parts have common dish structure and never trace fossils, indicating rather rapid deposition for the whole parts of the set. Consequently, the sedimentary characteristics shown from the parallel-laminated beds of the Nishizaki Formation are attributed to the return flow of tsunami to the deep-sea. We considered that such deep-sea parallel-laminated deposits of pumiceous clastics occur just after a large earthquake which forms the debrite or turbidite at the lowermost part.

OS22B-1153 1330h POSTER

Tsunami Inundation Mapping for Alaska Communities of Homer, Seldovia, and Seward

Elena Suleimani[1] (1-907-474-7997; elena@giseis.alaska.edu)

Duncan Marriott[1] (1-907-474-5529; duncan@giseis.alaska.edu)

Roger Hansen[1] (1-907-474-5533; roger@giseis.alaska.edu)

Rod Combellick[2] (1-907-451-5007; rod@dnr.state.ak.us)

[1]Geophysical Institute, University of Alaska Fairbanks , P.O.BOX 757320, Fairbanks, AK 99775-7320, United States

[2]Alaska Division of Geological and Geophysical Surveys, 794 University Avenue, Suite 200, Fairbanks, AK 99709-3645, United States

The Geophysical Institute of the University of Alaska Fairbanks and the Alaska Division of Geological and Geophysical Surveys continue to participate in the National Tsunami Hazard Mitigation Program by evaluating and mapping potential inundation of coastal communities in Alaska. The two Kachemak Bay communities of Homer and Seldovia were selected in coordination with the Alaska Division of Emergency Services. We considered two earthquake scenarios as potential sources of tsunami waves that can affect Homer and Seldovia. For both communities, we calculated the extent of maximum inundation for the two scenarios, depths of inundation on dry land, and the maximum velocity current distribution in the inundation zones. The work is under way for Seward, the next community on the list. One of the most significant sources of errors in tsunami inundation mapping is inaccuracy of topographic and bathymetric data used in the model. Many of the Alaskan communities of interest have topographic data of limited quality, and new data must be developed in order to produce accurate inundation maps. The Alaska Tsunami Modeling Team cooperated with the local USGS glaciology office to perform photogrammetry in the Seward area. Using ten air photos and the APEX software, along with several precisely located GPS points, we developed a new georeferenced and highly accurate DEM with a 5-meter grid spacing. A variety of techniques was used to remove the effects of buildings and trees to yield a bald earth model. Finally, we resampled the new DEM to match the finest resolution grid, and combined it with all other data, using the most recent and accurate data in each region. The new dataset has contours that deviate by more then 100 meters in some places from the contours in the previous dataset, showing significant improvement in accuracy for the purpose of tsunami modeling.

OS22B-1154 1330h POSTER

Volcanic Tsunami Generation in the Aleutian Arc of Alaska

Christopher F Waythomas[1] (907-786-7122; chris@usgs.gov)

Philip Watts[2] (562-498-9407; phil.watts@appliedfluids.com)

[1]U.S.Geological Survey Alaska Volcano Observatory, 4230 University Drive Suite 201, Anchorage, AK 99508, United States

[2]Applied Fluids Engineering, Inc., Private Mail Box #237, 5710 E. 7th Street, Long Beach, CA 90803, United States

Many of the worlds active volcanoes are situated on or near coastlines, and during eruptions the transfer of mass from volcano to sea is a potential source mechanism for tsunamis. Flows of granular material off of volcanoes, such as pyroclastic flow, debris avalanche, and lahar, often deliver large volumes of unconsolidated debris to the ocean that have a large potential tsunami hazard. The deposits of both hot and cold volcanic grain flows produced by eruptions of Aleutian arc volcanoes are exposed at many locations along the coastlines of the Bering Sea, North Pacific Ocean, and Cook Inlet indicating that the flows entered the sea and in some cases may have initiated tsunamis. We evaluate the process of tsunami generation by granular subaerial volcanic flows using examples from Aniakchak volcano in southwestern Alaska, and Augustine volcano in southern Cook Inlet. Evidence for far-field tsunami inundation coincident with a major caldera-forming eruption of Aniakchak volcano ca. 3.5 ka has been described and is the basis for one of our case studies. We perform a numerical simulation of the tsunami using a large volume pyroclastic flow as the source mechanism and compare our results to field measurements of tsunami deposits preserved along the north shore of Bristol Bay. Several attributes of the tsunami simulation, such as water flux and wave amplitude, are reasonable predictors of tsunami deposit thickness and generally agree with the field evidence for tsunami inundation. At Augustine volcano, geological investigations suggest that as many as 14 large volcanic-rock avalanches have reached the sea in the last 2000 years, and a debris avalanche emplaced during the 1883 eruption may have initiated a tsunami observed about 80 km east of the volcano at the village of English Bay (Nanwalek) on the coast of the southern Kenai Peninsula. By analogy with the 1883 event, previous studies concluded that tsunamis could have been generated many times in the past. If so, geological evidence of tsunamis, such as tsunami deposits on land, should be found in the area around Augustine Island. Paradoxically, unequivocal evidence for tsunami inundation has been found. Augustine Volcano is the most historically active volcano in the Cook Inlet region and a future tsunami from the volcano would have devastating consequences to villages, towns, oil-production facilities, and the fishing industry, especially if it occurred at high tide (the tidal range in this area is about 5 m). Numerical simulation experiments of tsunami generation, propagation and inundation using a subaerial debris avalanche source at Augustine volcano indicate only modest wave generation because of the shallow water surrounding the volcano (maximum water depth about 25 m). Lahar flows produced during eruptions at snow and ice clad volcanoes in the Aleutian arc also deliver copious amounts of sediment to the sea. These flows only rarely transform to subaqueous debris flows that may become tsunamigenic. However, the accumulation of loose, unconsolidated sediment on the continental shelf may lead to subaqueous debris flows and landslides if these deposits become mobilized by large earthquakes. Tsunamis produced by this mechanism could potentially reach coastlines all along the Pacific Rim. Finally, recent work in the western Aleutian Islands indicates that many of the island volcanoes in this area have experienced large-scale flank collapse. Because these volcanoes are surrounded by deep water, the tsunami hazard associated with a future sector collapse could be significant.

OS22B-1155 1330h POSTER

Holocene Tsunami Deposits From Large Tsunamis Along the Kuril Subduction Zone, Northeast Japan

Futoshi Nanayama[1] (+81-29-861-3967; nanayama-f@aist.go.jp)

Ryuta Furukawa[1]

Kenji Satake[1]

Yuji Soeda[2]

Kiyoyuki Shigeno[3]

[1]Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology, Site 7, 1-1-1 Higashi, Tsukuba 305-8567, Japan

[2]Historical museum of Hokkaido, 53-2 Sho-nopporo, Atsubetsu-cho, Atsubetsu-ku, Sapporo 064-0006, Japan

[3]Meiji Consultant Co. Ltd., W1-3, S7, Chuou-ku, Sapporo 064-0807, Japan

Holocene tsunami deposits in eastern Hokkaido between Nemuro and Tokachi show that the Kuril subduction zone repeatedly produced earthquakes and tsunamis larger than those recorded in this region since AD 1804 (Nanayama et al., Nature, 424, 660-663, 2003). Twenty-two postulated tsunami sand layers from the past 9500 years are preserved on lake bottom near Kushiro City, and about ten postulated tsunami sand layers from the past 3000 years are preserved in peat layers on the coastal marsh of Kiritappu. We dated these ten tsunami deposits (named Ts1 to Ts10 from shallower to deeper) in peat layers by radiocarbon and tephrochronology, correlated them with historical earthquakes and tsunamis, and surveyed their spatial distribution to estimate the tsunamisO inland inundation limits. Ts10 and Ts9 are under regional tephra Ta-c2 (ca. 2.5 ka) and represent prehistorical events. Ts8 to Ts5 are between two regional tephra layers Ta-c2 and B-Tm (ca. 9th century). In particular, Ts5 is found just below B-Tm, so it is dated 9th century (Heian era). Ts4 is dated ca 13th century (Kamakura era), while Ts3, found just below Us-b and Ta-b (AD 1667-1663), is dated 17th century (Edo era). Ts2 is dated 19th century (Edo era) and may correspond to the AD 1843 Tempo Tokachi-oki earthquake (Mt 8.0) recorded in a historical document Nikkanki of Kokutai-ji temple at Akkeshi. Ts1 is inferred 20th century and may correspond to the tsunami from the AD 1960 Chilean earthquake (M 9.5) or the AD 1952 Tokachi-oki earthquake (Mt 8.2). Our detailed surveys indicate that Ts3 and Ts4 can be traced more than 3 km from the present coast line in Kirittapu marsh, much longer than the limits (< 1 km) of recent deposits Ts1 and Ts2 or documented inundation of the 19th and 20th century tsunamis. The recurrence intervals of great tsunami inundation are about 400 to 500 years, longer than that of typical interplate earthquakes along the Kuril subduction zone. The longer interval and the apparent large tsunami inundation indicate unusual origin of these tsunamis.

OS22B-1156 1330h POSTER

Far-field tsunami magnitude determined from ocean-bottom pressure gauge data around Japan

Toshitaka Baba[1] (+81-45-778-5972; babat@jamstec.go.jp)

Kenji Hirata[2] (hiratak@jamstec.go.jp)

Yoshiyuki Kaneda[1] (kaneday@jamstec.go.jp)

[1]Institute for Frontier Research on Earth Evolution, Japan Marine Science and Technology Center, 3173-25 Showa-machi, Kanazawa-ku, Yokohama 236-0001, Japan

[2]Deep Sea Research Department, Japan Marine Science and Technology Center, 2-15 Natsushima-cho, Yokosuka 237-0061, Japan

Tsunami magnitude is the most fundamental parameter to scale tsunamigenic earthquakes. According to Abe (1979), the tsunami magnitude, Mt, is empirically related to the crest to trough amplitude, H, of the far-field tsunami wave in meters ($\mathrm{Mt} = \log H + 9.1$). Here we investigate the far-field tsunami magnitude using ocean-bottom pressure gauge data. The recent ocean-bottom pressure measurements provide more precise tsunami data with a high signal-to-noise ratio.

Japan Marine Science and Technology Center is monitoring ocean bottom pressure fluctuations using two submarine cables of depths of 1500 - 2400 m. These geophysical observatory systems are located off Cape Muroto, Southwest Japan, and off Hokkaido, Northern Japan. The ocean-bottom pressure data recorded with the Muroto and Hokkaido systems have been collected continuously since March, 1997 and October, 1999, respectively.

Over the period from March 1997 to June 2003, we have observed four far-field tsunami signals, generated by earthquakes, on ocean-bottom pressure records. These far-field tsunamis were generated by the 1998 Papua New Guinea eq. (Mw 7.0), 1999 Vanuatu eq. (Mw 7.2), 2001 Peru eq. (Mw 8.4) and 2002 Papua New Guinea eq. (Mw 7.6). Maximum amplitude of about 30 mm was recorded by the tsunami from the 2001 Peru earthquake.

Direct application of the Abe's empirical relation to ocean-bottom pressure gauge data underestimates tsunami magnitudes by about an order of magnitude. This is because the Abe's empirical relation was derived only from tsunami amplitudes with coastal tide gauges where tsunami is amplified by the shoaling of topography and the reflection at the coastline. However, these effects do not work for offshore tsunami in deep oceans. In general, amplification due to shoaling near the coastline is governed by the Green's Law, in which the tsunami amplitude is proportional to $h^{-1/4}$, where h is the water depth. Wave amplitude also is doubled by reflection at the fixed edge (coastline). Hence, we introduce a water-depth term and a reflection coefficient of 2 in the original Abe's empirical relation to correct tsunami amplitude for open oceans and obtain $\mathrm{Mt} = \log(2H/h^{-1/4}) + 9.1$, where h is the depth of the ocean bottom pressure gage. The modified empirical relation produces tsunami magnitudes close to those determined using tide gauges.

OS22B-1157 1330h POSTER

A Framework for the Probabilistic Analysis of Tsunami Hazards

Eric L. Geist (egeist@usgs.gov)

U.S. Geological Survey, 345 Middlefield Rd., MS 999, Menlo Park, CA 94025, United States

A framework for analysis of tsunami hazards is proposed that is based on probabilistic seismic hazard analysis (PSHA), though with some important modifications. PSHA is a convenient methodology to adopt for the analysis of tsunami hazards in part because, for most regions in the United States, seismic source model specifications have been developed through the U.S. Geological Survey's National Seismic Hazard Mapping Project. The two main modifications to PSHA that are needed are (1) incorporation of far-field sources (i.e., distant earthquakes) that can generate damaging tsunamis and (2) a numerical hazard model (i.e., runup and inundation in tsunami hazard analysis) rather than an empirical model (i.e., ground motion in seismic hazard analysis). An important step in the development of probabilistic tsunami hazard analysis (PTHA) is the definition of uncertainties. For local tsunamis, variation in slip distribution patterns is a significant source of uncertainty that is inherently unpredictable (i.e., an aleatory uncertainty). Stochastic source models can be used in PTHA to estimate the range of possible nearshore tsunami amplitudes for a given magnitude and rupture geometry. Other important sources of uncertainty for local tsunami generated by subduction zone earthquakes include occurrence of secondary faulting near the trench, and triggered submarine and coastal landslides. For distant tsunamis, in addition to the fundamental tsunami source parameters of seismic moment and epicentral distance, source radiation pattern and propagation raypath are important factors in hazard calculations. Tsunami propagation from both local and distant sources is also sensitive to nearshore variations in bathymetry (which itself maybe a source of epistemic uncertainty) that is analogous to site response in PSHA. In contrast to past method for forecasting tsunami hazards, a PSHA-based method permits incorporation of uncertainties into the probabilistic forecast. PTHA as outlined in this study is compared to log-frequency/maximum runup height curves derived from historical data that were used in the past, especially in light of new probability analyses of complex systems. An important final consideration for PTHA is how probabilistic results are formatted and presented to different end-user communities.

OS22B-1158 1330h POSTER

Modeling and Experimental Validation for Tsunamis Generated by Submarine Mass Failure

Francois Enet[1] (1-401-874-6139; enet@oce.uri.edu)

Stephan T Grilli[1] (1-401-874-6636; grilli@oce.uri.edu)

Philip Watts[2] (1-562-498-9407; phil.watts@appliedfluids.com)

James T Kirby[3] (1-302-831-2438; kirby@udel.edu)

[1]Department of Ocean Engineering, University of Rhode Island, Narragansett, RI 02882, United States

[2]Applied FLuids Engineering Inc., PMB #237, 5710 E 7th Street, Long Beach, CA 90803, United States

[3]Center for Applied Coastal Research, University of Delaware, Newark, DE 19716, United States

Numerical models of tsunamis generation by Submarine Mass Failure (SMF) were developed in earlier work by the authors. More recently, this included a three-dimensional (3D) SMF tsunami source model, based on Fully Nonlinear Potential Flow equations (FNPF) (Grilli et al., 2002), and the integration of this model into a Boussinesq wave propagation and runup model (Watts et al., 2003a). The combined model for SMF tsunami generation, propagation, and runup, referred to as GEOWAVE, was successfully applied to a number of case studies, including PNG 1998, Skagway 1994, and Unimak 1946 (e.g., Watts et al., 2003ab). In the present work, we first describe recent improvements made to the model components of GEOWAVE, and their application to historical case studies. One recent addition to the Boussinesq propagation model, in particular, is its implementation in spherical coordinates, which allows using it over larger scale tsunami propagation areas. This is useful to study both transoceanic SMF tsunami near- and far-field propagation within the same dispersive long wave model. Second, we report results of recent large scale three-dimensional experiments performed at the University of Rhode Island, to investigate tsunami generation by underwater landslides. Each experiment consists of a solid landslide of idealized smooth shape sliding over a plane slope. Surface elevations are measured using capacitance gages placed at strategic locations. Gage calibration is performed using a newly developed automated system. Runup at the shoreline is measured using a remotely operated digital camera. Landslide acceleration is measured with a micro-accelerometer embedded at the landslide center of mass and an optical system also measures landslide displacement, as a way of cross-validation. The repeatability of experiments is first investigated, and then by varying the initial depth of the landslide, different conditions of wave nonlinearity and dispersion are generated and compared. Third, we present the comparison of these recent experiments with results of the 3D-FNPF model mentioned above. The agreement of computations with experiments is quite good for surface elevation. Model results can thus be analyzed to gain insight into the physics of SMF tsunami generation. For instance, in the model, horizontal velocities are found to be quite non-uniform over depth above the moving landslide. Further away from the landslide, however, horizontal velocities become quite uniform over depth, as would be expected for a long wave. **References:** Grilli, S.T., Vogelmann, S. and Watts, P. 2002 Development of a 3D Numerical Wave Tank for modeling tsunami generation by underwater landslides. *Engineering Analysis with Boundary Element*, **26**(4), 301-313. Watts, S. T. Grilli, J. T. Kirby, G. J. Fryer, and Tappin, D. R. 2003a. Landslide tsunami case studies using a Boussinesq model and a fully nonlinear tsunami generation model. *Natural Hazards and Earth System Sciences, EGS*, **3**, 1-12. Watts, S.

OS

T. Grilli and J. T. Kirby 2003b. Tsunami warning opportunities at Skagway, Alaska based on water wave records. *J. Science Tsunami Hazards* (accepted).

URL: http://www.oce.uri.edu/∼grilli

OS22B-1159 1330h POSTER

Boussinesq Modeling of the Complex 1975 Kalapana, Hawaii Geological Event

Stephan T Grilli[1] (1-401-874-6636; grilli@oce.uri.edu)

Philip Watts[2] (1-562-498-9407; phil.watts@appliedfluids.com)

Simon J. Day[3] (s.day@ucl.ac.uk)

James T Kirby[4] (1-302-831-2438; kirby@udel.edu)

[1]Department of Ocean Engineering, University of Rhode Island, Narragansett, RI 02882, United States

[2]Applied FLuids Engineering, PMB #237, 5710 E 7th Street, Long Beach, CA 90803, United States

[3]Benfield Greig Hazard Research Centre, Department of Earth Sciences, University College, London S01, United Kingdom

[4]Center for Applied Coastal Research, University of Delaware, Newark, DE 19716, United States

The potential for a catastrophic flank collapse of Kilauea, on the southern edge of the big island of Hawaii, has occupied scientists for decades. The tsunami hazard from such a potential collapse is hard to conceive of, and therefore deserves serious consideration. The 1975 Kalapana earthquake and tsunami may offer insight into the mechanics of Kilauea collapse, especially when combined with recent marine geology interpretations. The 1975 event is admittedly not of the scale of a catastrophic flank collapse. The reason why this insight is possible is because the tsunami observations and records constrain volcano failure, while at the same time supporting a new interpretation of volcano structures. Therefore, water wave information can also provide geological information. The flank of Kilauea is a complex structure, presumably capable of emitting seismic waves along multiple faults during an adjustment of the volcano flank. This has been recognized through a debate among seismologists as to the frequency content and orientation of a fault plane based on seismic records. We resolve the debate between two competing seismic mechanisms by accepting both. We recognize a steeply dipping fault just off of Halape that can explain high frequency earthquake content, as well as a shallow dipping thrust complex near the base of Kilauea that can explain low frequency earthquake content. Each earthquake provides a distinct tsunami source. The former tsunami source is necessary to explain eyewitness observations at Halape, while the latter is necessary to explain the far-field tsunami records. The two faults are apparently linked by a slumping of the Kilauea flank that ranges from the Hilina Pali system down to the base of Kilauea at over 5000 m deep. The slump, while not a new idea for the 1975 event, provides a third and essential tsunami source. The slump appears to be seismically quiet, which seems possible given recent observations of Kilauea displacement. We generate the three tsunami sources using TOPICS (which is based on fully nonlinear potential flow computations) and simulate tsunami propagation and inundation with the higher-order Boussinesq model FUNWAVE. The simulation results reproduce runups based on detailed accounts of survivors at Halape, in the near-field. They also describe maximum runup above sea level around the big island of Hawaii, including at Hilo. By far the nicest result is that our simulations of the 1975 event quite well reproduce the tide gauge records measured at Hilo (Big Island), Honolulu (Oahu), and Kahalui (Maui), the last two being in the far-field. The agreement of the numerical simulation results with observations supports our interpretation of Kilauea structures, even if overly simplistic as of now. These results raise doubt as to the potential for catastrophic collapse of the Kilauea flank.

OS22B-1160 1330h POSTER

Boussinesq Modeling of the 1975 Kitimat, British Columbia Landslide Tsunami

Tad Murty[1] (613-731-8900; tmurty@baird.com)

Philip Watts[2] (562-498-9407; phil.watts@appliedfluids.com)

Michael Fullarton[1] (613-731-8900; mfullarton@baird.com)

Stephan T. Grilli[3] (401-874-6636; grilli@oce.uri.edu)

Jim T. Kirby[4] (302-831-2438; kirby@udel.edu)

[1]Baird & Associates, 1145 Hunt Club Road Suite 500, Ottawa, ON K1V 0Y3

[2]Applied Fluids Engineering Inc., Private Mailbox #237 5710 E. 7th Street, Long Beach, CA 90803, United States

[3]Department of Ocean Engineering, University of Rhode Island, Narragansett, RI 02882, United States

[4]Centre for Applied Coastal Research, University of Delaware, Newark, DE 19716, United States

Mass failures near the head of Kitimat fjord in British Columbia produced water waves that caused severe destruction of waterfront facilities. We revisit this event with the latest numerical models in order to better understand the geological and tsunamigenic processes involved. Mass failure began around low tide near Moon Bay, possibly on account of construction activities taking place there. Retrogressive failure along the fjord floor proceeded over the next several minutes, until it reached the steep fjord head just underneath the Kitimat River. A mass on the steep slope then failed during a single event that is best characterized as an underwater slide in glacial sediments, resulting in an observed depression of the water within the middle of the fjord. This slide was much larger in volume than the initial mass failure, and consequently much more tsunamigenic. The Kitimat event presents many processes that appear to apply to tsunamis in fjords elsewhere. We examine the larger slide volume and linear dimensions based on the available bathymetry. The slide scar is relatively well discerned and extends along the entire slope, in what can be termed a typical fashion. We reproduce tsunami generation of the larger slide with TOPICS and simulate tsunami propagation and inundation with the Boussinesq model FUNWAVE. Our simulation results reproduce the tsunami runup observations, as well as the regions of damage incurred along the shoreline. We also reproduce far-field wave amplitude observations from fishing boats located further south. The agreement between the modeling results and observations suggests that landslide tsunamis in fjords are becoming well-studied events that can yield consistent processes and that can be accurately modeled.

OS22B-1161 1330h POSTER

A Novel Tsunami Inundation Mapping Technique

Philip Watts[1] (562-498-9407; phil.watts@appliedfluids.com)

Joseph S Walder[2] (360-993-8948; jswalder@usgs.gov)

Christopher F Waythomas[3] (907-786-7122; chris@usgs.gov)

[1]Applied Fluids Engineering, Inc., PMB #237, 5710 E 7th Street, Long Beach, CA 90803, United States

[2]USGS, Cascades Volcano Observatory, 1300 Southeast Cardinal Court, Building 10, Suite 100, Vancouver, WA 98683, United States

[3]USGS, Alaska Volcano Observatory, 4230 University Drive, Suite 201, Anchorage, AK 99508, United States

Traditional tsunami inundation maps have focused on maximum on-land inundation. Occasionally, the inundation maps are supplemented with information about maximum water velocity or timing. We demonstrate using several case studies the utility of producing maps showing 1) on-land inundation area, 2) maximum water velocity, 3) maximum water flux, 4) time of wave arrival, 5) time of wave maximum, and 6) time of wave departure. Map attributes 1-3 are related to water motion and are of particular value to scientists involved in tsunami hazard assessment. Attributes 4-6 are related to the timing of wave events and are of particular value to emergency managers. However, this raw form of inundation mapping is not easily interpreted within the usual GIS context because water velocities and fluxes are not readily understood by lay people. To improve on the GIS approach to portraying tsunami information, we employ simple engineering models illustrating the consequences of tsunami attack in a way that lay audiences can readily understand. In particular, we present maps that depict regions where a human would be knocked down, where cars would be moved, where various sizes of sediment would be moved, where anchors would break, and where ships would be moved laterally by a significant amount. Each map is separated into three distinct layers, each layer representing a different level of hazard. For example, the car movement map shows results for three sizes of automobile. Each region is depicted as a separate GIS layer. Given the uncertainty involved in numerical simulations, as well as the many local variables that can alter the outcome during a real event, these maps are meant to provide general guidelines as to the outcome of tsunami attack.

URL: http://www.tsunamicommunity.org

OS22B-1162 1330h POSTER

Relative Tsunami Hazard Maps, Humboldt County, California

Lori A Dengler[1] (7078263115; lad1@humboldt.edu)

Brian R Ludy[1] (7078263946; brl13@humboldt.edu)

Jason R Patton[1] (7078263931; jason@mcbaintrush.com)

[1]Humboldt State University, #1 Harpst St, Arcata, CA 995521, United States

We present a series of maps depicting the relative tsunami hazard of coastal Humboldt County in Northern California. Unlike inundation maps that show a single line to show the inland extent of flooding, these maps use a four-color zonation to represent relative risk. The highest hazard area has experienced tsunami or storm wave inundation in historic times. These areas include beaches and low coastal bluffs on the open coast and low areas adjacent to Humboldt Bay and major river deltas. The high hazard zones are also mapped as zone A (100 year flooding) or zone V (100 year flood with wave action) on FEMA Flood Insurance Rate Maps. Moderate hazard zones are areas likely to be flooded by a major tsunami generated by the Cascadia subduction zone based on published paleotsunami studies, numerical modeling (Bernard and others, 1994) and observations of recent tsunamis elsewhere. Current estimates of major Cascadia earthquake recurrence averages about 500 years. Low hazard zones show no evidence of flooding in the paleotsunami record and are likely to provide refuge in all but the most extreme event. No hazard areas are too high in elevation and/or too far inland to be at risk. A continuous gradational color scale ranging from red (high hazard) through orange (medium), yellow (low) to gray (no hazard) depicts the zones. The blurred boundaries help convey the continuum of possible events and the uncertainty in delineating distinct inundation lines. The maps are GIS based to facilitate ready adaptation by planners and emergency managers. The maps are intended for educational purposes, to improve awareness of tsunami hazards and to encourage emergency planning efforts of local and regional organizations by illustrating the range of possible tsunami events.

OS22B-1163 1330h POSTER

Public Awareness of a Long-Established Siren-Based Warning System for Tsunami in the Hawaiian Islands

Chris Gregg[1] (1-808-956-6213; cgregg@soest.hawaii.edu)

B Houghton[1] (bhought@soest.hawaii.edu)

D Paton[2] (Douglas.Paton@utas.edu.au)

D Johnston[3] (D.Johnston@gns.cri.nz)

[1]University of Hawaii, School of Ocean and Earth Science and Technology, Honolulu, HI 96822, United States

[2]University of Tasmania, Department of Psychology, Launceston, TAS 000, Australia

[3]Geological and Nuclear Sciences, Gracefield Research Centre, Lower Hutt 000, New Zealand

Tsunami represent one of the greatest threats in the Hawaiian Islands because much of the built environment is located in the coastal areas and has been constructed after the last statewide damaging tsunami (1960). Moreover, the threat posed by short warning times of locally generated tsunami suggests an urgent need for a well briefed and prepared society. The Federal Emergency Alert System (EAS) is employed to communicate emergency information to the Hawaiian population (1.2 million residents; 6.4 million annual visitors). A network of sirens located throughout the islands supplements the EAS. These sirens have been used since the mid 20th Century to provide emergency information to islanders. The siren is currently defined as an “Attention Alert Signal” i.e. is intended to prompt people to listen to the radio or television for specific information. The sirens are tested monthly. Since the inception of the sirens there have been a range of tones and number of soundings used to indicate various threats and prompt specific public responses. However, the impact of these changes on interpretation of the sirens has received little attention (Lachman et al. 1961). The long time during which the warning system has been in place and the routine tests of the sirens would suggest that the population in Hawaii is largely aware of the siren. We present data from four Hawaiian Islands showing the relationship between awareness of the routine tests and interpretations of the sirens. We link this to findings from a tsunami preparedness study in Hilo, Hawaii.

OS22B-1164 1330h POSTER

International Centre for Geohazards (ICG) Established at the Norwegian Geotechnical Institute in Oslo, Norway.

Anders Solheim[1] (47-22023059; as@ngi.no)

Farrokh Nadim[1] (47-22023047; fna@ngi.no)

[1]Norwegian Geotechnical Institute, P.O.Box 3930 Ullevaal Stadion, Oslo N-0806, Norway

As one of 13 new Centres of Excellence' awarded by the Norwegian Research Council with a 10-year funding schedule, the International Centre for Geohazards (ICG) was established at the Norwegian Geotechnical Institute (NGI), in January 2003. The Centre is formed through a co-operation between several institutions, which in addition to NGI are the Gelogical Survey of Norway (NGU), Norwegian Seismic Array (NORSAR), University of Oslo (UiO) and the Norwegian University for Science and Technology (NTNU). The Centre is located in the NGI building in Oslo, Norway. Funding is for 10 years, and the centre is staffed by researchers from the partner institutions, visiting scientists, postdoctoral fellows and Ph.D. students. With the ultimate goal of geohazard mitigation and preventing the loss of lives and damage to infrastructure and environment, key research topics of the Centre are: Unsaturated soils and mechanisms for precipitation-induced slides in steep slopes; Risk and vulnerability analysis for geohazards; Earthquake hazard, vulnerability and risk evaluation; Rock slope failures - models and risks; Landslides in soft clay slopes (quick clay), fjord margins and coastal zones; GIS applications to geohazards; SAR applications to geohazards; Slide dynamics and mechanics of disintegration; Tsunami modelling and prediction; and Offshore Geohazards. As prospecting for hydrocarbons move into increasingly deeper waters of the world's continental margins, research on offshore geohazard forms an important activity of the new centre. Main offshore geohazards include slope instability, effects of shallow gas and gas hydrates on the behaviour of seafloor sediments, mud volcanism and diapirism. Of these, slope instability is considered to be the major hazard, because of the potentially serious third party impact. The current offshore geohazards project within ICG consists of three main themes: Assessment of offshore geohazards (site surveys); Geophysical methods for offshore geohazard studies, including improved modelling; and Pore pressures in offshore sediments: prediction and measurements. Education is a highly prioritised task of the Centre, and new courses are being offered at NTNU and UiO. These courses aim at giving graduate level education in geohazards, with thesis work carried out on ICG projects.

URL: http://www.geohazards.no

OS22C MCC: 3000 Tuesday 1340h

Late Pleistocene and Holocene Paleoceanographic Variability Along the Pacific Margin of North America I *(joint with B, PP)*

Presiding: **L Beaufort,** Centre Europëen de Recherche et d'Enseignement de l'Environnement, CNRS**; T F Pedersen,** University of Victoria

OS22C-01 1340h

Late Quaternary History of the Northeast Pacific Ocean off Vancouver Island, Canada

Jennifer Lynn McKay[1] (514-987-4080; mckay.jennifer@uqam.ca)

Tom Pedersen[2] (250-721-6120; tfp@uvic.ca)

[1]GEOTOP, University of Quebec at Montreal, C.P. 8888, succursale Centre-Ville, Montreal, QC H3C 3P8, Canada

[2]School of Earth and Ocean Sciences, University of Victoria, Petch Building 168, 3800 Finnerty Road, Victoria, BC V8P 5C2, Canada

Data for marine sediment cores collected from the continental margin off Western Canada indicate that dramatic changes in productivity and oxygen minimum zone intensity occurred during the last 16 kyr B.P. During the late glacial marine organic matter accumulation in sediments was greatly reduced off Vancouver Island. This reflected low primary and export production because glacial-mode atmospheric circulation (i.e., the dominance of the Aleutian Low) did not drive upwelling in the region. At start of the Bolling warm period (14.3 kyr B.P.), and coincident with the retreat of glaciers from the continental shelf, there was a substantial increase in the burial of organic matter. Much of this organic material was old terrestrial organic matter derived from the erosion of shelf sediments. However, the accumulation of marine organic matter also increased in the Bolling and peaked in the Allerod (13.5 to 12.6 kyr B.P.). At this time the marine organic carbon accumulation rate was an order of magnitude higher than in the late glacial and Holocene. Other paleoproductivity proxies (i.e., bio-barium, opal and alkenone abundances) also indicate increased marine productivity during the Allerod. Since productivity in the region is controlled by the upwelling of nutrient-rich subsurface waters the data suggest enhanced upwelling, which is also alluded to by radiocarbon data (i.e., a decrease in benthic-planktonic age differences). Redox-sensitive trace metal and benthic foraminifera data suggest that the intensity (i.e., degree of oxygen-depletion) of the oxygen minimum zone (OMZ) also fluctuated during the deglacial. Notably, there is a prominent increase in OMZ intensity during the Allerod. The corresponding increase in marine organic carbon accumulation at this time and lack of any evidence of decreased ventilation suggests that OMZ intensification was a response to increased primary productivity and carbon export. Intensification of the OMZ during the deglacial is documented along the length of the entire California Current System, but it appears to have been delayed by approximately 1500 years off Vancouver Island.

OS22C-02 1355h

The Pacific Decadal Oscillation and the Growth and Decay of the Cordilleran Ice Sheet During the Last Glacial

Timothy N Cosma[1] (tcosma@uymich.edu)

Ingrid Hendy[1] (734-936-8458; ihendy@umich.edu)

[1]The University of Michigan, Department of Geological Sciences, Ann Arbor, MI 48109, United States

Late Quaternary growth and decay of the Cordilleran Ice Sheet left substantial terrestrial sedimentary deposits in the American Northwest and although this ice sheet has been the subject of numerous studies, the interaction between global climate and local ice sheet growth and decay is not fully understood. MD02-2496, drilled off the coast of Vancouver Island, Canada, (48°58'N; 127°02'W; 1190m water depth; 38.38m core length) provides the first high resolution Late Quaternary record of northeast Pacific ocean response to climate change that can be precisely correlated with Cordilleran Ice Sheet dynamics. Preliminary results indicate MD02-2496 contains a significant record of climate variability that shares many similarities with Greenland δ^{18}O records. From the base of the core to 31.5m terrigenous sediments dominate. Numerous drop stones, high magnetic susceptibility and δ^{18}O values suggest glacial conditions From 25-31.5m, higher Corg/terrigenous ratios are suggested by color reflectivity and low magnetic susceptibility similar to that of the core top. δ^{18}O values decrease during this interval and demonstrate unprecedented variability similar to the widely documented MIS 3 interstadial events. Magnetic susceptibility increases at 25m prior to an interstadial event (possibly IS 2). The sudden occurrence of bedded turbidite layers at 19.5m appears co-incident with high δ^{18}O values suggesting the Last Glacial Maximum. The incidence of turbidites decreases upcore to 7m. A dramatic shift in δ^{18}O toward lower values occurs at 9.5m marking the Bølling. The upper 7m of the core contains sediments with the same distinct color reflectivity shift and low magnetic susceptibility seen between 25 and 31.5m. Tentative interpretation of these early results suggests the core bottom (31.5 m +) preserves the first record of a possible MIS 4 glacial advance in the Juan de Fuca lobe. The interstadial events recorded in MIS 3 (25-31.5m) suggest glacial retreat and a return to a high sedimentary Corg/terrigenous ratio. The increase in magnetic susceptibility at 25m appears coincident with regional ice sheet growth, while the turbidite sequence beginning at 19.5m possibly signifies the maximum ice extent (20 ka) with the engulfing of Vancouver Island and ice expansion on the continental shelf. The sudden shift of δ^{18}O at 9.5m probably correlates with the Bϕlling and subsequent rapid decay of the Cordilleran Ice Sheet with modern oceanic conditions returning at 7m.

OS22C-03 1410h

Millennial and Centennial Variability of the California Current System During the Holocene Recorded in Santa Barbara Basin

Kevin G. Cannariato[1] (1-213-740-6733; cannaria@usc.edu)

James P. Kennett[2] (kennett@geol.ucsb.edu)

Douglas J. Kennett[3] (dkennett@oregon.uoregon.edu)

Justin S. Revenaugh[4] (justinr@umn.edu)

Bjorn A. Malmgren[5] (bjorn.malmgren@marine-geology.gu.se)

[1]University of Southern California, Department of Earth Sciences, Los Angeles, CA 90089, United States

[2]University of California, Department of Geological Sciences, Santa Barbara, CA 93106, United States

[3]University of Oregon, Department of Anthropology, Eugene, OR 97403, United States

[4]University of Minnesota, Department of Geology and Geophysics, Minneapolis, MN 55455, United States

[5]Goteborg University, Department of Earth Sciences-Marine Geology, Goteborg SE-405 30, Sweden

Understanding natural climate variability on millennial and centennial time-scales is necessary for predicting future climate change. Here we present planktonic foraminiferal oxygen and carbon stable isotope records at decadal resolution from Santa Barbara Basin documenting California Current system variability through the Holocene. Threshold mean-climate changes in SSTs and upper-water column structure occurred as well as significant millennial- and centennial-scale variability. A transition from warmer SSTs and a more stratified water column to cooler SSTs and a less stratified water column occurred between 4 and 3 ka and is associated with a global climate transition exhibited in records from the tropics to the poles. Millennial and centennial oscillations in SST and water column structure are associated with inferred atmospheric variability in the tropics, North Atlantic and Antarctic. These results suggest that interdecadal-like teleconnections may have been active on centennial and millennial time-scales. Furthermore, centennial periodicities imbedded in the records suggest possible forcing through variations in solar output.

OS22C-04 1425h

Regime Shifts in Productivity off Baja California During the Late Pleistocene?

Joseph D Ortiz[1] (330-672-2225; jortiz@kent.edu)

Suzanne E. O'Connell[2] (soconnell@wesleyan.edu)

Jeffery DelViscio[3] (jdelviscio@cspinet.org)

Alexander van Geen[4] (avangeen@ldeo.columbia.edu)

Luc Beaufort[5] (beaufort@cerege.fr)

[1]Department of Geology, Kent State University, Kent, OH 44242, United States

[2]Department of Earth and Environmental Sciences, Wesleyan University, Middletown, CT 06459, United States

[3]Center for Science in the Public Interest, 1875 Connecticut Ave. N.W.,Suite 300, Washington, DC 20009, United States

[4]Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, United States

[5]CNRS - CEREGE, Univ. Aix-Marseille III Technopole de l' Arbois - BP 80, Aix-en-Provence 13545, France

The eastern subtropical Pacific is a region of the surface ocean influenced strongly by ENSO but characterized by generally low sedimentation rates. Core MD02-2508 raised from 700m depth on the Magdelana Margin near the southern tip of Baja California during the IMAGES VIII MONA cruise exhibits high sedimentation rates and appears to extend beyond 100 ka based on a preliminary age model. Work on a piston core collected during a prior cruise to the same location (MV99-PC08) demonstrates a clear correlation between the GISP-2 d18O record, and sedimentary records of diffuse spectral reflectance, organic carbon, calcium carbonate, and benthic foraminifers per gram sediment during the past 52 kyrs. Peaks in organic carbon content, which occur during warm interstadial events, correspond to maxima in benthic foraminiferal absolute abundance that are as much as two order of magnitude greater than those observed during cool stadial events. Although the age model of the core MD02-2508 is preliminary, data from this new core appears to extend this correlation back beyond 100 ka. From 2400 cm to 0 cm, sediment in core MD02-2508, is only laminated during the strongest of the interstadial events and exhibits an inverse linear correlation between calcium carbonate content and organic carbon content. Sediment deposited below 2400 cm are radically different. The base of core MD02-2508 is more distinctly and continuously laminated, exhibiting greater variance in organic carbon and calcium carbonate content. Of perhaps greater significance, there is a positive, exponential relationship between calcium carbonate and organic carbon content off Baja California during this interval, except for brief periods of lower organic carbon and calcium carbonate that exhibit the negative correlation which

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