Discussions of ODP Leg 205 and Drilling of Middle America Seismogenic Zone

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Erosional convergent margins, where material is removed from the base of the upper plate and subducted on the lower plate, are fundamental features of the Circum Pacific. The erosional Middle America Trench convergent Pacific margin, remarkable for its broad diversity of dynamic environments, is a natural laboratory for studying convergent margin processes and seismogenesis. These environments include a shallow and deep trench axis, shallow- to steep-dipping plate interfaces, abnormally hot-to-cold subducting plate temperatures, and a subducting plate with smooth morphology bordering basement ridges and seamounts. The subducting topography accelerates erosion and localizes seismicity.

Potential drilling targets extend from the region of the 1992 tsunamigenic Nicaragua earthquake, to the uplifted plate boundary off the Osa Peninsula of Costa Rica. Subduction of the broad Cocos Ridge beneath the Osa Peninsula uplifts the seismogenic zone to depths reachable by drilling. Deep drilling here would answer questions regarding progressive physical, chemical, and hydrologic changes along down the plate boundary toward the seismogenic zone. Uplift provides access to a temperature window for slab dehydration processes that are critical to understanding prograde metamorphism of the lower plate during subduction.

Within the Integrated Ocean Drilling Program (IODP), one goal is to recover material from active seismogenic zones and install monitoring instruments downhole with the Japanese riser drill ship *Chikyu*. Drilling the dominantly erosional Middle America margin, a margin with frequent, damaging earthquakes and tsunamis, was the subject of a JOI/U.S. Science Support Program-funded workshop that took place prior to the 2002 AGU Fall Meeting in San Francisco. The 64 scientists attending the workshop came from seven countries and represented multiple scientific disciplines.

The objectives of the workshop were to obtain input from a broad community on science and drilling objectives along the Middle America margin; integrate new information into a Complex Drill Proposal (CDP) overview and Stage 1 non-riser drilling; and identify synergism between similar programs, promote coordination, and establish international contacts within the Middle America scientific community.

This meeting of the Middle America drilling community enlarged proponent groups and provided guidance for revision of IODP drill proposals. A new perspective on the seismogenic zone emerged during discussions.

Recently Acquired Data

Presentations of unreported and recent work established a common level of background information for later discussions. Results from ODP Leg 205 off Costa Rica, completed only three weeks prior to the workshop, were followed by presentations on geology and geophysics, geodesy and earthquake seismology, fluids, and heat flow. During Leg 205, long-term observatories were installed off the Nicoya Peninsula to monitor pressure and temperature changes due to active fluid flow, and to collect fluids and gasses. Disclosed in presentations were new estimates of erosion rates from older scientific drill samples that indicate rates fluctuating in time and along strike. Erosion rates correlate with subducting plate character, the pattern of earthquakes, and volcanic arc geochemistry.

Fore-arc diversity was illustrated with seismic records showing previously undocumented landward-dipping reflections that may correlate with an Eocene melange cropping out on the Osa Peninsula. In that area, preliminary forward modeling of global positioning satellite geodesy suggests increasing stress in a locked zone. Northwest of the peninsula, an on- and off-shore seismic network allowed precise location of aftershocks of the 1999 Mw 7.0 earthquake that cluster over a subducted ridge and are considered to define a local up- and down-dip extent of the seismogenic zone. Other clustering of seismicity over subducted seamounts is associated with simple patterns of strain release that may be typical of asperities over lower plate relief.

Heat flow measurements show complex temperature patterns within both the upper and lower plates. These are consistent with proposed fluid convection in the upper ocean crust and advection in the upper plate. Beneath the continental slope over Cocos Ridge, temperature along the plate boundary, modeled from surface temperature, is 150°C, a temperature commonly associated with seismogenic behavior and Subduction Factory processes. Diapiric mounds in the middle slope have mineral precipitates that are inferred to reflect fluid flow from regions of elevated temperature and are being tested with pore fluid geochemistry. The vigor of fluid flow along Middle America has become increasingly apparent.

Discussion Groups

The remainder of the workshop concentrated on discussions of the topical problems. Within the along-strike diversity of environments, a correspondence between subducted crustal morphology and composition, the flexural faulting seaward of the trench, earthquake epicentral patterns and magnitude, and the complexity of earthquake strain release invite comparison. Important processes to investigate include changes in interplate friction related to progressive metamorphism, the behavior of fluids, the effect of positive basement relief on seismicity, and the character of eroded material produced along the plate interface.

Progressive change in state of materials and fault structure down the subduction zone is linked to the behavior of fluids. The relatively high frequency of Middle American earthquakes is advantageous for study of pore pressure history during strain build-up and release. Hydrologists are interested in answering questions with drilling regarding the role of fluid flow in plate boundary dynamics, how fluid circulation in the upper ocean crust is modified when the lower plate subducts, and the chemical change in fluids with depth down the subduction zone. A strong interest exists in complementary drilling programs along the Nicaragua margin that would concentrate on fore-arc vertical tectonic histories, and on the lower slope and plate boundary where the nature of tsunami earthquakes may be investigated. Here, seismogenic rupture may have approached the trench axis, as suggested by tsunami modeling of the 1992 earthquake.

Another drill target is faulting in the Cocos plate seaward of the trench to investigate a proposed invasion of sea water to mantle depth along normal faults. Abnormally low upper mantle velocities are possibly due to serpentinization from the reaction of sea water with peridotite. The German Special Research Project, SFB 574, a special long-term project, has invested 5 months' worth of sea time investigating mud diapirs, seamount subduction, ocean plate faulting, and associated sea floor venting.

Processes governing the transition from stable sliding to stick-slip behavior, marked by the updip limit of seismicity, are poorly known and invoke many hypotheses. If mineral transformation and associated fluid geochemistry are important, those transformations are probably progressive instead of instantaneous. If fluid pressure is important, its cyclicity may indicate a migration of frictional resistance. This relation is closely linked with fluid circulation in ocean crust and its role once the plate subducts. All of these processes may move the transition to stick-slip over time.

Revised Concept of the Seismogenic Zone

Repeated questions concerned the role of lower plate relief on seismogenesis. Do asperities over positive relief on the lower plate produce local high friction? Do conditions over seamount asperities off Costa Rica differ from conditions over the subducted seamount along the Nankai Trough, which forms a barrier? Do positive relief asperities limit the size of earthquake rupture? Are low areas between positive relief locked, or are they characterized by stable sliding? Is there a resolvable difference in shear heating between regions of subducted asperities versus regions where smooth sea floor subducts? The evolving image of the seismogenic zone at the Middle America margin does not appear to be static with fixed up- and down-dip limits defined by isotherms. Instead, it appears to be a mosaic of frictional behaviors controlled by heterogeneous morphology, temperature, material composition, and the fluid pressure conditions. This evolving image needs to be elucidated through a drilling program.

A frequently discussed issue was how to better locate the up-dip limit of the seismogenic zone prior to drilling. Drilling capability restricts proposed sites to the shallowest, seaward-most edge of seismogenic behavior. In many earthquake seismological studies, seismogenic events are located to ±10 km, a precision that is unsatisfactory for locating drill sites. A more precise up-dip end of seismogenic behavior requires deployment of ocean bottom instruments. Currently, only a 2-month period of aftershock activity has been located with records from on- and off-shore seismometers near the area of proposed deep drilling. Off the Nicoya Peninsula, a longer period of on- and offshore monitoring indicated variations in the initiation of interplate seismicity, suggesting that the up-dip limit near a candidate drill site must be more precisely determined with ocean bottom seismometers spaced less than 5 km apart.

Most likely, the beginning of stick-slip behavior varies in space and time with changes in fluid pressure and chemistry, temperature—and locally—with subducting plate relief. To advance understanding of seismogenesis requires direct observation of its dynamic environment through a scientific drilling program. With its low sediment supply, fast convergence rate, abundant seismicity, tectonic erosion, and diverse subducting plate morphology, the Middle America margin offers an excellent complement to the Nankai Trough Seismogenic Zone Drilling Experiment.

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—ROLAND VON HUENE, University of California, Davis; GUILLERMO ALVARADO, Instituto Costarricense Elect., San Jose; KEVIN BROWN, Scripps Institution of Oceanography, La Jolla, Calif.; ROBERT HARRIS, University of Utah, Salt Lake City; MASA KINOSHITA AND KIYOSHI SUYEHIRO, JAMSTEC, Yokahama; KIRK MCINTOSH, University of Texas, Austin; JASON MORGAN, Geomar, Kiel; JULIE MORRIS, Washington University, St. Louis, Mo.; MARINO PROTTI, Universidad Nacional, San Jose; CESAR RANERO, Geomar Marine Geoscience Research Institute, Kiel; DAVID SCHOLL, U.S. Geological Survey, Menlo Park, Calif.; SUSAN SCHWARTZ, University of California, Santa Cruz

LETTERS

Is It Just a Rise in the Mean Sea Level?

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I have a suggestion for those numerous authors who almost invariably say that after a certain amount of land-supported ice melts, the sea level will rise "so much." It would be much more correct to say that the oceans will get "so much" deeper.

As is well known, there are over a dozen reasons for mean sea level changes. When land-supported ice melts, the amount of water in oceans increases and all of the oceans get deeper. This will cause an immediate increase in the pressure on every square meter of the ocean floor, which covers approximately 70% of Earth's surface. Due to the isostatic equilibrium between large surface areas, it would not be unreasonable to expect that the ocean floor would start to sink due to the increased pressure, and the rest of the Earth's surface—that is, the continents—will start to rise, especially where the ice melted.

For example, adding an extra layer of water 1 m thick to the oceans (pro-rate for smaller amounts as needed) from melting land-supported ice puts an extra pressure of 1 metric ton on every square meter of the ocean floor. As a result, the ocean floor will start to sink toward Earth's center, and, correspondingly, the continents will start to rise, negating much of the claimed sea level rise.

So, when the ocean waters deepen by 1 m, the sea level does not necessarily rise by 1 m.

—LASSE KIVIOJA, Purdue University, West Lafayette, Ind.

ABOUT AGU

Report of the Fellows Committee

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The AGU Fellows Committee is pleased to announce it has just elected 41 AGU members as new Fellows for their "eminence in geophysics." The total number elected each year is established by AGU's bylaws and is limited to 0.1% of the total membership.

The process of electing Fellows begins with the nominations submitted by the general membership to AGU, that are then sent to the section Fellows committees. The section committees review these nominations, prepare their rankings, and forward an allotted number of nominations with their rankings to the Union Fellows Committee. Additional "cosponsored" nominations supported by two or more sections are encouraged, and they have had a very high success rate in the final elections by the Fellows Committees. When the section committees do their jobs well, the Union Committee will review twice the number of nominations as the number of Fellows that can be elected. Each Union Committee member ranks the candidates based on the material presented in the nomination. This process works very well, and the Committee has been presented with an embarrassment of riches. This was certainly true in this year's selection meeting; the result of the election is listed here. Pictures and citations of the new Fellows will be presented in a future issue of *Eos*.

The Union Fellows Committee is made up of eleven Fellows and currently has two non-U.S. citizens and three women. None of its members sits on a section Fellows committee.

In the 13 September 1994 issue of *Eos*, an article by Ellen Druffel showed the numbers, proportions, and age distributions of female and male Fellows. As a follow-up to her article, I want to review progress in the following areas: (1) gender balance, (2) non-U.S. representation, (3) age distribution, and (4) cosponsored nominations.

1. Has the AGU and its Fellows Committees made any progress on the "gender front"?

The total number of Fellows has grown by 49% from 1994 to 2003, while the total AGU membership increased by 41% during the same period. The number of female Fellows has increased by 211%, which still is only 0.8% of the total female membership compared with the figure of 2.6% for males. Although the percentage of Fellows that are female elected each year fluctuates (Figure 1), they remain underrepresented. So are we making progress on this front? I think we are, although we have no reason to be complacent just yet. Members should continue efforts to identify and nominate worthy women as Fellows.

2. How well is its non-U.S. membership represented by non-U.S. Fellows?

Membership outside the U.S. has risen from 30% to 32% over the last 8 years, and the

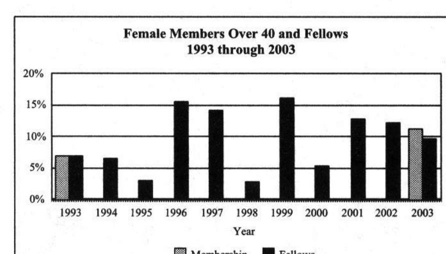

Fig. 1. Female Members Over 40 and Fellows.

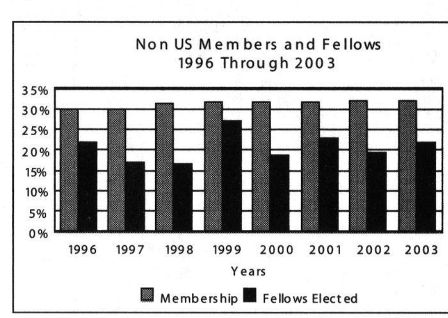

Fig. 2. Percent of Members and Fellows outside the U.S.