quake, or other hazard that may have precipitated the landslides.

Pallister said that Los Angeles tops the list of U.S. urban areas where rain-induced landslides pose a serious risk, followed by the San Francisco area. While a system of flood control works helps to protect the populace in Los Angeles from debris flows, many people live upstream from these engineering fixes. Other potential problem areas include Seattle, Honolulu, parts of the Rocky Mountain and Appalachian Mountain regions, and Puerto Rico.

Russian Roulette

If another major storm occurs during the San Francisco Bay area's annual wet period, it could trigger debris flows, the USGS said. Areas of particular concern include the Santa Cruz mountains, Marin County, the East Bay Hills above Oakland and Berkeley, Valeho, and the seaside town of Pacifica—locales where communities co-exist with the threat of natural hazards.

The odds of another Bay area storm dumping sufficient precipitation during a brief enough time period to weaken soils during the wet landslide season range between 1 in 3 to 1 in 6, according to USGS landslide geologist Raymond Wilson. He said that while the definition of a major storm may vary according to location, precipitation of about 7 centimeters falling in 6 hours or less in San Francisco could trigger a debris flow.

"One in six are the odds in Russian roulette. It is something you ought to be concerned about," noted Wilson. He said that whether a major storm actually materializes, "the only prudent thing to do is to assume a wet year."

During the Bay area's wet season—historically from November through March—about three-quarters of annual precipitation of about 53 centimeters falls and rehydrates the soil. If precipitation comes from small storms, and the ground has time to dry out, the likelihood of debris flows and mudslides lessens. However, the 2002–2003 season potentially could bring more moisture because of the El Niño and the movement of the North Pacific jet stream, with its subtropical sub-stream and its warm, moist air above the Bay area, Wilson said.

He said landslides can occur when water pressure builds up, weakens the frictional strength of grains of soil, overcomes the angle of repose of the slope, and causes a critical state and a transition of the soil from a solid to a gel. A little bit of pressure might be enough to trigger a slide where there is a steep slope, he stated.

"In loose soil, like acrobats in the circus standing on each others shoulders, if somebody's hand slips, the whole thing comes tumbling down," Wilson said.

History of Landslides

During the past several decades, the Bay area has weathered several severe landslide seasons. In January 1982, more than 18,000 rain-induced landslides carved through the region, catching by surprise much of the populace, as well as Wilson and other geologists, who had not realized the region was prone to that hazard. The landslides, which caused 25 fatalities and more than $100 million in direct damage costs in current U.S. dollars, rate as the third-biggest natural disaster in the Bay area, after the 1906 San Francisco earthquake and the 1989 Loma Prieta earthquake.

The 1982 landslides motivated USGS to develop landslide hazard maps and an Automatic Local Evaluation in Real-Time network of gages and piezometers to measure pore pressure in the water table. But the agency scaled back its efforts following a 1995 reduction-in-force and funding. Wilson, now the sole USGS scientist involved with research on rainfall induced debris flows in central California, operates with a small budget and issues occasional press releases in hopes that local authorities and residents will pay heed to landslide cautions.

"That's the only outreach [mechanism] I've got left," he said.

For more information on the NAS National Landslide Hazard Mitigation Strategy, visit the Web site: http://www4.nas.edu/webcr.nsf/ProjectScopeDisplay/BESR-U-01-05-A. To view the USGS framework paper for loss reduction as part of this strategy, visit the Web site: http://geology.cr.usgs.gov/pub/open-file-reports/ofr-00-0450/.

Randy Showstack, Staff Writer

'Subduction-Factory' Meeting Studies Izu-Bonin-Mariana Margin

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Subduction zones are regions in which the Earth's sedimentary layers and hydrosphere are recycled into the deep mantle. These downwellings provide most of the force needed to drive the plates and are the dominant mode of mantle convection. The cold material sinking in subduction zones releases water into the overlying mantle, causing mantle melting and fractionating elements between surface and deep mantle reservoirs. The term "subduction factory" captures the scale of these interactions and the fact that studying "balance sheets" of inputs and outputs provides powerful constraints for our understanding of how subduction zones work.

Learning more about the physics, chemistry, and biology of subduction zones requires efforts that are increasingly interdisciplinary and international. Because of the central role that subduction plays in the solid Earth system, as well as its role in maintaining equilibrium between the mantle and the hydrosphere, understanding how subduction zones operate is a highly important scientific challenge. U.S. National strategies for fostering this understanding favor focusing on a few end-member representatives, such as the 2800-km-long Izu-Bonin-Mariana (IBM) subduction system in the western Pacific Ocean.

A workshop on the IBM subduction system was held in Honolulu, Hawaii, 8–12 September 2002. The workshop was sponsored by the National Science Foundation's MARGINS Program and co-sponsored by the Japanese Institute for Frontier Research on Earth Evolution (IFREE). Both the United States and Japan have selected the IBM system for focused research. The Subduction Factory Science Plan (www.ldeo.columbia.edu/margins/SciPlan.html) addresses three fundamental issues: How do forcing functions such as convergence rate and upper plate thickness regulate production of magma and fluid from the subduction factory? How do the H_2O and CO_2 cycles impact chemical, physical, and biological processes from trench to deep mantle? And, what is the mass balance of chemical species and material across the subduction factory, and how does this balance affect continental growth and evolution?

The IBM arc has been selected as the intra-oceanic "cold-subduction" end-member example in which subduction factory topics can be addressed effectively by interdisciplinary teams. IBM is one of two focus sites for the U.S. Subduction Factory Initiative; Central America is the "hot-subduction" end-member.

The workshop was intended to stimulate interdisciplinary and international efforts to understand the IBM subduction factory by bringing a diverse group of scientists together and introducing them to the area, the science, and each other. About 100 scientists attended, with about 60% from the United States, most of the rest from Japan, and some from Europe. Abstracts and key visuals for scheduled talks and posters are available on the Web site at www.ldeo.columbia.edu/margins/SubFac/IBM/IBM02.html.

On the first day of the meeting, overviews of the outstanding problems of the chemistry and physics of subduction were followed by detailed reviews of the IBM arc, including its geological evolution, crust and mantle structure, thermal behavior, and seismicity. Special attention was given to the region near Tokyo, where the IBM arc continues to collide with Japan and deep exposures are visible onshore. There was also considerable discussion about thermal models of subduction zones and how these relate to mantle flow, which can be studied using seismic anisotropy. The second day focused on inputs—sediments—and outputs—volcanic, plutonic, and hydrothermal—to and from the IBM arc system; the third day returned to generic problems of the subduction factory. The series of scheduled talks concluded with presentations on other NSF, IFREE, and GEOMAR plans for work on subduction-zone processes, including possible drilling and submersible investigations by the International Ocean Drilling Program.

The workshop demonstrated that progress is being made in the IBM focus site toward the Subduction Factory Initiative's goals. Final plans or preliminary results were presented for all six of the U.S. MARGINS Subduction Factory projects that have been funded in the Mariana portion of the IBM arc since 1999. These projects include >5000 km of multichannel seismic profiling of crustal structure; a 50-ocean bottom seismometer, wide-angle seismic experiment for crustal structure; a passive seismic tomography experiment; investigations of the glass inclusions in arc phenocrysts, geochronology, and geochemical evolution of forearc islands; and marine geological and geochemical investigations of the Mariana arc southern seamount province. Results were also presented from ODP Leg 185, which drilled sediments and basaltic basement in the incoming Pacific Plate off both the Izu and Mariana arcs. Results from this drilling indicate that the variation of incompatible elements in IBM arc magmas may be related to chemical variations on the incoming plate.

One outstanding problem has been responsible for the failure of thermal models of subduction zones to predict temperatures sufficiently high for melting to occur beneath the active volcanic arc. A well-known model predicts a slab/wedge interface temperature of only ~550°C beneath the Izu-Bonin volcanic arc. Three new thermal models presented showed that with a temperature-dependent viscosity, slab temperatures may be much greater, on the order of 750°C. In addition, the new models show a mantle flow pattern that is compatible with upwelling and melting beneath the island arc.

Equally important has been the failure of previous dynamic models to properly predict observed bathymetry and the stress state of subduction systems, so it was welcome to hear M. Gurnis report that models incorporating more complex rheologies, particularly including a low-viscosity wedge, successfully predict extension in the back-arc, down-dip compression in the slab, and appropriate bathymetry for both fore arc and back arc. C. Hall showed how such models can spontaneously nucleate subduction zones when ridge-transform intersections undergo compression, which is one possible model for the birth of the IBM system. Of course, none of the models yet reproduces the full complexity of the subduction system, particularly along-strike variations such as the "hot fingers" with a lateral wavelength of 80 km that seem to underly the Japanese islands as determined from seismic tomography, gravity modeling, and volcano statistics.

New U-series disequilibrium data presented by B. Bourdon and others indicate that fluid-mediated fractionation of Ra occurs within 3000 years prior to eruption. Such rapid ascent seems to require channelized melt flow without time for chemical equilibrium. Crustal differentiation processes in IBM and similar arcs must take no more than a few thousand years to transform primitive magmas into andesites and dacites. Differentiation processes are so fast, and eruption volumes so small, that magma chambers large enough to be imaged seismically may not even exist beneath arc volcanoes that are not characterized by rhyolite.

Several Japanese scientists presented new results on tonalites from the IBM system. Because these tonalites share some of the major-element characteristics of mean continental crust, their presence has been taken to indicate the formation of continental crust in the IBM intra-oceanic arc. P. Kelemen, however, notes that they lack sufficient incompatible and compatible trace elements. This is further supported by the presence of a layer possessing the 6.2 km/s seismic velocity appropriate for tonalite beneath the Izu arc and possibly also beneath the Mariana arc. Meeting participants learned that some IBM tonalites formed as early as 38 Ma and as recently as 4 Ma, and as far apart as the Komahashi-Daini seamount on the Kyushu-Palau Ridge and the Tanzawa allochthons accreted to Honshu. Therefore, petrologic models need to account for widespread formation of tonalites throughout IBM arc history.

The meeting ended with a full day of small-group discussions of specific topics to identify what still needs to be done and how to do it. Brief summaries of these discussions can be found at the meeting Web site: http://www.ldeo.columbia.edu/margins/SubFac/IBM/IBM2002/IBM2002report.html. Some of the more important items are: planning for drilling in the IBM region, both on the islands and via IODP proposals (both conventional and riser ship); coordination between research groups, especially U.S. and Japanese; and how to best stimulate geologic studies on the volcanic islands, many of which are uninhabited and difficult to access.

Considerable discussion focused on critical studies that are needed to better understand the IBM subduction system, including heat-flow transects, inventories of volatile emissions from volcanoes and forearc serpentinite mud volcanoes, and better laboratory studies to link seismic observations to physical parameters, such as crustal structure and shear-wave anisotropy. In addition, one of the ancillary questions asked in the Subduction Factory Science Plan—how, why, and where are new subduction zones started—can be addressed at the IBM site, and good progress is being made to understand this process.

We recognize that special challenges and opportunities exist for advancing our understanding of the IBM arc system. Its great distance and almost entirely marine nature presents logistical obstacles for North American and European geoscientists, but the IBM arc system sits at Japan's back door. JAMSTEC welcomes proposals by foreign scientists and invites participation in joint studies.

Advancing our understanding of the IBM subduction factory through such joint studies may express the potential for a new era of international and interdisciplinary projects required for the success of the new International Ocean Drilling Project.

The NSF-IFREE-MARGINS Workshop Izu-Bonin-Mariana Subduction System was held 8–12 September 2002, in Honolulu, Hawaii.

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Potential of Airborne Geophysical Capabilities Discussed

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Antarctica is a key element in Earth's geodynamic and climatic systems. Nevertheless, on the eve of the 50th anniversary of the International Geophysical Year, we lack fundamental geologic and geophysical data from the deep interior of this vast continent. Meager exposures record the 3500-million-year history of a continent that participated in the formation and breakup of both the Rodinia and Gondwana super-continents. It continues to be tectonically active today, although its kinematic relationship to the global plate circuit and its role as substrate to the world's major ice sheets remain in question.

The early Cenozoic breakup of Gondwana resulted in a major rearrangement of the continental masses, which isolated Antarctica from mid-latitude oceanic influences by establishing the powerful circum-Antarctic current. This event was largely responsible for development of the massive west and east Antarctic ice sheets that blanket 98% of the continent and fundamentally influence world climate today. The west Antarctic ice sheet (WAIS) contains enough grounded ice to raise global sea level 5 m, if it were to melt completely, and hosts ice streams that could potentially evacuate the ice over short geologic time scales. Recent measurements show that the ice sheet is undergoing rapid and dramatic change in some regions and reveal an ice sheet-wide history of large fluctuations in extent and volume.

Although the east Antarctic ice sheet is apparently more stable, it exerts a profound influence on global climate and covers numerous sub-glacial lakes that may have existed for millions of years. Major interest lies in the age of these lakes, their tectonic history, their resident biota, and the record of Antarctic climatic history that may be contained in the sediments beneath them.

Global geodynamics was and continues to be a major influence on the formation, nature,