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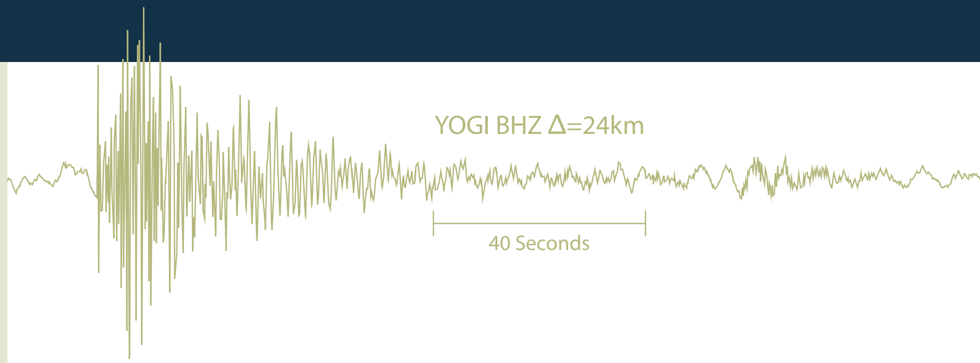

Record from a small aftershock that occurred about 7 minutes after the M_w 6.3 earthquake on May 26, 2006 in Java, Indonesia. This trace is from a new station near Yogyakarta intalled by GEOFON.

For more information, see inside back cover.

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Tsunamis and Texans

Better real-time seismic monitoring in the Caribbean is expected from the presidential initiative following the December 2004 Indian Ocean tsunami, an important goal in light of the tsunami hazard in the Virgin Islands and Puerto Rico. But residents of coastal Texas are not similarly threatened, and they are not the "Texans" that are a second theme among the articles in this issue of the Newsletter.

TSUNAMI PREPAREDNESS

The December 26, 2004, earthquake and tsunami highlighted the world's explosively growing hazard exposure. Through urbanization in vulnerable locations and inappropriate construction, each year millions more people are at risk of death or injury and economic devastation.

Even the most vulnerable populations can be partially protected from tsunamis by rapid warning systems. Sociological aspects of evacuations are beyond the expertise of seismologists, but real-time earthquake monitoring is the first step.

Seismologists around the world met their responsibility to act while they had the attention of government policy officials. The result is significant progress protecting populations around the Indian Ocean and the Caribbean Sea, and improvements to global monitoring systems. Tsunami-related articles on pages 5-11 of this issue report on several of these efforts.

"TEXAN" INSTRUMENTS

The PASSCAL inventory includes a panoply of instruments to support studies ranging from multi-year deployments of one or two dozen broadband stations to active source experiments that may be completed in weeks but involve many hundreds of recording sites.

One of the versatile elements of this inventory is the "Texan" – RT125 and 125A single-channel recorders, which were developed in a joint project between Refraction Technology and the Texas Universities Seismic Instrumentation Alliance. Optimized for use with controlled sources and short period or high frequency sensors, Texans facilitate enormous projects that would otherwise be unfeasible and small-scale experiments that might otherwise be unfundable.

Texans have been used in investigations of deep crustal and upper mantle structure motivated by fundamental geological questions, in basin studies that facilitate seismic hazard microzonation, and in shallow geophysical surveys that address environmental concerns. The three Texan experiments described in articles on pages 2, 12 and 16 offer snapshots from this panorama of applications. ■

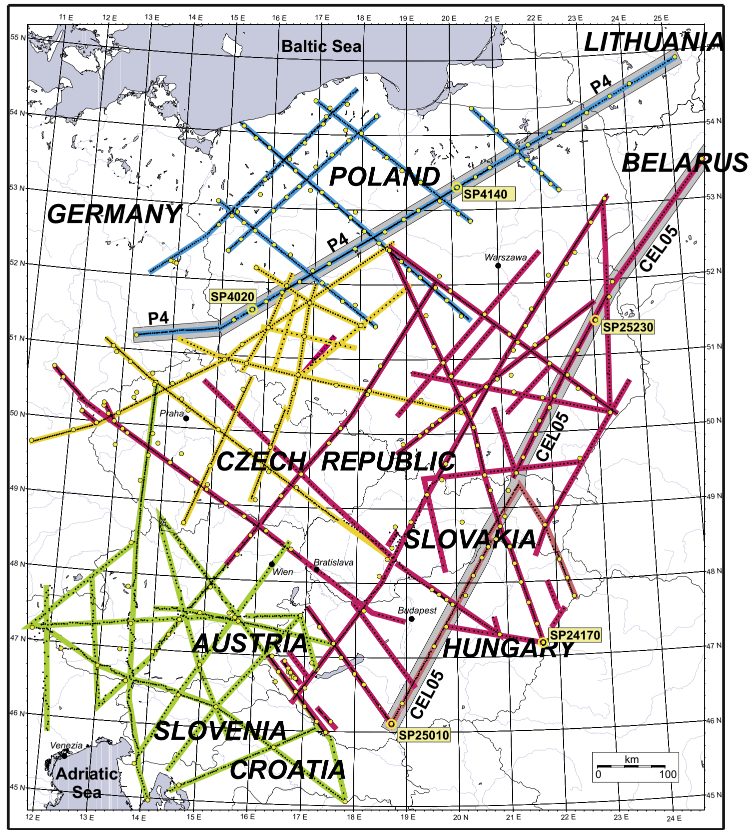
Controlled Source Experiments in Central Europe

G. Randy Keller • University of Texas at El Paso (now at the University of Oklahoma)

INTRODUCTION

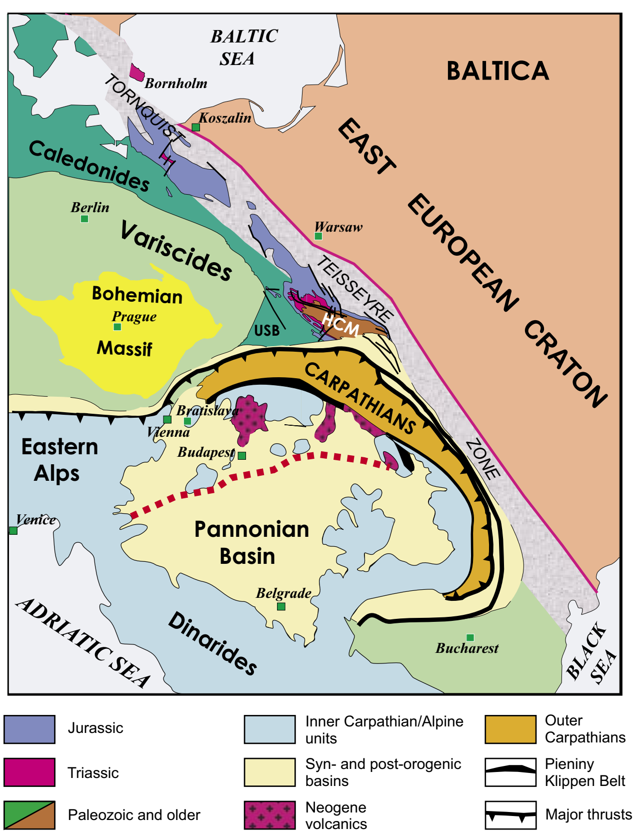
Targets for geophysical studies abound around the world, and the further back in time we look, the more important it is to consider features that are not on the same continent today. For example, geological evidence indicates that the cratonal cores of North America (Laurentia) and Europe (Baltica) were neighbors for much of their geologic history. About 1.4 billon years ago, a huge belt of anorogenic granitic magmatism swept across southern Laurentia from California to northeastern Canada, and vestiges of this event have been found in southern Baltica. This event occurred as Laurentia was growing southward by a series of Proterozoic accretionary events that primarily occurred from about 1.8 Ga to 1.6 Ga and culminated in the Grenville Orogeny at about 1.1 Ga. A similar process was at work while several Archean terranes came together to form Baltica at about 1.8 Ga. Evidence of a linkage can be found in southern Baltica where an approximately Grenville age event called the Sveconorwegian orogeny is found. In the Laurentia-Baltica region, these events were the final stages of the growth of the supercontinent Rodinia.

Rodinia did not last long before it began to break up, and by the Cambrian, rifting had formed passive margins all around Laurentia (Appalachian, Ouachita, and Cordilleran margins) and along the southern margin of Baltica (Norwegian-Baltic Sea – Central Europe region). These margins were deformed in the Paleozoic during the various stages of the formation of the Appalachian-Ouachita orogenic belt and during the corresponding Caledonian and Variscan orogenies. This orogenic activity was part of the formation of the supercontinent Pangea. Laurentia and Baltica began to drift apart again when Pangea broke up and the modern Atlantic Ocean began to form in the early Mesozoic, and they have been going their separate ways tectonically ever since. However, western North America and southern Europe have experienced extensive and complex Cenozoic tectonism with some similarities although there are no direct tectonic connections. For example, in southern Poland, several structural blocks such as the Malopolska massif (USB-HCM region) are located adjacent to Baltica and were probably transported laterally along it similar to the Cenozoic movement of terranes along the western margin of North America.



Large controlled source experiments in Central Europe targeting parts of the Trans-European Suture Zone (TESZ) and surrounding terranes.

Color	Experiment	Tectonic Target	Noted Profile
Blue	*POLONAISE '97*	Caledonide Mtns., East Euro. Craton	P4
Red	*CELEBRATION 2000*	Carpathian Mtns., Pannonian Basin	CEL05
Green	*ALP 2002*	Eastern Alps	TRANSALP
Orange	*SUDETES 2003*	Bohemian Massif	



Tectonic features Central Europe.
Red dashed line – Mid-Hungarian line;
USB – Upper Silesian block;
HCM – Holy Cross Mountains

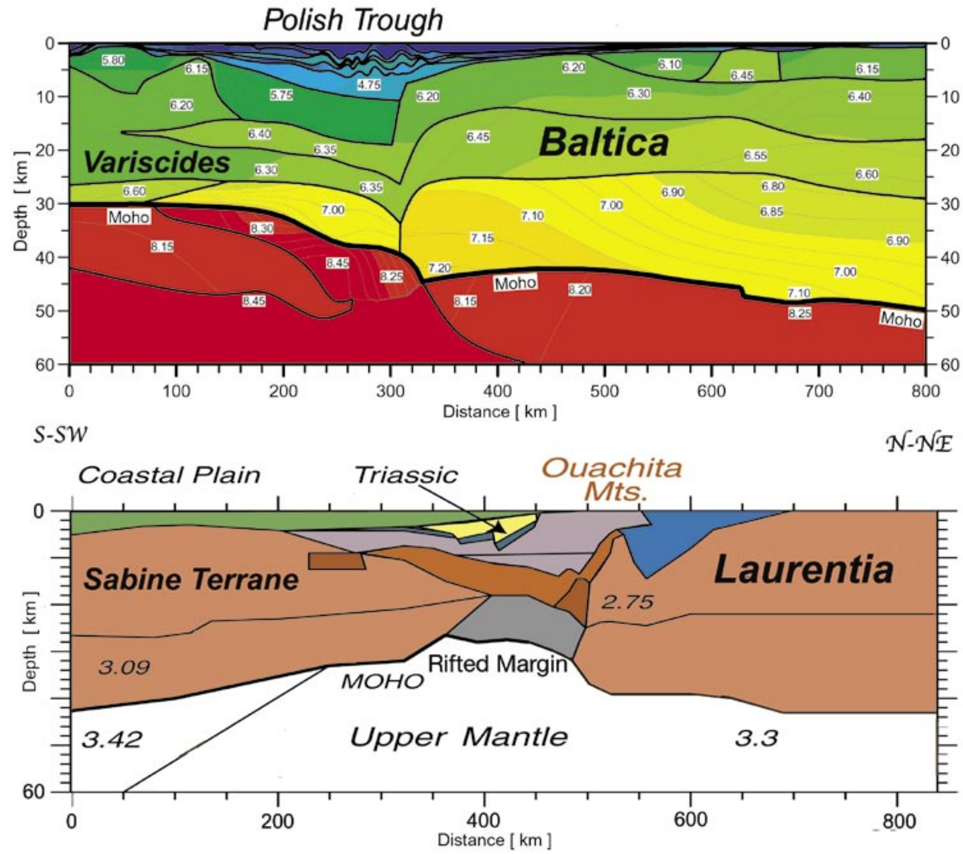
THE SEISMIC EXPERIMENTS

In order to address some of these tectonic questions, Central Europe has been the target of a series of ambitious geophysical experiments built around large deployments of PASSCAL instruments that featured the Texan recorders. The largest of these efforts was *CELEBRATION 2000* (Central European Lithospheric Experiment Based on Refraction, 2000) that targeted the structure and →

evolution of the complex collage of major tectonic features in the Trans-European Suture Zone (TESZ) region, as well as, the southwestern portion of the East European craton (southern Baltica), the Carpathian Mountains, the Pannonian basin, and the Bohemian massif. *CELEBRATION 2000* was a huge international cooperative effort that involved 28 institutions from Europe and North America and was based on the successful collaborations forged during the *POLONAISE '97* experiment.

The *ALP 2002* project followed *CELEBRATION 2000* and targeted the Eastern Alps and surrounding areas. The Alps are one of the most famous and interesting mountain belts in the world and have intrigued geoscientists for centuries. They can be thought of as the southern boundary of the relatively stable lithosphere of western and central Europe. The western and central Alps have been the target of many lithospheric-scale geophysical experiments, but such data were sparse to the east. The TRANSALP profile was the easternmost major study and passed through western Austria where the Alps are a classic collisional orogen. However, in the far eastern Alps and adjacent areas to the east and south (Carpathians, Pannonian Basin, Dinarides), the plate tectonic regime is very complex. For example, the Pannonian Basin represents an unconstrained plate margin that is extending. Although there is much debate about the details of the processes at work, the lithosphere east of the Alps was extruded laterally eastward in the Oligocene and Miocene as indicated by many types of data, including present day seismicity. Thus, a complex pattern of simultaneous extension and compression has been at work in the region for several tens of millions of years.

SUDETES 2003 was the latest in this series of experiments focused on the Bohemian massif, which is mostly located in the Czech Republic and is a large, complex terrane whose origin can be traced to northern Gondwana (Africa). The Eger graben is part of the Central European rift zone which cuts across this massif and is associated with earthquake swarms, late Cenozoic volcanism, and geochemical signatures of mantle thermal anomalies. The suture between the Bohemian Massif and Baltica is a key region in efforts to understand the interactions between the Caledonian and Variscan orogenies and the postulated lateral movements involved. The specific geologic targets of this experiment included: 1) the deep crustal structure and geodynamics of the northern part of the Bohemian Massif (the largest outcropping of the Late Paleozoic Variscan orogen in Central Europe) and 2) the Late Paleozoic through Recent history of reactivation of crustal weaknesses in the northern portion of the Bohemian Massif, namely in the Elbe zone and Eger graben regions.



Velocity model for the *POLONAISE '97* profile P4 (see map at left) and integrated seismic-gravity model of the 1986 PASSCAL *Ouachita* experiment in southwestern Arkansas and northwestern Louisiana.

In a regional sense, the main scientific targets of these experiments were primarily a better understanding of the assembly of Europe in the Middle to Late Paleozoic, delineating the structure and evolution of the features along the main suture zone associated with this assembly (the TESZ), delineating the structure and evolution of the Eastern Alps and Western Carpathian Mountains, and a better understanding of the Cenozoic extension in the Pannonian basin and Eger graben. The younger features are the result of intricate Mesozoic/Cenozoic plate interactions in the Mediterranean region as the Tethys Ocean closed during convergence of Europe and Afro-Arabia. During the Cenozoic, complex interactions among small plates caused the Carpathian arc to evolve into its strongly arcuate shape. These plate interactions have been interpreted to involve subduction of oceanic areas and produced considerable Neogene volcanism. Back arc extension was the dominant process that formed the Pannonian basin that contains up to 8 km of Neogene strata in its sub-basins. This region is still tectonically active as evidenced by seismicity that extends to depths of about 200 km in the Vrancea region north of Bucharest. The Vrancea region was the target of two other international collaborative experiments that involved major deployments of PASSCAL/UTEP Texan instruments to record both refraction and deep seismic reflection data.

THREE DIMENSIONS

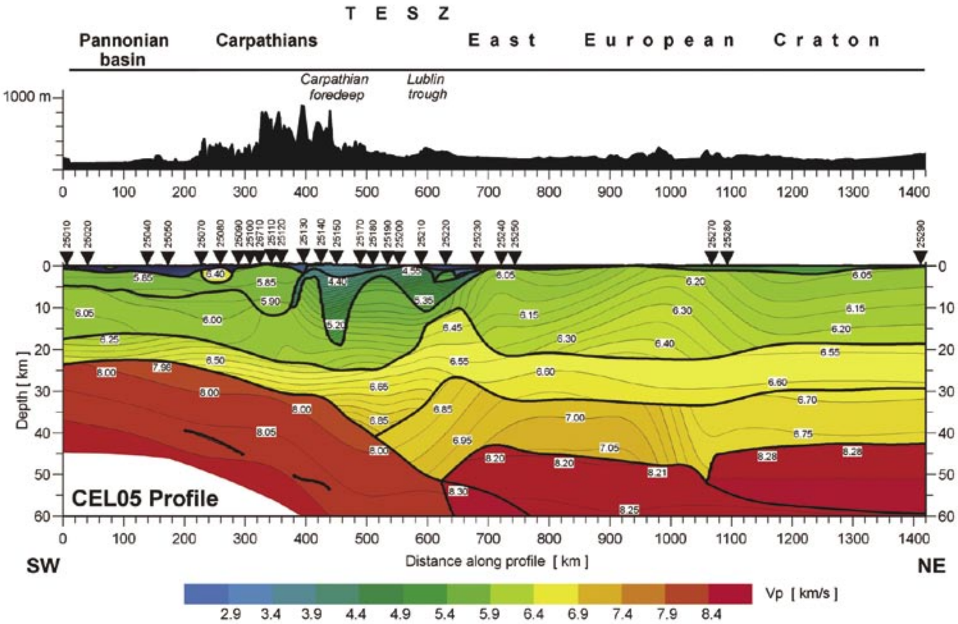
Since the lithospheric structure in the target area is very complex, the need for a 3-D approach was clear early in the planning process for these experiments. Thanks to recent advances in seismic instrumentation catalyzed by IRIS, many more instruments are available (mostly Texan recorders) so that 3-D approach could be implemented. *POLONAISE '97* →

occurred before the Texan recorders were developed, but included an element of 3-D coverage. The *CELEBRATION 2000* effort was substantially 3-D in that it consisted of three overlapping deployments of 1230 instruments forming an array that migrated southward during the experiment [*Grad et al.*, 2006]. About 800 of these instruments were Texan recorders, with 540 of these being from the PASSCAL/UTEP pool. An additional fifty 3-channel instruments from the PASSCAL pool were deployed in the Czech Republic. The moving recording array formed a network of interlocking profiles whose total length was about 8900 km and the station spacing along the profiles was 2.8 or 5.6 km. The layout of the sources and receivers provided 5400 km of traditional profile data in addition to the array. Scientific organizations in Poland, Hungary, the Czech Republic, the Slovak Republic, Austria, Russia, Belarus and Germany provided the sources in their countries. The size of the sources ranged from 90 kg to 15 metric tons and averaged about 500 kg. Some of the sources were relatively small and could not be recorded by all of the receivers, but we estimate that about 100,000 usable seismograms were obtained.

The subsequent *ALP 2002* and *SUDETES 2003* experiments relied heavily on the Texan recorders and also involved substantial 3-D coverage. The total length of all profiles made during the *POLONAISE'97, CELEBRATION 2000, ALP 2002*, and *SUDETES 2003* experiments is about 19,000 km. About 300 large explosive sources were employed and seismic recordings were made at about 7,000 sites. Densely spaced shots and receivers along the network of profiles produced high-quality data extending to long offsets that resolve seismic models of the crust and lower lithosphere.

SOME RESULTS

These experiments are the subject of many papers that have been published and that are in preparation. Here we can only highlight a couple of the more interesting results. The model derived for *POLONAISE* profile P4 [*Grad et al.*, 2003], one of the two longest profiles in all of these experiments, clearly shows the rifted margin of Baltica and the strong contrast in crustal structure between Baltica and the accreted crustal blocks to the southwest. The TESZ is characterized by a complex interfingering of layers in the model beneath the deep basin that includes the passive margin strata and about 5 km of younger strata. The similarity of this structure with the structure of the Laurentian margin across the Ouachita orogenic belt in Arkansas and Louisiana is remarkable. This latter structure was delineated by the first PASSCAL controlled source experiment in 1986 [*Keller et al.*, 1989]. In both cases, the preservation of the Early Paleozoic margin, even though a younger orogenic belt is present, indicates that the Ouachita and Variscan collisions were "soft".



Velocity model from the *CELEBRATION 2000* profile CEL05 (see map on page 2).

Further south, the structural variations from Baltica across the Carpathians into the Pannonian Basin are very different. The thin crust in the Pannonian Basin is very similar to the crustal structure of the Basin and Range. The big surprise here is the apparent northward dip in the deep structure, which is at odds with the south dipping features in the surface geology. One way to reconcile these observations is an indenter geometry in which Baltica is the rigid feature. This geometry would not exclude eastward subduction beneath Romania, but does indicate that eastward extrusion of material from the Alps was taken up primarily by transcurrent movements that were approximately parallel to the Western Carpathians.

THE FUTURE

These controlled source experiments have created a data set that will take years to completely interpret. Many young scientists have used these data in theses and dissertations, and the community of scientists that has formed based on these huge collaborations will last for years. The scientific progress achieved is substantial and high levels of integrated analysis are now underway.

We have just completed a passive source deployment across the Alps following ALP01, the westernmost long profile of *ALP 2002*. At present, another passive source deployment, *PASSEQ*, is underway that extends approximately along the P4 profile and British colleagues are deploying a passive array across the Carpathian region. Integrating these new data into our analysis will certainly provide new insights, particularly about mantle structures.

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Improving Global Earthquake and Tsunami Monitoring

"The USGS Response to a Presidential Initiative"

Dan McNamara, Lind Gee, C. Bob Hutt, Harley Benz, and Jean Weaver • US Geological Survey

The magnitude 9.0 Sumatra-Andaman Islands earthquake of December 26, 2004, increased global awareness to the destructive hazard posed by earthquakes and tsunamis and highlighted the contributions of the Global Seismographic Network (GSN) to global earthquake monitoring. With several hundred million people now living in coastal areas surrounding the Pacific and Atlantic Oceans, it is not a question of whether another destructive tsunami will occur, but when. In response to the December 2004 Indian Ocean tsunami, the United States government committed $37.5 million for a presidential initiative to upgrade earthquake and tsunami monitoring systems operated by the US Geological Survey (USGS) and National Oceanic and Atmospheric Administration (NOAA). The USGS received $13.5 million of this funding, which includes $8.1 million as part of Emergency Supplemental funding in fiscal year (FY) 2005 and a base increase of $5.4 million in FY 2006 appropriations. These funds are being used by the USGS to:

- upgrade communications at 37 GSN stations,
- expand monitoring capabilities in the Caribbean with nine new broadband stations,
- establish a 24/7 monitoring operation at the National Earthquake Information Center (NEIC), and
- study tsunami hazard in the Caribbean, Atlantic, and Gulf of Mexico.

The USGS, through the President's initiative, has committed to improvements that underlie its role and responsibility to deliver time-critical earthquake information in order to ensure rapid response to earthquakes and tsunamis. Close international cooperation will be essential to ensure success, and the USGS is working with partners such as NOAA, the National Science Foundation (NSF), IRIS, the University of California, San Diego (UCSD), the Comprehensive Test Ban Treaty Organization (CTBTO), the Air Force Technical Applications Center, the US Navy and a number of host countries. *Sipkin et al*. [2006] review upgrades to the NEIC and the Advanced National Seismic System, while the focus here is on upgrades to the GSN.

GSN COMMUNICATIONS UPGRADE

GSN data are critical to the NEIC's capabilities to detect, locate and fully characterize earthquakes around the world and contribute to USGS rapid earthquake information products. Given the importance of GSN contributions, adding or upgrading communications was identified as a priority in the Emergency Supplemental funding in order to maximize the number of stations whose data is available in real-time.

Successful GSN operation is based on many critical partnerships and the USGS efforts to upgrade and expand communications have been supported by contributions from numerous other organizations. It is anticipated that 37 GSN stations will have new or improved communication links by September 30, 2006.

In the past year, new telemetry has been installed at a total of six sites (CHTO, DAV, GRFO, KIEV, LCO, and PAB), one link has been upgraded (ADK), and the establishment of communications to FURI is anticipated soon. The USGS has made an award to the group at UCSD (which operates and maintains one-third of the GSN stations through a subaward from IRIS's NSF funding) to enhance or expand communications capabilities at five sites (SHEL, HOPE, MSEY, EFI, and RAYN).

In cooperation with NOAA, the Albuquerque Seismological Laboratory is expanding the number of stations on the GSN Pacific VSAT network. This IRIS-NOAA-USGS collaboration currently carries data from WAKE, MIDW, and RPN directly from the stations to the Pacific Tsunami Warning Center in Honolulu, Hawaii. As part of the communications upgrade, new VSATs were installed at AFI and FUNA in June and PMG and XMAS will be added in August.

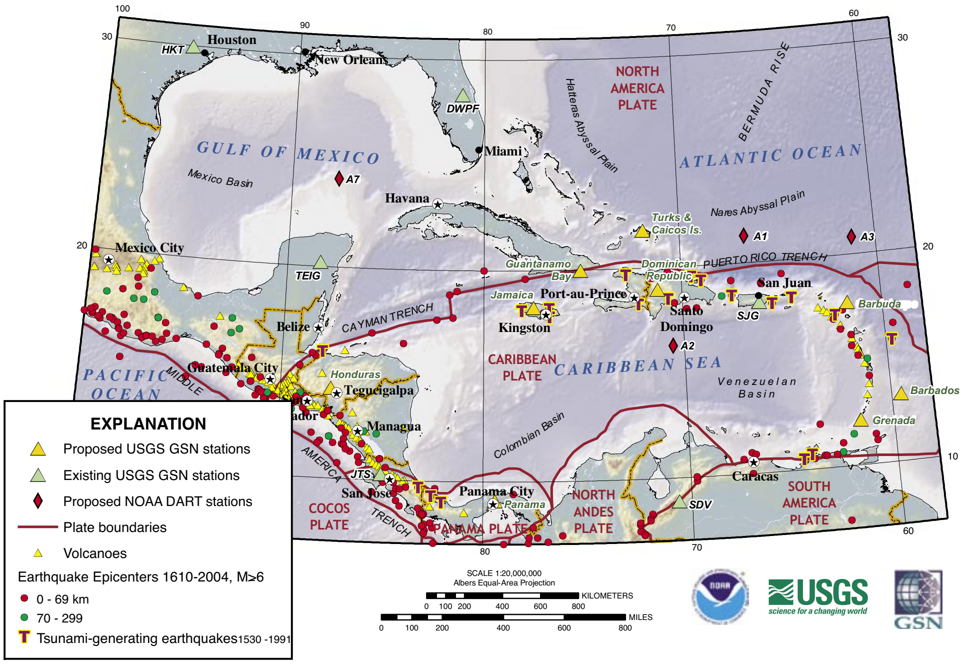
In parallel with these efforts, the CTBTO is upgrading their satellite communications links by doubling the bandwidth in the Indian Ocean, Pacific Ocean, Atlantic Ocean, and European regions of their Global Communications Infrastructure. The expanded bandwidth will be sufficient to support both the link to the International Data Center in Vienna, Austria and to the USGS and IDA data collection centers. This CTBTO upgrade will improve the communications at more than 20 GSN sites, although some maintenance work may be required to take advantage of the capabilities.

New wind generator at ADK, installed as part of the GSN telemetry upgrade. Photograph by Ted Kromer.

IMPROVED CARIBBEAN MONITORING

The second main GSN project under the President's initiative will enhance capabilities for rapid detection and notification of earthquakes in the Caribbean [*McNamara et al*., 2006]. The USGS is working with the Puerto Rico Seismic Network, the Seismological Research Unit at the University of West Indies, and eight host countries to install or upgrade seismic monitoring sites targeting earthquake source zones in the region. The nine new stations will be affiliated with the GSN and long-term operation will be conducted by the USGS in cooperation with partners from the host countries. Also as part of the initiative, NOAA is installing four Deep-ocean Assessment and Reporting of Tsunami bouys in support of a Caribbean-wide tsunami warning system.

The planned stations are located in Antigua/Barbuda, Barbados, Cuba (U.S. Naval Base at Guantanamo Bay), Dominican Republic, Jamaica, Honduras, Panama, Turks and Caicos, and Grenada. Early efforts have focused on identifying and evaluating sites for each of these stations, obtaining Memoranda of Understanding/Agreement (MOU/MOA)→



Seismicity and tectonic setting of the Caribbean region, as well as planned USGS and NOAA stations that will improve earthquake and tsunami monitoring. The seismic stations will be affiliated with the GSN. Map by A. Tarr.

and associated permits, and procuring equipment. In addition, USGS staff have worked closely with partners in host countries to identify station operators, plan data exchange, and conduct planning for both implementation and operation of these stations. Instrumentation will consist of a Quanterra Q330 digitizer, an STS-2 seismometer, Episensor accelerometers, and real-time VSAT communications, consistent with the standards of the ANSS "backbone" network. Satellite telemetry will transmit the data to NEIC, where the data will be redistributed to NOAA, the Universities of Puerto Rico and the West Indies, the IRIS Data Management Center and other agencies.

In January, Grenada became the first country to sign a MOU for the Caribbean network. The site preparation work was completed in February and the installation of the station will be completed in July. In May, a second MOU was signed between the USGS and the Smithsonian Tropical Research Institute for a station on Barro Colorado Island in Panama. In June, three additional MOUs were signed by Barbados, Honduras and the Dominican Republic. Between July and September, site infrastructure will be built and instrumentation will be installed. The USGS is currently awaiting permits or signed MOUs for the remaining sites (US Navy, Jamaica, Turks and Caicos, Antigua/Barbuda).

CONCLUSION

Working with numerous US government agencies and countries, the USGS is delivering on the President's tsunami warning initiative by establishing 24/7 seismic monitoring operations (started Jan. 9, 2006), improving seismic monitoring capabilities in the Caribbean and Central America, providing better real-time data for global monitoring research and assessment activities (funded through NEHRP and NSF), and improving understanding of historical tsunamis and their effects in the Caribbean, Atlantic, and Gulf of Mexico. ■

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Australia's Tsunami Warning System

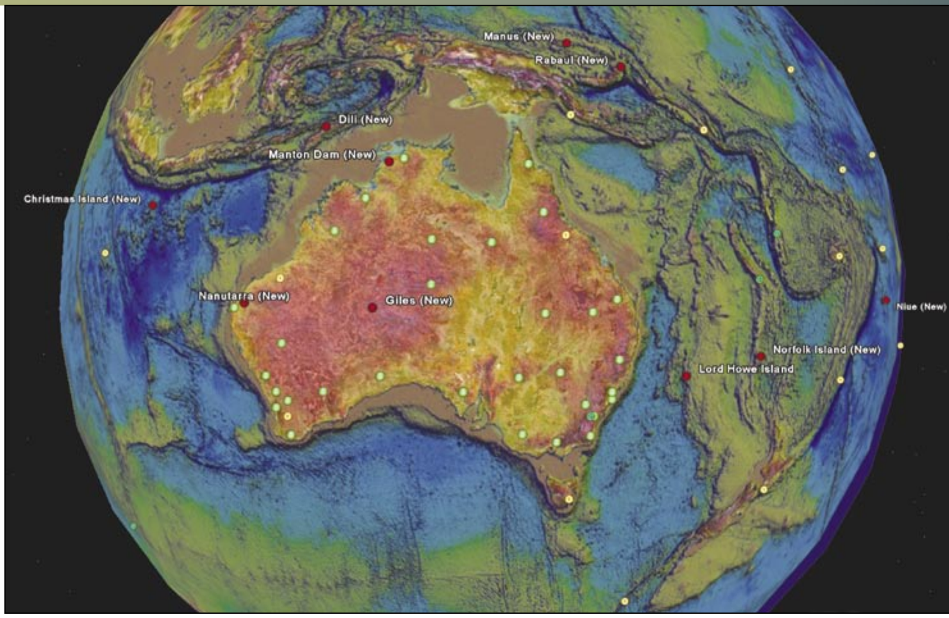
Daniel Jaksa and Spiro Spiliopoulos • Geoscience Australia

Australia is surrounded by about 8,000 km of active tectonic plate boundaries that are capable of generating megathrust earthquakes causing massive tsunamis with the potential to reach the Australian coastline within two to four hours. One third of earthquakes worldwide occur along these boundaries, a fact that reinforces the long-standing Australian scientific consensus on the need for an Indian Ocean Tsunami Warning System (IOTWS) and clearly demonstrated by the Sumatra-Andaman tsunami of December 2004.

In the May 2005 Federal Budget, the Australian Government provided $68.9 million over four years to establish a national tsunami warning system to be managed jointly by Geoscience Australia and the Australian Bureau of Meteorology. It will join the planned network of national systems which will collectively form the Indian Ocean Tsunami Warning System.

The objectives of the joint-agency Australian Tsunami Warning System project are to provide a comprehensive tsunami warning system for Australia; support international efforts to establish an Indian Ocean tsunami warning system; and contribute to the facilitation of tsunami warnings for the southwest Pacific.

This initiative will provide a 24/7 tsunami monitoring and analysis capacity for Australia, integrated into the well-established emergency management arrangements at the state and national level. The existing respective sea-level gauge and seismic monitoring networks of the Bureau of Meteorology and Geoscience Australia will be upgraded and expanded to ensure accurate and timely tsunami warnings. Support will be provided to the development of the IOTWS, including coordination and secretariat support through enhancement of the Regional Office of the Intergovernmental Oceanographic Commission in Perth. Sea level and seismic information collected by the system will also facilitate warnings in the southwest Pacific made by the Pacific Tsunami Warning Center in Hawaii. →



Regional seismic stations used in the Australian Tsunami Alert Service. Stations in red and green are new and existing Geoscience Australia seismic stations, respectively (overseas stations are jointly operated); stations in yellow are IRIS stations; stations in blue are GEOSCOPE stations.

Given the substantial international focus on the establishment of an IOTWS and the facilitation of tsunami warnings for the southwest Pacific, the Australian Department of Foreign Affairs and Trade is coordinating the program. Other agencies participating in the program are Geoscience Australia, the Bureau of Meteorology, Emergency Management Australia and the Australian Agency for International Development (AusAID).

Geoscience Australia's seismic network is being expanded with the installation of ten new stations, all using Streckeisen STS-2 broadband seismometers, Quanterra Q330HR digital data acquisition recorders and Marmot B remote field processors. Two stations will also use KS54000 borehole seismometers. The Bureau of Meteorology is also expanding and upgrading their extensive regional network of tide gauge stations and installing four DART buoys. This includes providing real-time sea level data.

Geoscience Australia now receives real-time seismic data from 108 stations around the region, about 60 more stations than Geoscience Australia previously recorded before the Australian Government announcement.

The Australian Tsunami Warning System will be fully operational from July 2009. Until that time, an interim Australian Tsunami Alert Service provides around the clock seismic monitoring of the existing network. The Australian Bureau of Meteorology is provided alerts for earthquakes over magnitude 6.5 in offshore regions posing a threat of tsunami in the Pacific, Indian and Southern Oceans.

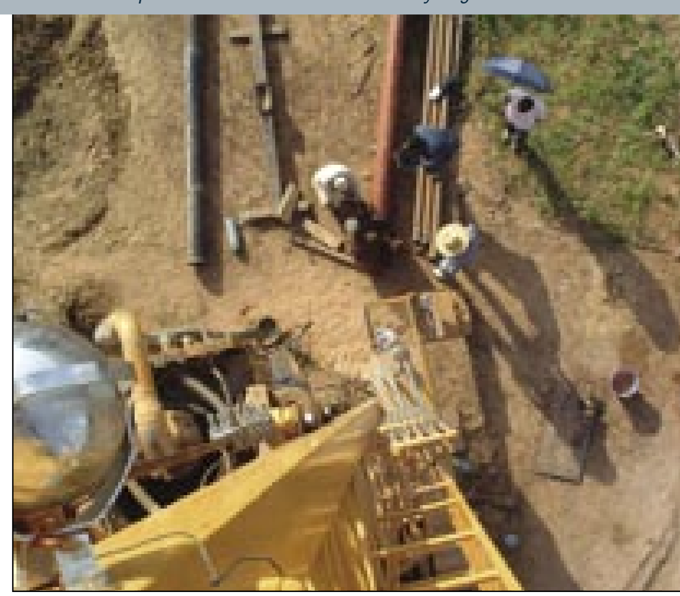
CTBTO Contribution to Tsunami Warning Efforts

S. Barrientos, L. Zerbo and G. Suárez • Provisional Technical Secretariat of the Preparatory Commission for the Comprehensive Nuclear Test Ban Treaty Organization

The Comprehensive Nuclear Test Ban Treaty (CTBT), banning nuclear test explosions in any environment, was negotiated at the Conference on Disarmament in Geneva and opened for signature in New York on September 24, 1996. As of May 2006, the Treaty has been signed by 176 countries and ratified by 132. The Treaty provides for an International Monitoring System (IMS), an International Data Centre (IDC), consultation and clarification procedures, on-site inspections and confidence-building measures. This comprehensive verification regime results from years of negotiations to ensure that non-compliance can be detected promptly.

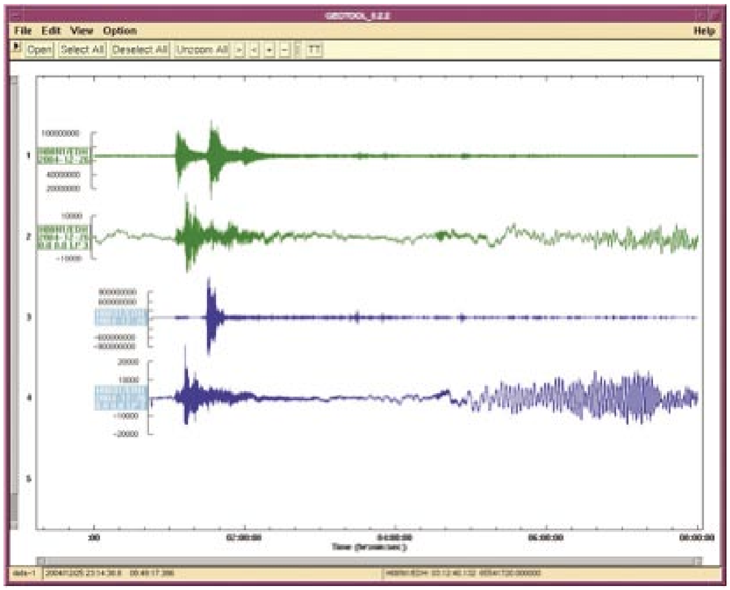
The complete IMS will include 337 facilities in four technologies: 16 radionuclide laboratories and 80 radionuclide stations as well as 60 infrasound, 11 hydroacoustic and 170 seismic stations. Of the seismic monitoring stations, 50 are primary and 120 are auxiliary, responding to requests from the IDC to better characterize events detected by the primary network. In the eight years since build-up of the IMS began, important milestones have been reached in all technologies. Nearly 70% of the stations are now installed worldwide. More than 150 stations are sending data to headquarters of the Commission in Vienna, where they are being processed, analyzed, archived, and distributed to State Signatories to support the development and testing of the verification system.

The 50 primary seismic stations and the hydroacoustic network send continuous data to the IDC to form the backbone of event detection. These two networks are designed to detect and locate events magnitude of 4 and above anywhere in the world with enough accuracy for possible on-site inspections (epicentral location errors within 1000 km^2).



Drilling a borehole in Torodi, Niger for the 16-element seismic array.

More than 70% of the primary seismic network is completed, with another 10% to be executed by the end of 2006. Data from more than 70 auxiliary stations currently contribute to IDC standard products. →



Hydroacoustic data from north and south of Diego Garcia; tsunami signals are enhanced in the filtered versions below each trace.

RESPONSE TO THE TSUNAMI

A special meeting of the CTBTO Preparatory Commission was held on March 4, 2005, in light of the tragic events of December 2004 across the Indian Ocean. At the meeting, the Provisional Technical Secretariat (PTS) of the Commission was asked to explore, together with tsunami warning organizations recognized by UNESCO, how IMS data might be used to contribute to the warning efforts of these organizations. The PTS was asked to embark on technical tests and to report back on progress.

The Intergovernmental Oceanographic Commission (IOC) of UNESCO recognized the Pacific Tsunami Warning Center (PTWC) in Hawaii and the Northwest Pacific Tsunami Information Center (NWPTIC) in Tokyo for the purpose of these tests. This is significant because these two centers have agreed to provide an interim warning service to States in the Indian Ocean region while a system for that region is being designed and implemented. Following requests, the first priority was to forward IMS data on a continuous basis to these centers. It is important to remember that authorized users in those States that are signatories to the CTBT can already receive all IMS data and products (including near-real-time continuous data) from the PTS. Indeed, it is likely that some IMS data are already contributing to disaster warning systems in this way.

In 2005, data from selected stations began to be forwarded on a test basis from the IDC to the two tsunami warning centers recognized by UNESCO. Currently, the IDC is forwarding continuous data to at least one of these centers from seven primary and twelve auxiliary seismic stations, and one hydroacoustic station.

THE FUTURE

In summary, the Preparatory Commission of the CTBTO has a unique network of monitoring stations and a state-of-the-art global satellite communications system, as well as a capability for processing, archiving and distributing IMS data and IDC products. Any future contribution to tsunami and other disaster warning systems will depend upon the decisions of the Commission in the coming months. Nevertheless, the December 2004 tsunami has highlighted an urgent need for policy decisions and technical developments in this area, especially in regard to the circumstances in which IMS data may be made available for 'civil and scientific uses'. The CTBTO looks forward to playing its role under the guidance of the Preparatory Commission. ■

GEOFON and the German Indian Ocean Tsunami Warning System

Winfried Hanka, Jörn Lauterjung and the GITEWS Team • GeoForschungsZentrum Potsdam (GFZ), Germany

The tsunami tragedy following the great Sumatra earthquake of December 26, 2004, included more than 500 German victims among the approximately 230,000 in total and it became obvious to a broader public that, in today's global village, natural disasters can affect everybody. The German human aid program for the Indian Ocean region started immediately after the disaster and included substantial funding (€45M) for the proposed German Indian ocean Tsunami Early Warning System (GITEWS). The government of Indonesia was the first to accept the German offer of providing a substantial part of their planned tsunami early warning system. Meanwhile more cooperative agreements with Sri Lanka and other countries in the region are under negotiation.

GEOFON was appointed to design and implement the land based seismic component of GITEWS, based partly on its expertise in Internet-based near real-time data acquisition [*Hanka et al.*, 2003], automatic near real-time earthquake alerts (*http://geofon.gfz-potsdam.de/new/eq_inf.html*) and virtual seismic network management [*van Eck et al.*, 2004]. The other components involved are CGPS (continuous GPS) buoys, ocean bottom units (pressure and presumably seismic broadband sensors), coastal stations (tide gauges, CGPS, strong motion sensors) and CGPS stations.


Palembang in Eastern Sumatra is typical of the swampy regions of Indonesia, which required development of a fully water tight fiber vault (on left) to overcome difficulty sealing concrete vaults.

The challenge for a tsunami warning system for Indonesia is that the tsunamigenic earthquakes happen in the Sunda →

trench subduction zone very close to the coastline of the Indonesian island chain. Only a few minutes are available, not only to detect and locate a potential tsunami generating earthquake, but also to determine as many additional parameters for the extended earthquake source capable to choose the most likely tsunami scenario from several thousands pre-calculated models. Success in tsunami early warning for Indonesia also will benefit the other Indian Ocean rim countries. Therefore international cooperation is the key, both for primary data exchange (e.g. seismic data) but also for the exchange of warning bulletins.

NETWORK AND STATION DESIGN

GITEWS station locations are based on an Indonesian proposal that includes densifying its own regional network and using data from six CTBTO stations. Locations for the international backbone network were negotiated with Germany (25 stations), Japan (NIED, 15) and China (CEA, 10). For an earthquake occurring at any point along the Sunda trench, two to five of these stations will receive the first arrivals so quickly that a first internal alert based on rough estimates for location and amplitudes of rupture start can be issued after one to two minutes. More precise values are expected after three to five minutes together with first estimates on rupture direction and fault plane parameters based then on the recordings of more than 20 stations. Each sub-network functions independently, but also feeds data into a single virtual network to be processed jointly.

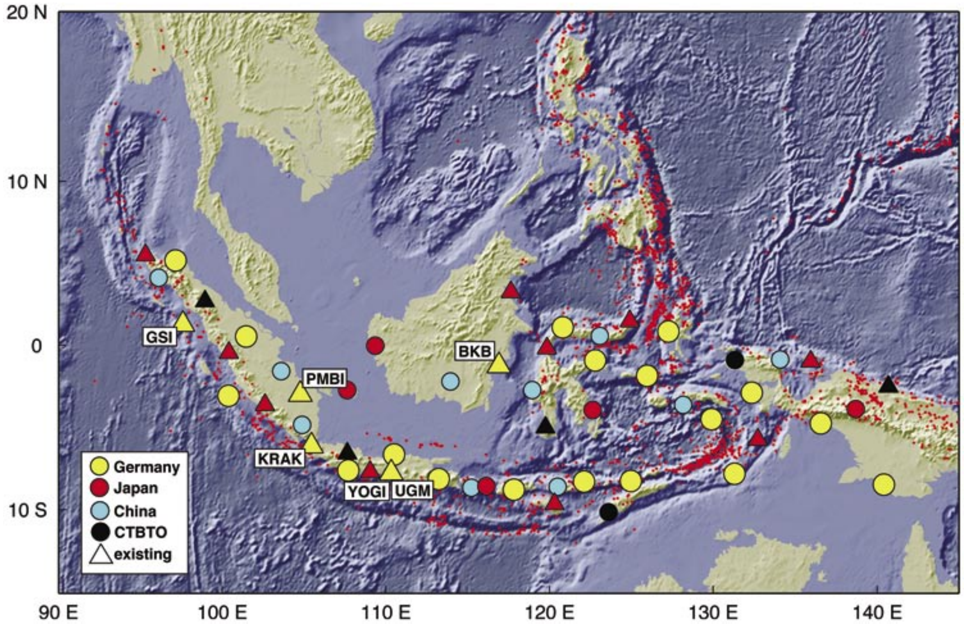
Comprehensive earthquake monitoring of the Sunda trench and the whole Indian Ocean area also requires data from far regional and teleseismic distances. Open real-time data are presently available from Australia, Malaysia and Singapore, the GSN and GEOSCOPE. Comprehensive cooperation has been agreed with Australia and South Africa, and direct data exchange with Malaysia and Singapore is arranged. Plans include two new stations and a seismic control center in Sri Lanka, and additional stations may be possible in the Maldives, Madagascar, and East Africa. A fully redundant VSAT system is envisaged with the main hub in Jakarta and a backup in Darwin. South Africa can also help to provide regional gateway functionality.

Besides the optimum recording of the full seismic spectrum relevant both for early warning and seismological research, the main station design goal is high reliability and minimum maintenance. The main VBB seismometer is an STS-2 with additional shielding, proved to increase the VLP performance significantly at previous GEOFON stations. A strong motion sensor is also attached to a six channel Q330HR. About half of the seismic stations will be co-located with real-time GPS. To protect against humidity, swampy conditions, frequent floods and vermin, the station equipment will be buried in specially designed two-chamber water- and air-tight fiber vaults with a steel-bottom construction providing optimum attachment to a bed of concrete.

Comprehensive software is being developed to provide full functionality, such as operator process and state-of-health visualization and interaction, and sophisticated tools for regional and teleseismic analysis. The system will provide optimum reliability and redundancy including possibilities for advanced distributed real-time data processing, avoiding the necessity to bring all data streams in real-time to one place.

PROGRESS ALREADY

Already in 2005, GEOFON stations have been installed in Indonesia at four BMG (Meterological and Geophysical Service of Indonesia) sites with existing VSAT links on Nias, Sumatra, Java and Kalimantan, two of them with CGPS. Also, two tsunami test buoys with broadband OBS were deployed offshore Sumatra. After installation of a VSAT system in June 2006, completion of the seismic network in Indonesia and Sri Lanka is planned within two years. On the eastern side of the Indian Ocean area, a communication concept must be developed first before stations can be sited. Already since June 2005 a copy of the GEOFON automatic near real-time earthquake information system was installed at BMG as a provisional automatic alert system. It was using at first only external stations imported via Internet but the different partners have already installed 28 real-time stations in Indonesia, cutting the alert times for earthquakes in Indonesia to four to seven minutes. ■



The GEOFON/GITEWS network and real-time broadband seismic stations from Japan (NIED), China (CEA) and CTBTO are integrated into a joint virtual network.

ACKNOWLEDGEMENTS

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Tsunami Warning System Training in Sri Lanka

Pete Davis • University of California, San Diego

The 2004 Sumatra-Andaman Islands earthquake and tsunami took the lives of more than one-quarter million persons worldwide and left another million homeless. Following this disaster, scientific and technical aid agencies from many nations have been working with local governments to develop a tsunami warning system as well as the capacity for local and regional organizations to operate and maintain their associated technical infrastructure. One organization playing a role in this important task is IRIS and, as a result, I recently had the privilege of participating in a training course on seismology and tsunami preparedness in Sri Lanka.

During the first week of April, UNESCO/IOC, US AID and the USGS sponsored a technical training session held in Colombo, Sri Lanka, to brief local professionals on key seismological issues related to developing a tsunami warning system. Twenty geologists and engineers from the Sri Lankan Geological Survey and Mines Bureau (GSMB), universities throughout the country and government emergency response agencies took part in the five-day session. The group included the two IRIS/IDA station operators, Saman Perera and Nalin de Silva, who took a particular interest in the proceedings. While the staff of the GSMB includes many trained geoscientists, they have no specialists in seismology – not surprising, given the low level of seismicity on the island. Because of the 2004 earthquake's horrific impact, however, the staffing needs of the agency are being re-evaluated.

Course organizers Laura Kong of the IOC International Tsunami Information Center, Honolulu, and Walter Mooney of the USGS, Menlo Park, pulled together an international team of instructors that included me, Jim Mori of Kyoto University, J. R. Kayal of the Geological Survey of India, and Annabel Kelly of the USGS. Each of us shared the tasks of briefing the group and of coaching the participants as they completed several laboratory exercises.

Pete Davis (center) with GSN station operators Nalin de Silva (left) and Saman Perera (right).

Presentations included the tectonic setting of Sri Lanka, the history and theory of seismology, interpretation of seismograms, earthquake hazard, modern seismic instrumentation, and networks and arrays. The final day's session focused on theory of tsunamis and response to their effects. Computers were available to aid instruction and a number of programs familiar to IRIS members, including EqLocate, Seismic/Eruption and Seismic Waves, were used to help the class members familiarize themselves with interpreting seismic data. This proved to be the most popular part of the course by far! The students thoroughly enjoyed examining recordings of real earthquakes and identifying various wave arrivals using information provided to them during the theory lectures. I recall with pleasure how their eyes lit up and smiles broadened when they realized how it really was possible to sort out Love and Rayleigh waves on suitably rotated traces.

Annabel Kelly (standing) and Laura Kong (seated) address the group.

Following the final instructional session, the participants were asked to reflect upon how useful they found the content and the teaching methods and to what extent the new information/tools would be applicable in their daily work. The consensus on the course's utility was quite clear: while they had learned much about seismology and earthquake hazards, they also recognized they had far to go before they knew enough to be able to operate their own warning system. They asked us many questions about the kinds of seismic analysis software packages publicly available and how adaptable these are to their specific needs.

During the concluding ceremony, Mr. Sarath Weerawarnakula, Director of the GSMB, thanked the participants and emphasized for everyone the importance of the work yet to be done before a warning system is operational. A follow-up conference in Sri Lanka is planned for 2007 and similar courses will be taught elsewhere.

The opportunity to use my professional skills to assist those so profoundly affected by the 2004 tsunami was particularly rewarding. Like many other people, I contributed money to aid organizations helping survivors of that disaster, but I believe that the best long-term assistance we can give is through education and preparation for future events. While several IDA engineers have traveled to Sri Lanka to install and maintain the GSN station, this was the first time I had ever visited the region. Meeting the station operators and members of the GSMB administration, as well as inspecting the station firsthand, helped me to appreciate the local context of our station. Likewise, we help ensure local interest in effective operation of the station by providing this additional training for our operators and by assisting the GSMB to integrate GSN data flow into their future warning system. Lastly, it was a great pleasure to meet so many interesting and hospitable people and to tour a part of this beautiful land, if only for a brief time.

Tsunami Warning System Training in Indonesia

Bruce Beaudoin • New Mexico Tech

Masahiro Yamamoto (top center) watches BMG students participate in a hands-on exercise picking travel times and locating earthquakes.

I had the privilege to participate as an instructor at the Indonesia Training Program in Seismology and Tsunami Warnings recently held in Jakarta, Indonesia. The course was co-sponsored by the Indonesia Bureau for Meteorology and Geophysics (BMG), the Intergovernmental Oceanographic Commission (IOC), the U.S. Geological Survey (USGS), and the U.S. Agency for International Development (USAID). Laura Kong (IOC) and Walter Mooney (USGS) organized the training course. My task was to teach a three-day course on portable broadband seismology. I definitely had the resources to accomplish this task. It was just a question of time. As typical, the week prior to my departure was hectic. In part, this was due to the extracurricular nature of this project and, in part, it was due to collating and developing this course for the first time.

GETTING ORIENTED IN JAKARTA

I arrived at the Soekarno-Hatta Jakarta International Airport (named after Indonesia's first president and vice-president) early on the morning of May 9 and my host, Dr. Fauzi, was there with warm greetings. After our friendly introductions, he proceeded to inform me that the equipment I was intending to use for my training course was stuck in customs. As tired as I was from traveling for the last 24 hours, I realized that this was not ideal. So much for door-to-door service and shipper's promises (I picture a chorus of nodding PASSCAL user's heads). Fortunately, my Indonesian colleagues were tenacious and experienced with Indonesian customs; BMG staff secured release of the equipment by the end of my first day of training.

The afternoon of the 9th I arrived at the training center. I was surprised to see that the size of the class had grown from the expected 20 students to close to 50. I spent the rest of my afternoon running various training scenarios though my head. I brought four dataloggers with the intent that five students per datalogger was reasonable, but 12 each would be a challenge.

A REWARDING EXPERIENCE

The instrument training was structured similar to a PASSCAL training session. The first day consisted of a series of lectures covering: an introduction to IRIS; the functions of an instrument center; an overview of dataloggers; an overview of broadband seismometers; communications options; power requirements and systems; and siting and vault design. Day two covered common sensor problems and a practical session on setting up and programming a datalogger. Day three was a mock service run with data offload and an introduction to the tools available for performing basic quality control.

The students were enthusiastic and sincere, and were the reason for this course being one of my most satisfying teaching experiences. They were engaged and tolerated my propensity for speaking quickly as evidenced by the questions posed. The students' excitement was most evident with the hands-on exercises. Despite the large student to instrument ratio, the students exhibited a level of cooperation I had not expected. They continually swapped roles so that by the end of the day, I believe all 50 students had a chance to have hands-on experience with the equipment.

Bruce Beaudoin (right) demonstrates how to program a datalogger.

I thoroughly enjoyed working with the staff of BMG and look forward to fostering these new acquaintances into future collaborations and friendships. I have already established dialog with several students who have requested more information on topics ranging from VSAT communications to SEED channel naming conventions. I especially value my association with Dr. Fauzi. His selfless effort to ensure that our equipment cleared customs was pivotal to the success of my training session. Dr. Fauzi has expressed interest in repeating the instrument training next year and I hope that once again I have the opportunity to interact with the dedicated staff of BMG. ■

Peace and Science in the Middle East

Uri ten Brink • U.S. Geological Survey, Woods Hole Science Center; Abdallah Al-Zoubi • Al-Balqa' Applied University; Steven Harder • University of Texas at El Paso; Yair Rotstein • Geophysical Institute of Israel (now at U.S.-Israel Binational Foundation); Isam Qabbani • Natural Resources Authority; G. Randy Keller • University of Texas at El Paso (now at the University of Oklahoma)

The ancient cultures of the Middle East and the modern political conflicts there are shaped by a surprisingly diverse and youthful landscape. The landscape of the region is dominated by the rift valley, a 20-30 km wide valley, much of it below sea level. It is sunken between the western highlands of Israel and the Palestinian Territories and the eastern highlands of Jordan. The topographic barriers were significant enough to help create different kingdoms and cultures, yet not significant enough to prevent interaction among these cultures through commerce and war. The north-south oriented rift valley was also an important migration route for early humans, and is still a migration route for fauna, particularly birds from Africa to Eurasia.

What caused this landscape of a rift valley and the uplifted shoulders? The Dead Sea rift is a strike-slip fault, or a continental transform, that offsets the Arabian plate against the African plate. Other continental transforms, such as the San Andreas and the Northern Anatolian faults, do not exhibit a rift-like morphology. Therefore, some other forces or processes must be active here in addition to the lateral displacement of two plates. These processes could include transtensional motion along the fault, sub-lithospheric mantle flow extending northward from the Red Sea, or flexural uplift resulting from a break of a pre-stressed continental lithosphere, or transtensional motion along the fault.

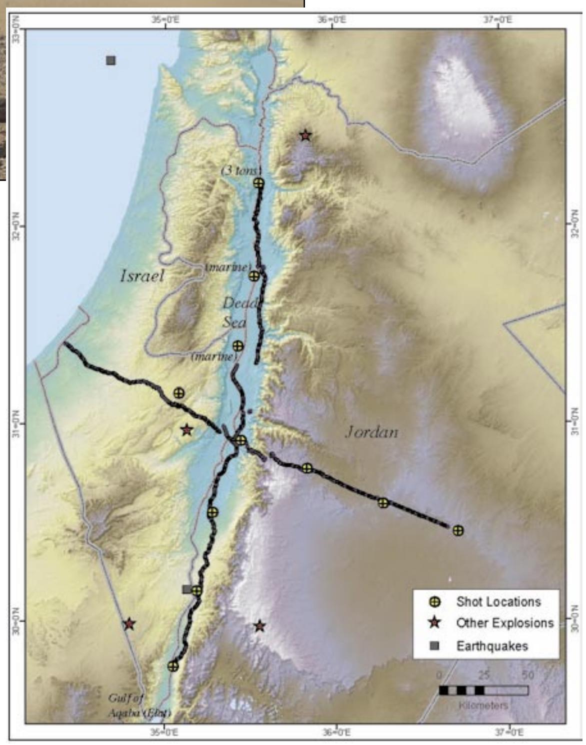
The rift geology has been studied in detail for almost a century, but the answer to this question is still elusive. Regional subsurface studies have been hampered by the political situation in the region. The peace treaty between Jordan and Israel, and the Oslo agreement between Israel and the Palestinians opened the door for scientists to cooperate on regional projects, although the security situation and the occasional conflicts still pose substantial hurdles. As part of a USAID-funded project, a plan to collect high-resolution seismic reflection profiles across the Dead Sea fault systemwas developed, but was not carried out after months of preparations because of security concerns.

THE PASSCAL EXPERIMENT

A new plan was devised and executed within four months that included using explosives instead of vibrator trucks as acoustic sources, and stand-alone seismometers instead of the Geophysical Institute of Israel's (GII) cabled multichannel seismic acquisition system. The University of Texas at El Paso (UTEP), and IRIS provided 755 seismometers, seismic recorders, and support staff on short notice. Permits were obtained to deploy seismometers along the Jordan River, a closed military zone, and within the property of the Arab Potash Company, and to transport and detonate 16.5 metric tons of explosives, in some cases in closed military zones. Commercial companies in Jordan and Israel were contracted to carry out the drilling, loading, and the detonation of the explosives.

The experiment, which took place in October 2004, consisted of two wide-angle seismic reflection and refraction profiles: a 280-km long profile along the international border between Jordan, Israel and the Palestinian Territories at the center of the Dead Sea rift, and a 250-km long profile from Gaza Strip to eastern Jordan across the Dead Sea rift. Eleven large underground explosions were detonated including a 3-ton explosion that was detonated at the bottom of a 35-meter hole in the Jordan Valley and two 750-kg explosions, each suspended at a depth of 50 meters below buoys in the Dead Sea. The 3-ton explosion was part of a US Department of Energy grant to Dr. Yefim Gitterman of GII. The marine explo- →

The lower Jordan River Valley about 10 km north of the Dead Sea. The brush-covered area is the actual river valley, which is incised within the 20-30 km wide rift valley. The western highlands rise in the background.



(left) Two vehicles mark the location of shotpoint 3, 50 km south of the intersection of the two profiles shown below. (below) Seismic refraction experiment location map. Black dots are seismometer locations. The various sources used in the experiment are identified in the legend.

sions were recorded on the permanent GII seismic network as the equivalent of earthquakes with local magnitude of 3.2 and 3.0. The study was augmented in 2005 by a survey of the gravity and magnetic fields along the seismic lines.

Miniature stand-alone seismic recorders (Texans) attached to single vertical 4.5 Hz geophones recorded the acoustic signal. Both the geophones and the recorders were buried a few inches below the surface to improve the signal quality and to prevent vandalism. The instruments were sent to the Middle East, (169 to Israel, and 598 to Jordan), and were deployed in the field, generally at distance intervals of 650 m with occasional larger intervals. At total of 409 instruments were deployed along a north-south line within the rift valley in Jordan and the remaining 334 instruments were deployed along an east-west line crossing the rift at the south-central part of the Dead Sea basin.

Instruments could not be left in the field for more than a week because of limited battery power. Eight teams worked simultaneously to speed the deployment and collection of this large number of instruments. Each team consisted of two people, and occasionally a soldier. Deployment lasted one to two days and the collection took another day. Local Bedouin guards were hired in a few places to prevent theft and vandalism. Nevertheless, five instruments were lost and four could not be found. Jackals carried one instrument into a minefield where it remains today because it is too dangerous to retrieve. Jackals also pulled up geophones of several other instruments, but only a handful of recorders had electronic problems.

For security reasons, all 11 explosions were detonated during daylight hours. Jordanian boreholes also had to be shot on the same day they were loaded, while Israeli boreholes could be loaded a day or two in advance. All 11 shots were detonated in two consecutive days making for a tight schedule. Time windows for shots were assigned to the Israeli and Jordanian shooting teams. Additionally, natural earthquakes and commercial mining explosions were recorded during this time period. The entire dataset of explosions, earthquakes, and mine shots is being used to obtain 2-D models of P-wave velocity along and across the Dead Sea rift, as well as 3-D tomographic images of the sediment and crust of the area.

INITIAL RESULTS

First results from the seismic profile across the rift show the Dead Sea basin fill to extend to between 6.5 and 8 km depth, with a low P-wave velocity (5.4-6.3 km/s) under the basin extending to 17 km depth, which may include pre-rift sediments and upper crustal rocks. However, there is no effect of either the basin or the plate boundary on the crustal structure between 17 and 30 km depth. As expected, there is significant difference in the structure of the upper crust between the east and west shoulders of the rift. Shallow P-wave velocity within 20 km east of the rift is high because uplift and erosion have brought crystalline basement close to the surface. Interestingly, the deformation involved with the uplift of the rift shoulders may not extend deeper than 15 km or farther than 100 km from the rift. These results may indicate a stratified rheology of the continental crust and may be significant in understanding lower crustal deformation in strike-slip regimes. ■

ACKNOWLEDGEMENTS

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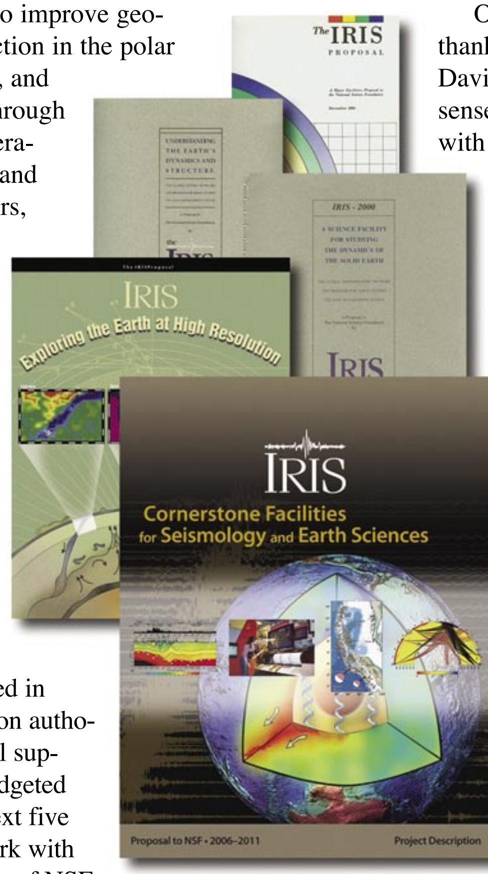
National Science Board Authorizes IRIS Funding

The wait is over! In response to a proposal from IRIS last summer, on May 10 the National Science Board (NSB) authorized the NSF Director to make an award for renewed support of IRIS's facilities and programs. The proposal received excellent rankings from mail reviewers and was endorsed by a Special Emphasis Panel and the EAR Instrumentation and Facility Panel, each of which inspected an IRIS facility during the fall. In January the IRIS Board of Directors responded to written questions that arose in the course of the reviews, and over the ensuing months I&F Program Director David Lambert worked with other NSF staff members to prepare the award materials.

The NSB reviewed the proposal because funding anticipated under the cooperative agreement exceeds 1% of the total budget for NSF's Geosciences Directorate. Materials prepared by David Lambert and IRIS are reported to have helped NSF Assistant Director Margaret Leinen "set a new standard" in excellence of presentations to the Board.

The award is expected to be made as a new Cooperative Agreement that will run from July 2006 to June 2011. IRIS plans to continue operating its Education and Outreach Program, the Data Management System, the PASSCAL experiment support program and, in cooperation with the USGS, the Global Seismographic Network. Seeking to improve geophysical data collection in the polar regions, the oceans, and around the world through ever-stronger cooperation with domestic and international partners, IRIS will pursue innovation within and cutting across all of the four programs.



As with past awards, the NSB recognized strong scientific justification for more activities than NSF's Earth Sciences Division may be able to support, and included in their recommendation authorization for potential support beyond that budgeted by EAR over the next five years. EAR will work with IRIS, other divisions of NSF, and other government agencies to identify possible funding sources for some of the other ambitious ideas from the IRIS community to facilitate geophysical research.

Offering his personal thanks, IRIS President David Simpson said "The sense of renewal that comes with an intense review of our activities makes the enormous effort worthwhile. All of us can be very proud of the facilities that we have created and the respect that they receive. A significant factor in the success of the proposal was the evidence of the use of IRIS facilities provided by contributions from scientists describing their research based on IRIS resources and data." The proposal and an accompanying volume of research accomplishments are available at: *www.iris.edu/about/publications.htm* ■

Long-Term Instrument Loans

In June IRIS announced "long term loans" of instruments that are suitable for permanent geophysical observatories. The instrument loans are intended to advance IRIS's mission of facilitating cooperation among seismologists and fostering free and open exchange of seismological data.

Examples of projects that are consistent with these goals include:

Create a Regional Capacity-Building Project: The AfricaArray project shows that a broad consortium of US universities, foreign educational institutions, and government mission agencies can achieve educational and other goals that extend beyond scientific research. IRIS could promise instruments to even a nascent consortium, to help it leverage other long-term funding commitments.

Establish an Earthquake Alert System: In the aftermath of major disasters affecting developing countries, such as the tsunami that resulted from the 2004 Sumatra-Andaman earthquake, wealthy national governments sometimes promise high levels of funding to support recovery and prepare for a similar event in the future. IRIS instruments could help a newly established system exchange data→

INSTRUMENT LOAN GOALS

- Help densify global coverage of stations offering free and open data access by complementing other efforts to expand or establish permanent broadband seismic networks.
- Advance partnerships and encourage IRIS Affiliates to adopt standards and policies that support free and open data exchange.
- Advance Earth sciences in regions that would benefit from the introduction of digital broadband instrumentation.
- Foster capacity building by making loans to institutions with a technical capability to operate instruments independently and an intention to educate students.

and integrate more effectively with other geophysical monitoring networks.

Expand an Existing Monitoring Network: Occasionally a state or national government may recognize that an existing geophysical monitoring network may not be dense enough or cover a large enough area to completely characterize a hazard. IRIS could promise to indefinitely loan instruments as one element of a broader plan to acquire all of the required equipment.

The first instruments that IRIS is making available are PASSCAL data loggers that have been superseded by a new generation of instruments. Although cumulative wear and tear has made these instruments unsuitable for repeated shipment and use in short-term experiments, IRIS is having a selected set of them refurbished by the manufacturer to perform in conformance with original specifications. IRIS Member and Affiliate Institutions interested in borrowing instruments can find information about submitting an instrument loan application at: *www.iris.edu/instrumentloan/*

USArray Receives Plaudits from EFEC

The USArray project was highly praised for its accomplishments by the EarthScope Facility Executive Committee (EFEC) and the National Science Foundation (NSF) following the annual USArray site review held on May 17, 2006. The EFEC and NSF were extremely pleased with the solid progress being made in each of the USArray's components, especially impressed by the quality and dedication of the senior staff assigned to the project, and very satisfied with USArray's improved and effective implementation of the Earned Value Management (EVM) process and other EarthScope management tools.

The site review was held in Socorro, New Mexico, at IRIS' PASSCAL/USArray facility. More than 30 representatives from the EarthScope Office and each of the EarthScope projects, the NSF, and the USArray Advisory Committee were in attendance for the USArray presentation. During the morning briefing, the USArray Project Managers provided an in-depth overview of the major USArray elements, including the Transportable Array, the Flexible Array, the Permanent Array, Magnetotellurics, and Data Management. The respective Project Managers addressed the current status of their USArray component in terms of progress, schedule, and budget; identified issues of concern; and responded to questions raised by the EFEC and NSF. The presentation (as a PDF file) can be downloaded at: *www.iris.edu/USArray/EFEC_Overview.pdf*

Following the briefing, participants toured the IRIS Instrument Center and Warehouse on the campus of New Mexico Institute of Mining and Technology. USArray and IRIS staff provided a detailed explanation of the computerized and barcoded inventory system used to track USArray equipment and components throughout their lifetime – from the time an item is received in the warehouse, to the time it is shipped to the field, to the time it is returned back to the warehouse. The tour also included visits to the facility areas where sensors and other equipment are bench-tested and repaired. Of particular interest to the attendees was a display in the building lobby of a full-size model of a Transportable Array station. Other displays included a real-time feed of Transportable Array data being received at the Array Network Facility and posters of Siting Outreach activities.

The EFEC endorsed several initiatives suggested by the scientific community and being considered by USArray, EarthScope, and NSF. USArray was encouraged to work with regional networks to both enhance the networks' capabilities and to leave a scientifically valuable legacy of the Transportable Array. The EFEC also requested USArray to develop a plan and evaluate the use of Transportable Array stations to achieve uniform coverage in the backbone reference network, including any cost and schedule impacts this action would have on construction of the facility and on the O&M phase.

The EFEC is composed of the EarthScope Project Director and EFEC Chair, Gregory E. van der Vink, and a Principal Investigator and Representative from each of the three EarthScope projects. For the Plate Boundary Observatory, the Principal Investigator and Representative are Eric Calais and William Prescott, respectively. Mark Zoback and Stephen Hickman serve as the Principal Investigator and Representative for SAFOD. The USArray Principal Investigator and Representative are David Simpson and Thorne Lay; however, because of their roles, they do not participate in the assessment of the USArray project. The NSF was represented by Kaye Shedlock, Program Director for EarthScope, James Whitcomb, Head of the Deep Earth Processes Section, and Mark Coles, Deputy Director for Large Facility Projects.

Earthquake Hazard Investigations in the Las Vegas Valley

Catherine M. Snelson • University of Nevada, Las Vegas

Faculty members and students at the University of Nevada, Las Vegas have conducted a variety of seismic experiments in the Las Vegas Valley over the past several years, motivated partly by the pressing need for further research on local earthquake hazard. In addition, however, our experiments have led us to fundamental discoveries about the processes that developed the current tectonic setting in southern Nevada, which is why our "Earthquakes in Southern Nevada" project includes a structural geologist (Wanda Taylor) as well as a seismologist (Catherine Snelson), a geotechnical engineer (Barbara Luke) and a structural engineer (Ron Sack).

Southern Nevada has undergone a significant amount of extension that continues today, resulting in a series of normal faults as well as strike-slip faults, such as the Las Vegas Valley Shear zone, that cut across the region and that have contributed greatly to the formation of the Las Vegas Valley. Gravity and seismic reflection data suggest that the Las Vegas basin is 4 to 5 km deep, but many faults in the basin lack surface expression, so some may yet to be identified. Indeed, we have not yet resolved the evolution of several prominent features, such as Hidden Valley, which is bounded on all sides by volcanic rock of the relatively unextended central and northern McCullough Mountains.

SOURCES OF SEISMIC ACTIVITY IN THE LAS VEGAS REGION

Well-located earthquakes in the Las Vegas Valley are infrequent and diffusely distributed, suggesting a low seismic hazard. But this conclusion is provisional, at best, because the region has not been consistently monitored and there have been only a few paleoseismic studies. Recently *Slemmons et al.,* [2001] reclassified at least eight major faults in the immediate area of Las Vegas, three of them in the central portion of the city, and concluded that they could generate earthquakes with moment magnitudes of 5 to 7. Las Vegas is a city of nearly 1.5 million people that overlies a deep basin that has been shown to have varying amplification factors. Although several regional earthquakes have shaken Las Vegas over the past 15 years, many residents are unaware of their vulnerability.

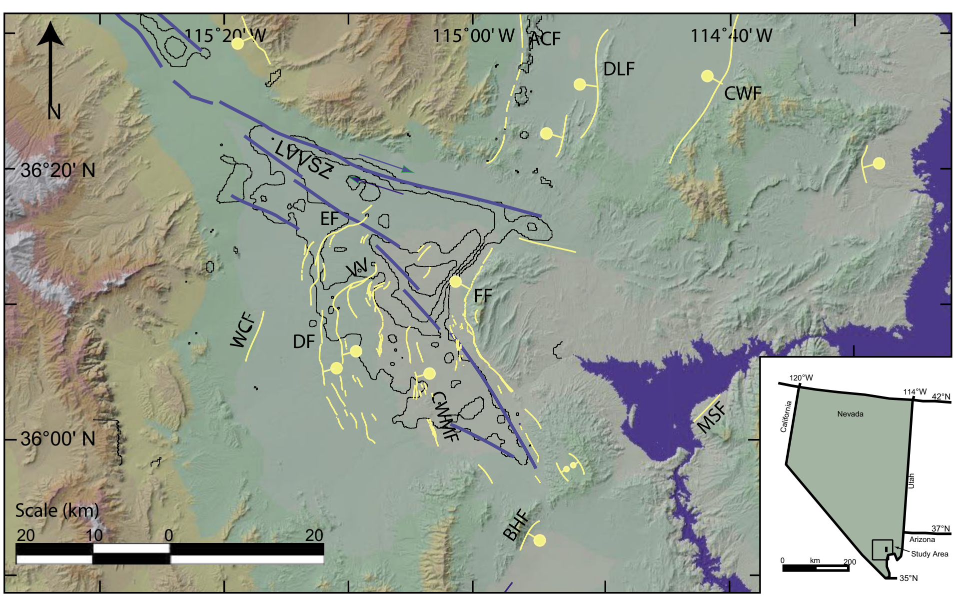
Smith et al., [2001] summarize the macroseismic observations of southern Nevada, including recent small events, such as a M_W 3.8 near Red Rocks, NV in March, 2001, which was felt widely throughout the Valley, and historic earthquakes with magnitudes near 5 during the mid-1900's near Boulder City. There is risk of ground shaking in the Las Vegas basin from distant earthquakes in western and northern Nevada, southern California, and western Utah, as well as potential strong ground motion from testing at the Nevada Test Site (NTS). Historic earthquakes from western and northern Nevada and western Utah ranging from magnitude 5 to 6 were felt widely throughout the basin in 1902, 1916, and 1966. More recently, the 1992 Landers earthquake (M_W 7.3) and the 1999 Hector Mine earthquake (M_W 7.1), which is over 200 km away, were felt strongly all across the Valley. A major concern is a large earthquake in Death Valley, only about 150 km away.

RECENT SEISMIC EXPERIMENTS

Much of our work to study the Las Vegas Valley started in 2002 in collaboration with Lawrence Livermore National Lab (LLNL) under the Test Site Readiness program. The University of Nevada, Las Vegas (UNLV) along with the University of Texas at El Paso deployed "Texans" across the Valley and used quarry blasts as sources in May 2002. We wanted to develop a general velocity model across the Valley, but the small sources at the quarries did not allow us to obtain as detailed an image as we had hoped.

In September 2002, we recorded a conventional blast (Watusi) from the NTS using 400 Texans. Our goal was to discern whether or not there was is a geologic structure in the subsurface that may enhance focusing of energy into Las Vegas Valley from the NTS. Forward modeling of these and other data produced a 268-km crustal velocity profile from Kingman, AZ, to the NTS with higher resolution than previous models. Crustal thickness increases from 28-29 km near Kingman to 33-34 km near the NTS. We discovered a possible structural feature 12-15 km underneath Indian Springs, NV that may focus seismic energy into the Las Vegas basin. A density model confirms the main outline of the structural feature and suggests a mafic body 5-12 km beneath the basin. The dipping structure might be a relict thrust or metamorphic core complex, or it might simply represent apparent dip on the Las Vegas Valley Shear Zone.

Based on these results, we designed "Seismic Investigations of the Las →



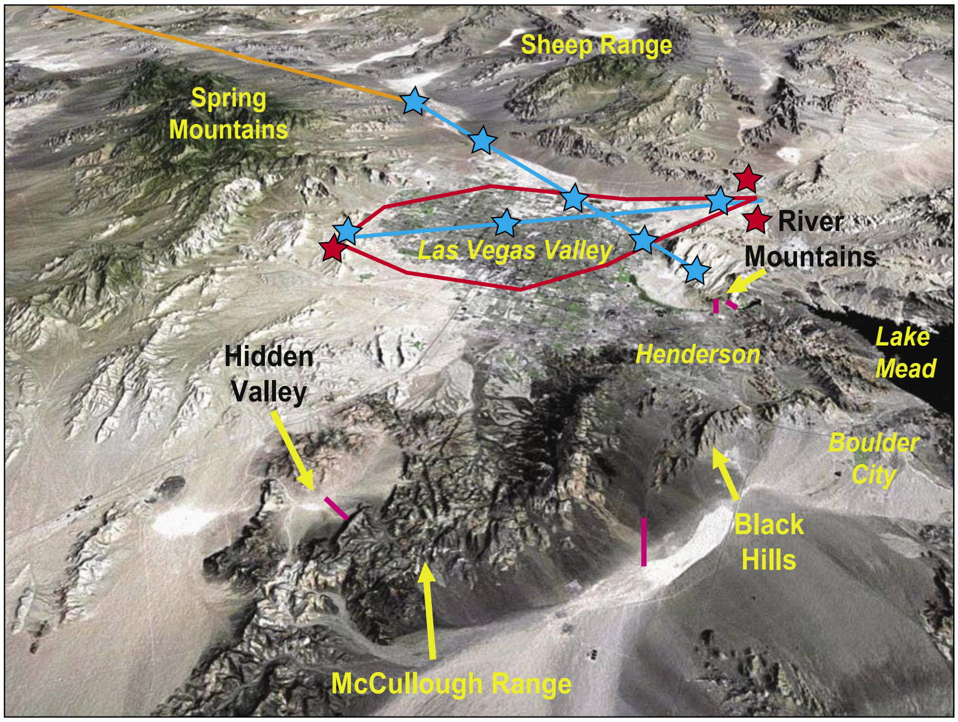
Fault map of the Las Vegas region. Blue lines are the traces of the Las Vegas Valley Shear Zone (LVVSZ). Yellow lines are the traces of active normal faults. Gray contours are the basin thickness from Langenheim *et al.,* [2001]. The center of the basin is estimated at almost 5 km depth.

Vegas Valley: Evaluating Risks" (SILVVER), a more extensive experiment with the goal of obtaining a detailed 3-D velocity model for the entire basin. SILVVER was carried out in August 2003 with funding from LLNL, the US Geological Survey National Earthquake Hazards Reduction Program, and UNLV. We used about 800 PASSCAL instruments – twenty-five RT130s with three-component geophones and the 775 Texans – with a nominal spacing of 100 meters to record nine chemical blasts ranging from 50 to 1000 lb within the Las Vegas Valley. Our 3-D velocity model shows a large sub-basin within the main basin, indicating a change from unconsolidated sediments to more consolidated materials. The velocities range from 2.5 to 4.5 km/s within the basin and increase to 6 km/s at the basin floor, indicating crystalline basement. Several zones of high velocity correlate to faults that have been mapped at the surface. The model shows that the deepest portion of the Valley is located to the northeast, as previously estimated. Integration with the geologic and geotechnical results indicates that amplification results not only from the basin thickness, but also from significant clay deposits in the shallow subsurface. The SILVVER project, for the first time, imaged several faults that cut into the crystalline basement, evidence that the faults in Las Vegas Valley are, in fact, tectonic rather than subsidence-related, as previously thought.

Now we are focusing on particular areas and faults in the shallow subsurface using PASSCAL's 60 to 120 channel Geometrics system, which help us to look in detail at the faulting in the subsurface, and tie our results directly back to geologic data. An east-west trending high-resolution seismic reflection profile in Hidden Valley is helping us to determine the relationship between volcanism and extension. From the eastern edge of the basin moving west, we acquired a 2.2 km profile extending just beyond the center of the valley using alternating hammer sources to resolve the shallow part of the basin and 15-second linear Vibroseis sweeps to resolve the mid-basin. Shot gathers suggest a thin fill on the eastern edge of the basin over basaltic basement. The fill thickens to the middle of the valley, possibly associated with faulting. Depth of signal in the deepest part of the valley is approximately 500-700 meters with shallowing to the east. Although preliminary results show little faulting, which would strengthen the evidence for volcanic sagging, further processing could reveal normal faulting, which alternatively would suggest a half-graben and indicate a possible seismic hazard. Future work will constrain the evolution of Hidden Valley and the role of extension in the volcanic terrain of the northern McCullough Range.

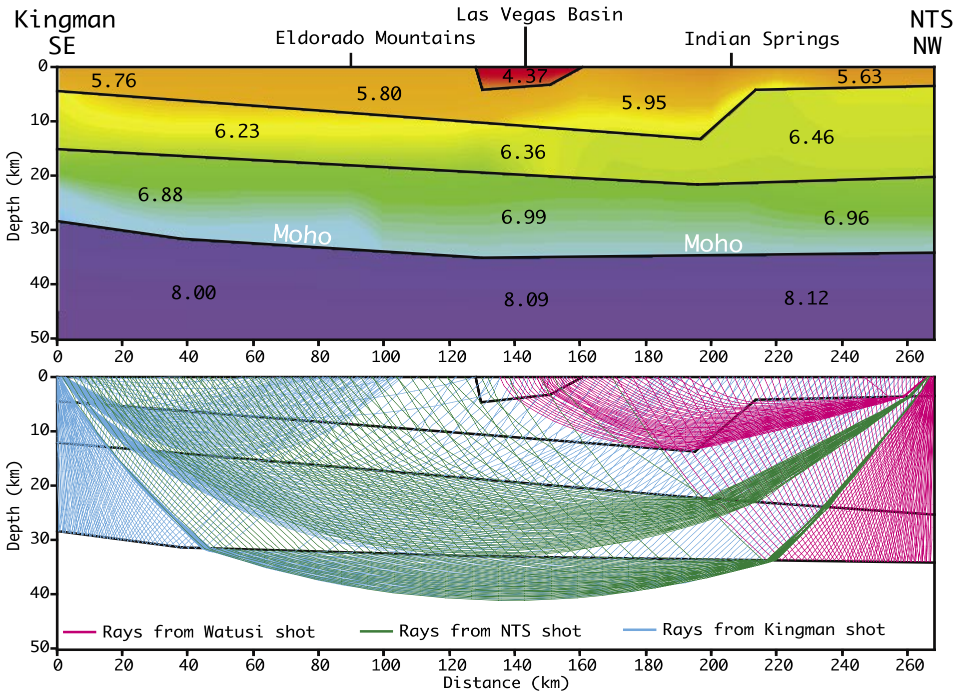
A UNLV graduate student deploying a Texan in one of the SILVVER deployments.

A similar high-resolution seismic reflection experiment imaged subsurface geologic structures south of the Black Hills fault scarp, an east-dipping normal fault that forms the northwestern structural boundary of the Eldorado basin and lies 20 km southeast of Las Vegas. A recent trench study indicated that the fault offsets Holocene strata and is capable of producing earthquakes with moment magnitudes as large as 6.8, suggesting a subsurface rupture length at least 10 km greater than the length of the scarp. Previous attempts to image the fault with shallow seismics have been inconclusive, but a preliminary look at our data indicates the existence of two faults. This would be in agreement with the inferences from trenching and may confirm an implication from gravity studies that the fault continues in the subsurface south of the scarp. →



Satellite image of the Las Vegas Valley. Red lines and stars are the location of the Quarry blast project. Orange line is the location of the Watusi project. The blue lines and stars are the location of the SILVVER project. The small pink lines are the high-resolution seismic reflection profiling.

Our most recent high-resolution seismic reflection survey in the River Mountains using our mini-vibe source.



Velocity model and ray diagram from the Watusi experiment. Notice how the rays from the NTS are re-directed under Las Vegas. Velocity is in km/s.

WHAT'S NEXT?

These data have been the basis for three Master's theses, one undergraduate senior honors project, and an undergraduate research experience. In addition, the numbers of volunteers that have helped on these projects are tremendous – well over 100 at this point, including many students from several IRIS institutions. We recently acquired a mini-vibe source, which is allowing us to be even busier than before. With the mini-vibe, we can image down to about 500 meters depth, filling in some of the gaps between the geotechnical, geologic and basin-scale seismic data. We have already discovered a new Quaternary fault on the edge of Las Vegas Valley and expect more to come as we continue our investigations. ■

ACKNOWLEDGMENTS

The projects were partially funded by Lawrence Livermore National Laboratory B525097, US Geological Survey NEHRP Program 03HQGR0016, University of Nevada Las Vegas Applied Research Initiative 2122-272-76FC, and Department of Energy DE-FG02-04ER63855. The students who have used these data for their research are Shelley Zaragoza, Aaron Hirsch, and Sandra Saldana. We want to thank Steve Harder, Galen Kaip, and Steve Azevedo for their help in the field and the PASSCAL and UTEP Instruments centers for the use of the instrumentation. Many thanks to the numerous participants in these projects from UTEP, Stanford, UNR, UNLV and the Las Vegas Valley community.

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Staff News

For the past eleven years, Susan Strain has been the friendly and efficient face of IRIS to our community. She has set a standard of quality and friendliness for our workshops and meetings that has helped to make them productive and highly respected. She has made our DC office an enjoyable and friendly place to work. She has been a source of valued support and advice for many of us personally. It is with regret (for ourselves) and excitement (for her) that we announce that Susan decided to pursue another of her passions – the art of cooking. Susan left IRIS to join "L'Acadamie de Cuisine", a cooking school in Bethesda, Maryland. We thank her for all she has done for IRIS and wish her all the best as she embarks on a new life adventure! She will be dearly missed.

The IRIS Corporate Headquarters welcomed two new employees in May. Josephine Aka, the newest member of the Business Office, takes over responsibility for the accounts payable function. Although Josephine originally comes from South Africa, she grew up and was educated in France, where she received her technical business degree. Prior to joining the IRIS staff, Josephine worked for the National Fish and Wildlife Foundation as an accounts payable coordinator.

Leslie Linn steps into the recently re-designed position of Executive Assistant. Foremost among her responsibilities is providing administrative support to David Simpson. Leslie comes to IRIS from the Coalition for Juvenile Justice, another Washington based non-profit organization, where she served as the Manager of Conferences and Training. Prior to that, she worked for Dreyer's/Edy's Grand Ice Cream for more than a decade in positions ranging from executive assistant to strategic sales analyst.

This Issue's Bannergram

Aftershock of the M_W 6.3 in Java, Indonesia on May 26, 2006

Although it is much smaller than other recent large earthquakes, the M_W 6.3 earthquake that occurred on May 26, 2006 near Yogyakarta, Indonesia was the deadliest in the world since the Muzaffarabad, Pakistan, earthquake on October 8, 2005. No alerts or bulletins were issued by tsunami warning centers on May 26 because of the earthquake's moderate size. Local coastal populations experiencing strong shaking were reported to have evacuated inland nevertheless, perhaps indicating some success in public education efforts.

More than 6000 people are reported to have died in the heavily populated region and Indonesia's Department of Social Affairs estimates that approximately 100,000 were left homeless. There are grave public health risks, economic development has been set back, and Indonesian and international relief organizations find themselves pressed to respond to yet another disaster.

Nearby Mt. Merapi was already active before the earthquake – gas plumes were said to be observed on almost a daily basis at least since early May – and while the relationship to this large tectonic earthquake is uncertain, volcanic activity appears to have increased during the following weeks. The Smithsonian Institution's volcano bulletin for the week of June 7-13 reported that the lava dome was growing at a rate of 100,000 cubic meters per day and that pyroclastic flows had prompted evacuation of more than 15,000 people.

Broadband station YOGI recorded the seismogram of an early aftershock that is shown on this page and on the front cover. YOGI was installed recently as part of GEOFON's contribution to an Indian Ocean tsunami warning system, which is described in the article by Hanka and others on pages 8-9. Broadband data from this network should soon be useful for quickly generating sophisticated source descriptions – for example that the mainshock had a strike-slip focal mechanism and a rupture zone that was entirely onshore, which would rule out the possibility of a threatening tsunami even from a larger magnitude earthquake. ■

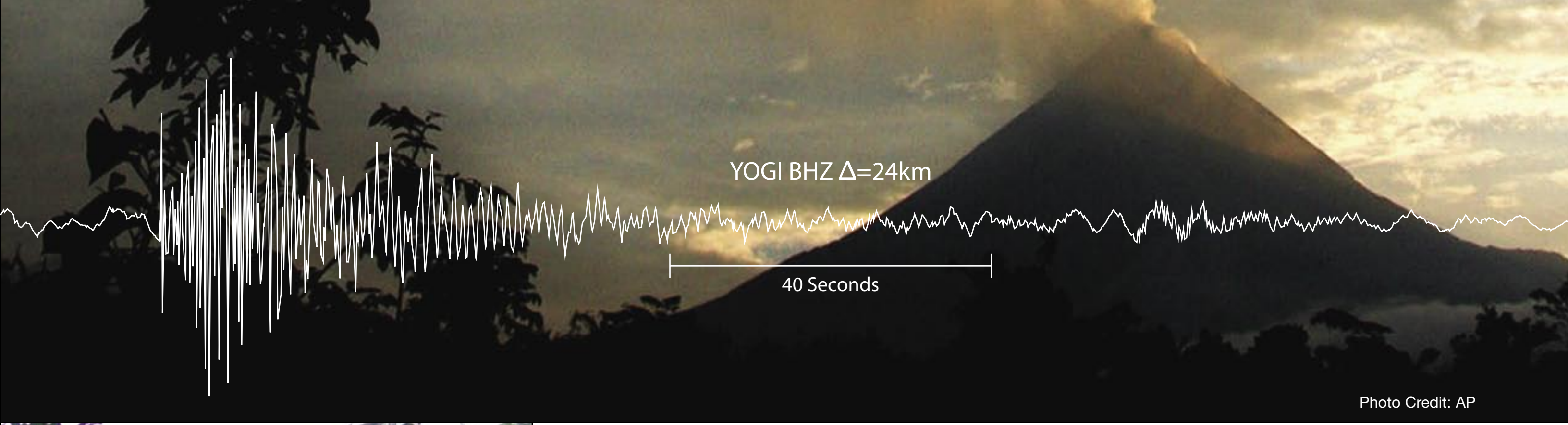

Photo Credit: AP

A building in Java, Indonesia, destroyed by the mainshock. (c) Erwin Günther, GFZ Potsdam

IRIS Newsletter

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The Incorporated Research Institutions for Seismology (IRIS) is a university consortium of more than 100 research institutions dedicated to facilitating investigation of seismic sources and Earth properties, promoting exchange of geophysical data and knowledge, and fostering cooperation. IRIS programs contribute to scholarly research, education, earthquake hazard mitigation, and monitoring underground nuclear explosions. IRIS core programs are operated through a Cooperative Agreement with the National Science Foundation under the Division of Earth Science's Instrumentation and Facilities Program. IRIS is also responsible for operating USArray as component of the NSF's EarthScope project. Funding is provided by the National Science Foundation, the Department of Energy, other federal agencies, universities, and private foundations. All IRIS programs are carried out in close coordination with the US Geological Survey and many international partners.

The IRIS Newsletter welcomes contributed articles. Please contact one of the editors.

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2007 IRIS/SSA Distinguished Lecturership Series

The Incorporated Research Institutions for Seismology (IRIS) and the Seismological Society of America (SSA) are pleased to announce the selection of two experienced speakers from the Earth science research community for the fifth annual IRIS/SSA Distinguished Lectureship Series. The lecturers will be presenting talks aimed at general audiences during 2007. The speakers and their topics are:

DR. ANNE SHEEHAN, UNIVERSITY OF COLORADO, BOULDER

SEEING BENEATH MT. EVEREST: DEEP STRUCTURES BENEATH THE HIGH HIMALAYA

Dr. Sheehan's talk will focus on a recent PASSCAL experiment in Nepal and Tibet. The work combines an adventurous field experiment in an exotic location, earthquake hazards in a vulnerable location (the recent Pakistan earthquakes), local culture, an ongoing civil war, and logistical challenges including scorpions and cobras. All of these factors will make for an exciting talk for a general audience.

DR. BRIAN ATWATER, U.S. GEOLOGICAL SURVEY

THE ORPHAN TSUNAMI OF 1700 -- JAPANESE CLUES TO A NORTH AMERICAN EARTHQUAKE

Dr. Atwater's talk will tell a paleoseismic story about the tsunami of 1700 and the quest to find its origin. From Japanese clues and evidence found in the Pacific Northwest, Dr. Atwater will piece together the story of one of the largest earthquakes in the conterminous U.S. This intriguing trans-Pacific mix stirs interest and enthusiasm for both the history and the science.

This Lecture Series will start in January 2007. If you are interested in requesting a speaker for the 2007 Lecture Series please, contact Gayle Levy (levy@iris.edu, 202.682.2220) for details. For more information on the Distinguished Lectureship program, please visit: *www.iris.edu/services/lectures/iris_ssa.htm*

AUGUST 27 - SEPTEMBER 1, 2006

International Disaster Reduction Conference
Davos, Switzerland
www.davos2006.ch

SEPTEMBER 3-8, 2006

European Conference on Earthquake Engineering and Seismology, Geneva, Switzerland
www.ecees.org

OCTOBER 31-NOVEMBER 2, 2006

EarthScope Imaging Science / CIG Seismology Joint Workshop
Washington University in St. Louis, MO
www.geodynamics.org

DECEMBER 11 - 15, 2006

AGU Fall Meeting
San Francisco, California
www.agu.org/meetings/fm06

MARCH 27 - 30, 2007

EarthScope National Meeting
Monterey, California
www.earthscope.org/meetings

MAY 14 - 16, 2007

International Conference on Seismology & Earthquake Engineering
Tehran, Iran
www.iiees.ac.ir/SEE5

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