The final GCM-derived perturbation of the baseline climate (GCM percentage anomaly x baseline observed climate) is shown in the panels in Figure 3.

Assessment and Caveats

By using the GCM percentage change, the derived absolute magnitude of the perturbation is naturally a function of the magnitude of the baseline climatology. Consequently, when comparing Figures 2 and 3, it is apparent that the spatial expression of the derived anomaly has differences even where the spatial component of GCM large-scale anomaly field is the same for different locations. The perturbation thus captures the spatial differences of the existing climate, while maintaining agreement with the large-scale response of the GCM, the scale better associated with the model skill, as opposed to the single-grid cell values. Of note here is that the two models in Figure 3, which have notable differences in their control climatologies (not shown), indicate a degree of convergence in the regional anomaly pattern as derived here. Both models clearly indicate similar west-east patterns of wet-dry anomalies, and the HadCM3-derived anomaly is, to a large extent, very similar to a "dry-shifted" ECHAM4-derived anomaly.

Such agreement does not necessarily indicate that the models are right in their future projection of climate, but does suggest that there is some common response, giving credibility to the plausibility of the anomaly. For impact assessment research, this is exactly what is needed in initial studies; namely, that one has a plausible, credible perturbation on which to develop initial understanding of the regional sensitivities to climate change forcing.

Thus, assuming that regional climate boundaries do not undergo dramatic lateral shifts, the results suggest that this approach provides a future climate perturbation at spatial scales appropriate for initial sensitivity studies in a range of impact assessment activities. Related to this is the important requirement that the GCM does not misplace, or fail to resolve, fundamental physical climate boundaries. For example, if the GCM allows one climate domain (say, maritime) to extend into the adjacent but different climate region (say, continental arid zones), this will result in inappropriate application of the GCM anomaly in that region. This serves to highlight the need to carefully evaluate the GCM fields prior to application.

Finally, although this is not a downscaled product, and does not include local feedbacks and other forcings under future climates, it does represent a regional-scale perturbation in accord with the GCM first-order response to greenhouse gas forcing. Using this approach with a range of GCMs allows one to undertake an assessment of fundamental regional sensitivities to climate change that are not arbitrary, but guided by the envelope of future climate, as characterized by GCMs. The approach is computationally simple and appropriate for a broad range of researcher sectors. The procedure is equally applicable to large areas and for single station time series, and lends itself to data-sparse regions, as commonly found in developing nations. Hence, especially for many developing regions (although not excluding impact assessment work in developed nations), this approach serves to provide a first look at the regional climate change envelope.

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Geophysical Project in Ethiopia Studies Continental Breakup

PAGES 337, 342–343

As continental rift zones evolve to sea floor spreading, they do so through progressive episodes of lithospheric stretching, heating, and magmatism, yet the actual process of continental breakup is poorly understood. The East African Rift system in northeastern Ethiopia is central to our understanding of this process, as it lies at the transition between continental and oceanic rifting [*Ebinger and Casey*, 2001].

We are exploring the kinematics and dynamics of continental breakup through the Ethiopia Afar Geoscientific Lithospheric Experiment (EAGLE), which aims to probe the crust and upper mantle structure between the Main Ethiopian (continental) and Afar (ocean spreading) rifts, a region providing an ideal laboratory to examine the process of breakup as it is occurring. EAGLE is a multidisciplinary study centered around the most advanced seismic project yet undertaken in Africa (Figure 1). Our study follows the Kenya Rift International Seismic Project [e.g., *KRISP Working Group*, 1995], and capitalizes on the IRIS/ PASSCAL broadband seismic array [*Nyblade and Langston*, 2002], providing a telescoping view of the East African Rift within this suspected plume province.

EAGLE fieldwork was undertaken between October 2001 and March 2003. Many results will be presented in a session at the "The East African Rift System: Development, Evolution and Resources" Meeting to be held in Addis Ababa in June 2004. The lead Ethiopian institutions were the Geophysical Observatory, the Department of Geology and Geophysics of Addis Ababa University, the Ethiopian Geological Survey, and the Petroleum Operations Department of the Ethiopian Ministry of Mines. The lead European and U.S. institutions were the universities of Leicester, Royal Holloway London, Leeds, and Edinburgh, together with Stanford, the University of Texas, El Paso, Southwest Missouri State, and Penn State universities. The entire project was coordinated in Ethiopia by the Commission of Science and Technology of the Democratic Republic of Ethiopia.

Models for Continental Breakup

The three-dimensional structure of oceanic rifts is primarily controlled by the supply of magma [e.g., *Phipps-Morgan and Chen*, 1993], whereas that of youthful continental rifts is controlled by the spatial arrangement of large displacement border faults [e.g., *Hayward and Ebinger*, 1996]. Thus, magmatic processes increase in importance as rifting proceeds to sea floor spreading, but there is no consensus as to when or how this transition occurs. The volume of melt produced and its seismic velocity structure provide critical constraints on mantle dynamics as continental breakup proceeds to sea floor spreading, but there remain fundamental questions regarding the three-dimensional distribution of strain and melt as continents rift apart.

Our approach in EAGLE is to examine the nature of crust and upper mantle along a highly extended, magmatically active continental rift prior to the modifying effects of post-rift sedimentation, erosion of the uplifted rift flanks, and thermal decay. In the Ethiopian Rift we can (1) trace the evolution from broadly distributed to focused strain during rift development; and (2) study the active processes of continental breakup associated with a mantle plume (or other upper mantle convective upwelling), while avoiding interactions between subducted slabs and asthenospheric flow; the region has been tectonically stable since 600 Ma.

Ethiopia-Afar Rift Zone

There is general agreement that the broad uplifted Ethiopia-Yemen plateau and Oligocene flood basalt province have been affected by one or more Cenozoic plumes [e.g., *Nyblade and Langston*, 2002]. A synthesis of ^{40}Ar/^{39}Ar data shows that flood basalts were erupted across an ~1000-km diameter region at ~31 Ma, presumably coincident with plume head contact with Afro-Arabian lithosphere [e.g., *Hofmann et al.*, 1997]. Previous geophysical studies show crustal thinning northward into the Afar depression. Refraction profiles in Afar, interpreted as near-one-dimensional structures due to the very small number of shots and receivers, suggest thinned 25-km-thick crust underlain by a 10-km-thick layer with anomalously low upper mantle P-wave velocities above apparently normal mantle [*Berkhemer et al.*, 1975].

Young (< 10 Ma) continental rifts, as in southern Kenya, commonly comprise asymmetric rift basins bounded by steep border faults that accommodate most of the strain across the rift. The older, more evolved Asal Rift in Djibouti illustrates a much narrower zone of magmatic accretion and faulting immediately after the onset of sea floor spreading. Project EAGLE focuses on the transitional rift sector at the northern end of the Main Ethiopian Rift, where strain and magmatism have migrated from the border faults to a narrow zone within the rift valley [*Ebinger and Casey*, 2001].

The Main Ethiopian Rift shows two stages of along-axis segmentation marking distinct differences in strain partitioning. During the early stages, strain localized along large-offset border faults bounding broad basins. During the last 2 Ma, strain and magmatism have localized to narrow zones of aligned volcanoes in the central rift valley, termed magmatic segments. The en echelon arrangement of the "new" magmatic segments shows little correlation with the older border fault segmentation (Figure 2). Geodetic data show that ~80% of the strain across the rift is accommodated across the magmatic segment, although teleseismic activity attests to some deformation outside this zone [*Bilham et al.*, 1999]. To first order, geochemical data from the magmatic segments indicate that upwelling plume material sampled in central Ethiopia incorporates depleted mantle during ascent beneath the more highly extended portions of the rift [*Furman et al.*, 2003].

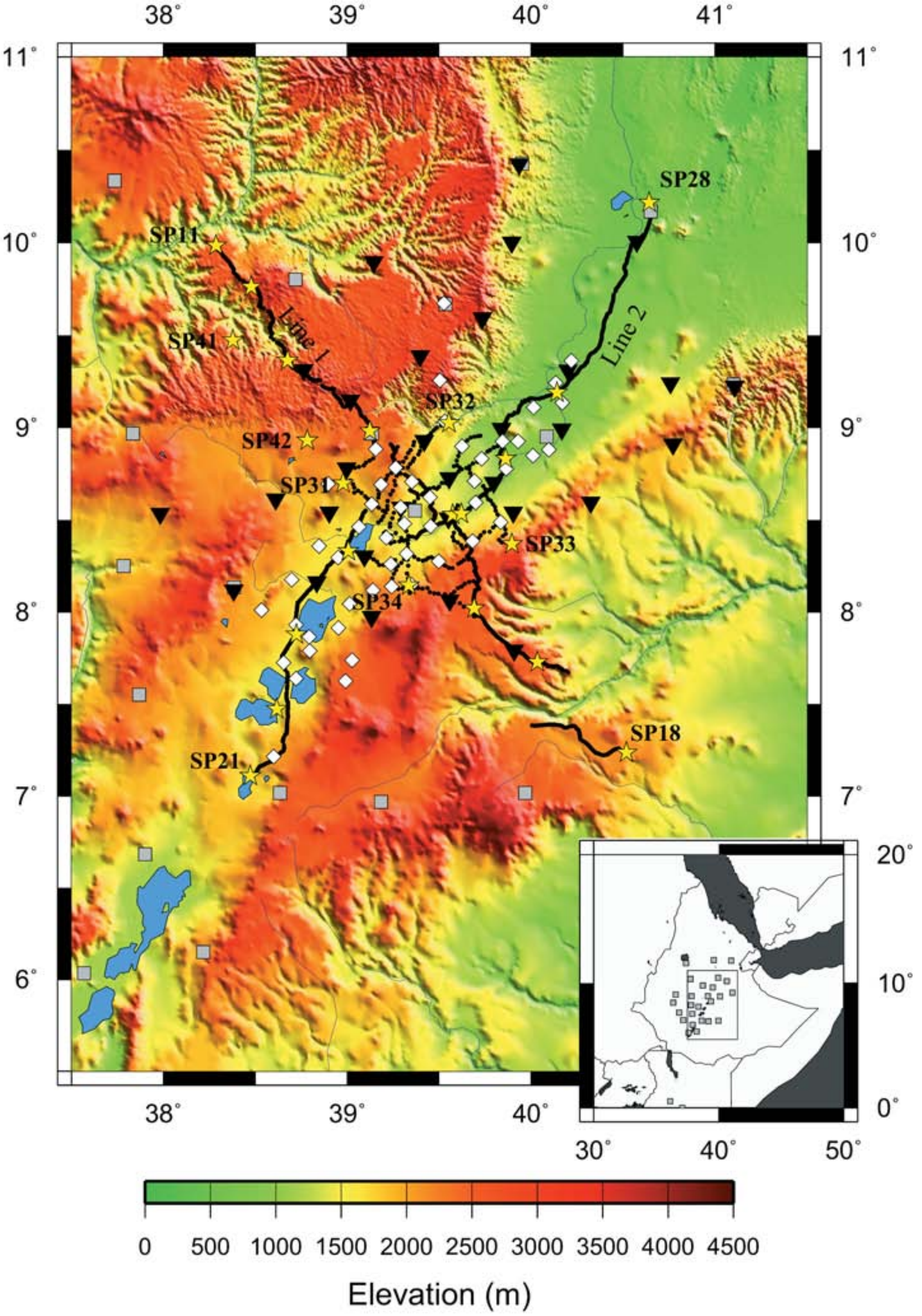

Fig. 1. Topographic map of the central Ethiopian Rift showing the locations of the EAGLE Phase I (inverted black triangles), Phase II (white diamonds), and Phase III (black dotted lines) instruments. Phase III shots are identified by yellow stars (e.g., SP11). MT soundings (Phase IV) were taken along the central 200 km of Line 1. Also indicated are the locations of the Penn State array (grey squares) [Nyblade and Langston, 2002].

Project EAGLE

Project EAGLE aims to define the anatomy of a rift immediately prior to breakup. We carried out a three-phase seismic experiment (Figure 1), followed by a magnetotelluric project and a variety of supporting efforts that collectively provide a diversity of data for integrated analysis:

- Phase I consisted of deployment of 30 SEIS-UK [*Maguire et al.*, 2002] broadband seismometers for a period of 16 months over a 250 km x 250 km area of the rift valley and its uplifted flanks. The primary aim is to help define the shape of the Moho, and to improve images of the uppermost mantle across the underlying mantle plume province. P- and S-wave tomography and receiver functions will provide images of deep Earth structure, while S-wave polarization analysis will be used to assess the nature of seismic anisotropy and its interpretation in terms of mantle dynamics, tectonic fabric, and stress regime.
- Phase II consisted of the deployment of additional 50 SEIS-UK three-component broadband instruments for a period of 4 months over a 200 km x 100 km area encompassing four magmatic segments. The array will be used to locate local earthquakes, to analyze fault plane solutions, and to conduct receiver function analyses. The aims of Phase II are to estimate strain partitioning and lithospheric strength variations in three-dimension, and to identify the distribution of magma reservoirs beneath the narrow magmatic segments.
- Phase III consisted of the deployment of an additional 1100 seismic instruments during a controlled source seismic project involving 20 seismic charges being fired into one 450-km cross-rift profile (Profile 1), one 450-km axial profile (Profile 2), and a dense two-dimensional array of instruments in a 150-km diameter circle around the profiles' intersection (Profile 3), all centered on the magmatically active Nazret region (Figure 2). The crust and upper mantle velocity models to be derived will be used to provide estimates of total crustal thinning across the rift, to assess the role of basement in the location of major faults and magmatic segments, and to determine whether significant underplating takes place during the syn-rift stage. The high-density array around the intersection of the two profiles was designed to image any magma bodies beneath the Boset magmatic segment.
- Phase IV featured the recording of a magnetotelluric profile along the central ~200 km of Profile I. The electrical conductivity structure of the crust and immediate upper mantle should provide additional constraints on the nature and distribution of crustal heterogeneity,

and image melt accumulation zones. New gravity and geodetic information have also been acquired.

Initial Results

Phase I, II, and III were completed in January/February 2003. Phase IV continued until March 2003.

Phase I: Preliminary results from SKS splitting analyses show delay times between the fast and slow S-waves varying from ~1.6 seconds on the Ethiopian plateau (Nubia plate) in the west, to ~2 seconds toward the eastern flank (Somalia plate). Within the rift valley there is a consistent south-to-north increase in these delay times, which increase from 1.0 second in the south to 2.1 seconds in the north (Figure 2). The increased splitting delay times toward the Somalia plate may arise from stretched/fractured lithosphere, or alternatively represent a different tectonic domain. The increased splitting delay times northwards toward Afar correlate with an increase in strain, which is accommodated both by faults and dikes, as well as with lower crustal residence times for erupted lavas [*Furman et al.*, 2003].

Outside the rift, the polarizations of the fast shear wave lie on a NE-SW rift parallel trend. Within the rift, the orientations swing to more northerly azimuths parallel to the volcanic centers and perpendicular to the geodetically determined opening direction.

Initial tomographic inversions of relative teleseismic residuals show low velocities underlying the Ethiopian Rift down to depths of at least 200 km. The anomaly appears to be tabular in shape beneath the continental part of the rift in the SW region of our deployment. Toward Afar, the anomaly is less focused and more triangular in shape. In one region, the low velocity anomaly extends perpendicular to the rift axis and correlates with off-rift volcanoes south of Addis Ababa (I. Bastow, pers comm., 2003).

Phase II: Station spacing was kept at 15–20 km based on the distribution of schools, state farms, game parks, and secure buildings within the region. Initial analyses of the local event data from Phase I and Phase II suggest a concentration of seismicity along the western margin of Afar (Figure 2). Relocations of explosive shots using a simple one-dimensional velocity model show position accuracies of ~500 m (D. Keir, pers comm., 2003).

Phase III: Preparations for the controlled source effort began in April 2001, and 91 broadband instruments were first deployed at a nominal 5-km interval along the 450-km cross-rift profile in November-December 2002. The experiment took place in January 2003, and involved eighteen sources of up to 2.5 tonnes in boreholes (typically 1-tonne dynamite per 50-m hole) and two ~1-tonne sources in lakes (Shalla and Arenguade) together with the deployment of ~1000 short-period recorders. An environmental impact assessment required by the Ethiopian government, incorporating a full report on the lake flora, fauna, and chemistry both before and after the shots were detonated, should provide data of immense value for future seismic studies elsewhere in the world.

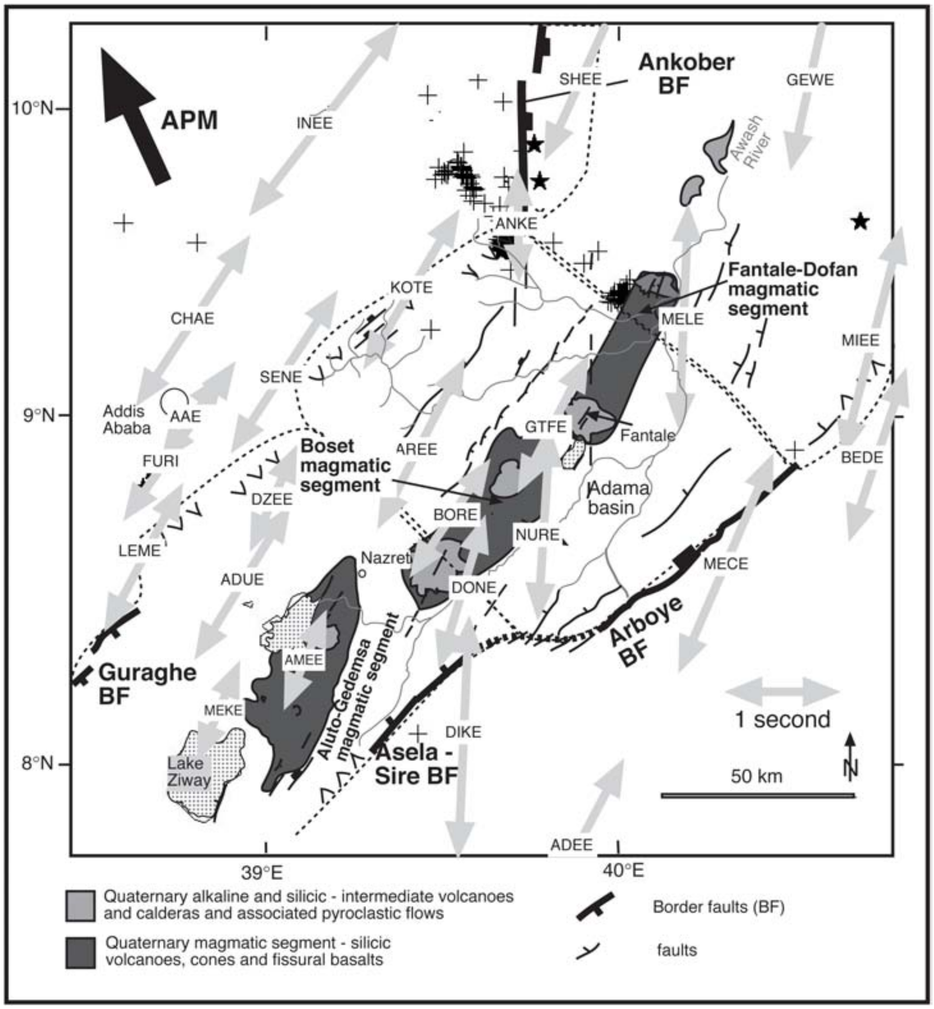

Fig. 2. Tectonic setting of the EAGLE study area [from Wolfenden, 2003] *showing border faults, magmatic segments, and seismicity in the zone of intersection between the Northern Main Ethiopian Rift and Southern Red Sea Rift basins. Crosses are epicenters from EAGLE Phase I instruments, and stars are epicenters from combined Phase I and Phase II instruments (Figure 1). Also indicated are SKS shear-wave splitting results for an event on 02 December 2001, origin time 13:01:54, Mb 6.1, recorded on the named Phase I instruments (e.g., CHAE). The orientation of the arrows shows the fast splitting direction; their length illustrates the amount of splitting delay. The absolute plate motion is shown by the arrow marked APM.*

Examples of the record sections from two of the borehole shots are shown in Figure 3. These sections show good energy propagation along the entire length of the profiles, but with an increase in ambient noise at the southern end of Profile 2. As well as wide coverage of Pg (the diving wave traveling in the uppermost crust), PmP (the reflection from the Moho), and Pn (a diving wave in the uppermost mantle), at least two reflectors from intracrustal interfaces can be observed prior to the PmP arrival on a number of the sections. The PmP arrival is observed with a critical offset of ~180 km in the south and ~150 km to the north, suggesting a crustal thinning from c. 35 to c. 30 km northwards (Figure 3a). Crustal thinning is also observed beneath the rift along Profile 1 based on the early arrival of PmP from shotpoint 12 on the rift flanks (Figure 3b) and an increase in this critical offset from SP25 east of the rift (Figure 3c).

Future Directions

Analysis of the bulk of the EAGLE data is just beginning. Our results should have broad implications for our understanding of processes at work during the breakup of continents, and will be of value not just to the international Earth science community. Ethiopia is a country beset by humanitarian difficulties, but it is also demonstrably capable of supporting a major international scientific effort. EAGLE served as a catalyst to unite academic, government, and private geoscientists who are now combining efforts in other collaborative projects. The results of EAGLE have longer-term implications for hydrocarbon and geothermal energy assessment and hazard reduction within Ethiopia, providing a framework for prioritization of exploration targets and much valued information for the country's long-term development: on the distribution of Mesozoic sediments beneath the Tertiary flood basalts on the Ethiopian plateau; of interest to the

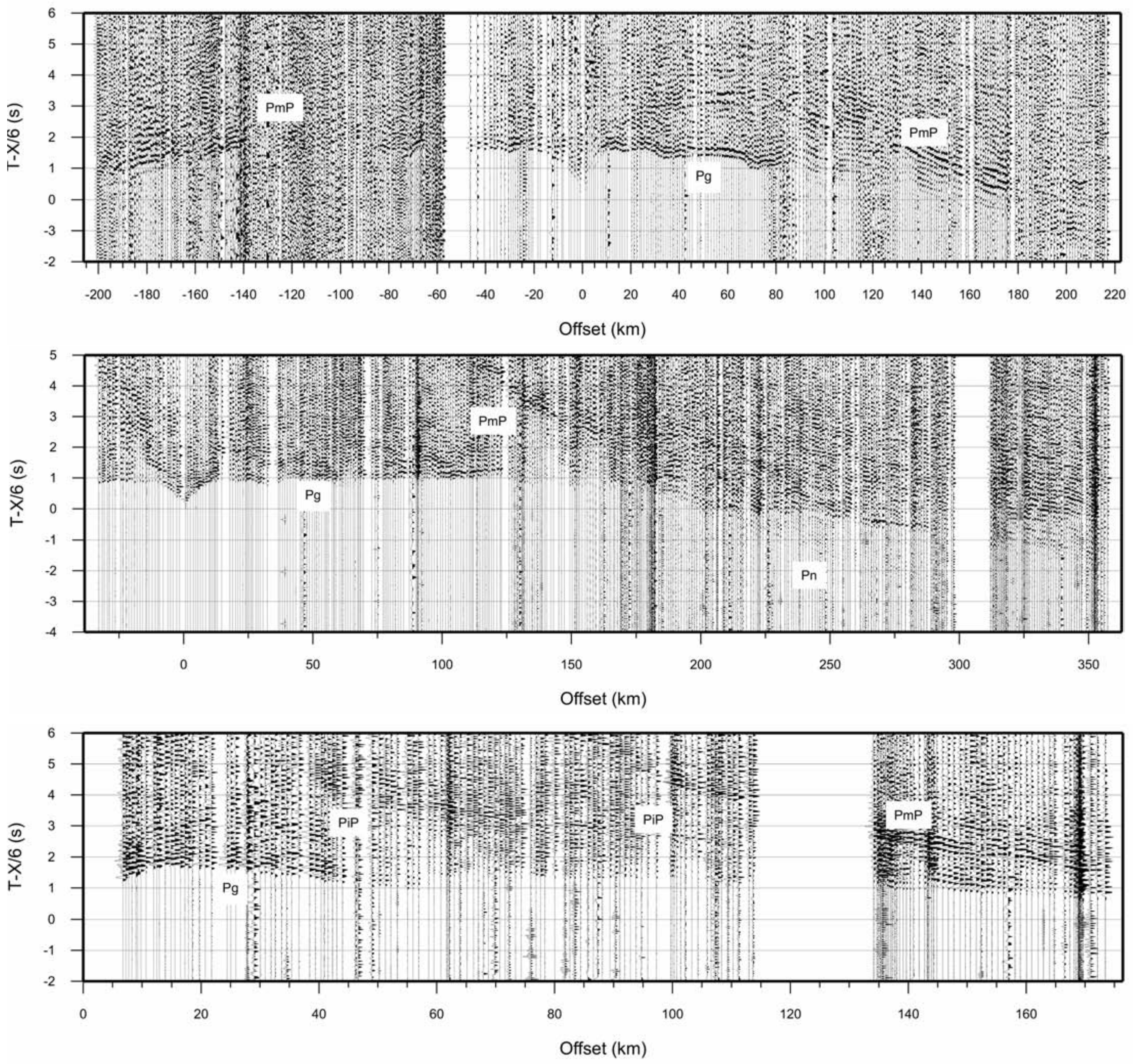

Fig. 3. Example seismic record sections from (a) the central SP25 into Profile 2, (b) SP12 on the northwestern rift flank into Profile 1, and (c) SP25 into the eastern end of Profile 1. Sections have been reduced at 6 kms^{-1} and bandpass filtered. Pg – crustal diving wave; PmP – Moho reflected phase; Pn – mantle diving wave; PiP – intra-crustal phases.

Petroleum Operations Department of the Ethiopian Ministry of Mines; on the distribution of magma intrusions within the crust; of relevance to the Geothermal Division of the Ethiopian Geological Survey; on the local seismicity, important for both seismic and Volcanic hazard studies in the Ethiopian Rift; and even, despite our limited information, from the water depths identified in the seismic shot holes, being of relevance to the country's hydrogeological development.

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Europe: University of Leicester, University of London, Royal Holloway, University of Leeds, SEIS-UK, University of Edinburgh, University of Copenhagen, Dublin Institute for Advanced Studies, University of Vienna, and the University of Stuttgart.

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Enrollment in Graduate Geosciences Programs Appears Unaffected by Changes in U.S. Immigration Regulations

This is the first of a series about how academic programs and research in the geosciences in the United States have been affected by tightened U.S. immigration regulations.

PAGE 338

New stringencies and requirements of U.S. immigration regulations are creating additional obstacles for citizens of other countries planning to study science or do scientific research at U.S. universities and institutions.

The terrorist attacks in the United States on September 11, 2001 and subsequent events have prompted U.S. authorities to develop new rules and procedures to more carefully screen individuals who wish to enter the United States for any reason, and to more vigorously enforce regulations that were already in place.

The negative effects—real or imagined—on participation levels of non-Americans in graduate studies in the sciences and in the U.S. science labor force as postdoctorates and researchers, and on U.S. science more generally have been the subject of discussion in scientific circles and the general press. Public statements of concern have been issued by organizations that represent the interests of scientific endeavors. Attempts to quantify such effects have already been undertaken by various scientific societies.

As early as December of last year, Bruce Alberts, president of the National Academy of Sciences, issued an open letter stating that, "...recent efforts by our government to constrain the flow of international visitors in the name of national security are having serious unintended consequences for American science, engineering, and medicine." While referencing instances of people denied entry to speak at conferences, teach at universities, and conduct research, the Albert's letter said, "Perhaps most seriously, the list [of those denied visas] also includes a large number of outstanding young graduates and postdoctoral students who contribute in many ways to the U.S. research enterprise and our economy."

A recently-completed survey of graduate programs of physics in the United States by the American Institute of Physics showed that enrollment of foreign students decreased 3% in 2001–2002, and then dropped an estimated 7% in 2002–2003, even though applications by non-U.S. citizens to these programs were shown, by and large, to have remained steady or to have increased in the same period. The survey results, released 30 June, attributed the drop to "the ever-tightening rules on all immigrants" related to obtaining visas. These results show that students from China were most often denied entry, followed by students from Middle Eastern countries; though AIP noted that the more difficult environment for obtaining a visa is "not" targeted to specific countries." (To view the survey, see the Web site: http://www.aip.org/statistics/trends/reports/international.pdf).

(AGU will be conducting a similar survey of graduate programs at geosciences departments in the United States early this autumn.)

Experience of Some Geosciences Departments, U.S. Laboratories

However, interviews with 13 heads of geosciences departments, and heads of graduate study programs of U.S. universities around the country suggest that enrollment levels of non-U.S. citizens for graduate study in the geosciences have remained steady in the past 2 years, or have even risen.

Harvey Waterman, associate dean of academic affairs at Rutgers University in New Jersey, said that "applications from international students have been soaring upwards in the last 2 years, despite the additional problems such applicants face." He said, however, that "By contrast, enrollments are not soaring upwards," but attributed this to "constraints in funding" rather than to difficulties in securing entry to the United States.

Representatives of Los Alamos National Laboratory, which employs many non-U.S. citizens in postdoctorate positions and as researchers, told a similar story. They indicated that, in spite of the fact that it is now more time-consuming for such candidates to secure visas and other qualifying documentation to enter the U.S., the participation level of non-U.S. citizens in the facility's workforce has remained virtually unchanged in the past several years.

Only two of the officials of geosciences departments interviewed said they had accepted for graduate study non-U.S. citizens who subsequently were unable to enroll because they could not obtain a visa. Another—Craig Manning of the Earth and Space Sciences Department at UCLA—said that one accepted student had to delay his study for 6 months for this reason, but was eventually able to secure a visa and enter the U.S.

In contrast to concerns about students being unable to enroll, a much more common apprehension of those interviewed was the fear that, once inside the United States, it could be very risky for non-U.S. citizens to attend a scientific meeting outside the country or visit their home country. This was because the individual might be unable to obtain a visa to re-enter the United States.

For example, Kathryn Kelly, chair of the Air-sea Interaction and Remote Sensing Department of the Applied Physics Laboratory, University of Washington, said that one of her graduate students was unable to make a presentation at the recent IUGG Meeting in Sapporo, Japan, on her thesis work because the university's office that deals with international students had recommended that she not leave the United States "for any reason."

UCLA's Craig Manning said that last year "some returning students who were out of the country experienced delays in visa issuance. The worst case was a 6-month delay in returning."

Visa Interview Now Required

For individuals planning to study or do research in the United States, one of the most significant changes in the rules since September 11 is that visa applications now require a personal interview with a U.S. consular official in almost all cases. (It has always been the case that individuals who are not from visa waiver countries must obtain a visa if they contemplate studying in the U.S. or doing research here.) This creates additional work for administrative offices of U.S. universities that handle the paperwork for prospective students, but it can create difficulties for the students as well.