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Group Takes a Fresh Look at the Lithosphere Underneath Southern Kenya

KRISP Working Group

Since the turn of the century the well-developed Kenya rift has been a crucial location for studying the interrelationships between extension, uplift, and magmatism. In 1989–1990, an experiment conducted by the Kenya Rift International Seismic Project (KRISP) focused on the central and northern portions of Kenya (Figure 1) and provided a rich base of information regarding the structure and evolution of the rift, which answered many key questions and raised others. Does the crust thin to the south of the Kenya dome as it does to the north?, and if it does, which crustal layer would be mainly affected? How is the Chyulu Hills Quaternary volcanism related to the rifting process? What is the relationship between the crust and lithospheric mantle during extension?

In 1993, the KRISP working group began a new series of multidisciplinary field investigations in the rift in southern Kenya to study these issues. In February 1994 a long-range seismic refraction profile was recorded completely across southern Kenya extending from Lake Victoria to the Indian Ocean near Mombasa (Figure 1) to obtain a better understanding of lithospheric structure and rifting processes in the southern part of the Kenya rift and its flanks, including the Quaternary volcanic field of the Chyulu Hills, and to compare the results with the region to the north. The recording of deeply penetrating seismic waves, which can provide information on the dynamics of a mantle plume that appears to be present [e.g., *Keller et al.*, 1994], was of particular interest.

Findings of the Earlier Experiment

Interpretations of the 1989-1990 data were published in a recent special issue of *Tectonophysics* [*Prodehl et al.*, 1994]. One of the surprising findings was the nature of crustal thickness variations both along and across the rift (Figure 2). Along the rift axis, crustal thickness varies from 35 km in the south beneath the Kenya dome (Lake Naivasha, Figure 1) to 20 km in the north beneath the Turkana region (Figure 2a). This large variation is accomplished primarily by the thinning of the basal, high-velocity crustal layer. The northward decrease in crustal thickness can be correlated with changes in surface topography, rift width, and estimates of extension. In addition, the large northward increase of Bouguer gravity can be explained almost entirely by the change in crustal thickness.

Below the 600-km long axial rift profile, uppermost mantle Pn velocities are anomalously low—7.5–7.7 km/s (Figure 2a). A profile across the rift north of the Kenya dome at the latitude of Lake Baringo showed that this low uppermost mantle velocity and crustal thinning of 5–10 km are confined to below the surface expression of the rift (Figure 2c). An abrupt change in crustal thickness and Pn velocity occurs as the rift boundaries are crossed. Beneath the rift flanks, normal Pn velocities of 8.0–8.2 km/s occur.

Teleseismic experiment (Figure 1) results in the south-central portion of the rift showed

Kenya Rift geological setting and KRISP seismic lines

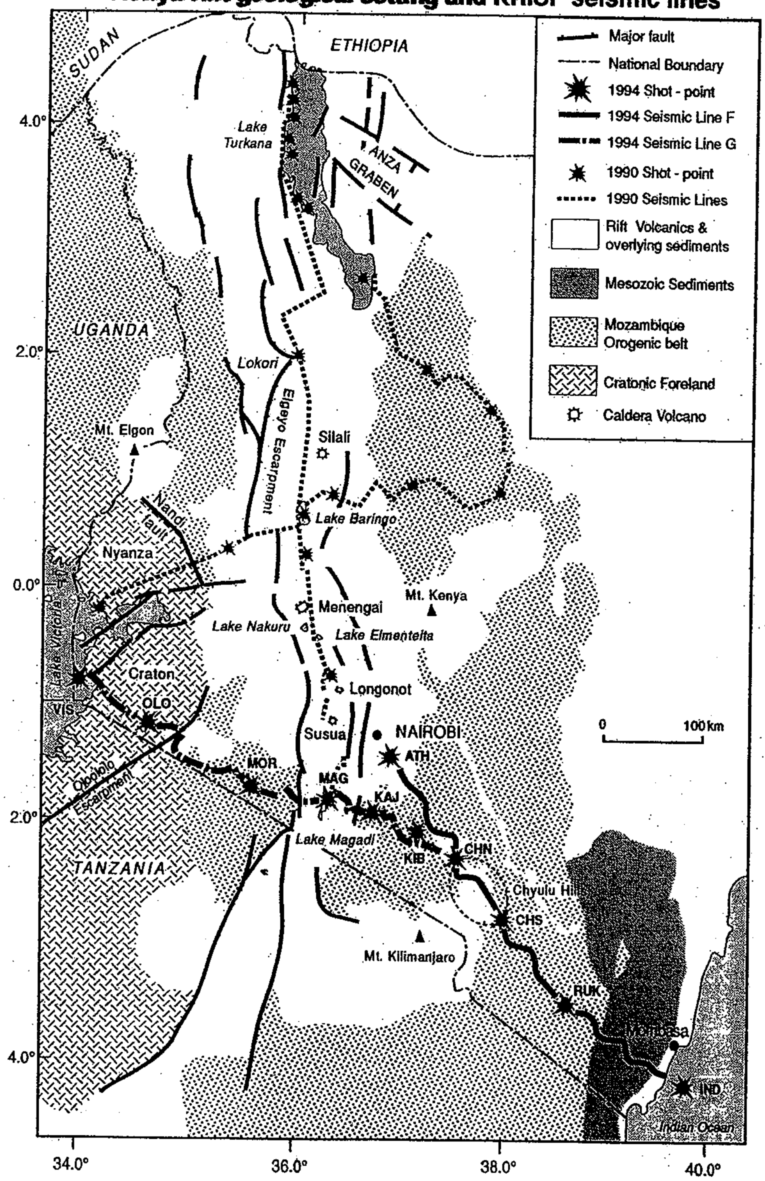

Fig. 1. Index map of the Kenya rift showing KRISP seismic lines recorded in 1990 and 1994. The 1990 seismic refraction profiles addressed the crustal structure along the axis of the rift, across the rift at the latitude of Lake Baringo, and on the east flank. The 1985 and 1990 teleseismic recording was centered in the area south of Lake Baringo. The 1994 seismic refraction profiles addressed the structure across the southern rift, and the 1994 teleseismic recording was centered on the Chyulu Hills area (dashed oval).

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that the anomalous region of low upper mantle P-wave velocities beneath the rift extends down to 100–150 km depth and is steep-sided [*Achauer et al.*, 1994; *Slack et al.*, 1994]. This region of low velocities is compatible with the presence of a few percent partial melt in the uppermost mantle beneath the rift axis. Under the northern part of the rift, two high-velocity layers were found embedded in the 7.5–7.7 km/s low-velocity upper mantle material, but there is no evidence that lithospheric thinning in the north is significantly greater than to the south below the Kenya dome. Thus under the Kenya dome, major lithospheric thinning due to the active uprising of hot mantle material is associated with major uplift and minor crustal thinning and extension, while in the northern part of the rift, under the Turkana region, major crustal thinning and extension are associated with minor uplift.

Latest Experiment Combines Various Components

The first element of the 1993 project was a teleseismic study of the Chyulu Hills region, which lies on the flanks southeast of the rift valley (Figure 1). This study was completed in autumn 1993 by the Universities of Karlsruhe, Leicester, and Nairobi. For 3 months, worldwide earthquakes were recorded with an array of 30 portable seismographs located within the dashed oval shown in Figure 1. This array also recorded many small earthquakes in the region.

A seismic-refraction experiment completed in February 1994 deployed 208 mobile seismographs at 1–3 km intervals along two refraction lines (F and G, Figure 1) and in a small array in the region between these lines (Figure 1). Ten borehole shots at 8 locations provided the main source of energy for the experiment. Two shot-point locations (CHN and MOR) were fired into both lines. In addition, the cooperation of a local quarry (KIB) provided another shot for each line. Underwater shots (two at Lake Victoria and one in the Indian Ocean) were fired into each line at the points shown in Figure 1. The coordinates of each seismic recording location and shotpoint were determined by differential Global Positioning System measurements, and gravity readings were also made at each of the sites. Major gaps in the regional gravity coverage in the southern rift area were filled in with the help of the Kenya Power and Lighting Company.

In July and August 1994, additional petrologic samples were collected by a U.S./Kenyan team to extend the earlier work [e.g., *Henjes-Kunst and Altherr*, 1992], and broadband seismic monitoring was initiated at two stations. The final element of this effort is a magnetotelluric survey in which long-period data are being recorded at about 40 sites along the seismic profile from Lake Victoria

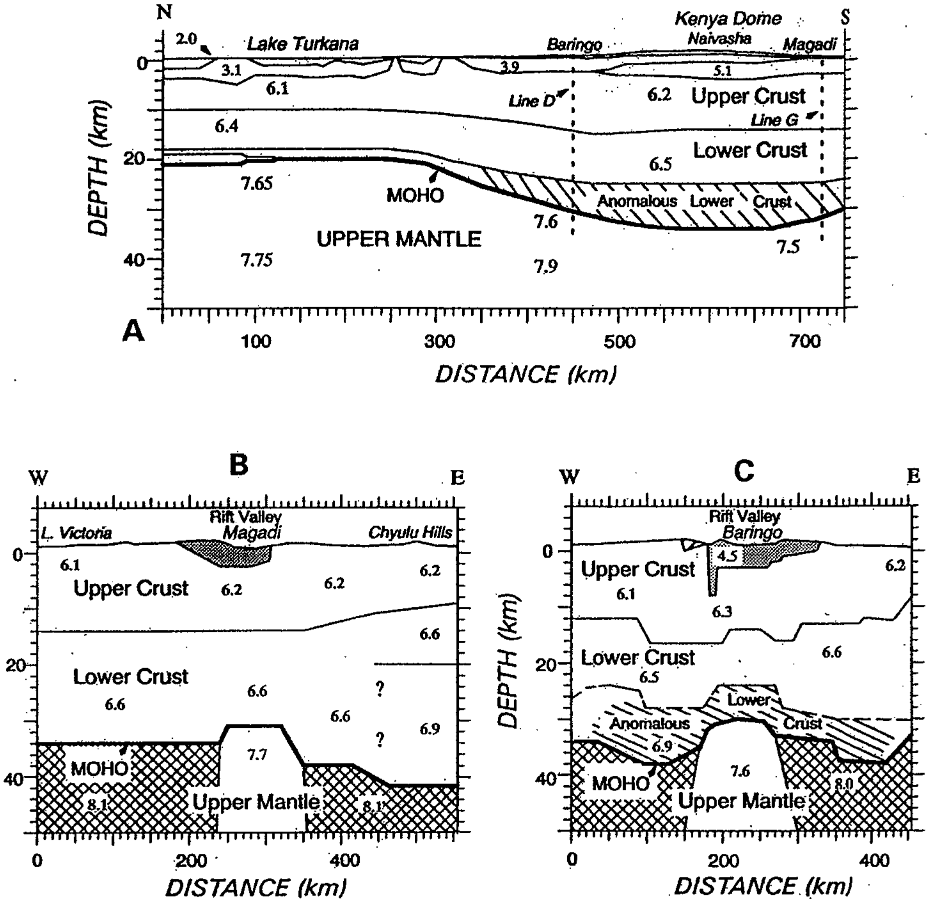

Fig. 2. Crustal cross sections of the Kenya rift: a) along the rift, b) across the rift (Line G) south of the Kenya dome, and c) across the rift (Line D) north of the Kenya dome. Cross sections a and c are from the 1989–1990 experiment and are more developed than the preliminary cross section, and cross section b is from the 1994 experiment. P-wave velocities are in kilometers per second.

to Mombasa. These long-period measurements, which will target depths of up to 100 km, will be augmented by short-period magnetotelluric and transient electromagnetic soundings to determine the conductivity structure of the uppermost crust.

The geophysical investigations of the Chyulu Hills are part of a multidisciplinary research program of the University of Karlsruhe and follow geological field studies in the central Kenya rift and petrological field studies of xenoliths at several sites along the eastern shoulder of the Kenya rift. Together with nearby Mount Kilimanjaro, the Chyulu Hills form an impressive Quaternary volcanic field which lies east of the physiographic rift valley (Figure 1). Petrologic data suggest that the crust is about 40 km thick in this area [*Henjes-Kunst and Altherr*, 1992]. Compositions and geothermobarometry of mantle xenoliths brought up by the Quaternary volcanics can be used to predict seismic velocities which can be compared to the measured ones [*Mechie et al.*, 1994], thus providing insight into the composition and thermal state of the lithosphere. This is an example of the integrated analysis which is being stressed during this phase of KRISP.

Preliminary Data Analysis

The major researchers involved in the active component of the seismic experiment met in Germany to conduct a preliminary analysis of the data. A full, integrated workshop will be held in March to complete this process. An initial look at the seismic record sections (Figure 3) reveals excellent seismic wave transmission across the rift with good signal-to-noise ratio provided by every shotpoint. A variety of crustal reflections and refractions observed will allow for the determination of relatively detailed crustal structure.

In addition to excellent crustal coverage from phases such as Pg (a refraction traveling in the uppermost crust) and PmP (a reflection from the base of the crust), a significant amount of data on upper mantle structure was obtained because the Pn phase (a refraction

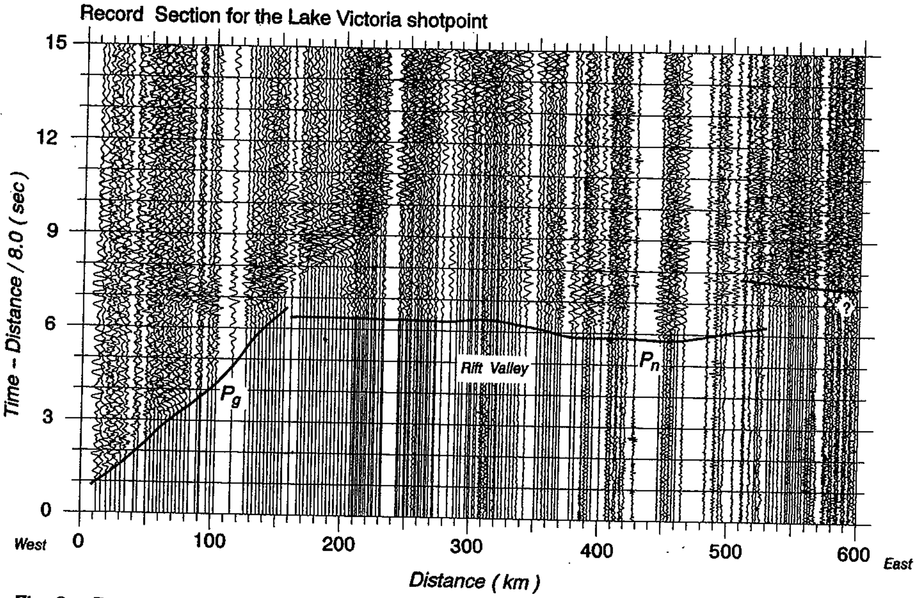

Fig. 3. Record section for the Lake Victoria shotpoint (VIS; Figure 1) of the 1994 experiment. Data from Lines F and G (Figure 1) have been merged to produce this plot. Pg-refracted wave traveling in the upper crust. Pn-refracted wave traveling in the uppermost mantle. The record section is typical of the data quality.

traveling in the uppermost mantle) and other mantle arrivals were found on most of the record sections out to the most distant recording station. Two western shotpoints (VIS and MOR) provided arrivals to distances of 600 km (Figure 3) and 450 km, respectively. As observed in previous experiments, transmission in the upper crust was more efficient outside the rift valley, but the differences disappeared for deeper penetrating phases such as Pn.

Preliminary interpretation of the new data shows unexpected new features underlying this classic geologic structure. Crustal thinning at Magadi (Figure 2b) about 100 km south of the Kenya dome is similar to that at Baringo about 100 km north of the dome (Figure 2c). However, the crustal thinning beneath the Magadi section of the rift valley south of the domal uplift is flanked by thicker crust to the east (38–42 km) than to the west (<35 km) where the major Nguruman fault bounding the rift in this area is located (Figure 2b). This is in contrast to the situation below the 1990 cross line through Lake Baringo north of the dome where the crust on either side of the rift tends to be of nearly equal thickness [*Braile et al.*, 1994; *Maguire et al.*, 1994] or slightly thicker beneath the western flank (Figure 2c), where the major Elgeyo fault bounding the rift in this section is found.

It was surprising to find relatively thin crust (<35 km) west of the rift valley all the way to Lake Victoria. In addition, some of the thickest crust observed beneath Kenya (38–42 km) extends eastward for over 300 km from the Lake Magadi region beyond the Chyulu Hills/Kilimanjaro area (Figure 2b).

Thinning of the lithosphere in this region was suggested by the earlier KRISP teleseismic surveys [*Achauer et al.*, 1994; *Slack et al.*, 1994]. Below the Quaternary volcanic field of the Chyulu Hills, the uppermost mantle velocity (Pn) is 8.0-8.1 km/s and about 20 km of the thick (>40 km) crust consists of a fast basal layer with a velocity of 6.8–6.9 km/s. The Pn velocity of 8.0–8.1 km/s seems to be in agreement with the xenolith-derived geotherm, corresponding to a surface heat flow of 60 mW/m^2, for the Chyulu Hills area [*Henjes-Kunst and Altherr*, 1992].

Further refinement of these preliminary observations combined with the ongoing conductivity, gravity, and petrological studies should lead to major advances in our understanding of the mechanisms of uplift, extension, faulting, and volcanism within and outside the Kenya rift. There is clearly a need to extend these integrated studies beyond Kenya to understand relationships with other major segments of the East African rift system. For example, the southern extent of the apparent axial symmetry in terms of crustal thickness has important implications for the nature of the processes that are causing the extension, volcanism, and uplift.

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References

Achauer, U., and the KRISP Teleseismic Working Group, New ideas on the Kenya rift based on the inversion of the combined data set of the 1985 and 1989/90 seismic tomography experiments, *Tectonophysics, 236*, 305, 1994.

Braile, L. W., B. Wang, C. R. Daudt, G. R. Keller, and J. P. Patel, Modelling the 2-D seismic velocity structure across the Kenya rift, *Tectonophysics, 236*, 251, 1994.

Henjes-Kunst, F., and R. Altherr, Metamorphic petrology of xenoliths from Kenya and northern Tanzania and implications for geotherms and lithospheric structures, *J. Petrol., 33*, 1125, 1992.

Keller, G. R., et al., The East African rift system in the light of KRISP 90, *Tectonophysics, 236*, 465, 1994.

Maguire, P. K. H., C. J. Swain, R. Masotti, and M. A. Khan, A crustal and uppermost mantle cross-sectional model of the Kenya Rift derived from seismic and gravity data, *Tectonophysics, 236*, 217, 1994.

Mechie, J., K. Fuchs, and R. Altherr, The relationship between seismic velocity, mineral composition and temperature and pressure in the upper mantle—with an application to the Kenya rift and its eastern flank, *Tectonophysics, 236*, 453, 1994.

Morley, C. K., W. A. Wescott, D. M. Stone, R. M. Harper, S. T. Wigger, and F. M. Karanja, Tectonic evolution of the Northern Kenyan Rift, *J. Geol. Soc. London, 149*, 333, 1992.

Prodehl, C., G. R. Keller, and M. A. Khan, Crustal and upper mantle structure of the Kenya rift, *Tectonophysics, 236*, 483 pp., 1994.

Slack, P. D., P. M. Davis, and the Kenya Rift International Seismic Project (KRISP) Teleseismic Working Group, Attenuation and velocity of P-waves in the mantle beneath the East African Rift, Kenya, *Tectonophysics, 236*, 331, 1994.

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