KARATAU, MAKANCHI, AND LOCATION IN WESTERN CHINA

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ABSTRACT

The introduction of the Karatau (KKAR) and Makanchi (MKAR) seismic arrays into central Asia is changing the nature of seismic event location in that region. This paper presents a preliminary look at location calibration issues associated with these stations. We are exploring the improvement in earthquake location in Central Asia made possible by data from the Karatau Array in Kazakhstan in conjunction with the Makanchi Array and Global Seismic Network (GSN) stations. Parts of central Asia are sparsely instrumented and we need to make the maximum possible use of all stations and arrays. The two arrays provide azimuth estimates to an event—in addition to seismic phase arrival times—thereby improving the location of small events recorded at only a few stations. The apparent velocity of an arrival across the arrays is also useful for confirming phase identification. Preliminary azimuth and slowness correction surfaces have been developed for both arrays and are being tested with the National Nuclear Security Administration's event location algorithms. At MKAR, azimuth corrections are of moderate size, with a standard deviation of about 7°, while slowness corrections have a standard deviation of about 0.028 sec/km. Azimuth and slowness corrections at KKAR are similar. Very preliminary travel time correction surfaces are also presented for MK31 and KK31, the broadband central stations at the arrays. These surfaces are much more sparsely populated than surfaces for azimuth and slowness due to tighter restrictions on event locations required for travel time data.

We believe that the Karatau seismic array frequently records useful Pg phases in cases where Pn is lost in the noise. Apparent velocity can substantiate the Pg identification and, if a correction surface can be formed, we may have an additional phase available at Karatau for locating some events. Examination of waveforms from a number of events at Karatau (and Makanchi) shows a clear error in some of the Reviewed Event Bulletin (REB) solutions, and we will add our phase picks and azimuth estimates to all available information to improve locations.

OBJECTIVES

The objective of this research is to improve seismic event location in western China using the Makanchi (MKAR) and Karatau (KKAR) seismic arrays.

RESEARCH ACCOMPLISHED

Azimuth and slowness corrections

We developed code to estimate the azimuth and apparent slowness for seismic phases arriving at a regional array. Using predicted values from a great circle path and an assumed earth model, the deviations of the estimates of azimuth and slowness, respectively, were used as residuals to derive the kriged correction surfaces. The derivations were performed in the Knowledge Base Calibration Integration Tool (KBCIT), using Modified Bayesian Kriging (*Schultz et al.,* 1998). We have also developed a procedure to estimate confidence bounds for the estimated azimuth and slowness (*Blandford*, 1974; *Shumway*, 1971).

We begin the procedure with an event at a regional distance from MKAR and/or KKAR and a published location. We specifically choose events large enough to be well located, so that we can expect to measure the errors in azimuth and slowness associated with the array analysis and not with an event mislocation. We identify and pick visible seismic phases or use appropriate group velocity windows for phases that are not readily selectable by a trained seismologist. For each phase we construct an energy surface of the simple delay and sum plane-wave beam for a grid of horizontal slownesses. We take the peak energy to be a first order estimate of the arrival and then define the region that is greater than a given fraction—for example, 70% of the peak beam energy. We normalize the beam energy surface for the region so that the total volume is 1, and treat the region and the normalized energy surface as defining a density function. We then compute the mean value and the second moments over the bounded slowness surface, treating the mean slowness as the refined estimate of the arrival and second moments as defining the confidence limits of the estimate of the arrival. The results are shown in the left panel of Figure 1, where the warmer colors (reds, yellows, oranges [i.e., lighter shades]) represent large beam energy and the white 'X' is the peak on the grid. The white elliptical region represents the border of the region used to define the density function. The right panel shows the time domain beam for the Pn-phase estimated azimuth and slowness and the time domain F-detector trace. The F detector exhibits a strong peak for the Pn arrival as shown in the red portion of the two waveforms (or the small/large amplitudes at the beginning of the beam/F-Detector waveforms, respectively). Unlike the beam, which has significant energy for later phases, the F detector shows much lower values for the later phases. This behavior is most probably caused by the poor coherence of later phases when beamed at the Pn slowness.

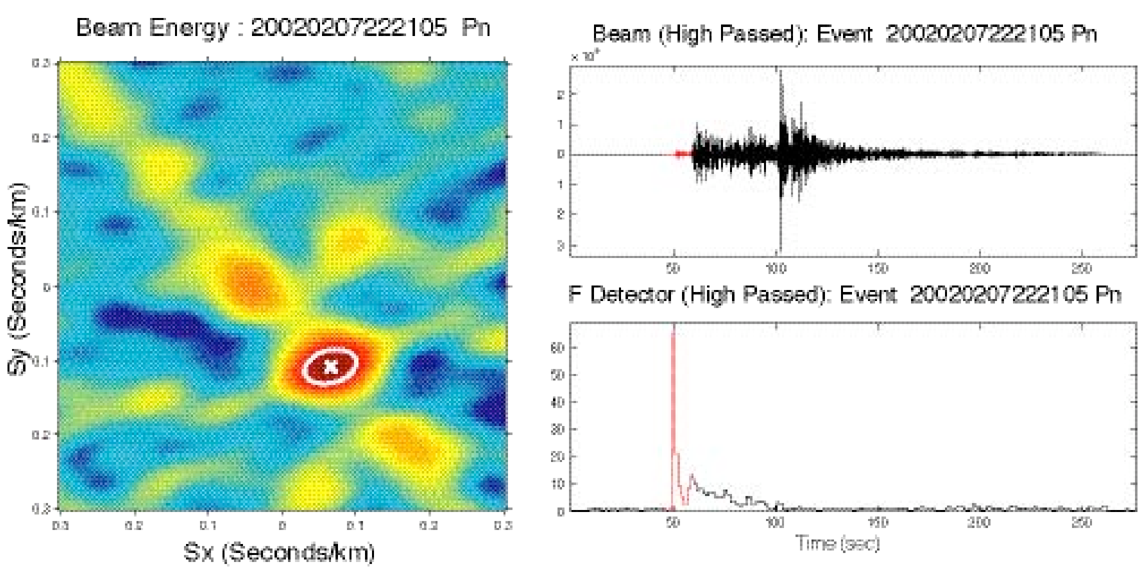

Figure 1. Seismogram, F-detection, and beam energy for an event seen at MKAR.

To produce azimuth and slowness correction surfaces, 234 events were processed for KKAR and 226 events were processed for MKAR. No ground-truth (GT) criteria were imposed to limit the data entered into KBCIT. However, events with bulletin depths greater than 51 km and, in the case for azimuth measurements, error standard deviations of greater than 15° were manually removed from the data. Following outlier removal, KKAR and MKAR azimuth pipelines consisted of 147 and 137 events, respectively. Conveniently, this process removed events close to the stations where mislocations could contribute signal to the residuals. Standard deviations of 6.5 and 7.0 degrees are observed at MKAR and KKAR. Slowness standard deviations are observed to be 0.028 and 0.022 s/km at MKAR and KKAR, respectively. It is possible that some deep events have remained in the event population used to form the surfaces, which could distort the corrections and will be investigated further. Figure 2 shows azimuth corrections for both MKAR and KKAR, and it is interesting to compare azimuth residuals for the two arrays from the west end of

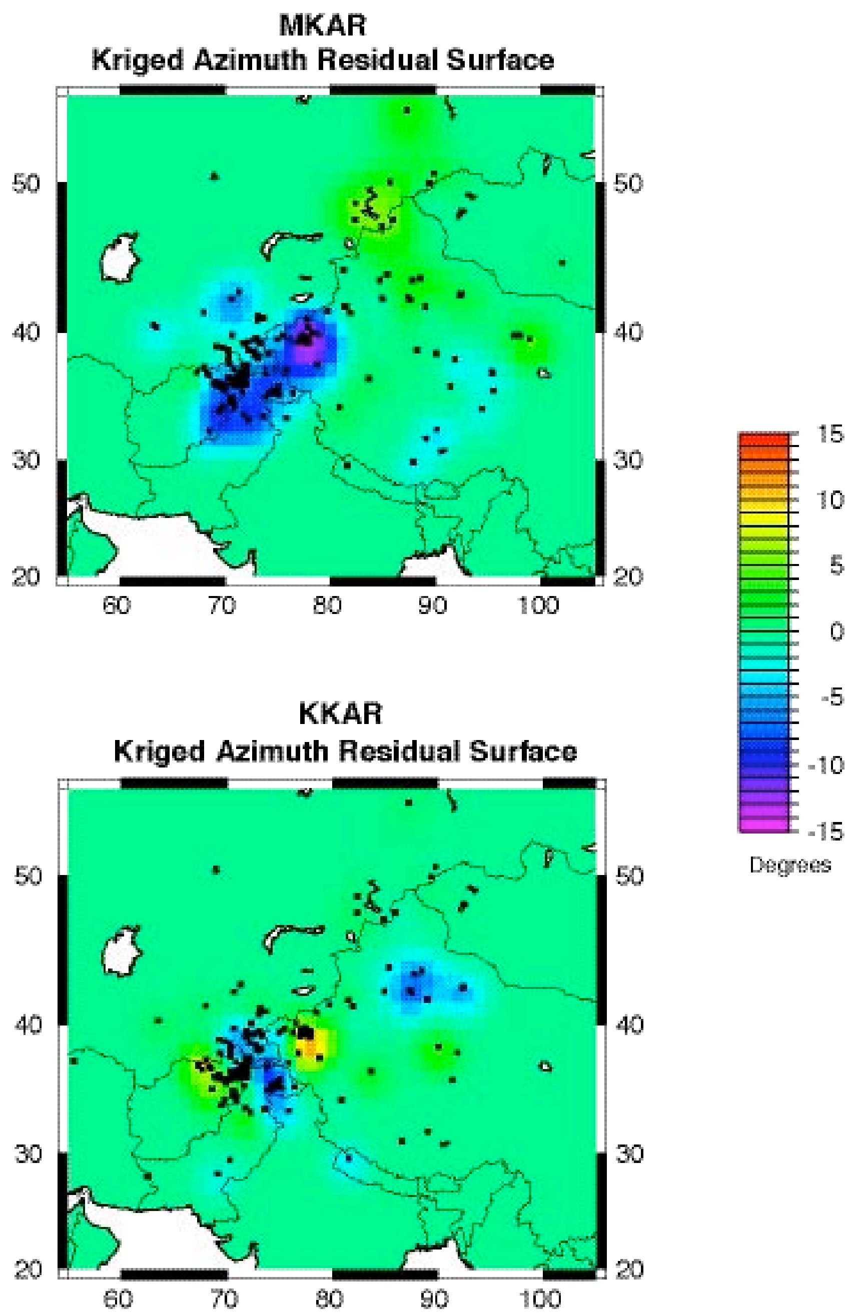

Figure 2. Kriged Pn azimuth correction surfaces for MKAR and KKAR.

the Tarim Basin, at about 40° latitude and about 78° longitude. It appears that the Tien Shan causes a defocusing effect for events from this location to the two arrays, which could be explained by thicker and slightly slower crust for this tectonic province compared to those surrounding it. Figure 3 shows slowness correction surfaces for the two arrays.

Travel time corrections

Preliminary travel-time correction surfaces are calculated for MK31 and KK31 using picks by Los Alamos National Laboratory (LANL) analysts. Ground-truth levels are required to be GT20 or better, based on the *Bondar et al.* (2003) criteria, and hence, fewer data are available for the construction of these surfaces than for those of slowness and azimuth.

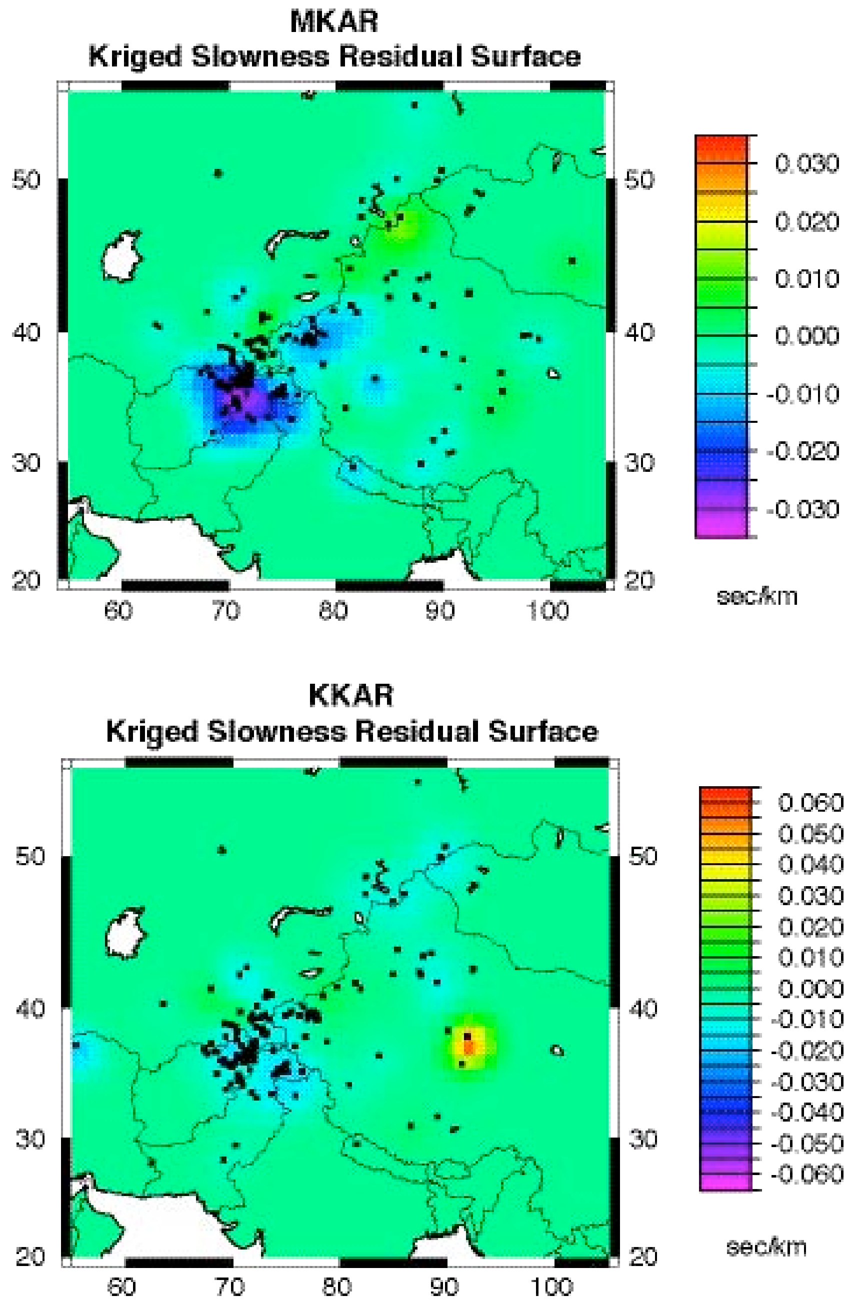

Figure 3. Kriged Pn slowness correction surfaces for MKAR and KKAR.

Data at KK31 were limited and only available for about a 5-month time period. Within this time frame, only 4 events had sufficient ground-truth quality to be included. Natural seismicity will eventually provide higher quality ground truth for this station. Figures 4 and 5 show kriged travel time correction surfaces. In Figure 5, the March 13,

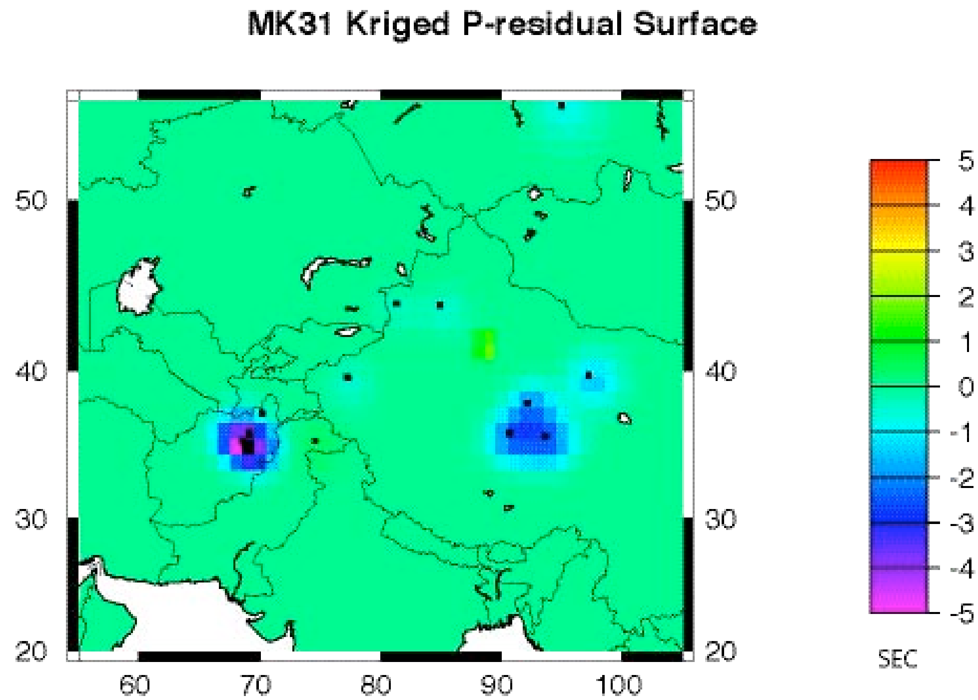

Figure 4. Kriged P travel-time correction surface for MK31.

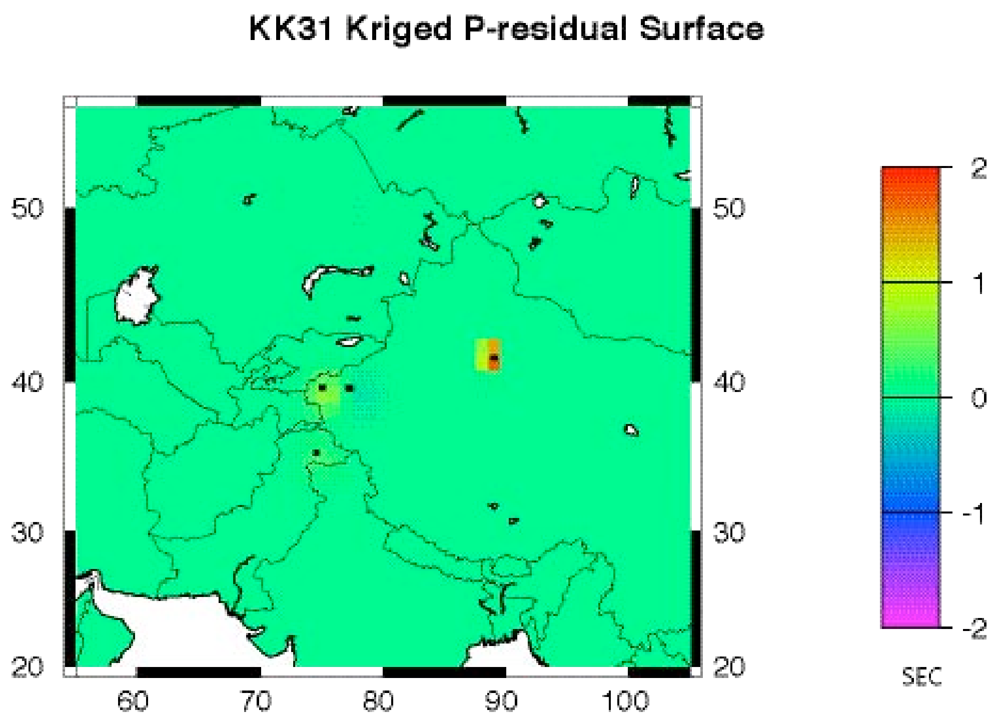

Figure 5. Kriged P travel time correction surface for KK31.

2003 earthquake near Lop Nor is the source of the “bright spot” at that location.

Phase detection at Karatau

We observe that the Karatau seismic array frequently records useful Pg phases in cases where Pn is lost in the noise. Apparent velocity can substantiate the Pg identification and, if a correction surface can be formed, we may have an additional phase available at Karatau for locating some events. To illustrate these phenomena, we use events from a mainshock/aftershock sequence near Kashgar in the Xinjiang province of China (Figure 6) that began on Feb 24, 2003. Figures 7 and 8 compare Pg propagation at MK31 and KK31—the broadband three-component stations of the MKAR and KKAR arrays. The Pg onset at KK31 is quite pronounced, particularly when compared to MK31. Figure 9 shows Pn disappearing into the noise at KK31, while Pg remains a prominent arrival. Adding KK31 Pg arrivals into our relocations where Pn is absent results in several additional convergent locations among the aftershock population. Examination of a number of events at Karatau (and Makanchi) shows a clear error in some of the REB solutions, and we add our phase picks and azimuth estimates to all available information to improve locations.

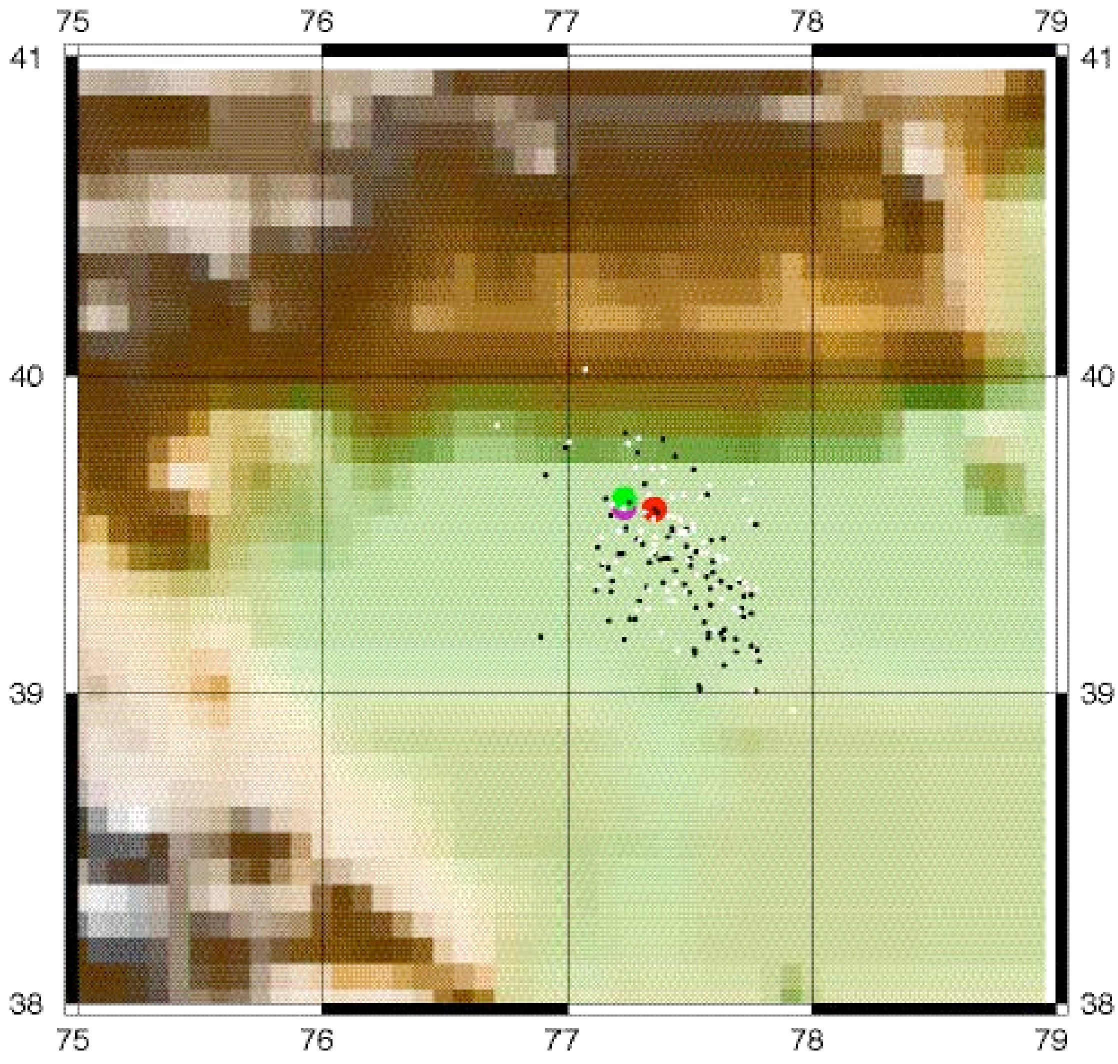

Figure 6. Mainshock/aftershock sequence in western China. Large dots are the mainshock locations from different sources: the rightmost (red or dark grey) dot is the REB solution, upper left (green or light gray) dot is the EDR Weekly solution, and lower left (purple or medium gray) dot is the LANL solution using a merged database. The small black dots are REB aftershocks and the small white dots are LANL relocations.

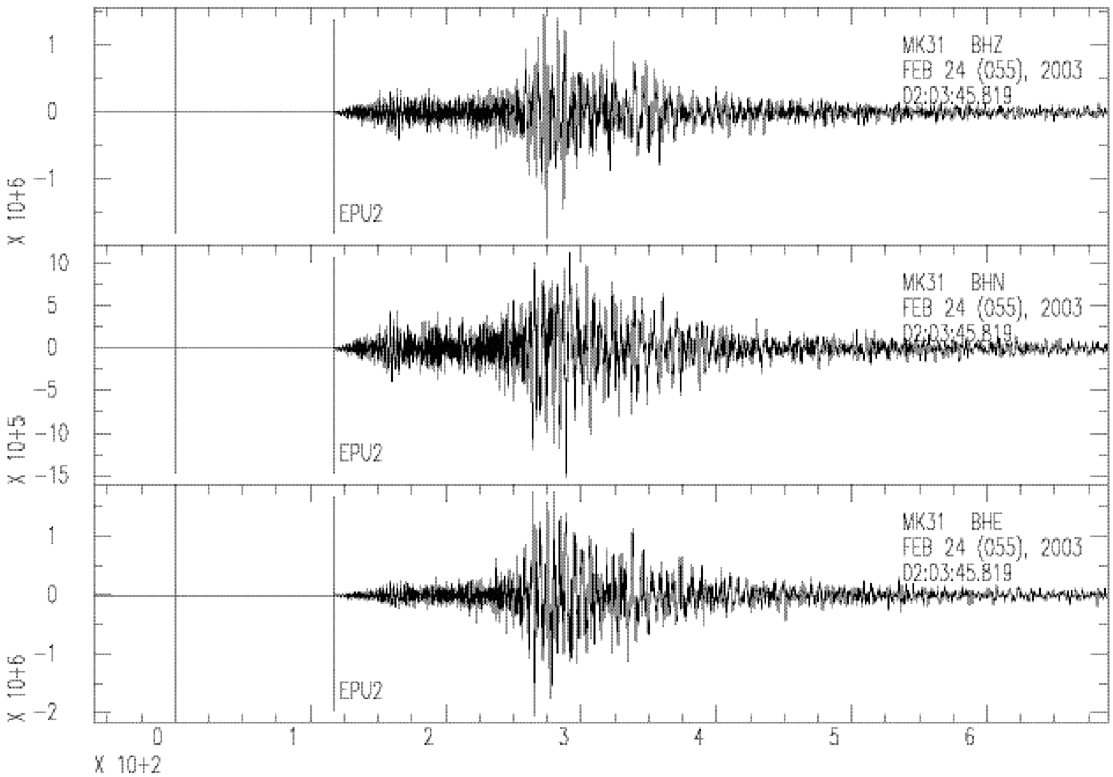

Figure 7. MK31 broadband seismograms for mainshock.

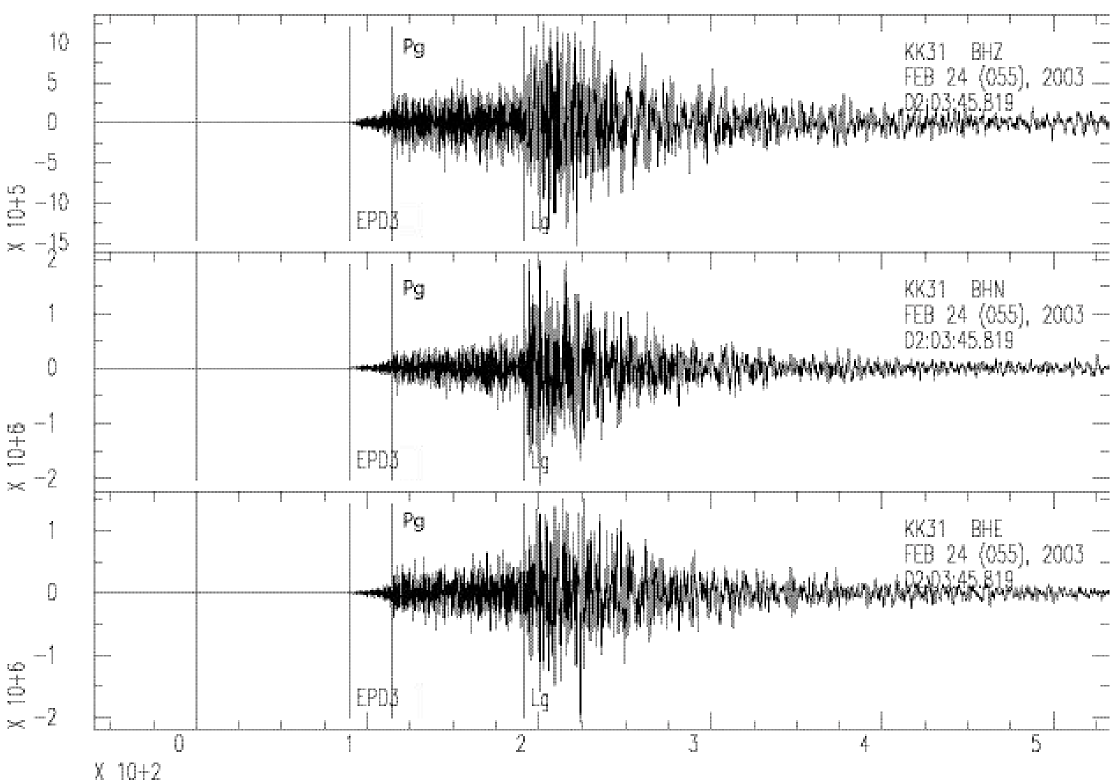

Figure 8. KK31 broadband seismograms for mainshock.

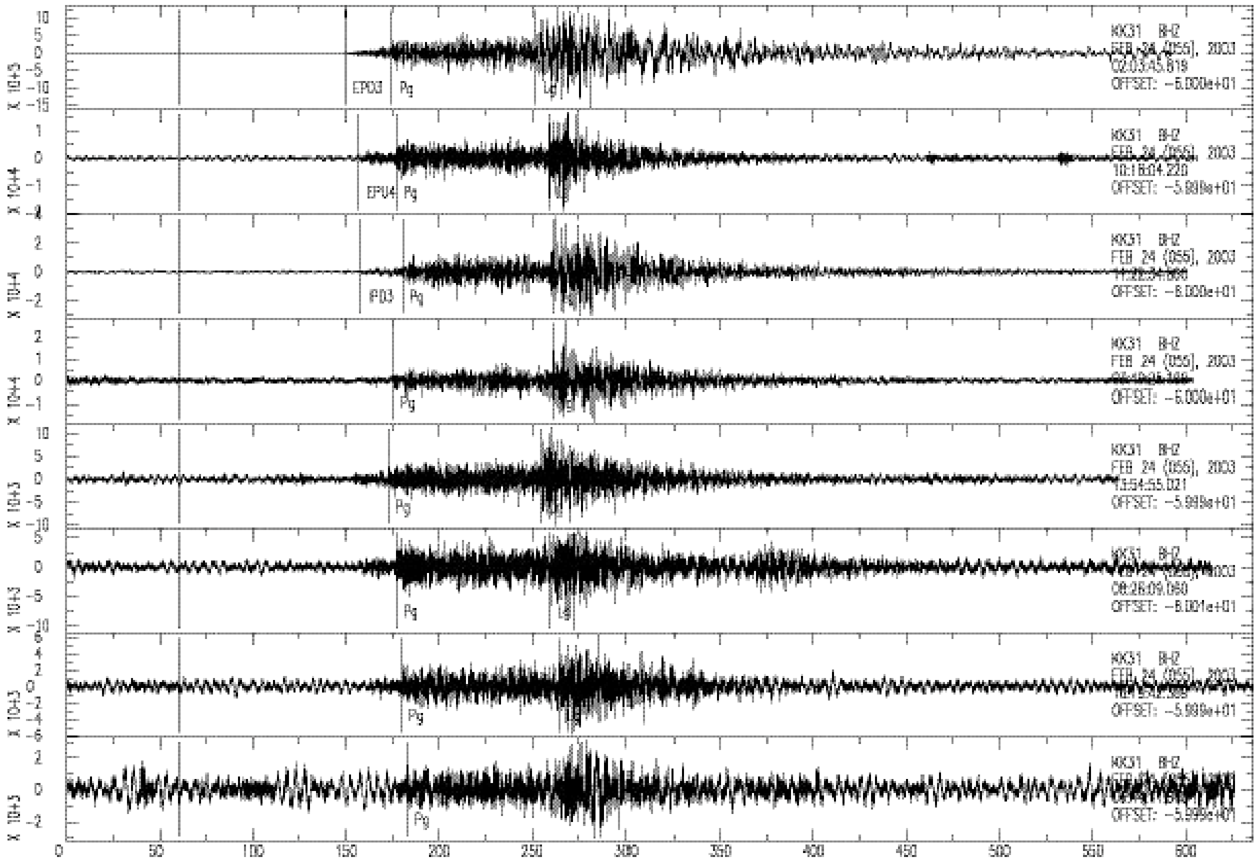

Figure 9. Mainshock (top) and selected aftershocks at KK31 showing Pn, Pg, and Lg phase picks.

CONCLUSIONS AND RECOMMENDATIONS

In our preliminary investigations, we find clear azimuth and slowness perturbations associated with regional arrivals seen at KKAR and MKAR. We will implement and test the effect of correcting for these perturbations, which should improve our location ability for smaller events. Travel-time data at KK31 are very sparse because of its short history. Over time, natural seismicity should rectify this shortcoming. Though station MK31 is more mature, secondary phases are also not plentiful. It is clear from regional wave propagation characteristics at these stations that correction surfaces for secondary phases—and here we use the term broadly to include all post-first-P arrivals—would be of great benefit to location efforts in this area.

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