AN INTERESTING REGIONAL SEISMIC EVENT FROM QINGHAI PROVINCE, CHINA

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ABSTRACT

We anticipate that regional seismology will play a key role in future monitoring for potential underground nuclear tests. Understanding the regional characteristics of wave propagation, including source, path, and site effects, will be required before such monitoring becomes routine. To prepare for such monitoring, we have been studying many seismic events from central Asia recorded at regional distances. Here we report on one particularly interesting event from Qinghai Province, China that provides a good example of why a comprehensive regionalization effort is required for successful monitoring.

On December 6, 1997, a seismic event with m_b near 4.5 occurred in a mountainous region (over 4000 meters elevation) of the east-central Qinghai Province, China. The event was detected and located by the prototype International Data Centre (pIDC) and by the National Earthquake Information Center (NEIC). Both organizations fixed the depth when estimating the event's location. The pIDC estimated an m_b of 4.2 and an M_S (using only 2 stations) of 3.4. Using the pIDC m_b:M_S event screening criteria this event falls within the earthquake population. From the regional waveforms for this event we observe, in general, that signal-to-noise ratios are poor for body waves at frequencies above about 2 Hz, except at stations WMQ (1350 km) and MAKZ (2000 km). Rayleigh and Love waves at periods between about 15 and 25 seconds generally have good signal-to-noise ratios at most regional stations. We merged arrival times from regional stations with times from the NEIC and pIDC bulletins and relocated the event. Our relocation moved the event about 10 km farther south, but we could not constrain depth.

At WMQ we observe that P_n above 1 Hz is exceptionally strong relative to the shear phases S_n and L_g, and P_n is also unusually strong relative to the Love and Rayleigh waves. From our experience with regional short-period discriminants in central Asia, we interpret such characteristics as indicative of an explosion. To better understand this event we modeled the Rayleigh and Love waves to estimate source parameters (moment, depth, source mechanism). We found a best-fit source model of a strike-slip double-couple earthquake with a source depth of near 20 km and an approximate seismic moment of 1.76×10^{16} Nm (M_w = 4.8). The strong P_n amplitude at WMQ may be attributed to the focal mechanism, rupture directivity, and energy focusing at the crust-mantle boundary along the path from the source region to WMQ. In summary, this earthquake provides a good example of how the relationship among source, path, and site effects must be understood in preparation for regional seismic monitoring.

Key Words: discrimination, seismic sources, regional seismology

OBJECTIVE

Over the past several years seismic verification research has emphasized the analysis of seismograms recorded at regional distances (between about 200 and 2000 km). The primary objective of this research has been to lower magnitude levels at which events can be detected, located, and identified. Our efforts have been directed at regional event identification in Asia. While conducting seismic regionalization research we have come across an interesting seismic event from Qinghai Province, China (Figure 1). The short-period body wave characteristics of this event are quite explosion-like, while the long-period characteristics are more similar to an earthquake. Below, we present a detailed analysis of this event. Our objective is to show how careful regionalization and discrimination research efforts are necessary for the future successful monitoring of nuclear-test-ban treaties.

RESEARCH ACCOMPLISHED

Observations

On December 6, 1997, at near 04h53m GMT, a seismic event occurred in a mountainous region of the east-central Qinghai Province, China (Figure 1). The event was detected and located by the prototype International Data Centre (pIDC) and by the United States Geologic Survey National Earthquake Information Center (NEIC). Both organizations used only teleseismic records when estimating the event's location, and neither organization attempted to estimate an event depth. The pIDC assigned an m_b of 4.2 and an M_S (using only 2 stations) of 3.4. The NEIC assigned an m_b of 4.5. We merged arrival times from regional stations with times from the NEIC and pIDC bulletins and relocated the event. Our relocation moved the event about 10 km farther south, but we could not constrain depth. Because the Qinghai Province is seismically active, and because this event was small enough that it was not associated with any damage reports, it generated little seismological interest. Further, the event did not occur near any nuclear test site, and thus was of little interest to the nuclear test monitoring community.

During routine processing of regional data recorded at station WMQ, we noticed that this event had unusually strong P_n amplitude relative to the S-phase amplitudes, suggesting a possible explosion source. Hence, we gathered additional waveforms, primarily form Chinese Digital Seismic Network (CDSN) stations, for further analysis. Unfortunately, stations LZH and and XAN were not operating on December 6, 1997 (Figure 1). In general, signal-to-noise ratios are low for body waves at frequencies above about 2 Hz, except at stations WMQ (1350 km) and MAKZ (2000 km) (Figure 2, top). Figure 2 (bottom) compares the 06 December event with a similarly sized earthquake that occurred in June 1988 only 16 km from the Qinghai event. The P_n(4-8 Hz) amplitude of the Qinghai event is much larger than the S_n(0.75-1.5 Hz) amplitude, while the S_n amplitude of the 1988 earthquake is greater than its corresponding P_n amplitude.

Rayleigh and Love waves at periods between about 15 and 25 seconds generally have good signal-to-noise ratios at most regional stations for the Qinghai event (Figure 3). Large nuclear explosions in Asia have been known to generate strong Love waves (Walter and Patton, 1990; Wallace, 1991) through tectonic release. Hence, observing both Rayleigh and Love waves for a given event can not necessarily rule out the possibility of an explosion source. From an initial examination of the surface waves, we can only assume that the event was not an unusually deep earthquake.

Forming P_n/S_n discrimination ratios using WMQ measurements (details found in Hartse et al., 1997) emphasizes the unusually strong P_n energy of this event (Figure 4, top). Note that the Qinghai event falls high on the ratio plot and within the population of Kazakh Test Site (KTS) explosions. Furthermore, the other presumed earthquakes from the Qinghai area (squares) do not display these characteristics. As suggested by the strong Rayleigh waves, however, the pIDC m_b:M_S event screening criteria place the Qinghai event within the Asian earthquake population (Figure 4, bottom).

Summarizing the waveform observations, the short-period data (where it exceeds noise levels) suggests the Qinghai event may be an explosion, while the regional surface wave data imply the event is a crustal-depth earthquake, but the surface wave data do not absolutely rule out an explosion source. Possible explanations for these observations could include some combination of these factors: (1) some type of a large mining explosion, (2) an earthquake with an unusual source radiation pattern, (3) unusually strong S_n and L_g attenuation (or phase blockages) along the path to WMQ, (4) unusual focusing of P_n energy due to the geometry of the crust-mantle boundary along the path to WMQ. To better understand this event, we used surface waves to estimate source parameters. We present the surface wave inversion results below.

Surface Wave Source Inversion

Although there are many approaches to source inversions using regional data (e.g., Dreger and Helmberger, 1993; Ritsema and Lay, 1993), we use the approach outlined by Randall et al. (1995), where we deconvolve the instrument response, window, and filter the data prior to the source inversions. We refine the filtering process by performing a phase-matched filter instead of a typical bandpass (Herrin and Goforth, 1977). Summarizing, our approach is as follows: we remove the instrument response, perform phase-matched filtering, calculate a suite a synthetics for chosen regional velocity models, time shift the seismograms, and then invert for the moment tensor. We further explore the uniqueness of the solutions by performing a focal mechanism grid search.

We obtained a major double-couple solution with strike, dip, and rake of 190º ±5º, 71º ±10º, and -27º ±5º, respectively. The errors reflect the formal inversion uncertainty, but we later explored how unique this solution is with a grid search technique. The moment is 1.76×10^{16} Nm (M_w = 4.8) with a 16% non-double couple component. This moment estimate is uncertain given the different elastic parameters for different models. We plot the normalized L2 error as a function of depth (Figure 5, top), and find the depth estimate to be between 15 and 20 km. We also plot the focal mechanism at the minimum. For this solution, we obtain an excellent fit to the data for both Love and Rayleigh waves, except for BJT. We underestimate the amplitude at BJT, but match the dispersion characteristics adequately.

Figure 5 (bottom) compares our moment tensor solution with the moment tensor solutions of two larger earthquakes from the Qinghai Province. The moment tensor solutions for the larger events indicate thrust mechanisms. This is in contrast to our strike-slip mechanism for the 06 December event. We know that the larger events occurred about 50 km northeast of the 06 December event. The June 1988 earthquake, with waveforms shown in the bottom of Figure 2, occurred much closer to the 06 December event. We plan to analyze the regional surface waves of the June 1988 earthquake and compare its focal mechanism to those mechanisms shown in Figure 5.

CONCLUSIONS AND RECOMMENDATIONS

Because we were able to use regional surface waves to obtain a stable long-period moment tensor solution with little non-double component, we can conclude that the 06 December 1997 event from Qinghai Province is most likely an earthquake. The unusually strong high-frequency P_n amplitude at WMQ may be due to one or many contributing factors. These include enrichment of P_n high frequencies due to rupture directivity, and possibly path effects that focus some of the P_n energy beneath station WMQ. We still do not fully understand this event, and we do not have a complete explanation for why the relative P_n/S_n ratios of the 06 December 1997 event and the June 1988 event are so different (Figure 2, bottom). For future work, we will analyze the surface waves of the June 1988 event to learn more about its focal mechanism.

This event highlights the difficulties of monitoring small magnitude events in the context of a nuclear-test-ban treaty. Clearly, there will be some small earthquakes that will appear explosion-like on some discriminants. Combining several discriminants is an obvious solution to the event identification problem. We have shown that regional surface waves can prove to be important for event analysis. Furthermore, requirements for successful regional monitoring include well-calibrated paths, special processing techniques such as phase-matched filtering, and source modeling capabilities. Thus, regional discrimination must incorporate a range of tools, techniques, and data types to be robust.

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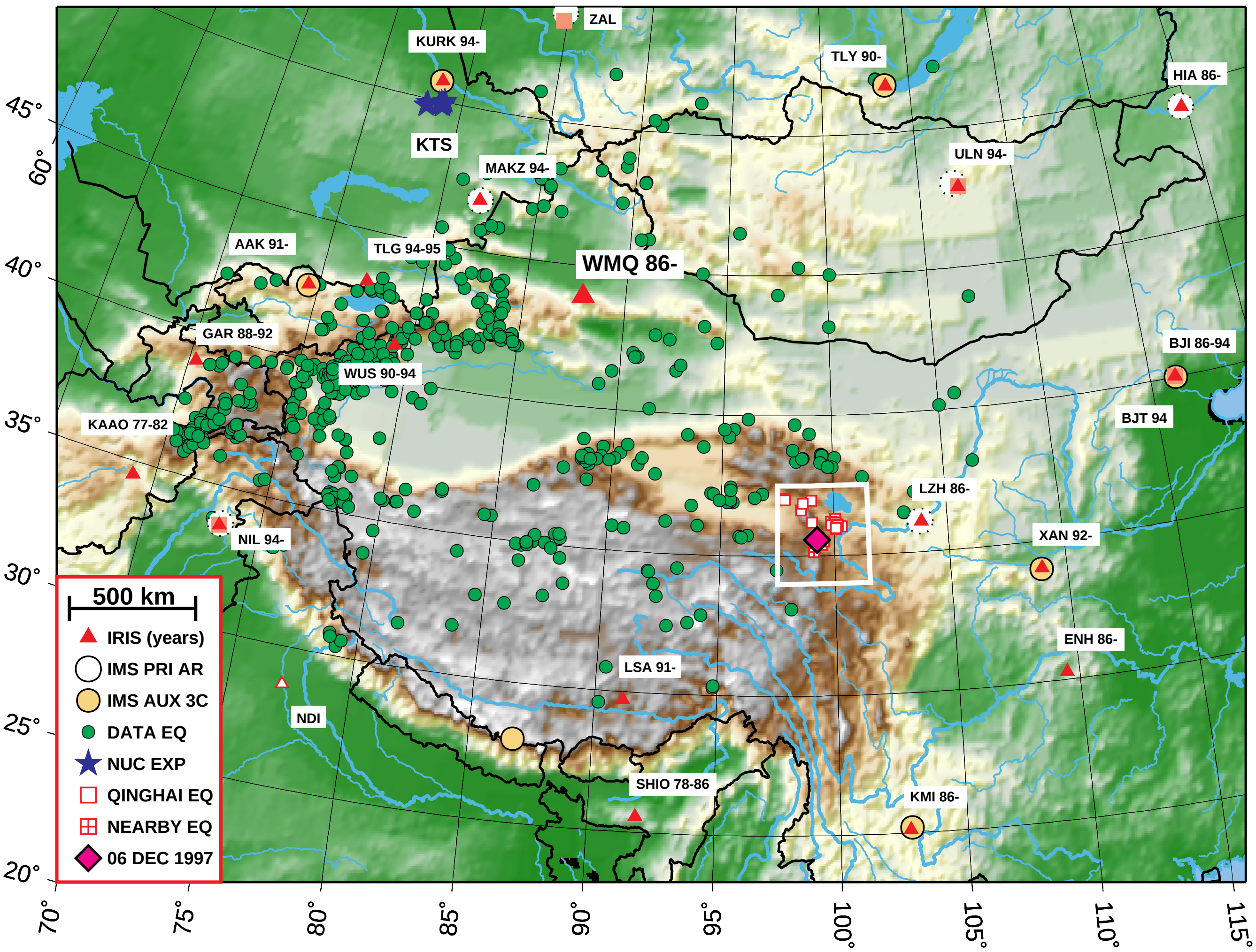


Figure 1. Map of central Asia showing Qinghai area inside white box. Stations LZH and XAN were not operational on 06 December 1997, when the Qinghai event (magenta diamond) occurred. We have primarily analyzed short-period waveforms recorded at WMQ, and surface wave data from the Qinghai event recorded at several regional stations. Earthquake locations are represented by green circles and red squares, and nuclear explosion locations are represented by blue stars from the Kazakh test site (KTS).

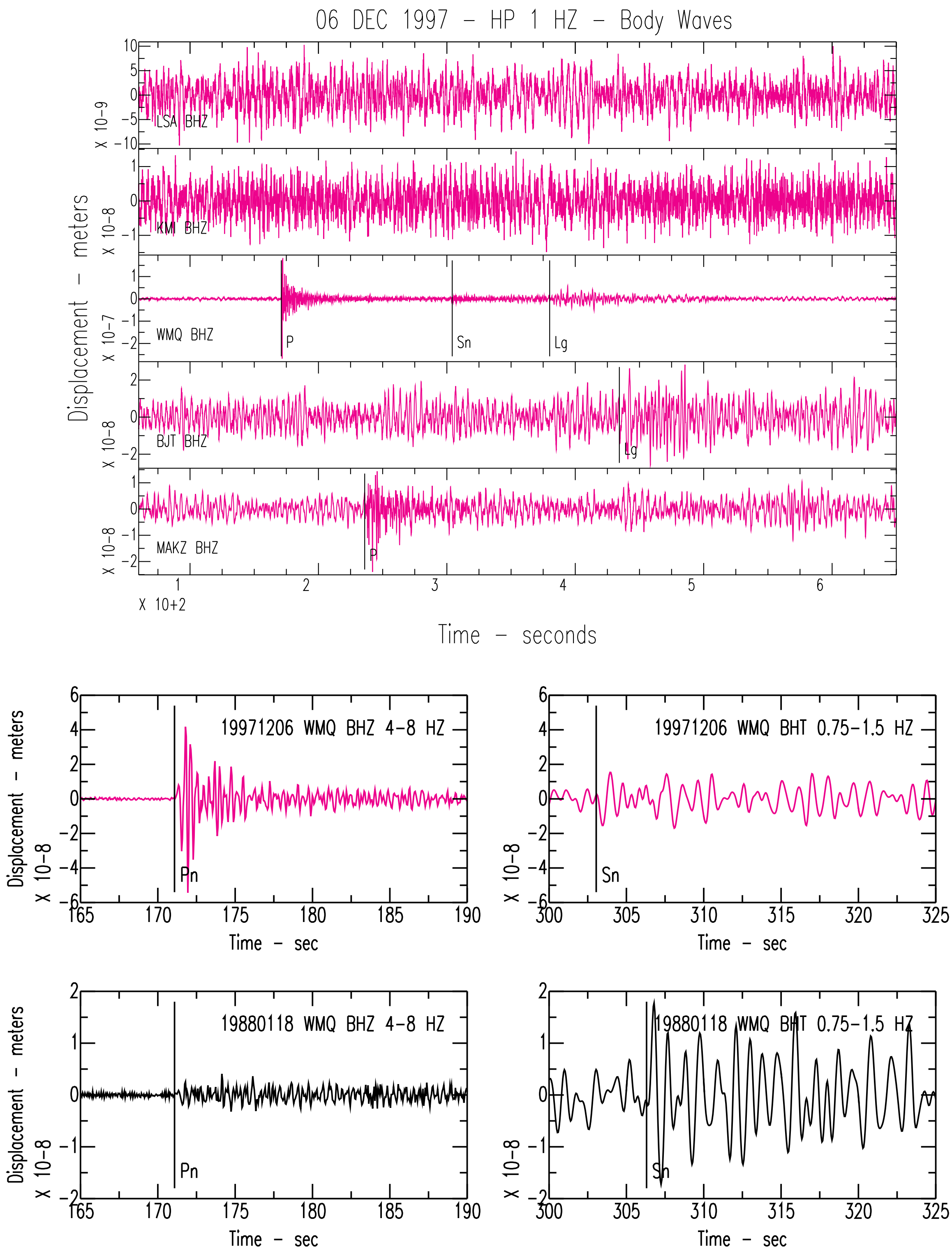
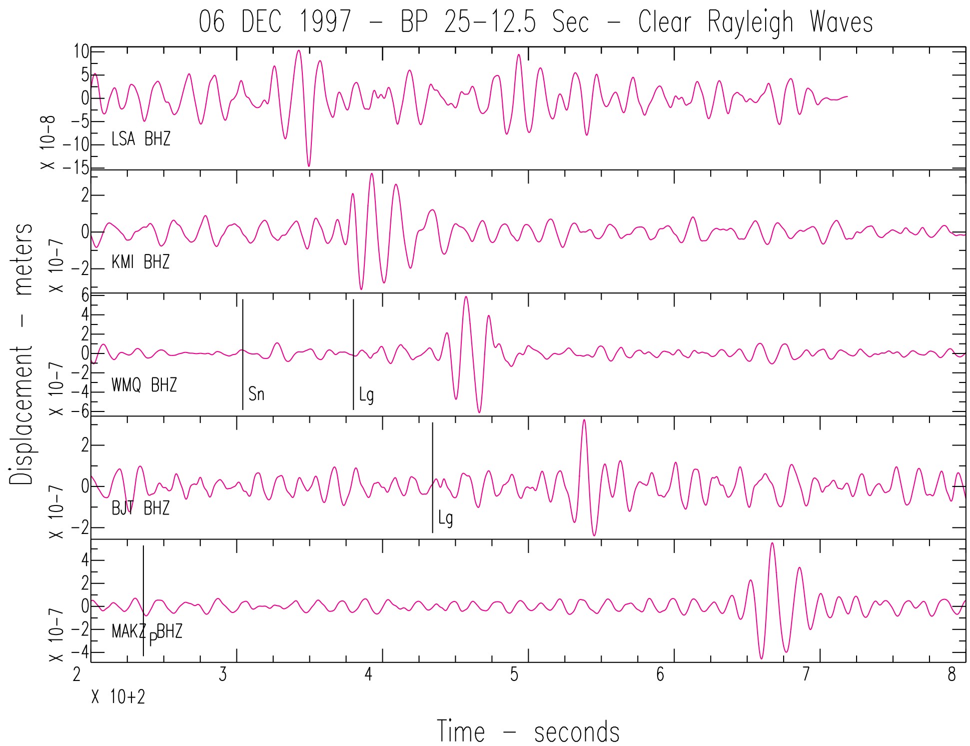


Figure 2. Regional body wave record section (top) of the Qinghai event as observed at stations LSA, KMI, WMQ, BJT, and MAKZ. With the exception of WMQ, most regional phase amplitudes fall within the background noise. The four bottom panels compare WMQ records of P_n and S_n from the Qinghai event to a similarly sized, nearby (16 km) earthquake from June 1988 (black traces). Note the unusually strong P_n amplitude of the Qinghai event relative to the S_n amplitude. Because of such a strong P_n amplitude, the Qinghai event falls within the explosion population on station WMQ P_n/S_n discrimination plots.



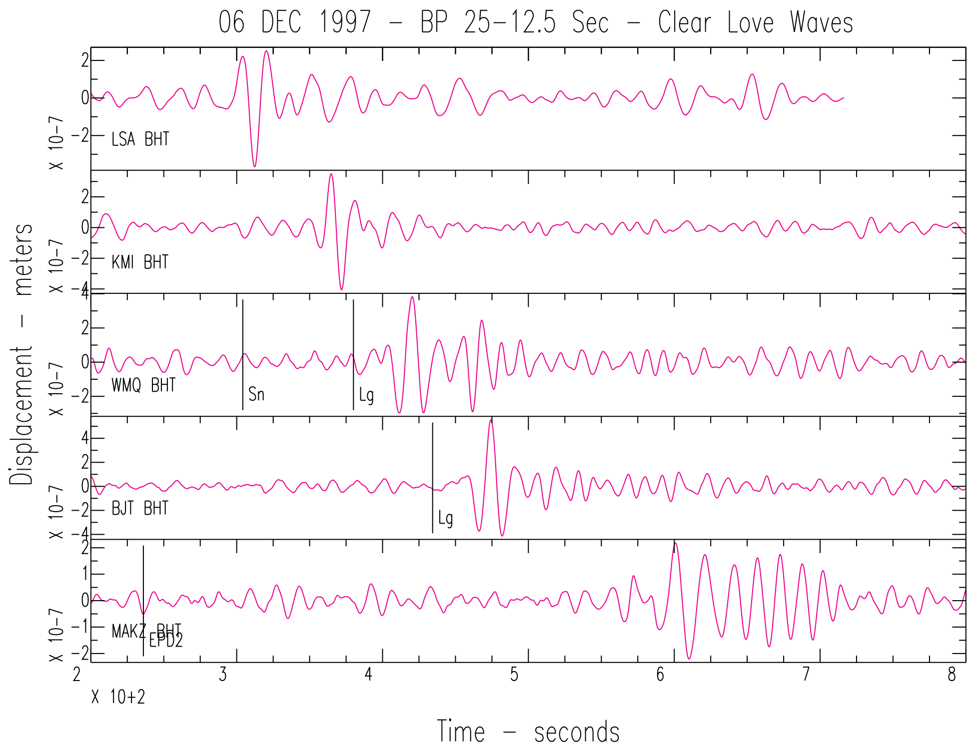


Figure 3. Regional surface wave record sections of the Qinghai event as observed at stations LSA, KMI, WMQ, BJT, and MAKZ. Clear Rayleigh waves (top) and clear Love waves (bottom) are observed at all stations. The strong surface waves of the Qinghai event suggest an earthquake source.

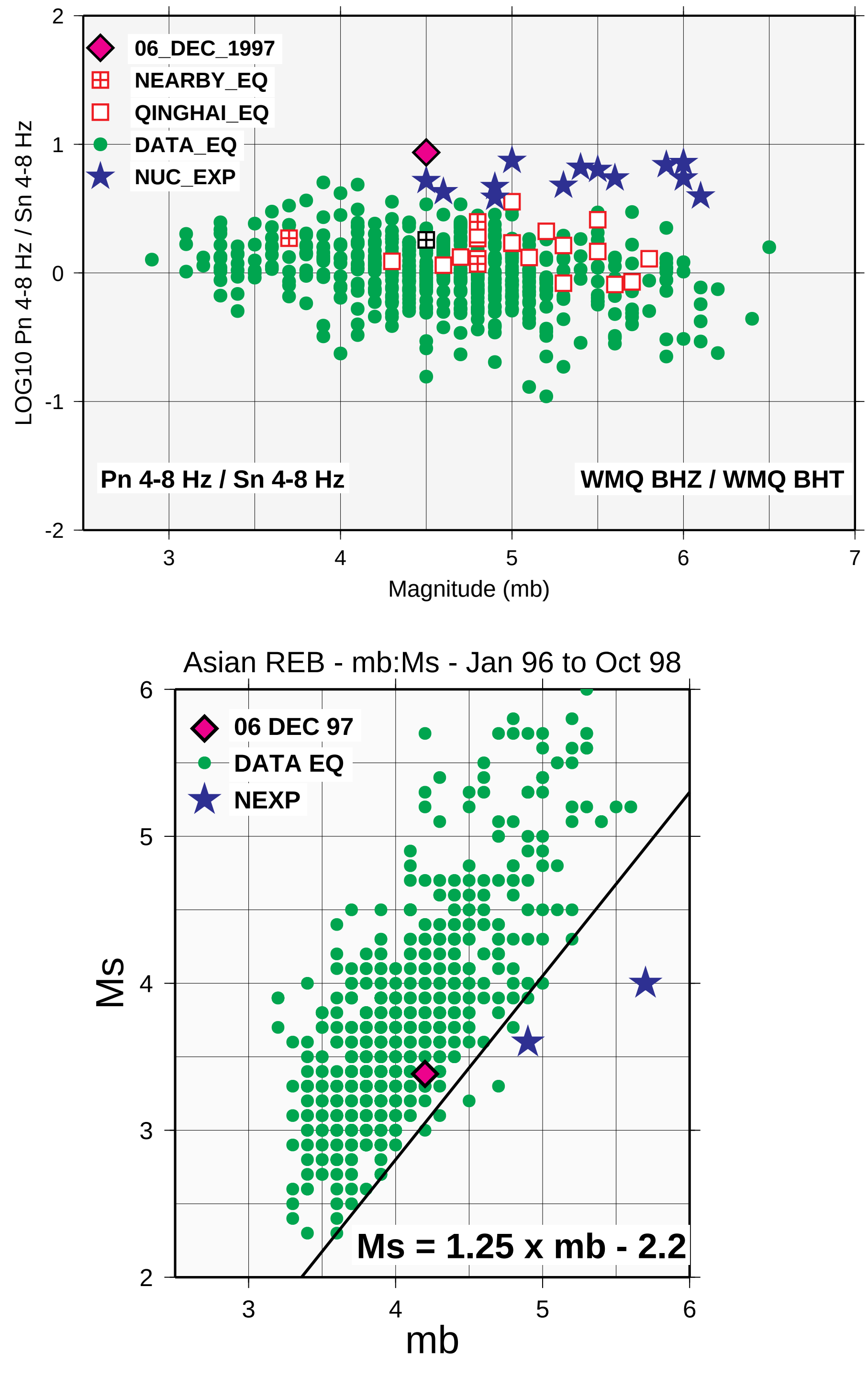


Figure 4. P_n/S_n ratio versus magnitude (top) for regional data recorded at station WMQ, and the teleseismic m_b:M_S relationship (bottom) based on the prototype International Data Center Reviewed Event Bulletin for Asian events between January 1996 and October 1998. Note that the Qinghai event (diamond) falls within the Kazakh test site explosion population at top, and it is distinctly separated from the other nearby Qinghai earthquakes (squares). The black square, well within the earthquake population, represents the June 1988 earthquake with WMQ waveforms shown in Figure 2. Note, however, that the Qinghai event falls within the earthquake population when surface wave magnitudes are considered as shown on the m_b:M_S plot (bottom).

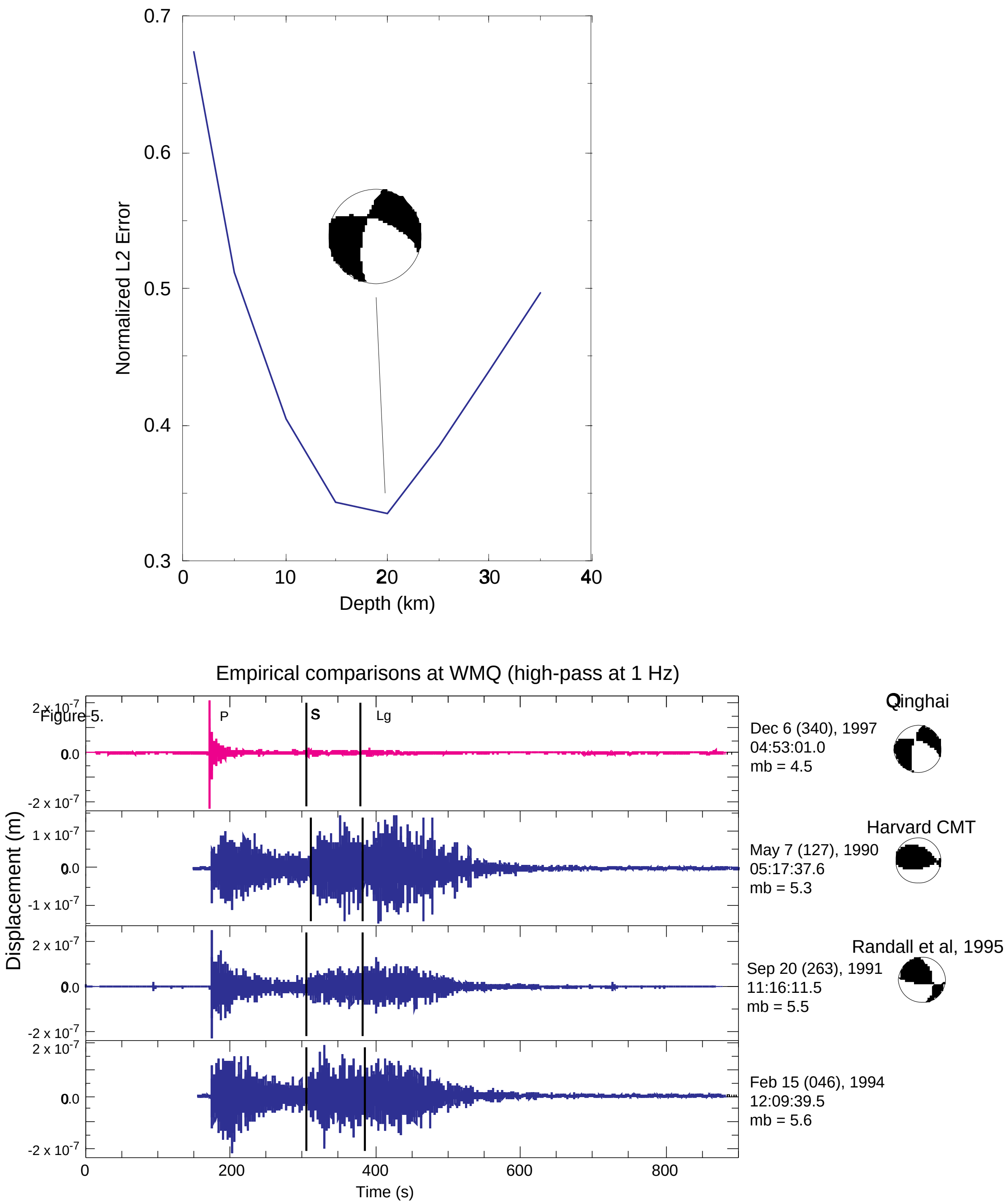


Figure 5. Error versus depth of our best-fit moment tensor solution for the Qinghai event (top). This solution was found by modeling regional Rayleigh and Love waves shown in Figure 3. Shown at bottom are the short-period waveforms and moment tensor solutions for the Qinghai event and other events from the Qinghai area. The Qinghai event is dominated by strike-slip motion while the other events are dominated by thrust motion.