KNOWING THE DEPTH OF A SHALLOW SEISMIC EVENT, HOW OFTEN CAN WE FIND DEPTH PHASES AT REGIONAL DISTANCES?

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ABSTRACT

Digital data from 14 events (magnitude 2.4 - 4.5) occurring during the 1981 Elk Lake, Washington earthquake sequence were examined for evidence of phases that could be used to establish focal depths from single recording stations at regional distances. Hypocentral parameters for the Elk Lake sequence are well known as a result of its occurrence within a dense monitoring network. Paths to stations at distances of 130 to 300 km are usually structurally complex. The P_n, P_mP, and P_g phases were found to propagate poorly, and consequently these phases are not promising candidates for use in depth determination. Phases that exhibit depth dependence were found at some stations, but at no station could two P phases be found whose time difference could be used to estimate focal depth. A pair of stations in the same azimuth showed observable time differences between phases that are a function of event focal depth. The time differences are small, 0.1 to 0.3 s for events having a 4 km range of focal depths. Our results suggest that good determination of focal depths from pairs of stations along the same azimuth is possible for events located in small source regions.

Objective

Focal depth determination of seismic events recorded at regional distances is potentially an important means of discriminating between small explosions and earthquakes. We are investigating the frequency with which identifiable crustal phases are recorded, the resolution of depth determination using crustal phases, and the frequency with which any given station can make such determinations.

Methodology

To test potential accuracy of regional phase focal depth determinations and applicability of the methodology to propagation paths through mixed or unknown structure, it would be desirable to study events in a region meeting the following criteria: (1) as many geologic provinces as possible located at regional distances; (2) known gross features of regional velocity structure; (3) widespread crustal seismicity with a good range of focal depths; and (4) well-determined hypocenters due to dense regional seismographic coverage. These conditions are met in the United States' Pacific Northwest.

Our procedure is to take events occurring at different depths in a small region and examine records from single stations for evidence of depth-related phases. We use two techniques. The first is ray-tracing through known structure and attempting to identify arrivals on the seismograms corresponding to the correct travel time for a particular phase. The second is to plot distance-normalized seismograms and look for evidence of phases whose travel-time is a function of depth. The second method is more robust and requires no other input than a known hypocenter.

Our initial analysis has been concentrated on the 1981 Elk Lake, Washington earthquake sequence (Grant *et al.*, 1984). This sequence consisted of over 1000 located events occurring on a nearly vertical right-lateral strike slip fault within the dense seismograph network installed to monitor Mt. St. Helens. More than 80 events were magnitude 2 or greater. These events were recorded by a large number of single-component telemetered stations located at epicentral distances between 150 and 300 km, in several velocity model provinces (see Figure 1). These stations were recorded digitally with 12 bit resolution by the University of Washington. A data set of 14 of the better recorded events (magnitude 2.4 or greater) recorded at about 25 stations has been investigated in detail.

To insure a consistent set of hypocenters, relative relocation of the Elk Lake sequence was performed using P waves at a nearly constant set of stations lying within 50 km of the epicenters and having good azimuthal distribution. Stations known to have large delays or characteristically having poor first arrivals were not used. A different delay model was used than that employed by Grant *et al.* (1984); it was selected on the basis of considering a 13 May 1981 0504 UTC event (M_L 4.5) as a master event. The locations of the largest events have root-mean-square errors of 0.01 to 0.02 s and are likely to be about the best that can be accomplished with the existing arrival time data. It is believed that location errors for the events we studied are about 200 m horizontally and 400 m vertically. The resulting hypocenters cluster to a greater degree than those of Grant *et al.* The fault length was 6 km, and the depth range of the aftershock activity was about 7 km. Because of the nearly vertical fault-plane orientation, events occurred having nearly the same epicenter but very different depths.

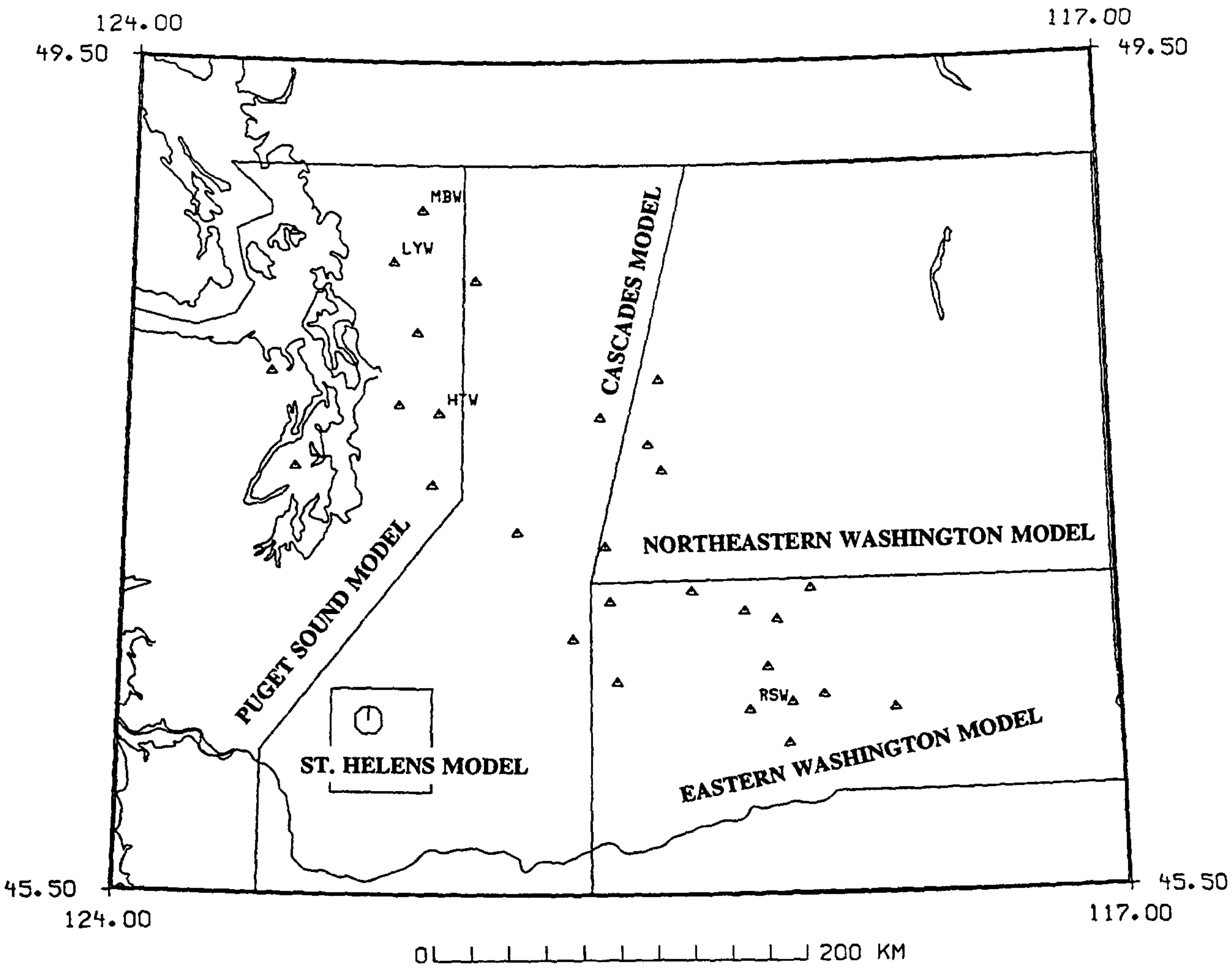

Figure 1. Regions of validity of University of Washington velocity models used in regular seismic event location. Recording stations whose data have been examined in this study are shown by triangles; stations whose data are discussed are identified by station code. The epicenter of the 1981 Elk Lake main shock is shown by an octagon.

The stations selected for study of secondary arrivals were those generally to the north, east and northeast of the epicenters. Ray-tracing of *P* waves was performed using RAYINVR (Zelt and Smith, 1992). Raypaths to these stations traverse two or three out of four separate crustal regions, as defined by routine University of Washington velocity models (Figure 1).

Seismograms for all stations were examined in a variety of frequency bands. We found that bandpassing the data with corners at 1 and 3 Hz gave the best tradeoff in improving the similarity of different events at the same station while retaining as much high frequency content as possible.

Preliminary Research Results

Complex *P* waveforms are observed to the north, east and northeast of the epicenters at distances of 130 to 300 km (see Figure 2). Surprisingly, P_n, P_g, and P_mP are weak phases, with P_n usually being near background noise levels for events in the magnitude 3+ range and the latter two phases often being unidentifiable (particularly P_g). Ray-tracing to identify arrivals was not particularly helpful. Some stations had identifiable arrivals, but strong unpredicted phases were often observed and arrivals expected to be strong often were not observed. These observations suggest it will be difficult to make single-station estimates of focal depth based on *P* waves travelling different crustal paths.

Seismograms for all 14 events were compared at each of the stations plotted in Figure 1. Same-station seismograms were plotted as functions of depth and of epicentral distance, using the well-determined origin times and the expected times of P_g (a phase whose travel time is virtually independent of focal depth at regional distances) to align the traces. At some stations, depth-related phases with small moveouts with respect to depth (of the order of 0.1 to 0.3 s) were observed. The stations having the clearest examples of such phases are identified by their station code on Figure 1. Figure 3 shows an example of a depth-related phase recorded at HTW. Figure 4 shows that the phase travel time is not as closely correlated with epicentral distance as with focal depth.

Since multiple depth-related phases with a differing dependence on depth were not observed on any single station, any determination of focal depth from the data we have studied so far requires 2 or more stations. Stations HTW and MBW were at essentially the same azimuth from the Elk Lake source area, making any time difference between their observed depth-related phases almost entirely a function of depth. Figure 5 shows the time differences, both corrected for small differences in epicentral distance and uncorrected. Both plots are similar, and indicate that there is depth dependence in the time difference. Again, the dependence is small. Nevertheless, we are encouraged that it is observable.

Preliminary Conclusions

Regional phases that have been commonly thought to be useful in focal depth determination (such as P_n, P_g, and P_mP) do not appear to be prominent phases in the data studied to date, making it difficult to estimate depth from a single station. Coherent depth-related *P* phases are observed at some stations and have travel times that differ by 0.1 to 0.3 s as a function of depth for a small source area. Time differences between such phases observed at two stations along the same azimuth have a similar depth dependence.

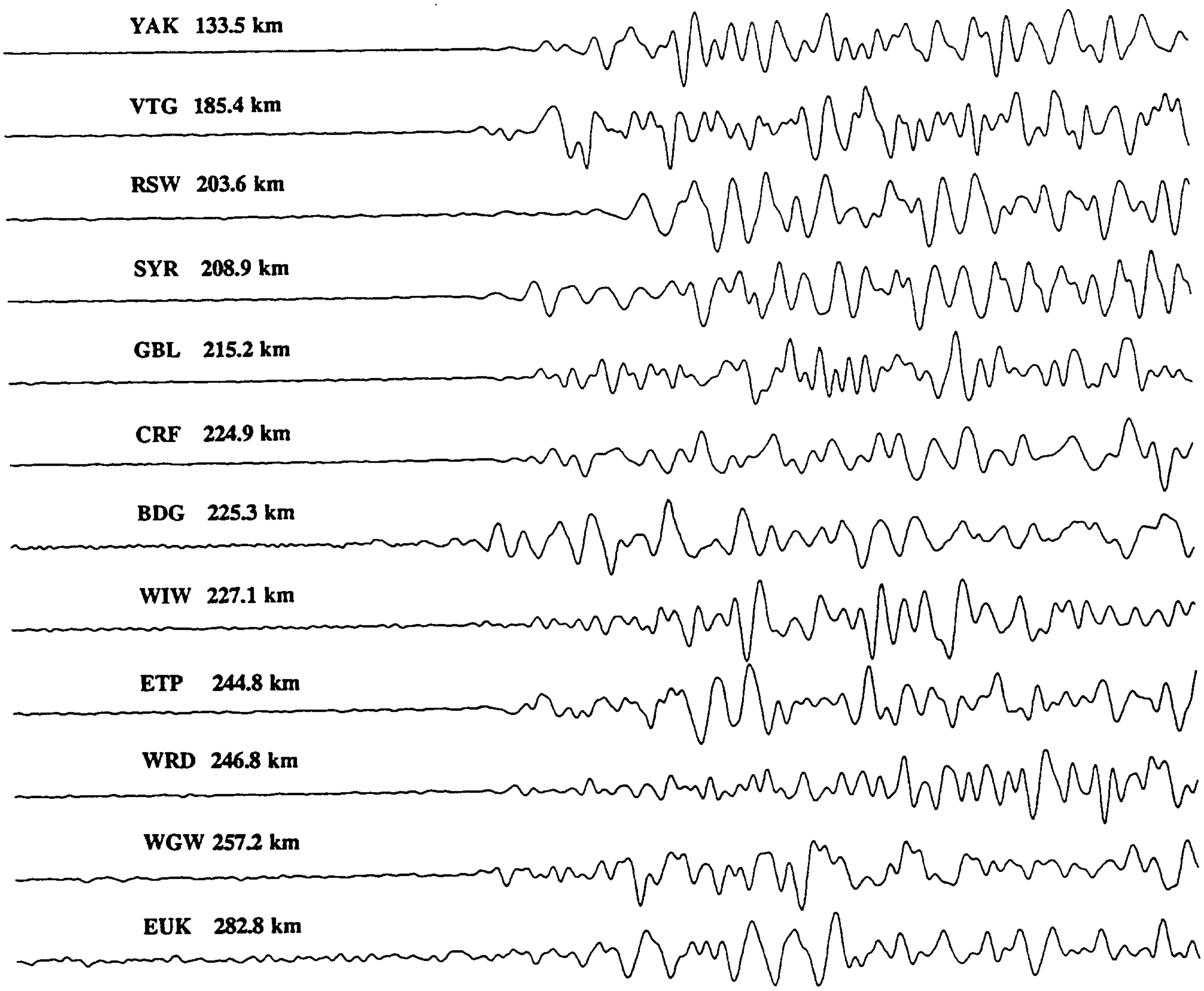

Figure 2. Seismograms from eastern Washington stations for aftershock of 14 February 1981 2127 UTC (magnitude 3.8, depth 7.8 km). Seismograms are 8.5 sec in length and are aligned on the observed first arrival time. Note weak and emergent first arrivals.

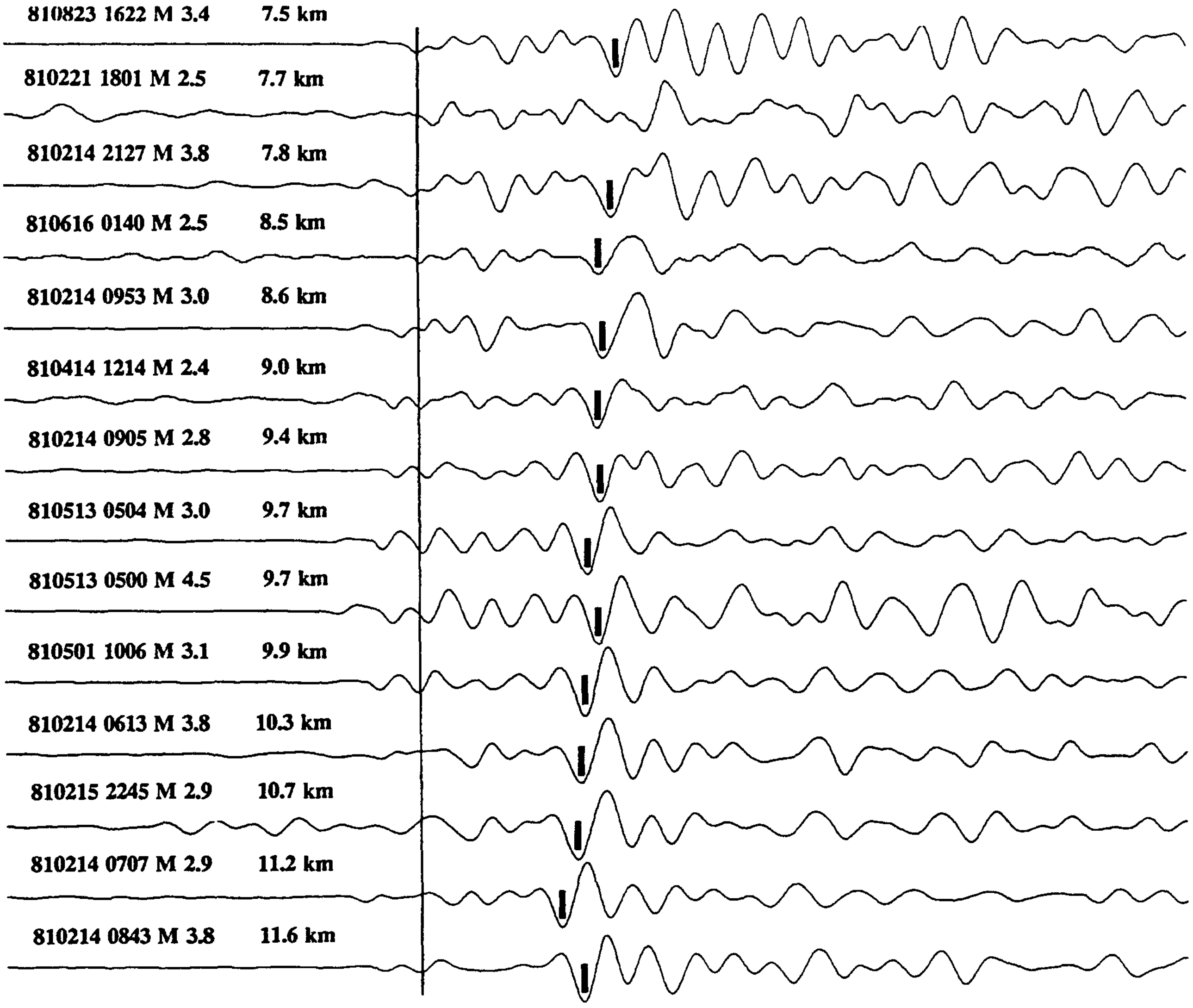

Figure 3. Seismograms from station HTW. Events' focal depths are shown. Seismograms are aligned on the predicted time of a direct wave with a velocity of 6.0 km/s, whose travel-time is nearly constant for the small range of distances and depths involved. Seismograms are 8.5 sec in length and are band-pass filtered with corners at 1.0 and 3.0 Hz. The vertical line is a reference line drawn through the trough of an arrival for the deepest event. Note that the offset from the reference line of an arrival marked with a bar decreases with increasing event depth.

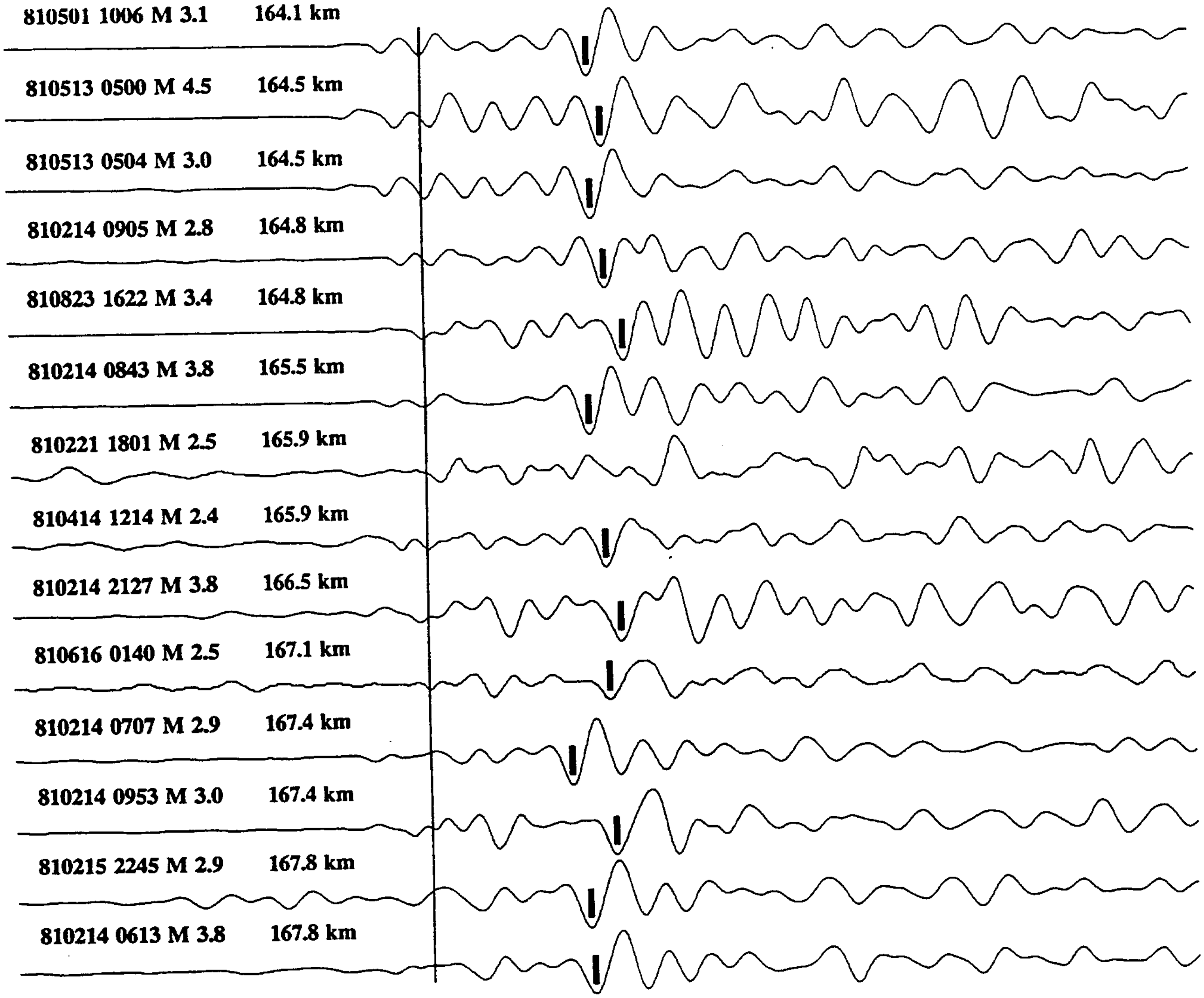

Figure 4. Seismograms from station HTW. Events' epicentral distances are shown. Seismograms are aligned on the predicted time of a direct wave with a velocity of 6.0 km/s, whose travel-time is nearly constant for the small range of distances and depths involved. Seismograms are 8.5 sec in length and are band-pass filtered with corners at 1.0 and 3.0 Hz. The vertical line is a reference line drawn through the trough of an arrival for the deepest event.

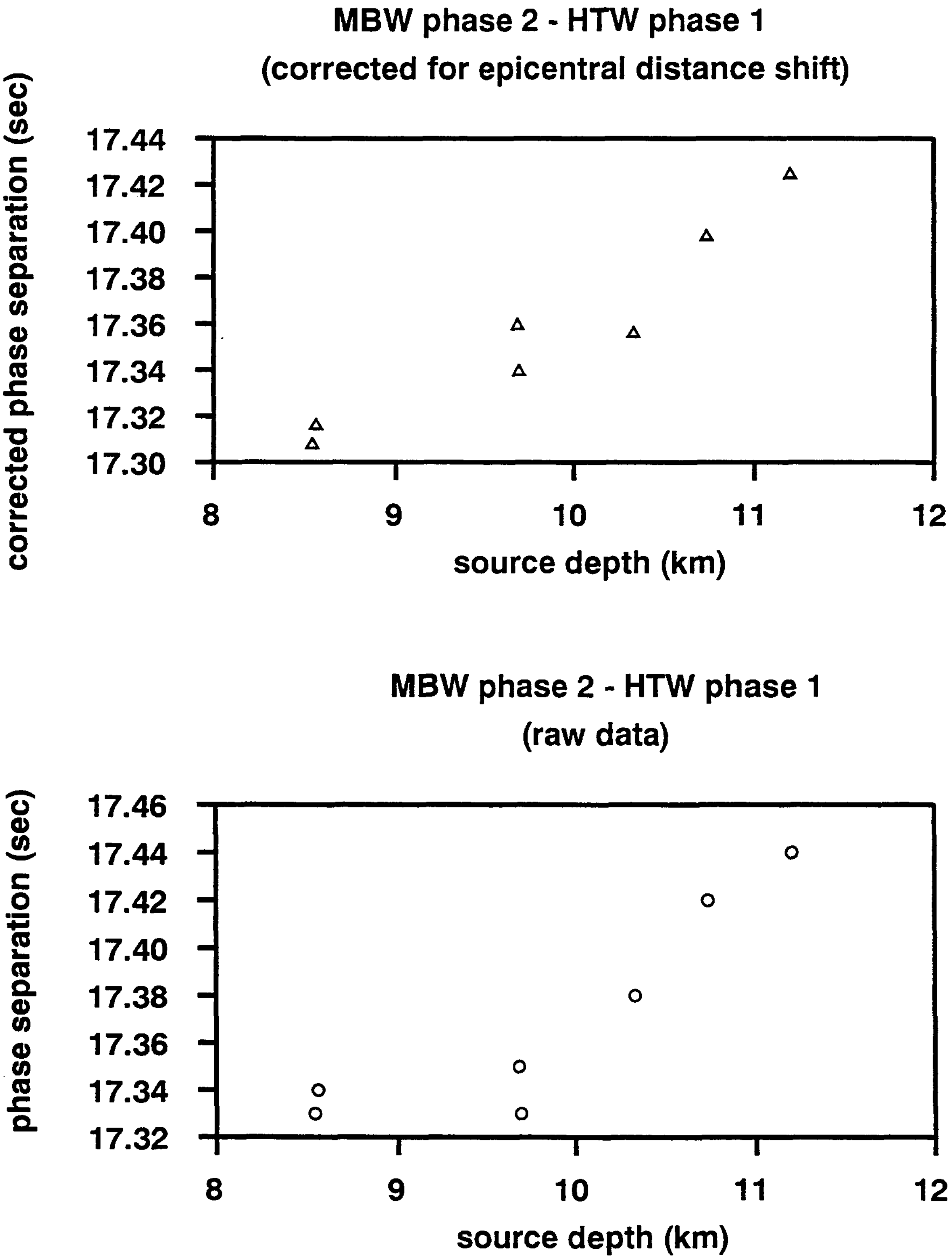

Figure 5. Time differences between secondary phases at HTW and MBW. Top plot shows the differences corrected for epicentral distance shifts using a correction velocity of 6.0 km/s, while the bottom plot shows the raw observations.

The implication for CTBT monitoring is that reliance on P_n, P_g, and P_mP in structurally complicated areas may not be appropriate. While depth-related phases have been found, they are apparent at a minority of the stations examined to date, indicating that site selection for CTBT seismic monitoring may not be trivial. Finally, although the depth-related phases observed to date appear to be capable of fairly good depth resolution over a small area like an aftershock zone, we do not yet know whether they can be traced over a larger region.

Future Plans

We are examining additional earthquake sequences at a variety of depths, in different geological environments, and with larger offset distances.

REFERENCES

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