UCRL-JC-134329
PREPRINT

Calibration of Seismic Wave Propagation In Jordan

D. Harris, K. Mayeda, K. Nakanishi, A. Rodgers,
S. Ruppert, F. Ryall, K. Skinnell,
A-Q Amrat, T. Al-Yazjeen, A. Al-Husien
F. Simon

This paper was prepared for submittal to the
21st Annual Seismic Research Symposium: Technologies for Monitoring the Comprehensive Nuclear-Test-Ban Treaty
Las Vegas, Nevada
September 21-24, 1999

July 23, 1999

Lawrence Livermore National Laboratory

DISCLAIMER

CALIBRATION OF SEISMIC WAVE PROPAGATION IN JORDAN

David Harris, Kevin Mayeda, Keith Nakanishi, Arthur Rodgers, Stan Ruppert, Flori Ryall, Ken Skinnell
Lawrence Livermore National Laboratory+
L-205, P.O. Box 808, Livermore, CA 94551

Abdel-Qader Amrat, Tawfiq Al-Yazjeen, Ahmed Al-Husien
Natural Resources Authority of Jordan

Frederick Simon
U. S. Geological Survey

Sponsored by U.S. Department of Energy
Office of Nonproliferation and National Security
Office of Research and Development
Contract No. W-7405-Eng-48

ABSTRACT

The Natural Resources Authority of Jordan (NRA), the USGS and LLNL have a collaborative project to improve the calibration of seismic propagation in Jordan and surrounding regions. This project serves common goals of CTBT calibration and earthquake hazard assessment in the region. These objectives include accurate location of local and regional earthquakes, calibration of magnitude scales, and the development of local and regional propagation models. In the CTBT context, better propagation models and more accurately located events in the Dead Sea rift region can serve as (potentially GT5) calibration events for generating IMS location corrections. The detection and collection of mining explosions underpins discrimination research.

The principal activity of this project is the deployment of two broadband stations at Hittiyah (south Jordan) and Ruweishid (east Jordan). These stations provide additional paths in the region to constrain structure with surface wave and body wave tomography. The Ruweishid station is favorably placed to provide constraints on Arabian platform structure. Waveform modelling with long-period observations of larger earthquakes will provide constraints on 1-D velocity models of the crust and upper mantle. Data from these stations combined with phase observations from the 26 short-period stations of the Jordan National Seismic Network (JNSN) may allow the construction of a more detailed velocity model of Jordan.

The Hittiyah station is an excellent source of ground truth information for the six phosphate mines of southern Jordan and Israel. Observations of mining explosions collected by this station have numerous uses:

- for definition of templates for screening mining explosions,
- as ground truth events for calibrating travel-time models,
- as explosion populations in development and testing discriminants.

Following previously established procedures for identifying explosions, we have identified more than 200 explosions from the first 85 days of recording. In addition, Hittiyah is being calibrated for coda magnitude estimation and is placed favorably to estimate mechanism and magnitude for earthquakes along the Dead Sea Rift and the Gulf of Aqaba.

+ This work was performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

OBJECTIVE

The objective of the project is to assemble events occuring in Jordan and surrounding regions suitable for calibrating travel-times for location, screening algorithms, discriminants and magnitude estimators. Two stations have been deployed to maximize coverage of Jordan and surrounding regions.

One research objective of the project is to determine whether observations of many mining explosions can be stacked to extend the range of calibrations. Waveform correlation studies indicate that mining explosions often produce highly reproducible signals, that, in theory, should be susceptible to stacking. In the Middle East and North Africa, the usual shot size is in the 10-25 ton range, and propagation conditions are such that observations beyond 300 kilometers are difficult to obtain even to quiet stations. For this reason, expensive dedicated calibration explosions are being proposed, and would require charges from the range of 5-10 tons in water to several hundred tons in boreholes on land for longer-range observations. The question to be answered is whether 20-100 shots in the 10-25 ton range at a single mine can be combined to extend the range of observation to comparable distances. Several technical hurdles have to be overcome. While explosion waveforms from the same mine often are highly similar, substantial variation is common. Variation can occur because the shots may be spread out over several kilometers at the larger mines. A cluster of mining explosions may constitute a source array where the exact location of the explosions is unknown. The waveforms may decorrelate across the source aperture. These facts complicate the alignment of waveforms for stacking and motivates the search for algorithms that do not require complete knowledge of the waveform moveout or correlation structure to provide stacking gain.

RESEARCH ACCOMPLISHED

Data collected

Figure 1 shows the locations of the Hittiyah and Ruweishid broadband stations that we have operated for approximately one year, as well as the locations of the 26 stations of the Jordan National Seismic Network. The broadband stations consist of three-component Guralp ESP-3T seismometers, Reftek RT72A-08 digitizers and GPS receivers for synchronizing the clocks. Data were collected initially at a 100 Hz sampling rate at both stations; at approximately day 300 in 1998, the sample rate was changed to 50 Hz.

With some breaks, the continuous data have been collected and archived from April, 1998 through March, 1999 for Hittiyah, and August, 1999 through March, 1999 for Ruweishid.

Mining Explosions

The station at Hittiyah is well situated to observe explosions at the large phosphate mines of Jordan and Israel. Figure 2 shows the paths and distances from the station to the 6 major phosphate mines of southern Jordan and Israel. Hittiyah is located only 37 kilometers from the major open pit mine at Shediyah, which simplifies identification of the daily explosions at that mine.

Explosions at the remainder of the mines are identified by previously established waveform correlation techniques [Harris, 1997]. These techniques have been applied to roughly the first 85 days of data recorded at the Hittiyah station to obtain an initial set of 242 correlated waveforms. Single-link cluster analysis was applied to classify these events into 14 clusters, the majority of which appear to be associated with mines. Waveforms from one of the larger clusters are shown in Figure 3. Note the substantial variation in the waveforms. Even though the clustering threshold was set at a correlation value of 0.7, the single-link algorithm can group events that have notable variations. The algorithm requires only that these events be related through a chain of comparisons, each link of which has a high correlation. We believe this algorithm to be appropriate for clustering mining events from extensive open-pit mines, since events distributed across the aperture of a large mine may be linked through a series of intermediaries. The key to preventing linkage between unrelated events is to insist on a high correlation value for each link, insuring that events involved in each step of the chain are close.

In addition to the Hittiyah work, we have processed a full year of data from EIL, resulting in delivery of waveforms for 155 explosions at the Al Hasa mine to the LLNL discrimination group. These events will be used to test P/S ratio discriminants [Walter, et al., 1999]. At minimum, an additional 200 events will be delivered for the Wadi Al Abyad mine and 100 events for the Shediyah mine.

We have attempted a stack on data from the Ruweishid station, for one of these event clusters, to ascertain whether usable observations can be obtained for calibrating travel time models. Ruweishid is too far from the phosphate mines for clear observation of any individual event. The event cluster we worked with is probably associated with the Al Hasa phosphate mine about 285 kilometers from Ruweishid. Our approach is to use the closer, and, as it happens, quieter Hittiyah station to identify the events and to provide approximate alignment for the Ruweishid signals. The alignment delays are obtained by cross-correlating waveforms recorded at Hittiyah; one event is chosen as a reference for alignment. Corresponding waveform segments are extracted from the Ruweishid data stream, and these segments are aligned using the Hittiyah-derived delays. Because the events are distributed in some unknown fashion over a mine aperture, the Hittiyah-derived delays are correct only for approximate alignment of the signals arriving at Ruweishid. Residual unknown delays exist among the Ruweishid signals due to the fact that the two stations observe the mine with different back azimuths.

We address this difficultly by choosing one of the better-recorded Ruweishid signals as a stacking reference waveform. The waveforms of the remaining events are used to predict the reference waveform by optimizing a finite-impulse-response filter with a range of lags large enough to compensate the residual delays:

$$r[n] \approx \hat{r}_k[n] = \sum_i a_{ik} s_k[n-i]$$

Here, $r[n]$denotes the reference event waveform and $s_k[n]$ the waveforms of the remaining events. The index k runs over the events. The stack is obtained by summing the reference waveform and the predictions:

$$r[n] + \sum_k \hat{r}_k[n]$$

The result of this operation is shown in Figure 4. All components of the three-component waveform have been stacked. Estimates of arrival times for the four major phases have been overlayed; the times were computed relative to the easily-picked Pg arrival at Hittiyah for the reference event. The P phases appear to be visible in the stack, though not of sufficient quality to be identified or picked.

An interesting problem with this approach is that the effective stacking velocity across the source aperture is not under control because the residual delays are unknown. It appears from Figure 4 that the uncontrolled stacking operation favors the P phases; the secondary phases are suppressed. Nonetheless, we consider this result promising and will attempt it again with improved algorithms and many more (perhaps ~100) stacking events.

Calibration Earthquakes

Another goal of the project is to collect observations of earthquakes that allow calibration of magnitude estimators and propagation models. Figure 5 shows the (predominantly) continental paths from earthquakes of magnitude 5 and greater to the broadband stations for which observations have been collected. These earthquakes are suitable as calibration events for crustal structure through full waveform modelling [Rodgers et al., 1999] and for the coda magnitude estimation [Mayeda et al., 1999].

Figure 5 also shows a reflectivity fit to a Zagros earthquake waveform recorded at Ruweishid made by optimizing an average 1-D velocity model for that path. This path traverses the northern Arabian plate, and shows deep sediments (average 6 km), low crustal velocities and a thinner crust than the southern Arabian peninsula. This analysis is being pursued systematically across the Middle East and North Africa [Rodgers et al, 1999]; the deployments in Jordan improve path coverage particularly in the northern Arabian plate.

References

Harris, D. (1997), Waveform correlation methods for identifying populations of calibration events. Proceedings of the 19th Annual Seismic Research Symposium on Monitoring a CTBT, pp. 604-613.

Mayeda, K. , R. Hofstetter, A. Rodgers, W. Walter (1999), Applying coda envelope measurements to local and regional waveforms for stable estimates of magnitude, source spectra and energy. Proceedings of the 21st Annual Seismic Research Symposium on Monitoring a CTBT, this volume.

Rodgers, A., W. Walter and T. Bredbeck (1999), Complete regional waveform modeling to estimate seismic velocity structure and source parameters for CTBT monitoring. Proceedings of the 21st Annual Seismic Research Symposium on Monitoring a CTBT, this volume.

Walter et al. (1999), LLNL's regional seismic discrimination research. Proceedings of the 21st Annual Seismic Research Symposium on Monitoring a CTBT, this volume.

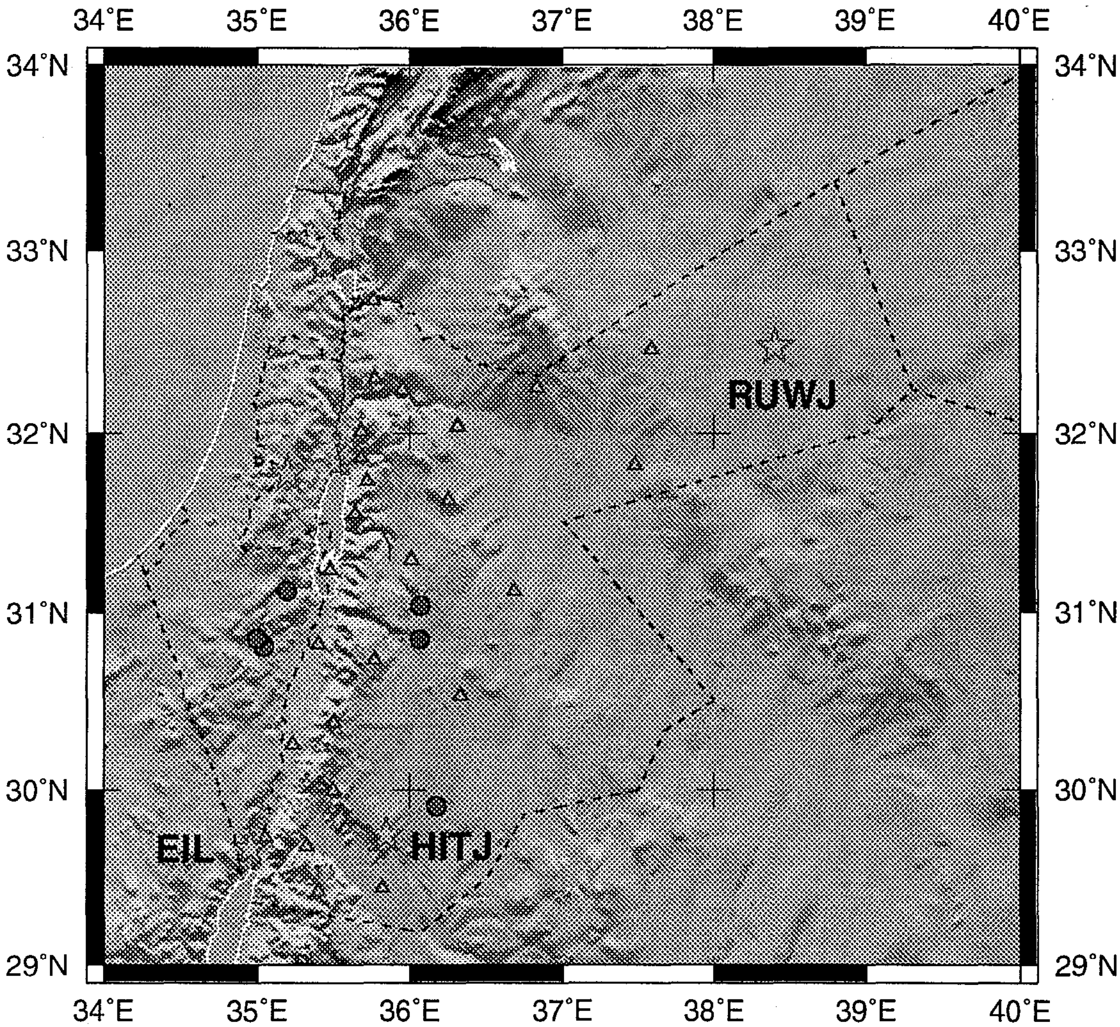

Figure 1 Locations of the two broadband stations (HITJ, RUWJ) operated jointly by the Jordan Natural Resources Authority, the USGS and LLNL. Broadband stations are indicated with stars, the stations of the Jordan National Seismic Network by triangles and the six major phosphate mines as circles. The other broadband station from which a significant amount of data has been collected is EIL in Israel.

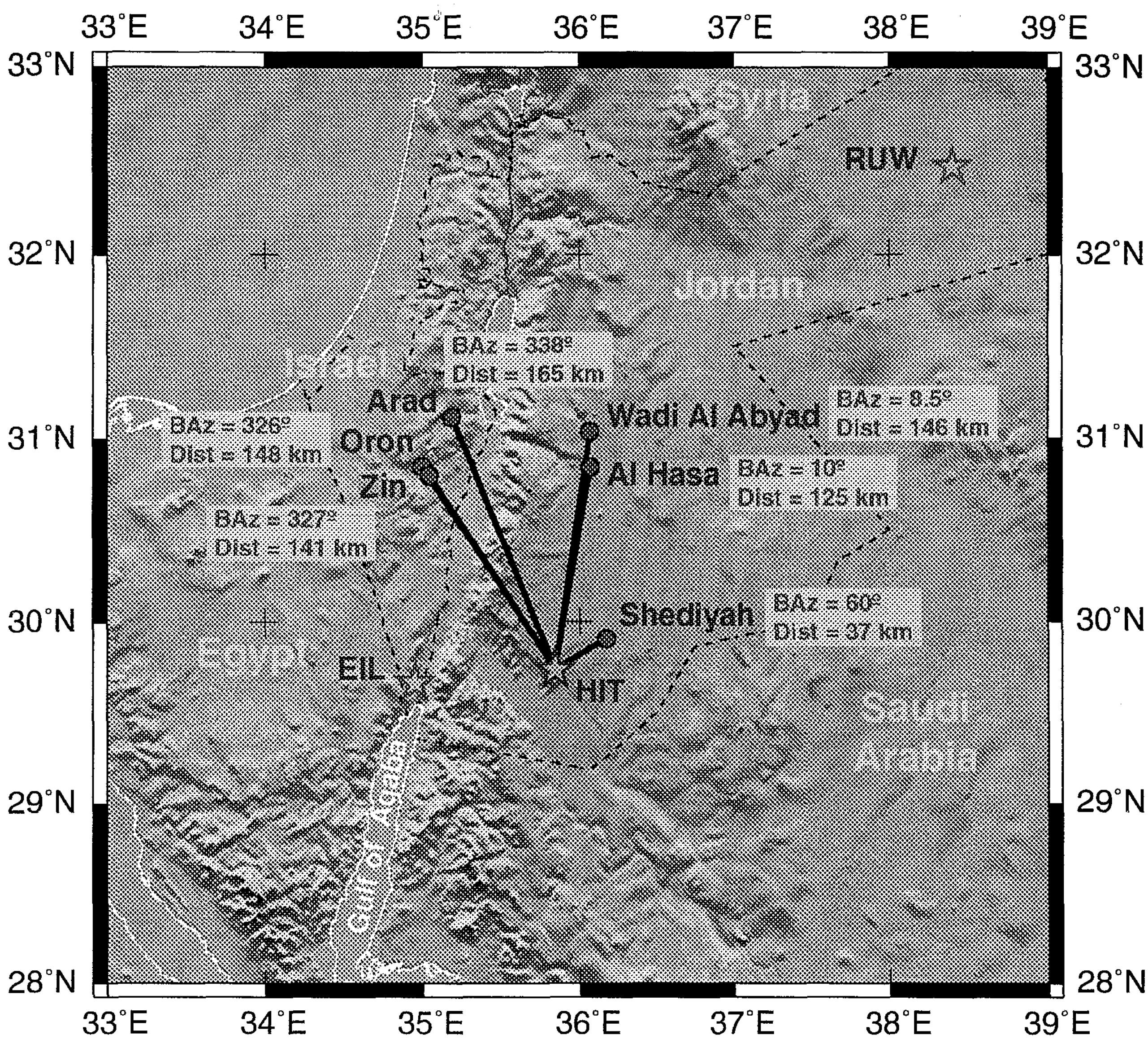

Figure 2 Distances and backazimuths of the major phosphate mines in Israel and Jordan with respect to the broadband station at Hittiyah.

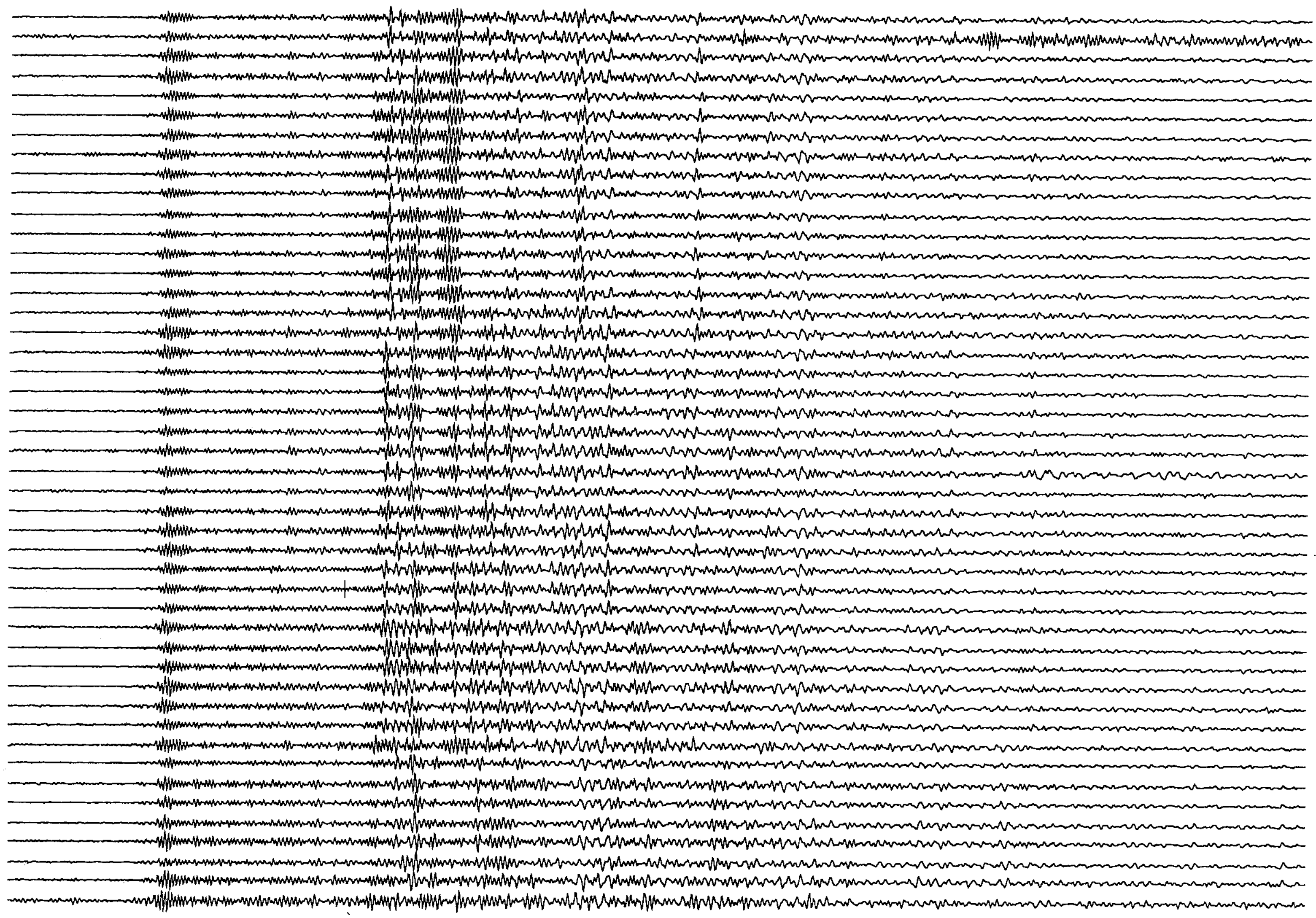

Figure 3 A large number of mining explosions are being obtained from the broadband stations. Using data from Hittiyah recorded from day 119 - day 204, 1998, 242 explosions have been detected; associations to particular mines are pending. The cluster of waveforms shown here was obtained by waveform correlation analysis using a single link algorithm run with a high (0.7) correlation threshold. The substantial waveform variations apparent, particularly in the secondary phases, may be due to migration of the working point within the mine or to the presence of multiple working points. 100 seconds of data are displayed.

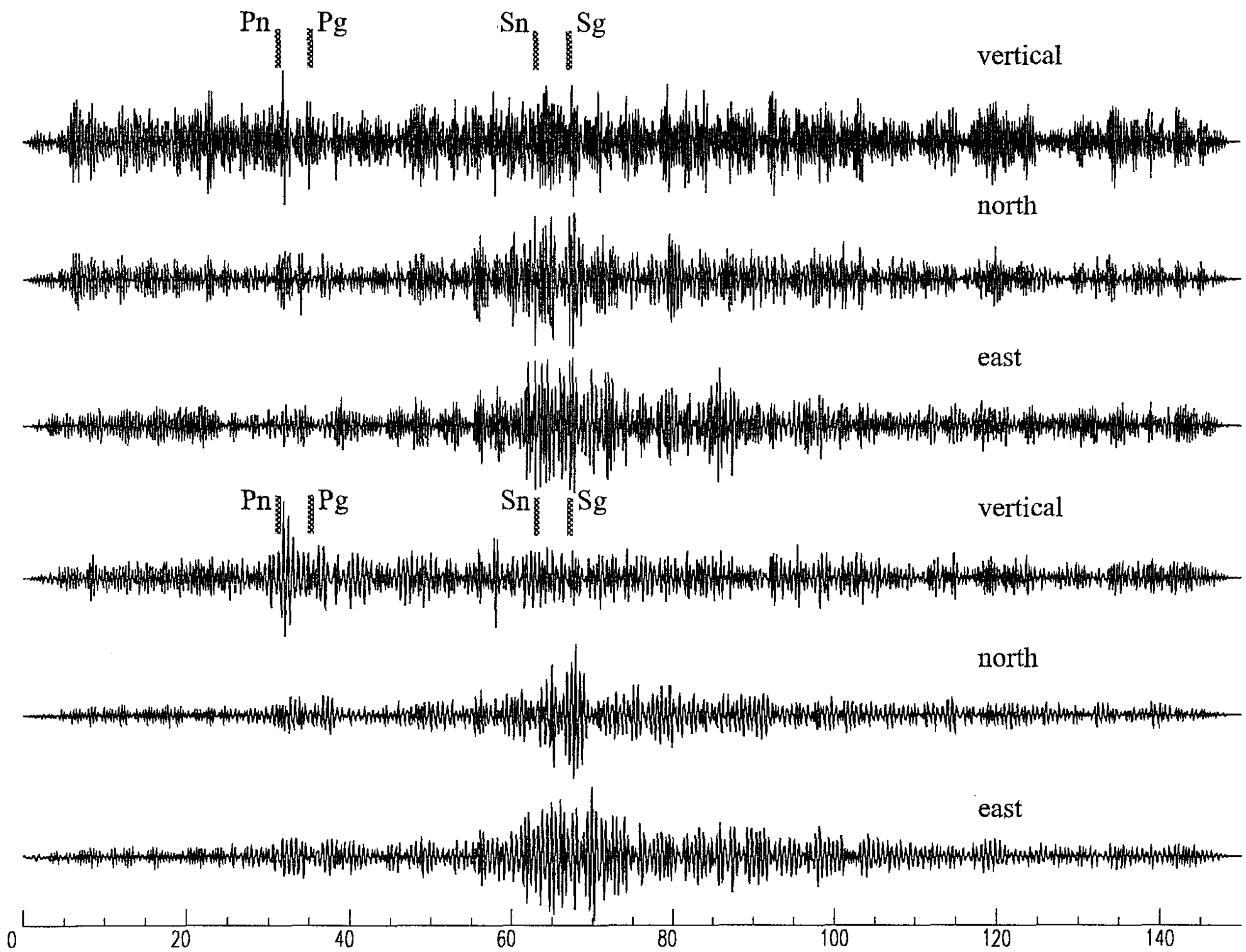

Figure 4 Results of stacking waveforms recorded at Ruweishid for 26 events at (probably) the Al Hasa mine. The top three traces are the original waveforms for the event best recorded at Ruweishid, selected as the reference event (see text) for stacking. The data have been filtered into the 1.5 - 3.5 Hz band. The 26 events were detected at Hittiyah, which provided relative delays for aligning the signals in the Ruweishid data. The bottom three traces are the stack. Arrival times for Pn, Pg, Sn and Sg predicted from the observed Pg arrival time of the reference event at Hittiyah and the AK135 travel time model are superimposed. Pn and Pg may be visible in the stacked traces. The results suggest that usable stacks may be obtained if the number of events is increased by a factor three or four.