

## **REGIONAL SEISMOLOGICAL RESEARCH IN THE MIDDLE EAST IN SUPPORT OF CTBT MONITORING**

Eric Sandvol, Dogan Seber, Khaled Al-Damegh, and Muawia Barazangi  
Institute for the Study of the Continents (INSTOC), Cornell University

Sponsored by the Defense Threat Reduction Agency  
Arms Control Technology Division  
Nuclear Treaties Branch

Grant No. DSWA 01-97-1-0006

### **ABSTRACT**

In order to decipher the character and pattern of regional seismic phase propagation we have continued to compile a large data set of regional and local seismograms recorded in the Middle East. We have mapped zones of blockage, inefficient, and efficient propagation for Lg and Sn. Two tomographic techniques have been developed in order to objectively determine regions of efficient and inefficient regional phase propagation. We have found that regional wave propagation in this region is very complex; hence the station density from our data set in this region is invaluable. We have collected data from Saudi Arabia, Oman, Turkey and Syria in order to further improve our resolution of our wave propagation tomographic models. Furthermore, this quantity of data will allow us to isolate the source, site, and path effects in the generation of Lg, Sg, and Pg.

We have also continued our study of crustal and upper-most mantle structure in the Middle East using receiver function interpretation and grid search waveform modeling. Data from our ongoing broadband experiment in eastern Turkey combined with three-component short period receiver functions in Syria have begun to give us an accurate idea of crustal thickness in the northern portion of the Middle East. We also plan to calculate receiver functions in Saudi Arabia in order to map crustal thickness variations across the Arabian Shield. We also have begun to collect all available travel time observations in the Middle East in order to accurately determine the mantle P and S-wave velocity structure. We have initially focused on Pn travel time tomography. This work will provide important new reliable models of variations in upper mantle seismic wave velocities. All of the above results will be integrated in the Cornell GIS system.

**Key Words:** Regional wave propagation, crustal velocity, upper mantle velocity, Middle East, CTBT

# Report Documentation Page

Form Approved  
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE <b>SEP 2000</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2000 to 00-00-2000</b>	
4. TITLE AND SUBTITLE <b>Regional Seismological Research In The Middle East In Support Of CTBT Monitoring</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Cornell University, Institute for the Study of the Continents, Ithaca, NY, 14853</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>Proceedings of the 22nd Annual DoD/DOE Seismic Research Symposium: Planning for Verification of and Compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT) held in New Orleans, Louisiana on September 13-15, 2000, U.S. Government or Federal Rights.</b>					
14. ABSTRACT <b>See Report</b>					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>10</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

## **OBJECTIVE**

The CTBT requires the development of credible strategies for effective monitoring, including the ability to detect, locate, discriminate, and characterize any suspect events for any region on earth. In order to accomplish this task necessary models and fundamental observations concerning seismic event location and regional wave propagation are required. Examples of such critical models are travel time models for individual IMS stations that can be used to correct for three-dimensional variations in seismic velocity structure. One dimensional travel time models are not sufficient for regions that contain substantial lateral variations in crustal thickness and uppermost mantle velocity. Furthermore, observations are required for the propagation of several key regional phases in the Middle East and North Africa since current knowledge is insufficient to accurately characterize regional wave propagation in this complex region. New seismological data are required to constrain both travel time and wave propagation models of very low yield events at regional distances. In order to make our final results available to the monitoring community we will include our data and results on the Middle East and North Africa into the Cornell GIS database.

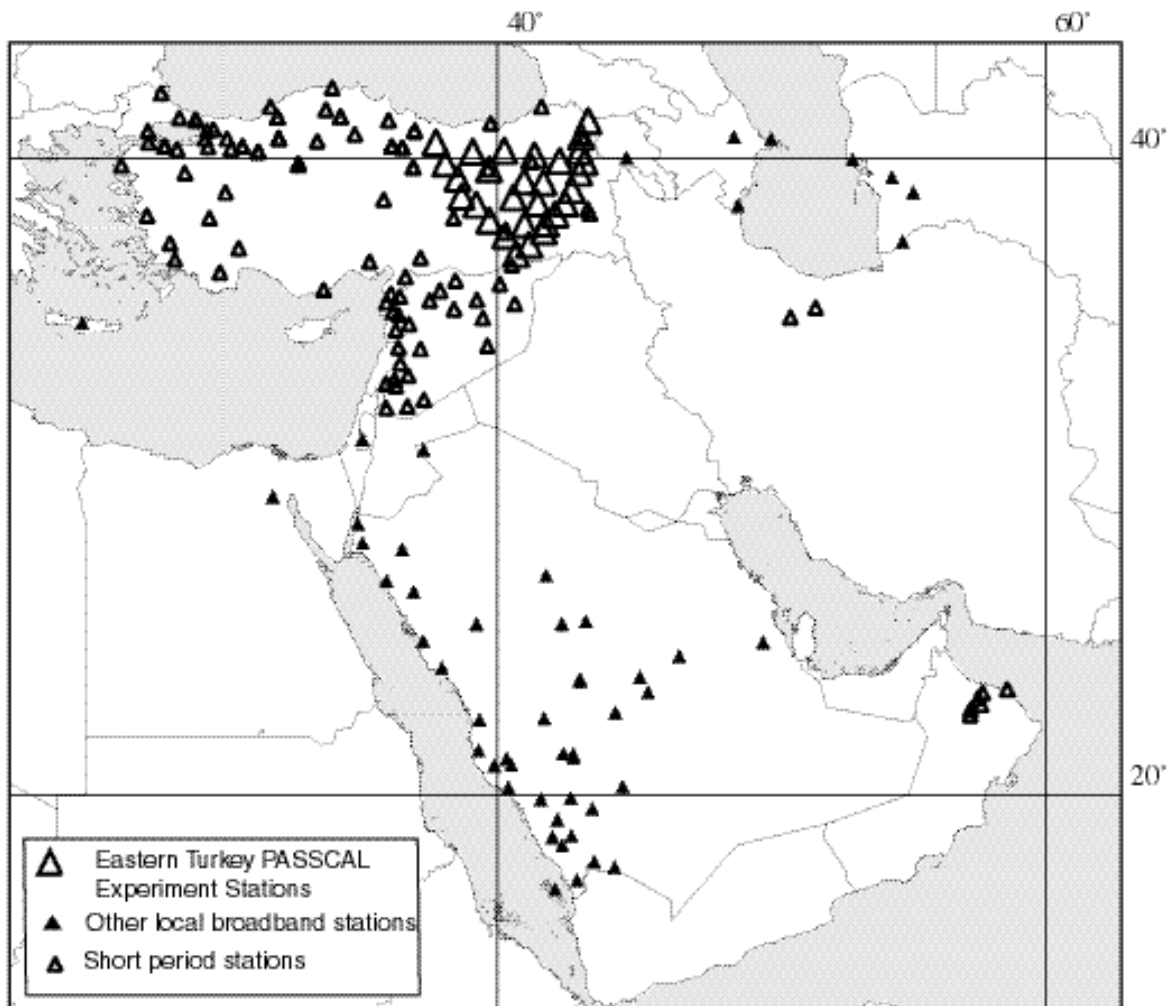
Our objective is to expand the existing geophysical/seismological information and to provide new knowledge of the Middle East and North Africa using data from both short period national networks as well as broadband temporary and global networks. In this paper we give two examples of techniques and observations that are critical to improving seismic event location and discrimination in the Middle East and North Africa.

## **RESEARCH ACCOMPLISHED**

### **Regional Wave Propagation in the Middle East**

Research on seismic wave propagation in the Middle East has demonstrated the necessity for a large number of seismic stations to be used to accurately characterize Lg and Sn behavior in this region (Figure 1). We have compiled a large data set of regional and local seismograms recorded in the Middle East. We have used this data set to decipher the character and pattern of regional seismic wave propagation. We have mapped zones of blockage as well as inefficient and efficient propagation for Lg, Pg, and Sn throughout the Middle East. Two tomographic techniques have been developed to objectively determine regions of lithospheric attenuation in the Middle East. The first technique used Lg/Pg ratios to characterize crustal attenuation as well as to determine the path effects on this commonly used discriminant. The second technique used discrete Sn propagation efficiencies that we defined after examining over 4000 seismograms. This technique allowed us to map the regions of inefficient and efficient Sn propagation in the Middle East.

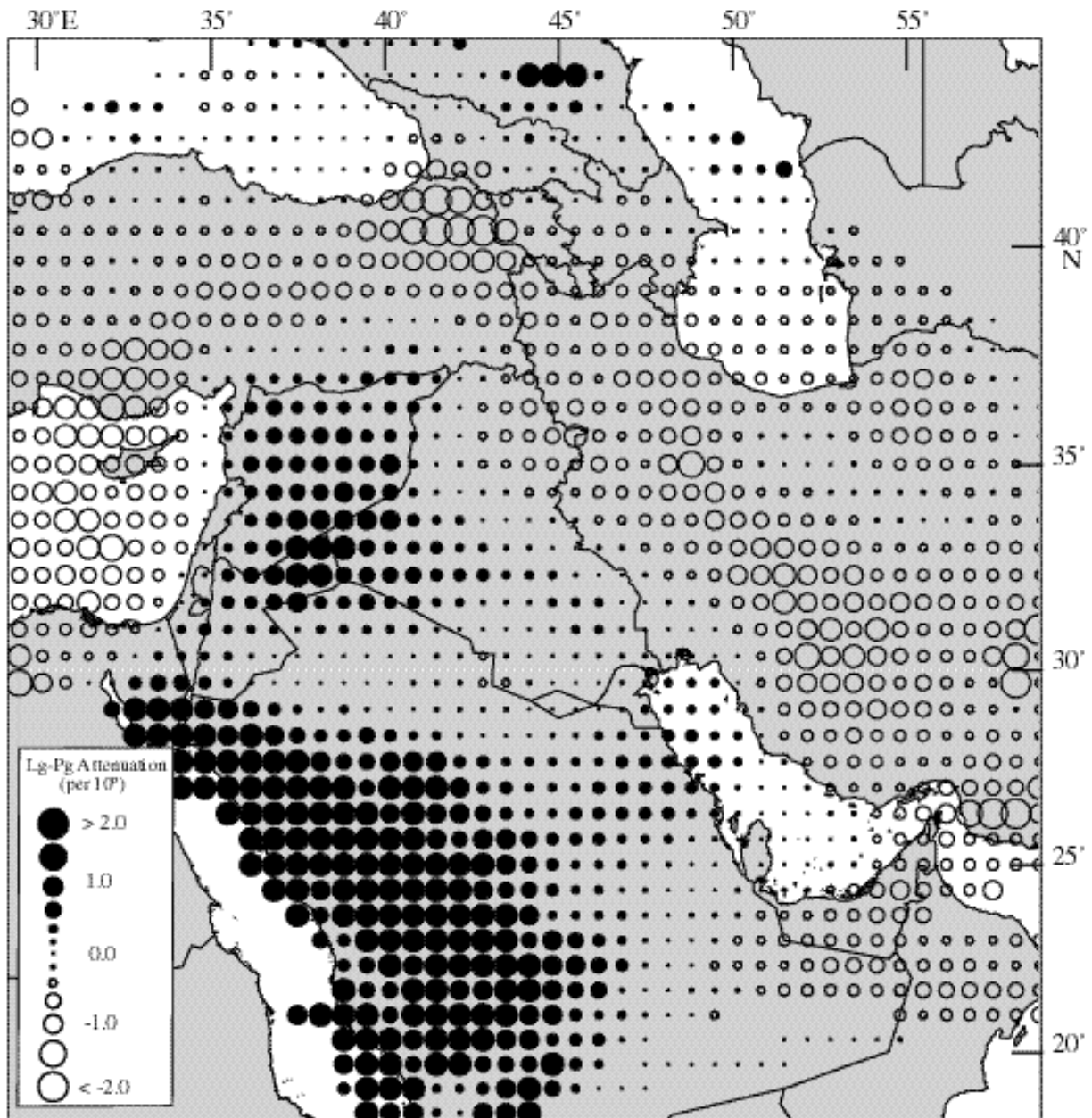
We observe evidence for a significant increase in Lg attenuation relative to Pg across the Bitlis suture and the Zagros fold and thrust belt, corresponding to the boundary between the Arabian and Eurasian plates (Figures 2a,



**Figure 1.** A map showing the seismic stations contained Cornell’s seismic waveform database in the Middle East.

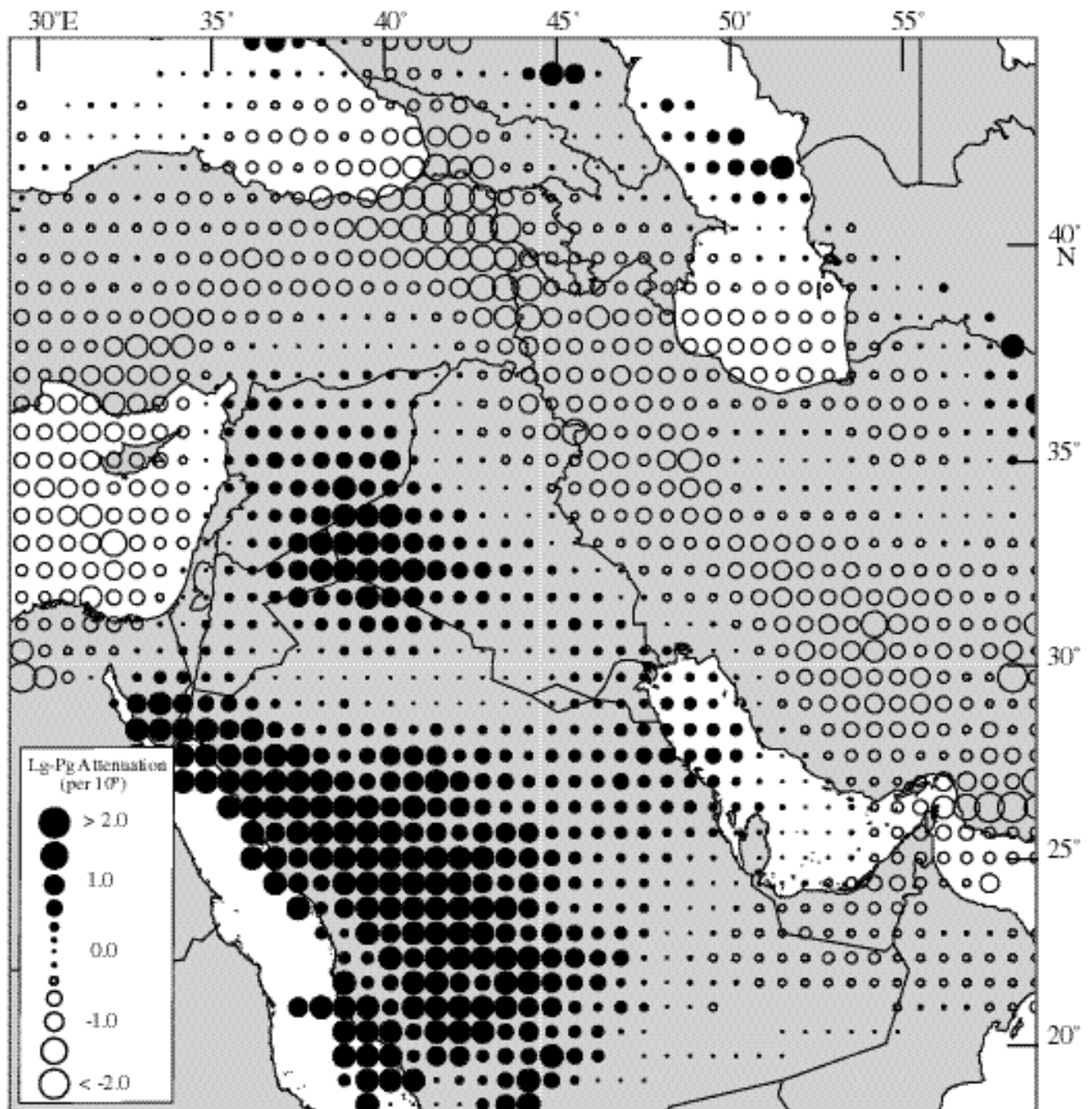
b, c). Generally Lg was blocked when the ray paths crossed either of these major tectonic boundaries. We also observed Lg blockage in the Mediterranean and southern Caspian Seas. We also found that within the Middle East, Lg propagation is most efficient in the Arabian Shield and in eastern Jordan and Syria in a region known as the Rutbah uplift. This region is thought to have very little variation in crustal thickness or variation in the thickness of the sedimentary cover. Our tomographic method assumes that variations in Lg/Pg ratios are due to path effects (Sandvol et al., 2000), neglecting possible differences in Lg excitation relative to Pg for different size or types of seismic events. We are currently creating a database in the Middle East large enough to allow us to simultaneously solve for the source and path effects.

We have also investigated the frequency dependence of Lg attenuation in the Middle East. We bandpass filter each of the regional seismograms for a given frequency band prior to calculating the Lg/Pg ratios. These

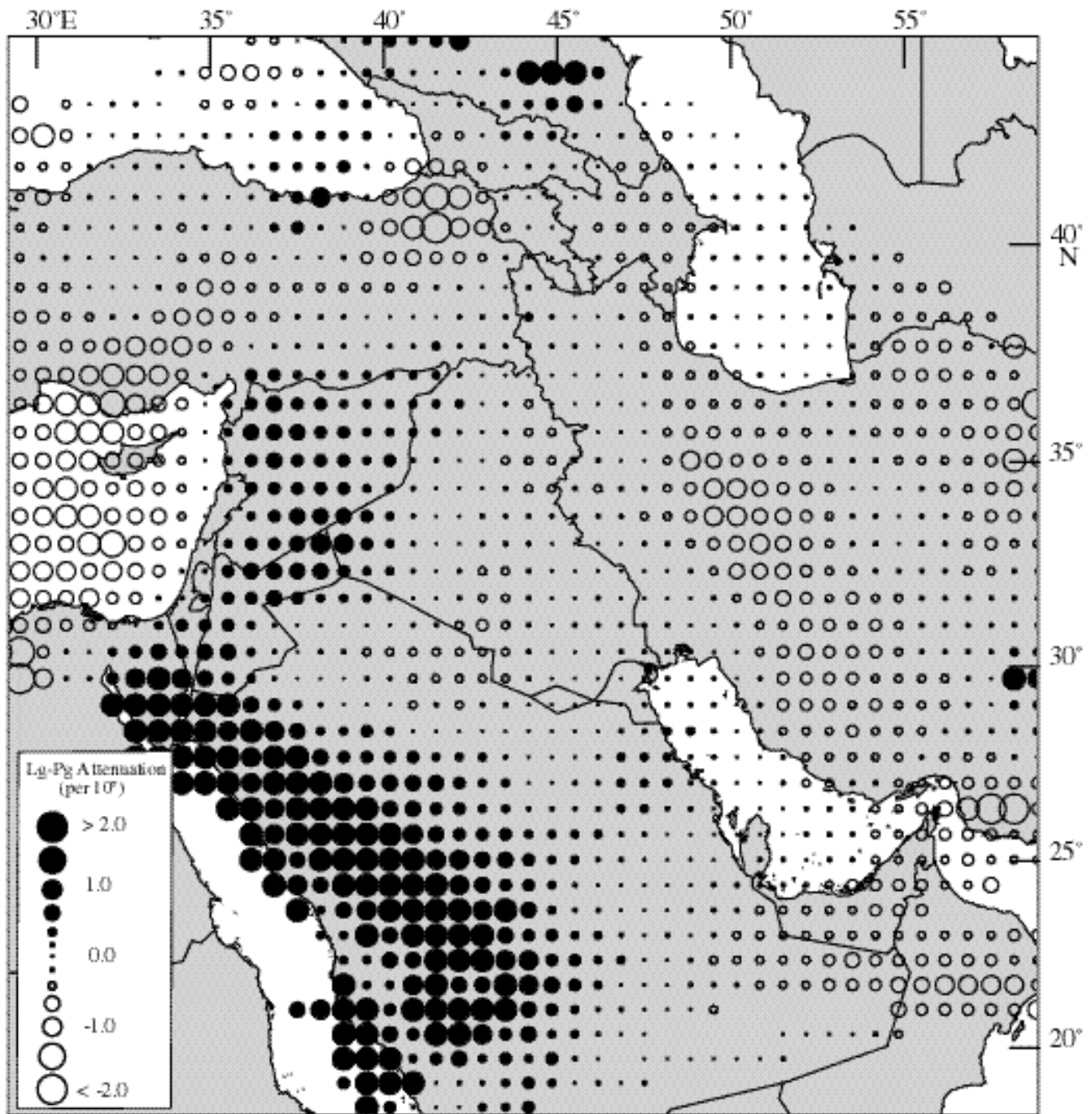


**Figure 2a.** A map showing the Lg/Pg ratio tomographic model for frequencies between 0.5 and 2 Hz. This image is based upon approximately 4400 regional waveforms.

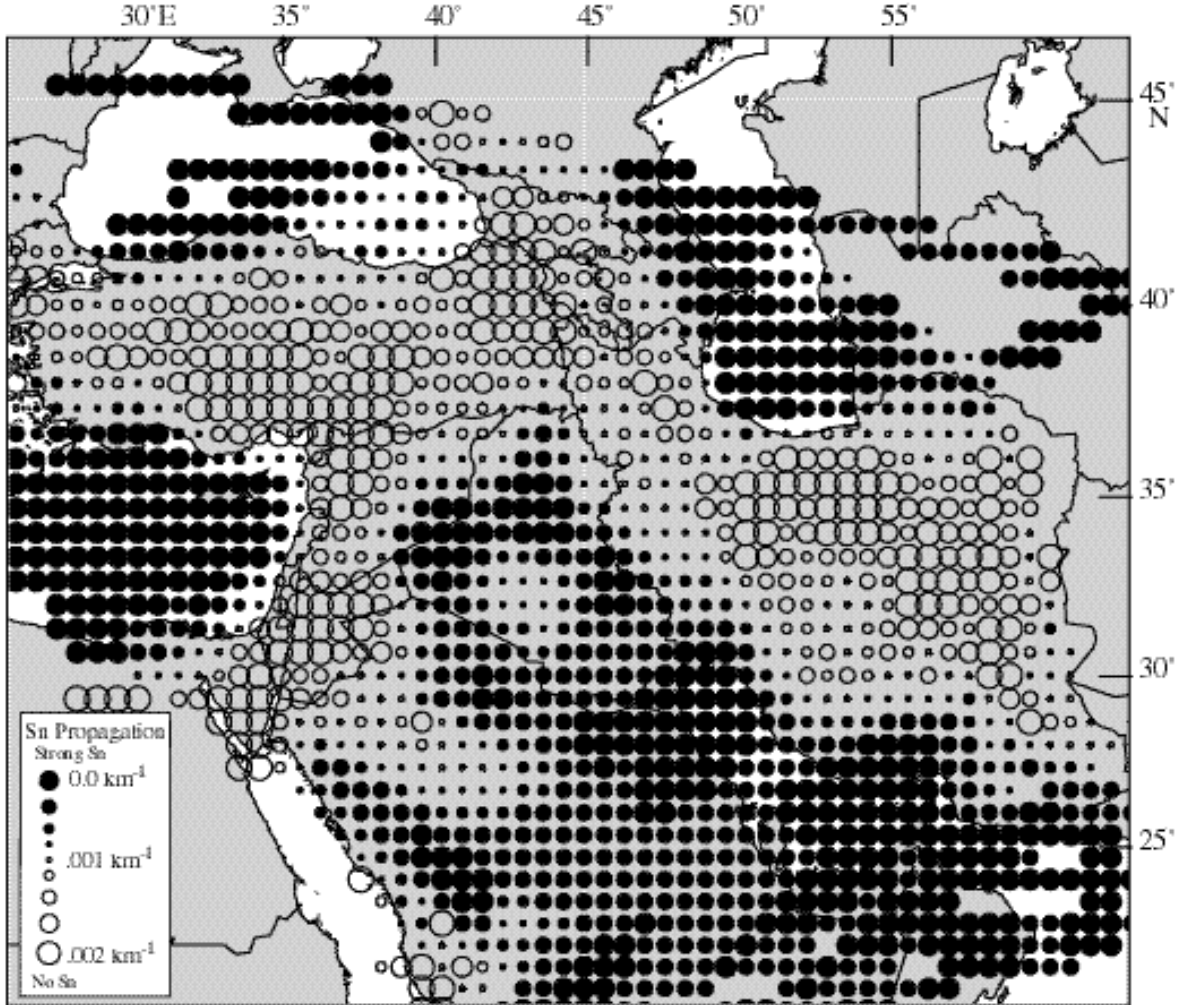
we have found only a small frequency dependence of Lg/Pg amplitude ratios in the Middle East. The difference that is observed between the lower and higher frequencies can be attributed to lower signal to noise ratio at the 2 to 4 Hz and the smaller number of events that satisfy our signal to noise criteria.



**Figure 2b.** A map showing the Lg/Pg ratio tomographic model for frequencies between 1 and 3 Hz.



**Figure 2c.** A map showing the Lg/Pg ratio tomographic model for frequencies between 2 and 4 Hz.



**Figure 3.** A map showing a tomographic model of Sn propagation efficiency in the Middle East. The model parameters in this image are the reciprocal of the Sn extinction path length. This image is based upon approximately 4200 regional waveforms.

We also observed a zone of inefficient Sn propagation along the Dead Sea fault system (Figure 3) that coincides with low Pn velocities along most of the Dead Sea fault system and with previous observations of poor Sn propagation in the Gulf of Aqaba (Rodgers et al., 1997). Our observations indicate that in the northern portion of the Arabian plate (south of the Bitlis suture) there is also a zone of inefficient Sn propagation that would not have been predicted from prior measurements of Pn velocities. However, existing Pn tomographic models have relatively poor ray coverage for much of the eastern portion of the Dead Sea fault system. We have begun to collect phase data from the Syrian National Seismic Network and our temporary PASSCAL array in eastern Turkey in order to obtain a better uppermost mantle velocity model for this region.



## **Crustal Structure in the Middle East**

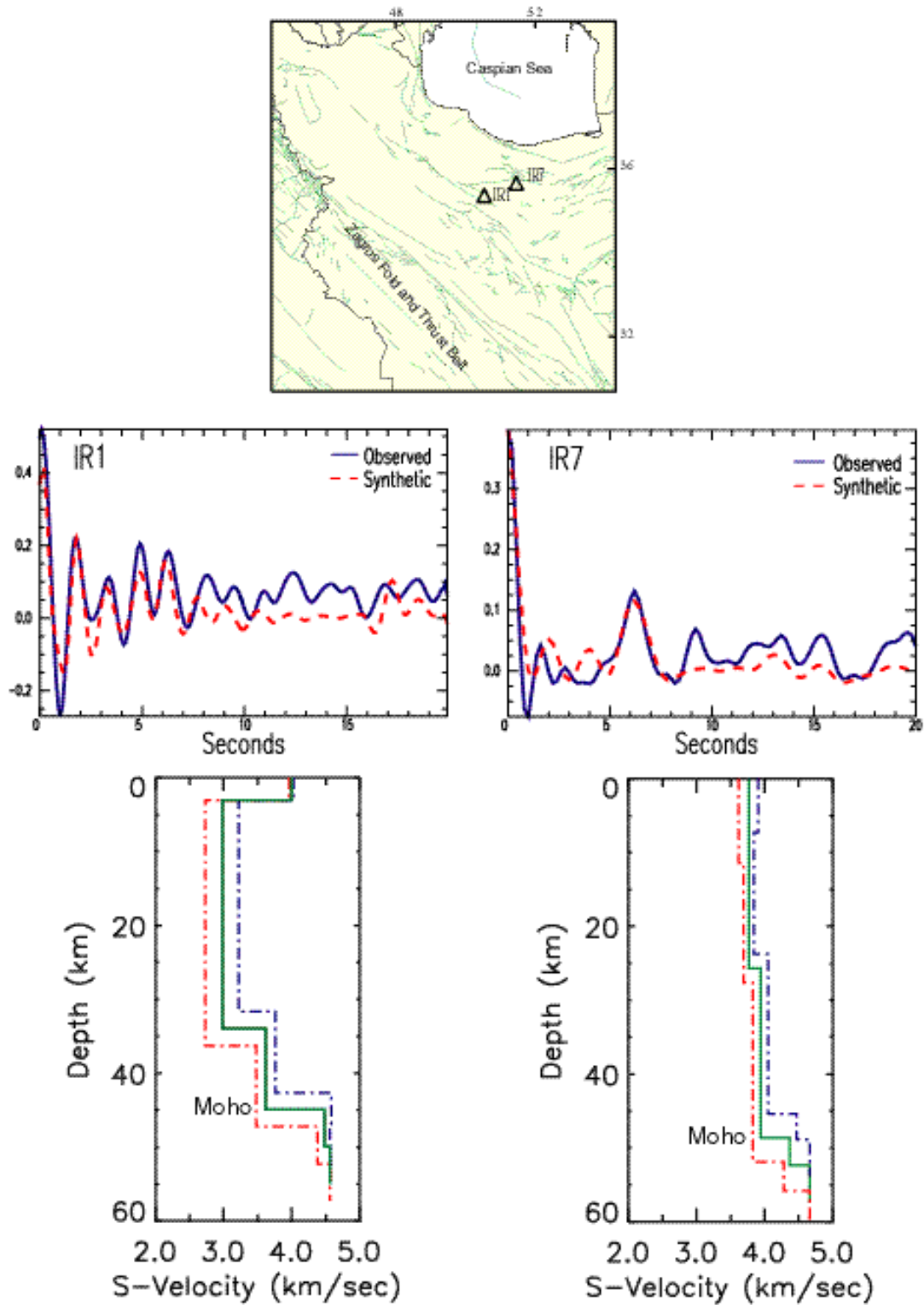
We are continuing to utilize a grid search modeling of receiver functions in the Middle East to help improve current Moho maps in the region (Sandvol et al., 1999). We have modeled receiver functions calculated from the ILPA array and found a low velocity zone at station IR7 located near the Alborz mountains (Figure 4). We have also obtained a velocity model for IR1 located 50 kilometers to the west of the Alborz mountains. We found a relatively similar crustal thickness as was observed at station IR1 (Figure 4). We have also begun to model receiver functions at station ABKT (Turkmenistan) and NIL (Pakistan). At station ABKT we have found evidence for a strong lateral heterogeneity in the crustal structure.

Preliminary receiver functions were also calculated from three component short period data from the Syrian National Seismic Network (SNSN). We were able to stack receiver functions for four of the six stations in the SNSN. The other two three-component stations were too noisy for receiver function analysis. Our preliminary receiver function analysis has indicated that there is a significant increase in crustal thickness along the northern margin of the Palmyride fold and thrust belt. This observation is consistent with a very sharp change in the gravity data in this region, however it is not consistent with the relatively small topographic signature of the Palmyride mountain belt. In order to verify this initial observation more quality three component data will need to be collect in Syria.

We have also calculated several preliminary receiver function profiles using the broadband three component data that we have collected from the ongoing eastern Turkey PASSCAL seismic experiment. We deployed 29 stations in October of 1999 and plan to dismantle the array in April of 2001. Our initial receiver function analysis indicates that there is no significant change in crustal thickness across the Bitlis suture. In easternmost Turkey, north of Lake Van we observe very rapid increases in crustal thickness over less than 50 km. These observations, however, are very preliminary and more data processing is required to insure that our models are robust.

## **CONCLUSIONS AND RECOMMENDATIONS**

Our study of regional wave propagation demonstrates that there are dramatic variations in Lg and Sn propagation in the Middle East. Furthermore, using Lg/Pg ratio tomography can, for the most part, determine the path effects on Lg/Pg ratio calculations and thereby is a method for isolating the source effects on Lg/Pg amplitude ratios. We have also begun to further improve our crustal thickness maps using receiver function inversions of stations in Syria, Iran, Turkmenistan and Pakistan. We have found important variations in crustal structure throughout these regions. It is essential for both discrimination and location research to have a reliable lithospheric velocity model for the Middle East.



**Figure 4.** Velocity models derived from grid search modeling of receiver functions for the two three component stations in the ILPA array. Note the large low velocity zone beneath station IR1.

## **REFERENCES**

Hearn T. and Ni, J., Pn velocities beneath continental collision zones: The Turkish-Iranian Plateau, *Geophys. J. Int.*, vol. 117, 273-283, 1994.

Rodgers, A., Ni, J., and Hearn, T., Propagation characteristics of short period Sn and Lg in the Middle East, *Bull. Seism. Soc. Amer.*, vol. 87, 396-413, 1997.

Sandvol, E., Seber, D., Calvert, A., and Barazangi, M., Grid search modeling of receiver functions: implications for crustal structure in the Middle East., *Journ. Geophys. Res.*, vol. 108, p. 26899-26917, 1998.

Sandvol, E., Al-Damegh, K., Clavert, A., Seber, D., Barazangi, M., Mohamad, R., Gok, R., Turkelli, N., and Gurbuz, C., Tomographic imaging of Lg and Sn propagation in the Middle East, *Pure and Applied Geophys.*, in press.