A COMPARATIVE STUDY OF NATURAL AND MAN-INDUCED SEISMICITY IN THE YANQING-HUAILAI BASIN AND THE HAICHENG AREA

Brian Stump, Christopher Hayward, and Rong-mao Zhou

Southern Methodist University

Sponsored by Defense Threat Reduction Agency

Contract No. DTRA01-02-C-0003

ABSTRACT

Natural earthquakes and mine-induced seismicity are health, life, and economic hazards. Seismic wave studies from such sources provide a mechanism for understanding local propagation path effects and constraints upon source mechanism dynamics. The geographic focus of this investigation is in two areas, the Yanqing-Huailai Basin around Beijing and northeast China along the Tan-Lu fault near the area of the 1975 Haicheng earthquake. Several regional stations and arrays from the Chinese Digital Seismic Network (CDSN) and the International Monitoring System (IMS) are available. A local network supplemented by a new high-frequency array already exists within the Yanqing-Huailai region. Within the Yanqing-Huailai Basin, earthquake risk and propagation path assessment are important because of Yanqing-Huailai Basin's high historical seismicity and Beijing's large population. Numerous underground mines regularly experience rock bursts and collapses resulting in mining operation disruptions, injury and occasional fatalities. The Haicheng area, the location of the first successfully predicted earthquake, is naturally seismically active as well. Mining operations are common in this region. Existing broadband regional data are being gathered and combined with local network data to provide an initial assessment of the earthquake and mine-induced seismicity in each region. The key to this study is the separation of propagation and source effects for these events. Once the background activity is quantified and understood, the path-source separation will be addressed with an experimental program. Plans call for an initial deployment of broadband instruments in the late summer.

OBJECTIVE

The goal of this collaborative study between Southern Methodist University (SMU) and the Institute of Geophysics, China Seismological Bureau, is to develop a ground-truth database that can be used to improve regional event locations, to characterize the nature of the event and to provide a physical understanding of the source. These goals contribute to earthquake risk assessments and mine safety issues, and this synergy motivated the collaborative empirical study. The two regions of focus (outlined in Figure 1) are the Yanqing-Huailai Basin near Beijing and the area around Haicheng along the Tan-Lu fault. Each region has an existing digital network that can provide limited ground-truth.

Our scientific goal is to use near-source instrumentation in combination with regional broadband instruments to assess path and source effects in the two regions. As part of the study, we are deploying portable instruments at both near-source and regional distances. These near-source recordings will significantly improve the source characterization and interpretation of the accompanying regional signals.

Regional signals recorded from events in Yanqing-Huailai Basin near Beijing and the area around Haicheng are strongly affected by crust and upper mantle structure that varies over the broad region diagramed in Figure 1. Geologic structure introduces path complexities that make it difficult to separate source and propagation effects in high-frequency regional signals. Thus, the signal interpretation becomes ambiguous. Simple effects, such as a regional travel-time variation, directly affect the location and origin time estimation. More complex effects lead to phase misidentification, poor magnitude estimates, and problems in event characterization.

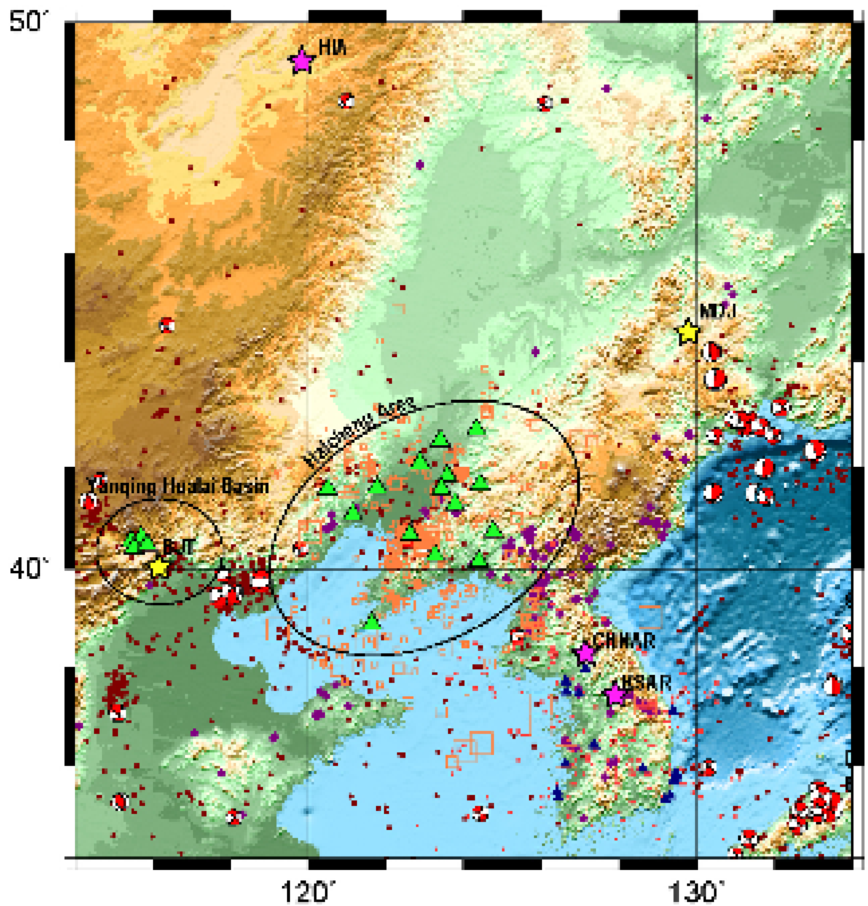

Figure 1: Map summarizing the two study areas (black circles). Regional CDSN and IMS stations (yellow stars) and arrays (purple stars) will be utilized in the study. Local seismicity is shown as brown squares and ISC locations purple circles. Fault plane solutions are from Harvard.

RESEARCH ACCOMPLISHED

Yanqing-Huailai Basin

The seismically active Huailai basin, northwest of Beijing, is the (Figure 1) initial region of focus in this work. Recent historical seismicity in the region illustrates the clustering of activity around the basin and motivates the instrument deployment (Figure 2). Fault plane and moment tensor studies of events in this region suggest that the faulting is consistent with the regional stress field, which is compressive in the ENE-WSW direction and tensile in the NNW-SSE direction. Mapped faults in the region are consistent with normal faults across the basin reflective of the NNW-SSE tensile stress directions (Yongkang *et al.,* 1995, 1996).

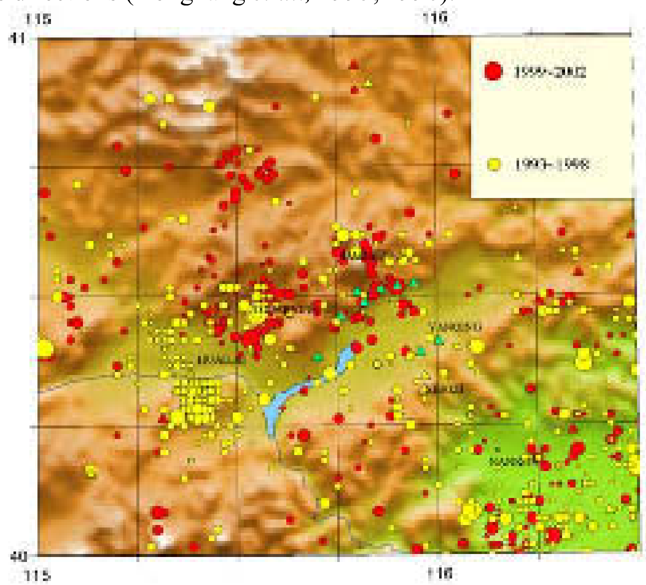

Figure 2: Locations of recent seismicity in the Huailai Basin.

Locations for the new near-source and regional broadband stations have been chosen with instrument deployment planned for the fall. Figure 3a illustrates the planned five near-source sites (crosses) while the planned regional sites are illustrated in Figure 3b. In each of these maps, the associated permanent seismic stations in the regions are denoted by triangles. This station distribution is designed to quantify near-source effects so that they can be separated from the regional propagation path effects.

Preliminary work is underway in developing and assessing source and propagation path effects in this region. A preliminary velocity model has been developed from a near-by reflection survey. This model and a simplified version are reproduced in Figure 4. This velocity model has been used for predicting arrival times. Near-source data from an earthquake within the Huailai basin is compared to the predictions in Figure 4. This starting model appears to be good for our initial studies.

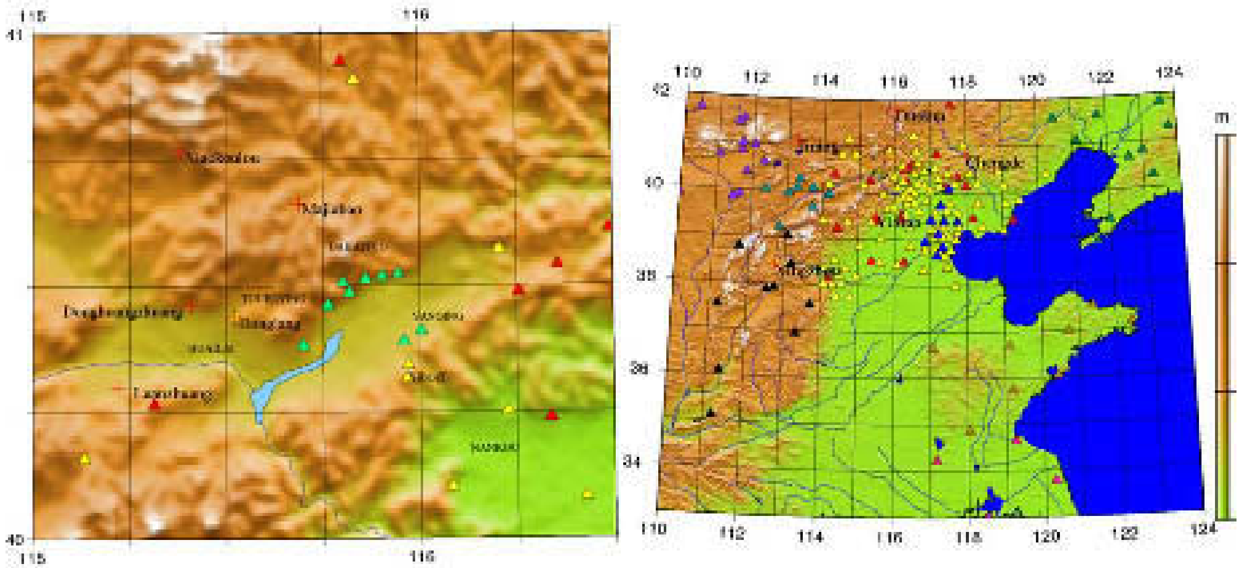

Figure 3a: Locations of planned near-source stations (crosses) and existing stations (triangles) in and around the Huailai Basin. 3b: Planned regional broadband stations (crosses).

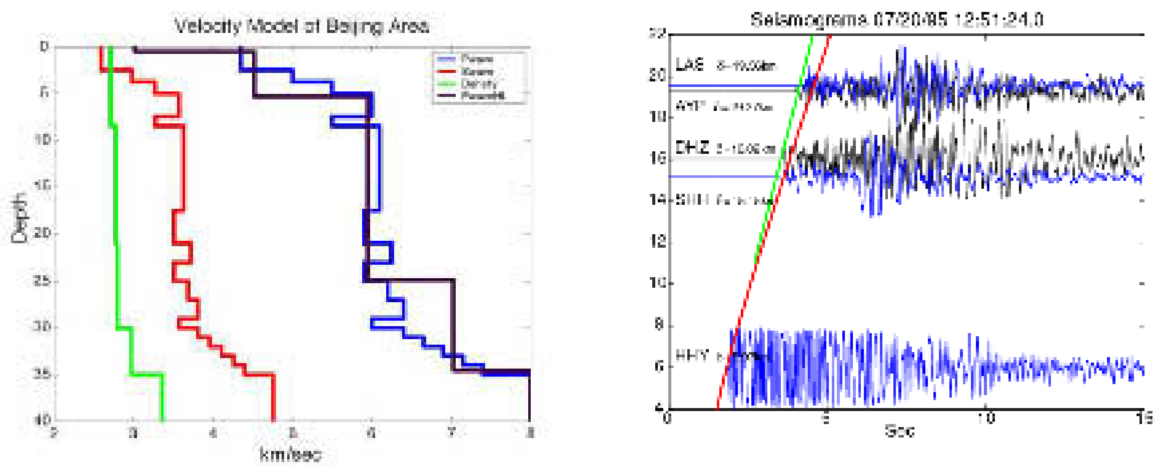

Figure 4: Preliminary velocity model for the Huailai Basin (left). Predicted arrival times are compared to near-source data generated by an earthquake within the basin.

In the Huailai Basin one of the local resources is the five, three-component station network of the Sino-European Cooperative Huailai Digital Seismograph Network (HDSN). Local sources in this region have been characterized using an empirical Green's function approach (Xu, Chen and Wang, 1999). Important source scaling information can thus be derived for regional signal interpretation. Three close-by events from this study are summarized in Table 1.

Table 1: Source Parameters for Sample Events from HDSN

	Latitude (^{0}N)	Longitude (^{0}E)	Depth (km)	M_L
Event 1	40.326	115.448	5.5	3.4
Event 2	40.323	115.447	5.1	2.0
Event 3	40.323	115.445	5.1	2.1

The basis of the Xu *et al.,* 1999 study used the fact that these events are less than a kilometer apart in their empirical Green's function source study. Figure 5 illustrates the near-source vertical waveforms from one event documenting the propagation path effects.

To illustrate the utility of near-source data in constraining earthquake source scaling effects, full record spectra were estimated for each of the three near-by events (Table 1) recorded at one of the near-source stations (Figure 6). These spectral data can be used to develop source scaling and source moment estimates for the events. Xu *et al.,* 1999, have used such data to constrain source models of the larger events. We believe that similar results will be useful in establishing magnitude-moment relations. The planned near-source stations illustrated in Figure 3a will provide additional data for constraining the sources. These data will be critical to the interpretation of the regional data and separation of propagation path and source effects.

The velocity models illustrated in Figure 4 can be used to develop synthetics for comparison to the near-source observations. Preliminary models were developed and compared to some of the near-source data recorded by the HDSN. Figure 5 summarizes these simple comparisons. The focus in this comparison is on the longer period data (2-10 sec) since the models are simple and preliminary. The two synthetics are similar to the observations and illustrate that the starting model for the Huailai Basin is consistent with the near-source recordings of the earthquakes as well as arrival times.

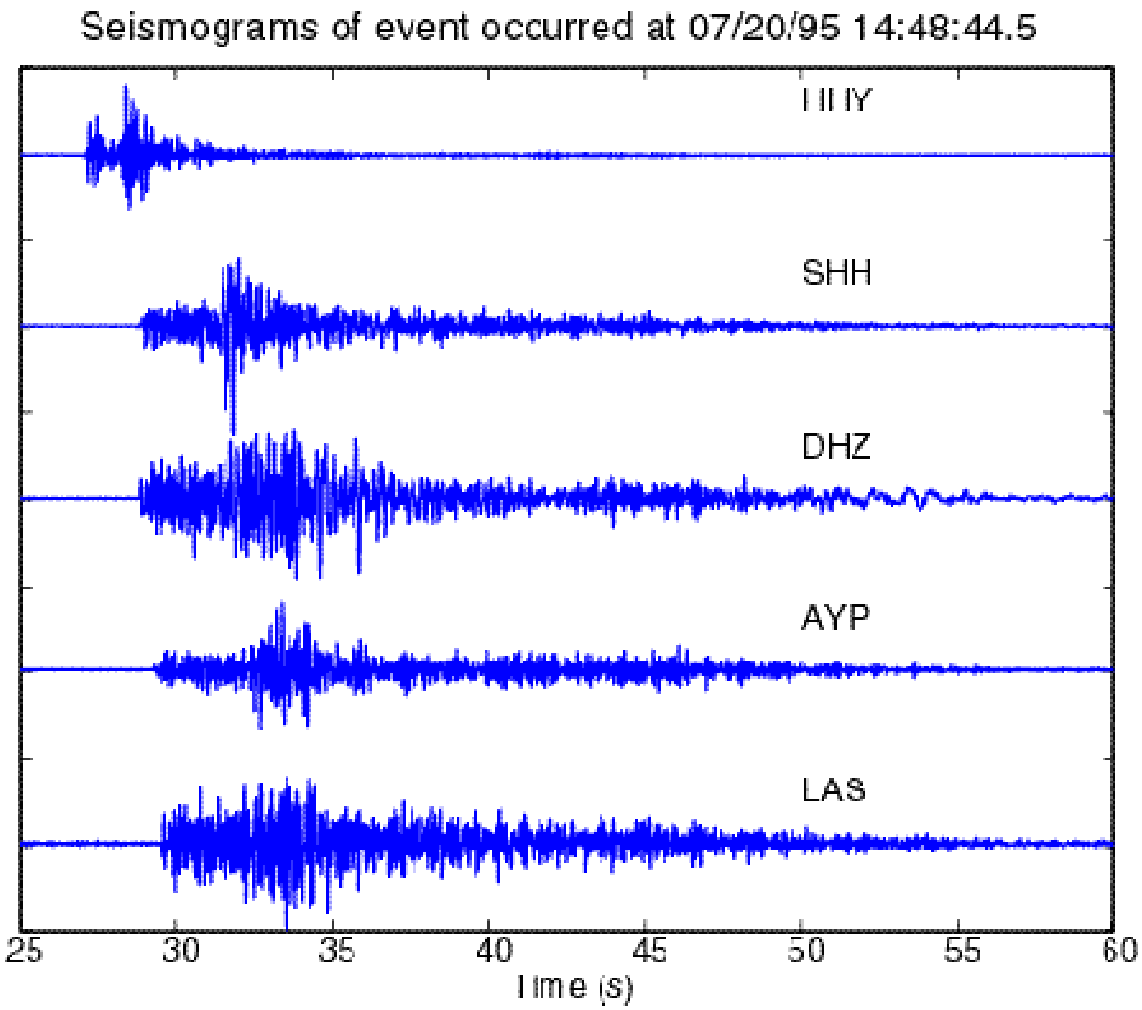

Figure 5: Vertical velocity waveforms from Event 2 (Table 1), the smallest in the sequence.

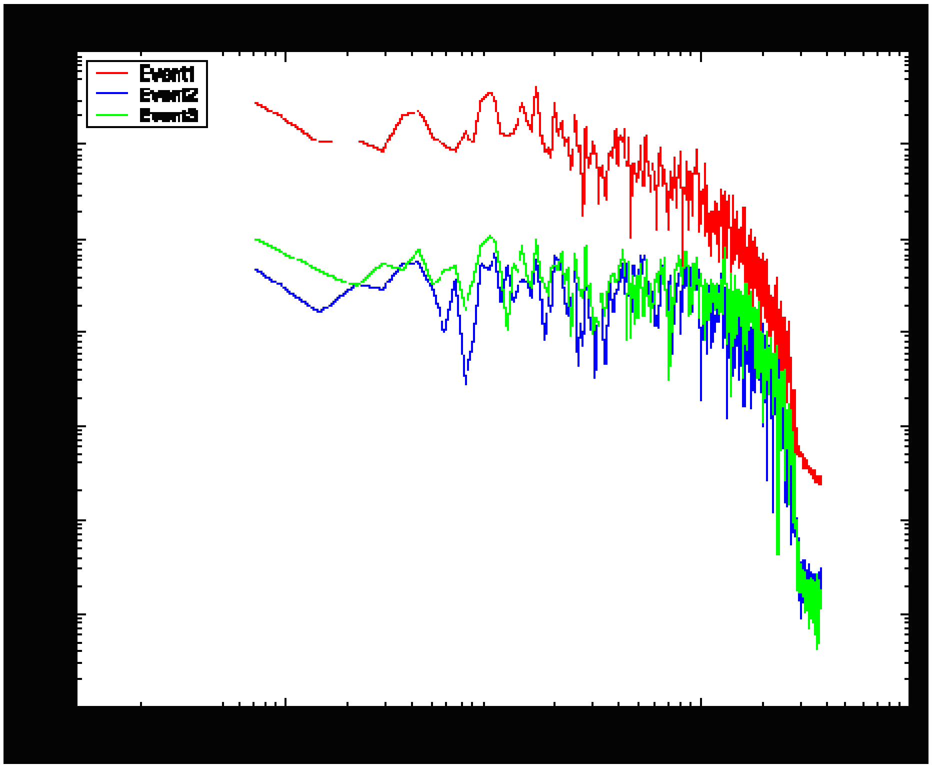

Figure 6: Vertical velocity spectrum from Events 1-3 (Table 1) recorded at AYP.

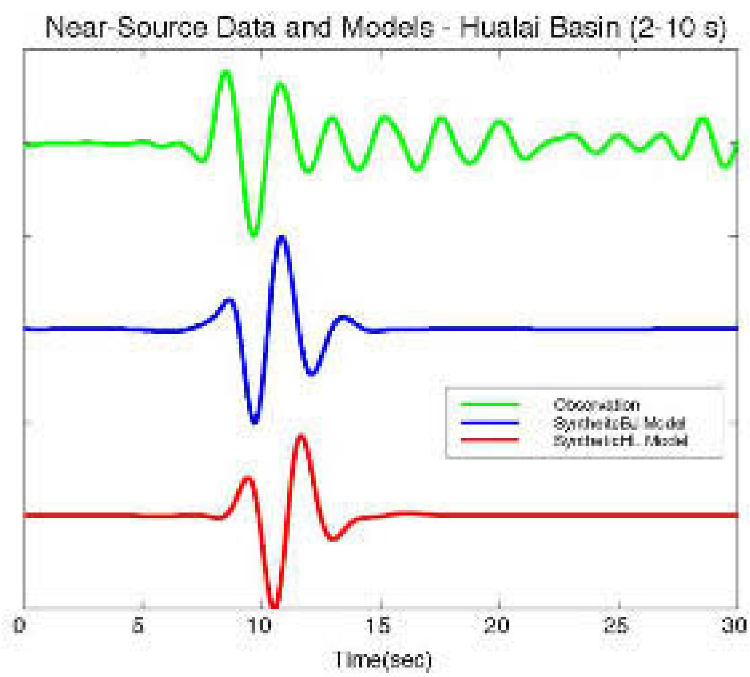

Figure 7: Comparison between long period observations (green) and synthetics developed from the preliminary velocity models for the Huailai Basin illustrated in Figure 4.

Heicheng Area

The second area for our combined near-source and regional broadband deployments is the Heicheng Area (Figure 1). Northeastern China can be divided into two primary tectonic blocks, the North China Block and the South China Block (Gilder *et. al.,* 1999). Some believe that the Tancheng-Lujiang (Tan-Lu) fault system is a boundary between these blocks extending from South China to the Bay of Okhotsk.

The 1975 Heicheng Earthquake, the first predicted in China, occurred in this region and motivates an interest to understand seismicity for hazard reduction. This earthquake was preceded by nearly 500 foreshocks for several days prior to the main event (Jones *et. al.,* 1982). The localized nature of these events and similarity in fault mechanisms (Xu *et al.,* 1982) led to the prediction. Despite the general NNE trend of faults and seismicity in the region (Figure 8), which is consistent with tectonic models for the region, the Haicheng earthquake occurred on a fault trend N67^{0}W (Jones *et al.,* 1982).

Our plan is to focus upon the Heicheng instrumentation deployment in the second year of our cooperative work. As a result, there has been little preliminary work in developing propagation path effects for this region.

Planned Instrumentation

In both areas we will deploy Global Positioning System (GPS) locked Quanterra Q330 instruments with one STS-2 seismometer in an appropriate vault at each site. Several of the broadband sites are co-located with existing short-period stations and therefore will be able to make use of existing vaults and facilities. New stations will be deployed in temporary shallow hard rock vaults. The Q330 data acquisition system is a three-channel (as configured here) 24-bit recorder with auxiliary lower resolution channels for mass position and state-of-health variables such as temperature. For this installation, systems will be configured as stand-alone data loggers. All systems (even those close to commercial power) will use solar power and recorded data will be stored locally. Data will be recovered and quality controlled by in-country personnel on a rolling schedule with data recovery occurring at least once every few months.

Because the Q330 is a new system and has been rarely fielded, the first 10 stations will be installed in the Huailai Basin near Beijing where they can be easily monitored and maintained. Once experience demonstrates their reliability. The second deployment will be done in the Heicheng area.

CONCLUSIONS AND RECOMMENDATIONS

A combined near-source and regional study of seismicity in the Huailai Basin and Heicheng Area has been described. This work is intended to quantify seismic sources in these regions with the near-source instrumentation providing data for separating source and propagation path effects at regional distances.

This cooperative project with the Institute of Geophysics, China Seismological Bureau and Southern Methodist University includes the planned deployment of broadband stations in both regions. The year 2003 will focus upon the deployment and operation of these stations in the Huailai Basin followed by a deployment to the Heicheng Area in 2004.

The sites for both the near-source and regional deployment in and around the Huailai Basin have been identified. Plans call for the instrument deployment in the fall of 2002.

Preliminary work has been done in developing velocity models for the Huailai Basin. The model is consistent with observed near-source travel times in the regions. These starting models also show promise in modeling long-period (2- to 10-s) near-source waveforms.

ACKNOWLEDGEMENTS

This project is done in cooperation with the Institute of Geophysics, China Seismological Bureau. Particular cooperation of Prof. Chen, Dr. Yang, Ms. You and Mr. Bai is noted.

REFERENCES

Gilder, S.A., P.H. Leloup, V. Courtillot, Y. Chen, R.S. Coe, X. Zhao, W. Xiao, N. Halim, J.-P. Cogne, R. Zhu, 1999. Tectonic evolution of the Tancheng-Lujiang (Tan-Lu) fault vis middle Triassic to early Cenozoic paleomagnetic data, *J. Geophys. Res.,* **104,** 15365-15390.

Jones, L.M., B. Wang, S. Xu, and T.J. Fitch, 1982. The foreshock sequence of the February 4, 1975, Heicheng Earthquake (M=7.3), *J. Geophys. Res.,* **87***,* 4575-4584.

Xu, S., L. Yang, M. Jones, X. Ma, and P. Shen, 1982. The foreshock sequence of Haicheng earthquake and earthquake swarm – The use of foreshock sequences in earthquake prediction, *Tectonophysics,* **85***,* 91-105.

Xu, X.-T., Y.-T. Chen, P.-D. Wang, 1999. Rupture process of the M_L = 4.1 earthquake in Huailai Basin on July 20, 1995, *Acta Seis. Sinica,* **12***,* 619-631.

Yongkang, R.., F. Zhongjing, L. Zhiyi, W. Jingbo, L. Rucheng, 1995. Paleoseismicity and Segmentation Along the Active Fault at the Northern Boundary of Huailai-Zhuolu Basin, Hebei Province, *Earthquake Research in China,* **9***, November 1, 1995.*

Yongkang, R., F. Zhougjing, D. Ruitao, L. Zhiyi, W. Jingbo, Y. Zhe, J. Fengju, and L. Jianping, 1996. Model for Paleoearthquake Recurrence Along Baying Segment of the North Margin Fault of Fanshan Basin in Hebei Province, *Earthquake Research in China,* **10***, November 1, 1996.*