DEVELOPMENT OF CALIBRATION DATASETS FOR SOUTHERN ASIA

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ABSTRACT

We have recently initiated the collection of waveform and event catalog datasets for seismic stations in southern Asia, spotlighting the Indian subcontinent, as high-quality regional data for this region continues to be lacking. In the initial phase of our database development, we have focused on the compilation of readily available regional waveform datasets from different sources. In subsequent phases, we will obtain local and regional network bulletins through on-going interactions with our Cambridge University and Indian colleagues. To date, we have collected broadband waveforms from over 1000 events with $m_b > 4.0$, as listed in the Prototype International Data Center (pIDC) Reviewed Event Bulletin (REB) between 01 January 1995 and 01 January 2000 as recorded on the GEOSCOPE station HYB. This station, currently operated by the National Geophysical Research Institute of India, has been in operation in south central India since 1989. We have also started assembling a waveform database for over 300 events recorded on the short-period Gauribidanur (GBA) array between 01 January 1995 and 27 July 1996. The data recorded at HYB and GBA, which are very high quality, supplemented with current studies in the region, will be used to develop improved velocity models as well as to highlight regional propagation effects that can be used for calibrating the stations in the region for future nuclear monitoring efforts. The final product will be an extensive, comprehensive waveform database that can be used to: 1) develop improved velocity models needed for enhanced location capability and 2) increase understanding of regional wave propagation, which is critically important for the development and validation of discriminants for this region of high monitoring interest.

KEY WORDS: seismic waveform data, ground-truth database, 3-D velocity model

OBJECTIVES

Introduction

The primary objective of this project is the development of a seismic research database (DB) for nuclear explosion monitoring in southern Asia. There are large regions of southern Asia, including the Indian subcontinent, for which current real-time seismic waveform data are unavailable for regional seismic characterization studies. However, during the past three decades, several open stations have operated within southern Asia for which data have been compiled at different locations for varying purposes. Thus, one of the tasks of our current research effort will be to determine the location of and gain access to historical databases for stations that have operated (or currently are operating) in southern Asia. The compilation of these data into a single DB with a consistent format will provide access to thousands of events with associated waveforms, preliminary analyses, and metadata. These data could be used to calibrate International Monitoring System (IMS) primary and auxiliary seismic stations in the region or other stations that may be needed to bridge gaps in station/data coverage. Upon completion of the seismic research DB, we will begin integration of the deliverables into the DOE Knowledge Base (KB) for future use and continued development.

The research DB will consist of primary data products, including raw waveform data, phase bulletins and event catalogs, ground-truth (GT) data, phase-pick information, and station data. The database is modeled after the

Lawrence Livermore National Laboratory (LLNL) research DB for the Middle East and North Africa as described by Ruppert *et al*. (1996). Our database will include the following categories of primary data:

- Waveform data for thousands of regional events of varying GT quality.
- Data analyses for determination of GT classification, including location and depth of the event, origin time, and source type.
- Metadata for the waveform data and analysis.
- Catalogs and phase bulletin data obtained from global and local organizations.
- Station information, including location, seismometer response files, and station noise data.

Ruppert *et al*. (1996) compiled additional data in the LLNL DB, which they designated derived data products, such as kriged correction surfaces, surface wave group velocity measurements, travel-time and velocity models, regional discriminants, and additional features that are all beyond the scope of our current DB development. We are currently in the initial phases of the development of this seismic research DB for southern Asia, and we will show the progress made in compiling the waveform data as well as in locating mining explosions as sources of calibration data.

RESEARCH ACCOMPLISHED

Data Retrieval

We have initiated the data retrieval phase of our project to develop a seismic research DB for southern Asia. Table 1 shows the stations for which we have started collecting historical data to populate the database, and during the remainder of the contract, we will continue to seek additional stations/sources of seismic waveform data. We have downloaded all events formed in the Reviewed Event Bulletin (REB) of the Prototype International Data Center (pIDC) between 1995 and 2000 within 25 degrees of the three-component (3-C) station in Hyderabad, India (HYB). HYB is part of the GEOSCOPE network operated by the Institut de Physique du Globe de Paris and has been in operation since 15 January 1989. It includes long-period and broadband sensors, and the data are teletransmitted from the station to the data center in France. The current telemetry status of data from HYB is lagging between 12 and 18 months of the present date. For our purposes, we query the GEOSCOPE data access page (http://geoscope.ipgp.jussieu.fr) for all available channels and components for HYB for events of interest. Figure 1 shows the location of over 1000 seismic events (blue circles) of HYB waveform data downloaded to our database. We only considered regional events with $m_b > 4.0$ for inclusion in the database. Examination of these data shows that, in some cases, only the longer period surface waves are available for analysis, whereas for other events, a full spectrum of body and surface waves is observed. In the upcoming months, we will supplement additional event data for time periods prior to the pIDC operation to complete our waveform database for HYB.

The second station we are currently downloading seismic data for is the Gauribidanur Seismic Array (GBA) in central India. This medium-aperture seismic array has twenty short-period seismometers arranged along two perpendicular arms (i.e. a cross array) with data sampled at 20 samples/sec for each sensor. The array was operated by the Atomic Weapons Research Establishment (AWRE) of the United Kingdom between 04 March 1979 and 27 July 1996, upon which station control and maintenance were transferred to local authorities. Since this transfer, GBA data are no longer readily available for study; however, a great deal of relevant data exist for the array prior to 1996. These data for GBA are available through AutoDRM at the AWRE, and we are in the process of downloading all regional REB events with m_b greater than 4.0 occurring during the last 1.5 years of open station operation. These events are shown in Figure 1 as the red plusses, and it should be noted that there is overlap with the data downloaded for HYB. We will continue to supplement the REB event data at GBA with additional historical events occurring prior to pIDC operation.

Table 1. Historical stations in southern Asia for which waveform data collection has been initiated for development of a seismic research database.

Station	Location	Type	Network	Latitude	Longitude	Operation Dates
HYB	Hyberabad, India	3C	GEOSCOPE	17.417	78.553	15 Jan 1989 - present
GBA	Gauribidanur, India	Array	AWE	13.6042	77.4361	04 Mar 1979- 27 July 1996
SHIO	Shillong, India	3C	USGS-GDSN	25.5666	91.8830	11 May 1978-15 Oct 1985

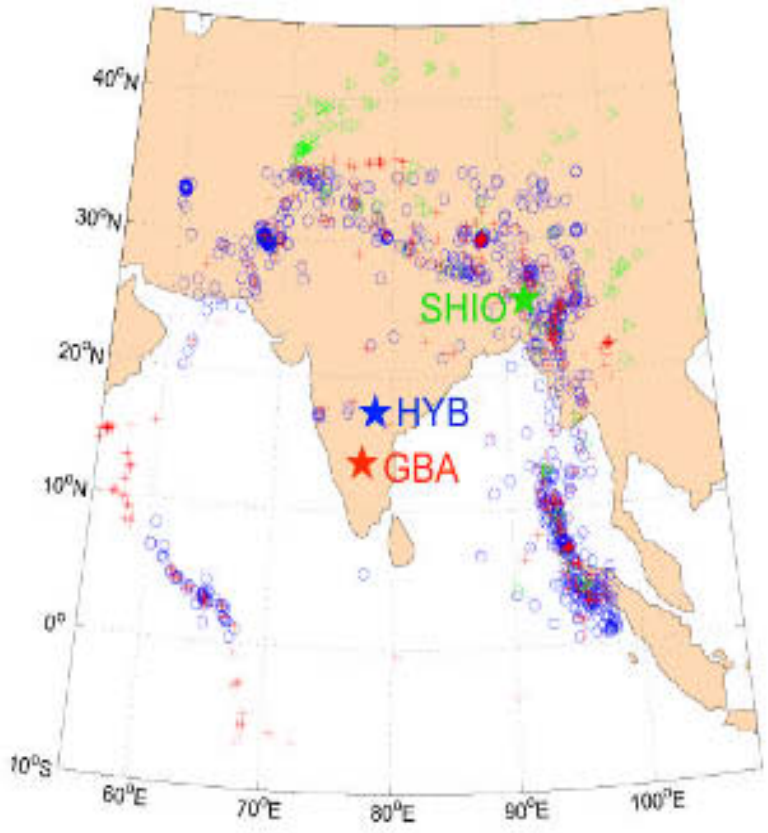

Figure 1. Locations of seismic events in southern Asia for which waveform data are being compiled in the research database. Red triangles show the GBA recorded events; blue circles designate HYB events, and green triangles show the location of SHIO recorded earthquakes.

The final station for which waveform data are being collected is Shillong, India (SHIO). This 3-C station was operated from 11 May 1978 to 15 October 1998 as part of the Global Digital Seismometer Network (GDSN). A limited dataset from SHIO has been compiled at the Incorporated Research Institutions in Seismology (IRIS) Data Management Center (DMC). We searched the United States Geological Survey's (USGS) Preliminary Determination of Epicenters (PDE) earthquake databases for all events within 25° of SHIO ($m_b > 5$) that occurred during periods of SHIO operation. We then used the AutoDRM capabilities at the IRIS DMC to download waveform data for these events (green triangles in Figure 1) for inclusion in the DB.

Database Structure

The data downloaded from each station are converted from their initial format (either SEED or GSE) into CSS3.0 as documented in Figure 2. We currently use MatSeis -1.5 (Harris and Young, 2001) to analyze each waveform. The waveforms are stored as .w files with header information compiled in the wfdisc files. Metadata compiled for each station include station operation dates, channel names and types, instrument specifications and responses, sampling responses, and locations. These metadata are usually in the form of CSS3.0 siteaux, siteremark, instrument, network, sensor, affiliation, site, and sitechan files. In addition to these CSS3.0 metadata files, we also are compiling the seed response files (SEED RESP).

We have access to various bulletins for southern Asia and have begun incorporating these data into the research DB. The pIDC REB bulletins and the USGS PDE catalogs and bulletins are also available through the database. The data are assigned a unique event identification number for relative ease in access.

Database Uses

Surface Wave Group Velocity Data. The database will ultimately provide scientists with the waveform and bulletin data necessary for seismic calibration of southern Asia. Weston Geophysical is currently using the database to aid in the development of velocity models for the region. For each event with measurable surface waves, we are determining group velocity dispersion curves through multiple filter analyses (Dziewonski *et al*., 1969) and phase match filtering (Herrin and Goforth, 1977) as coded by Herrmann (2001). An example of the results of this processing for regional events recorded at HYB is shown in Figure 3. We plan to use the surface wave dispersion curves for a tomographic velocity inversion in order to create a high-resolution 3-D shear wave velocity model of southern Asia.

Mining Explosions as Ground-Truth Data. Location calibration requires accurate travel-time tables that can often be empirically derived from GT data. GT events include earthquakes or explosions for which the uncertainties estimated for their locations are small. Mining explosions are an excellent source of GT data, especially when detailed information (such as blast location, source dimensions, and yield) can be obtained from the engineers responsible for the blasts. As part of the current study, we are actively pursuing sources of active calibration, and we are using the database to examine mining explosions in central India.

To identify mining explosion sources, we began parsing through the HYB data for January and February 1999. It became clear, based upon the number of detections during daytime versus nighttime hours, that over 95% of the routine seismicity recorded at HYB resulted from construction and mining practices (blasting that primarily occurs during daytime hours) at near-regional distances. We began compiling an event catalog for these data for events in which more than two phases could be associated with the same source. This excludes small events in which only the *Lg/Sg* phase is observed. For each catalogued event, we measured the *P*, *Lg/Sg*, and *Rg* arrival times, amplitudes, phase velocities, and polarization backazimuths. Three seismic signatures were repeatedly observed with well-dispersed fundamental mode Rayleigh waves (*Rg*), a phase that suggests the source is shallow (Kafka, 1990) and thus may possibly be a mining explosion. Since these events were repeated on a daily basis only during daytime hours, we assumed these events were the result of mining explosions. Figures 4, 5, and 6 show 3-C waveforms for these events as recorded at HYB as well as the results of the back azimuth calculation on the *Pg* phase. The relative amplitudes of *Rg* on the vertical and horizontal channels provide insight into the varying back azimuths for these three events.

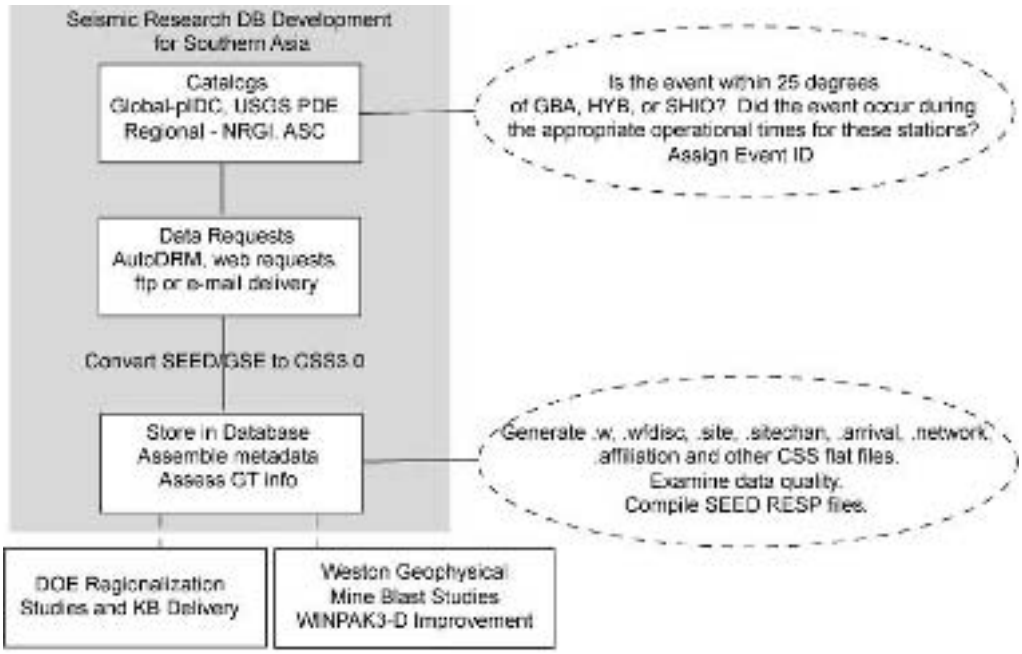

Figure 2. Schematic showing the process by which data are chosen for archiving, downloaded from various network data centers, and archived in the seismic research DB for southern Asia.

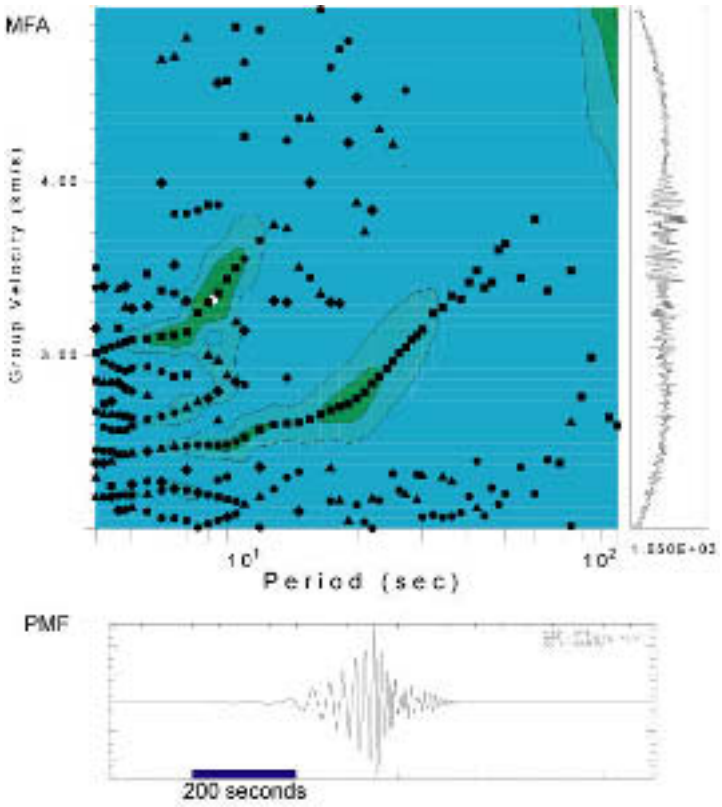

Figure 3. Weston Geophysical is using the seismic research DB to aid in velocity model studies currently ongoing in southern Asia. We are using multiple filter analyses (MFA; upper plot) and phase match filtering (PMF; lower plot) to extract surface wave dispersion curves for a future tomographic inversion.

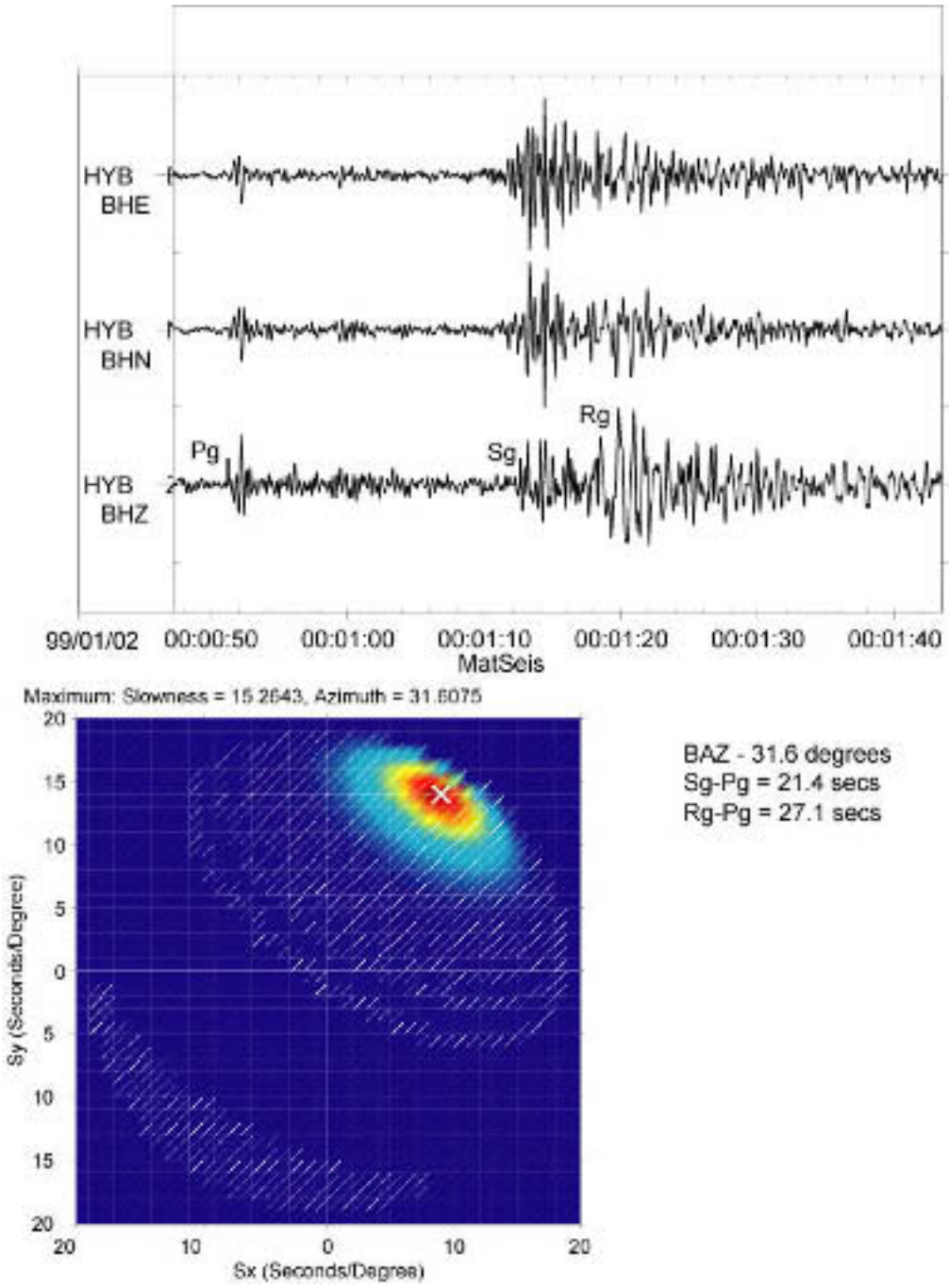

Figure 4. (Upper) Three-component waveforms recorded at HYB from an assumed mining explosion. (Lower) Results of polarization analysis for the Pg phase. Based upon the time separation of the Pg, Sg, and Rg phases and a backazimuth of 31.6 degrees, we locate the event near the Karimnagar coal-mining district.

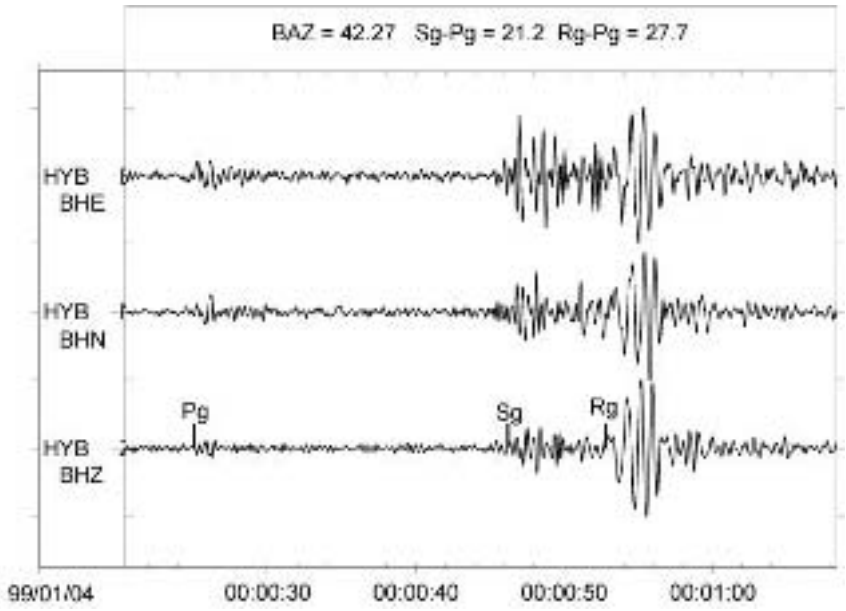

Figure 5. Three-component waveforms recorded at HYB from an assumed mining explosion. Based upon the time separation of the Pg, Sg, and Rg phases and a backazimuth of 42.3 degrees, we locate the event near the southern end of the Karimnagar coal-mining district.

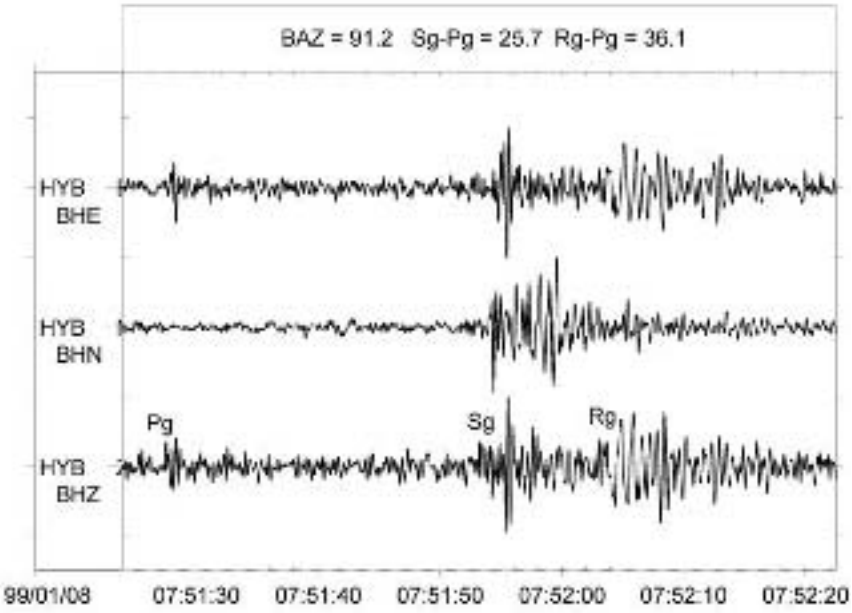

Figure 6. Three-component waveforms recorded at HYB from an assumed mining explosion. Based upon the time separation of the Pg, Sg, and Rg phases and a backazimuth of 91.2 degrees, we locate the event near the Khammam coal-mining district.

We incorporated the backazimuth together with travel-time curves obtained from previous studies (Rai *et al*., 2000) in the central Indian shield region to estimate the epicenter of the explosions. A search of the literature available on mining and mineral extraction in the Andhra Pradesh region (Infobase Pvt. Ltd, 2001) of India found the locations coincide with large coal-mining deposits on the Warangal Plateau (Figure 7). The separation of the locations into two distinct clusters is a result of blasting at mines in the Karimnagar and Khamman districts. We note that there is also a large coal-mining district in Warangal for which we did not observe explosions during our preliminary study. Using contacts with scientists working in the region, we hope to make contact with these mines to obtain detailed source information. These data will offer validation data for a 3-D model that we are currently developing for this region (Johnson and Vincent, 2001).

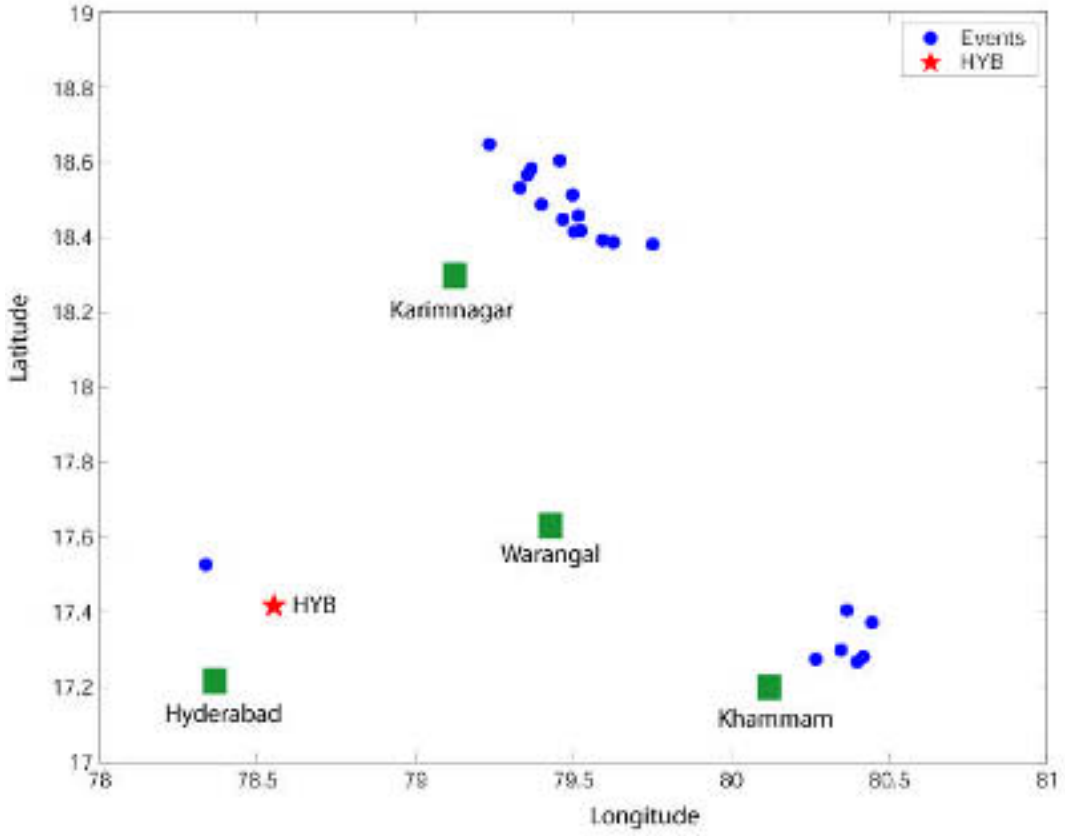

Figure 7. Locations (blue circles) derived from Sg-Pg travel-time tables and polarization backazimuths for mining explosions in southern India as recorded at HYB (red star). The locations correspond to coal mining districts north and east of the cities of Karimnagar and Khammam (green squares). There are also coal mines near Warangal; however, in our initial analysis of the data, we have not located any events near this district.

CONCLUSIONS AND RECOMMENDATIONS

The calibration of southern Asia for the purpose of nuclear explosion monitoring is complicated by minimal amounts of available data (both real-time and historical) within the region. Weston Geophysical is currently developing a seismic research database (DB) that will include as much historical seismic data from stations operating in Southern Asia as can be acquired. During the initial phase of this project, we have downloaded data from over 1200 events to the stations at HYB, GBA, and SHIO, and have included detailed station

metadata with the waveform files. During the remainder of this contract, we will continue to download and incorporate additional seismic data from these and other stations into the DB. The second phase of this project will include the collection of regional ground-truth data from mining explosions in southern Asia. Using contacts with scientists working in the region together with published mining literature for India, we have already identified several mines in the region as candidates for calibration and ground truth data. Ultimately, upon delivery to the KB, the DB will provide scientists with the waveform and bulletin data necessary for seismic calibration of southern Asia.

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