SEISMIC CHARACTERISTICS OF NORTHERN IRAQ AND SURROUNDING REGIONS

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ABSTRACT

This is a preliminary report on a field experiment to collect seismological data from the Middle East. Starting in November 2005, a network of 10 broadband seismic stations was deployed in stages over a period of 9 months throughout northern, northeastern, and central Iraq. The spatial distribution covers a large portion of the folded and foothill zones west of the Zagros continental collision boundary of the Arabian plate. These three-component digital stations have since been recording continuously at a rate of 100 Hz, yielding a rapidly growing database of numerous high quality local, regional, and teleseismic events that are characteristic of this relatively young and exceedingly active seismotectonic setting. Initial review of collected data and published bulletins confirms that a large number of small events (magnitude < 4) are either not being recorded or not being detected by distant stations, and/or they are not being reported by the scarce number of neighboring seismic stations in Turkey and Iran. Premature loss of Iraq Seismological Network (ISN) assets and contributions over the past two decades has further exacerbated this problem. Initial review of recorded seismograms, including high frequency phases, shows lateral variations, indicating signal blockage and attenuation that will require thorough mapping for the characteristics of wave propagation in the region to be understood. In addition, location of small events and relocation of internationally reported ones seem to identify source regions and trends that will be investigated in more detail when better velocity models are developed. Seismograms of events associated with these sources show remarkable similarity. Plans and preparations to utilize receiver functions and dispersion of surface waves are underway.

OBJECTIVE

Interaction between the Arabian, Eurasian, African, and Indian plates is the primary force defining the present-day seismotectonic framework of the Middle East. Figure 1 shows that interplate seismicity is significantly more important than intraplate activity. The plate margin seismicity is associated with a variety of boundaries that include spreading zones in the Gulf of Aden and the Red Sea, the transform fault along the Dead Sea rift and East Anatolia, the Bitlis suture in eastern Turkey, the northwest-southeast trending Zagros thrust zone, the Makran east-west trending continental margin and subduction zone, and the Owen fracture zone in the Arabian Sea. The apparently aseismic Arabian plate interior features an exposed young shield, a deformed platform and a foredeep that consists of extraordinarily thick layers of sediments and evaporites. Structural faults and folds cross these major tectonic regions.

Several investigators attributed the observed low intraplate seismicity to the lack of regional and local seismic stations, and to the scarce reporting of events by existing networks in and around the Arabian plate (Adams and Barazangi, 1984; Ghalib et al., 1985). Another feature of the interplate seismicity is its non-uniform distribution along the plate boundaries (e.g., the Zagros thrust zone), which seems to correlate with the presence of local seismic networks or individual stations (e.g., stations TAB and SHI and, more recently, the local Iranian networks along the central Zagros region).

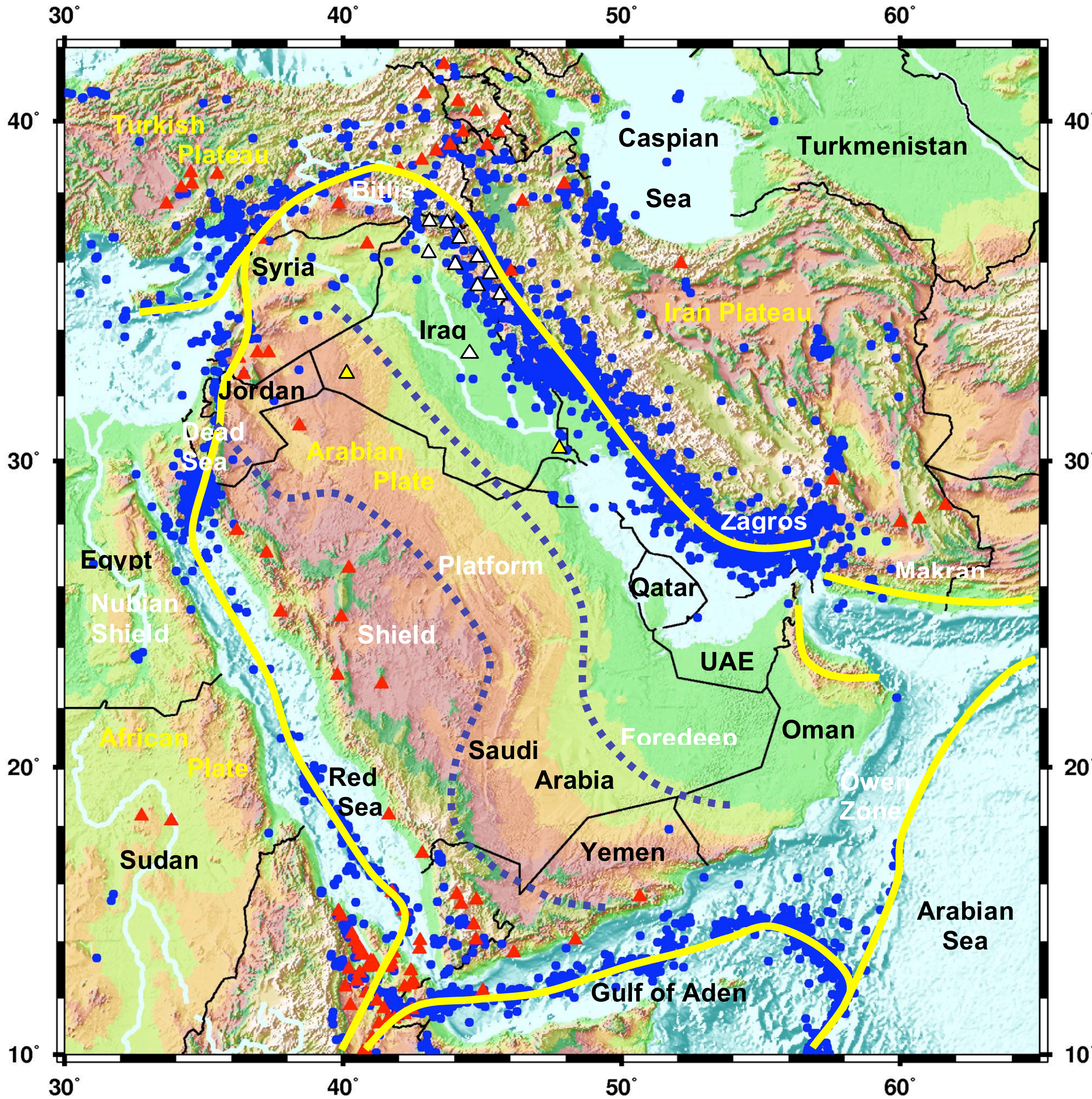

Figure 1. Map of the Arabian Peninsula and surrounding regions. The major geographic, tectonic, and geologic features are labeled. The plate boundaries are marked with yellow lines. Earthquakes and volcanoes are shown as blue circles and red triangles, respectively. White triangles represent the 10 stations that compose the North Iraq Seismological Network (NISN). The yellow triangles reflect the location of some Iraq Seismological Network (ISN) stations, currently not operational.

To study the seismicity and seismotectonic setting of the Arabian plate, its seismotectonic boundaries, and the surrounding regions, this effort commenced with the deployment of a network of broadband seismic stations in north and northeast Iraq to the south of the Bitlis suture zone and to the east and southeast of the Zagros thrust zone, an area that was partially monitored by the severely damaged five ISN stations. This ISN network was composed of stations BHD, SLY, MSL, RTB, and BSR outside the cities of Baghdad, Sulaimaniyah, Mosul, Al Rutba, and Basra, respectively. The instrumentation at these five stations included short-, intermediate-, and long-period analog as well as some digital systems procured from various vendors and manufacturers.

The primary objectives of this deployment effort are as follows:

1. Collect and analyze high-quality ground-truth seismic data from this area of Iraq and the surrounding region.
2. Precisely locate the events and characterize the signal and propagation of high-frequency waves in the region.
3. Estimate the seismic velocity and attenuation structures of the study area using the dispersion and receiver functions of observed surface and body waves, respectively.

RESEARCH ACCOMPLISHED

This is the first technical report on an effort in progress that entails the deployment and operation of a broadband seismological network of 10 stations to record local and regional seismic activity in north Iraq and the surrounding countries of Iran and Turkey, where the Zagros and Taurus (Bitlis) tectonic zones meet. Figure 2 shows the location and spatial distribution of these stations throughout Kurdistan province. In August 2005, the first two stations, KSLY and ERBL, were deployed temporarily at Sulaimaniyah and Erbil seismological observatories until the desired remote sites were surveyed and prepared for long-term deployment. These stations were later shut down and the instrumentation relocated to more remote and significantly quieter sites to complement the planned distribution and coverage of the NISN (see Figure 2).

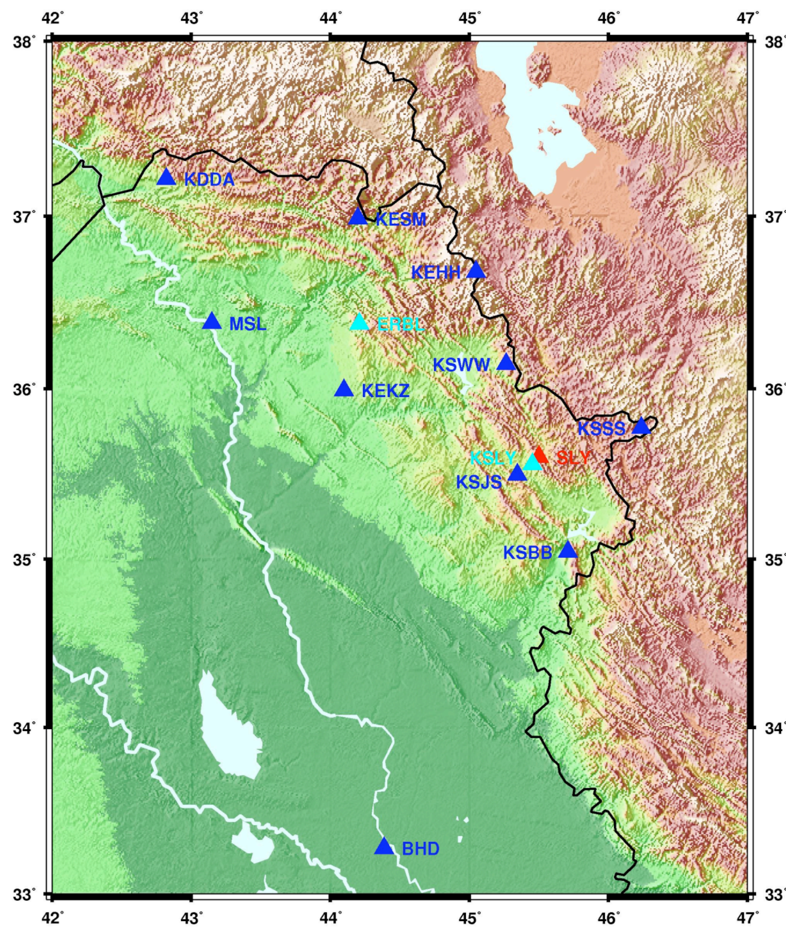

Figure 2. A map showing the distribution of NISN stations. The station locations are marked with blue triangles. Stations ERBL and KSLY (aqua triangles) are the temporary sites of these two stations. Station SLY (red triangle) belongs to the ISN. Stations BHD, MSL, and SLY are also part of the original ISN.

Figure 3 shows photographs of three of the stations in the foothills and along the NW-SE trending axis of the Zagros tectonic boundary. The photographs are of stations (a) KSSS, (b) KSWW, and (c) KEMS. The instrumentation for these 10 stations is provided by the Incorporated Research Institutions for Seismological Research (IRIS), PASSCAL Instruments Center. They have been continuously recording and storing on-site three-component data at 100 Hz. The data have been retrieved manually once every three months during maintenance visits to the sites.

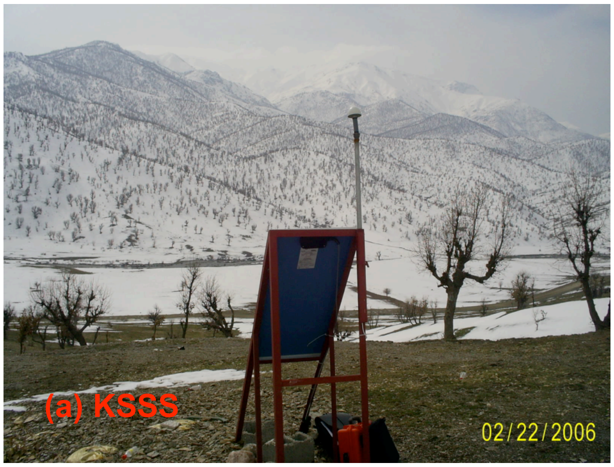

Figure 3. Photographs of three of NISN three-component broadband stations, (a) KSSS, (b) KSWW, and (c), KEMS taken at different seasons (see Figure 2 for the location of these stations). Only the solar panels and GPS antennae are showing. The STS-2 seismometer, Q330 digitizer, Baler data storage, power controller box, and battery are all buried underground in insolated heavy-duty plastic barrels. The seismometers sit on concrete piers that are cemented to the bedrock. At 100 Hz, the recorded data are retrieved approximately once every three months without the risk of losing any of the data.

Deployment of NISN stations took place in stages and over a 6-month period. The majority of the stations (8 out of 10) were deployed during November 2005. The installations of instruments at station BHD in Baghdad and at station MSL in Mosul were delayed until April 2006 due to the unrest in both cities. The parameters for all stations are given in Table 1.

Table 1. Parameters of the North Iraq Seismological Network (NISN)

North Iraq Seismological Network (NISN)						
No.	**Station Name**	**Latitude (degrees)**	**Longitude (degrees)**	**Elevation (meters)**	**Installation Date**	**Removal Date**
1	KSBB	35.0415	45.7092	550	11/25/2005	
2	KSSS	35.7696	46.2362	1515	11/26/2005	
3	KSWW	36.1493	45.2624	1310	11/28/2005	
4	KSJS	35.4965	45.3452	825	11/27/2005	
5	KEHH	36.6764	45.0470	1725	11/30/2005	
6	KESM	36.9846	44.1981	1000	12/01/2005	
7	KDDA	37.2125	42.8207	750	12/02/2005	
8	KEKZ	35.9893	44.0970	450	12/03/2005	
9	MSL	36.3817	43.1483	242	04/06/2006	
10	BHD	33.2744	44.3858	32	04/11/2006	
11	KSLY	35.5559	45.4534	912	08/23/2005	04/04/2006
12	ERBL	36.3772	44.2086		08/21/2005	11/29/2005

The Zagros is a relatively young orogenic belt known for its high level of seismicity. To date, eight NISN stations (excluding BHD and MSL) have provided approximately 40 gigabytes of high-quality local, regional, and teleseismic data. More data, including stations BHD and MSL, will become available shortly. Figure 4 shows a map of 190 events (red solid circles) recorded by NISN from November 30, 2005, to January 8, 2006, located using a generalized velocity model for the Zagros fold and thrust zones (Pasyanos et al., 2004). In an attempt to understand the capability and performance of the NISN, the events reported by the U.S. Geological Survey (USGS, blue crosses) and the International Seismological Center (ISC, green crosses) are also included.

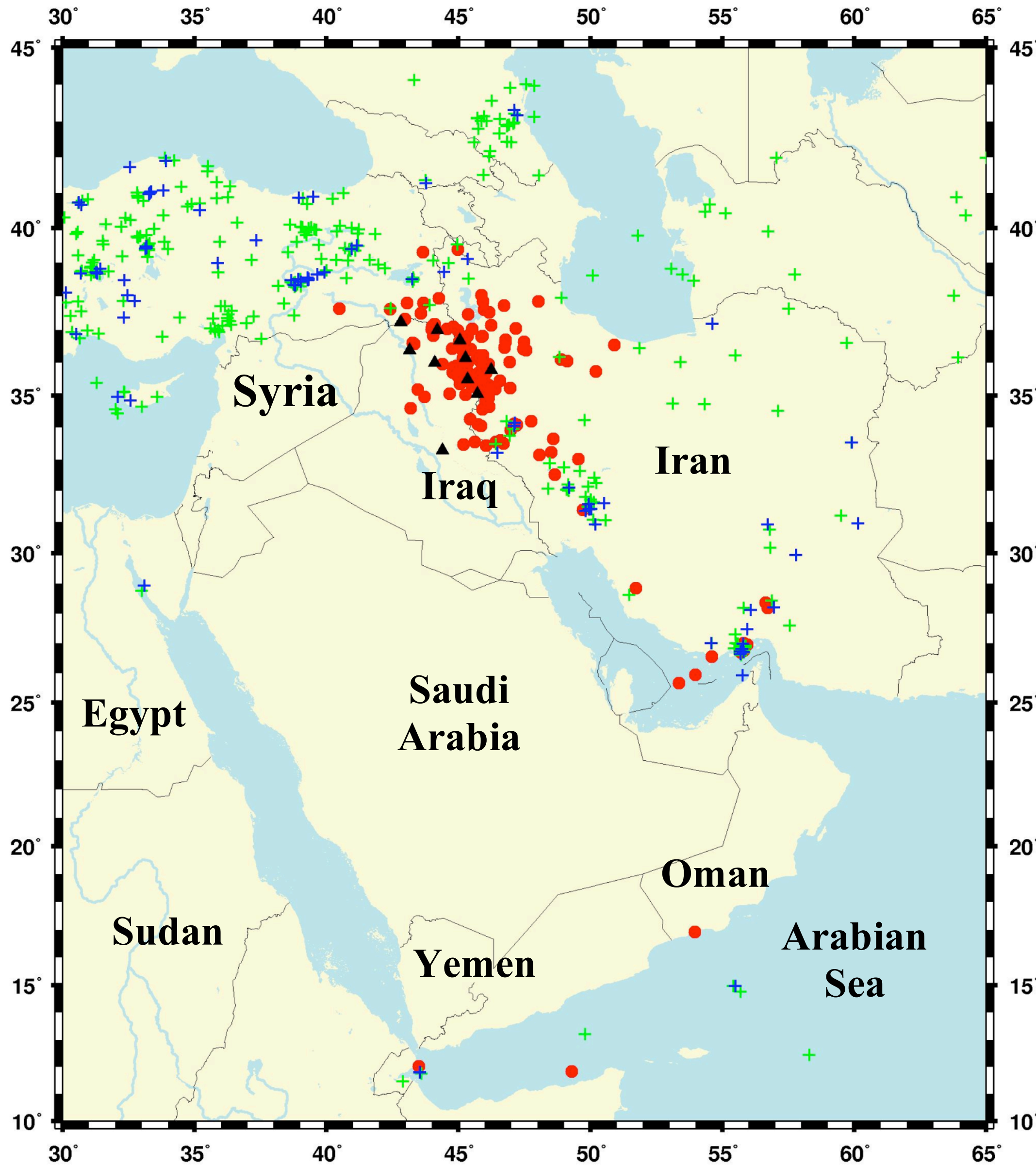

Figure 4. A map showing the location of 190 events recorded by NISN (red solid circles) for the period November 30, 2005, to January 8, 2006, ISC (green crosses), and the USGS (blue crosses) for the same period.

Although it is too early to draw affirmative conclusions, it is evident that most of the events recorded by NISN are found in neither the ISC nor USGS bulletins. The histogram in Figure 5 shows that during the period November 30, 2005, to January 8, 2006, NISN has recorded over five and eight times the number of events reported by the ISC and USGS, respectively. One obvious explanation is that many of the unreported events are small and may not have been detectable by regional stations in Turkey and Iran. Second, the degradation of ISN capability has significantly impacted monitor events in this region. Also noteworthy is that many of the events reported by the USGS and ISC seem to cluster around the local stations in Iran and Turkey that reported their parameters, leaving a major section of the Zagros and its foothills and folded belt to be covered by NISN in an effective and comprehensive manner.

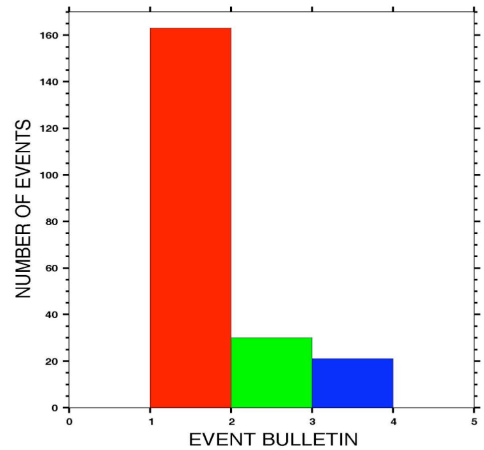

Figure 5. A histogram showing the number of events reported by NISN (red bar), ISC (green bar), and USGS (blue bar) for the same time period.

Figure 6 presents sample waveforms recorded by NISN stations. Example A shows waveforms from an event recorded at eight NISN stations in which the primary regional phases Pn, Pg, Sn, and Lg are clearly identified on most traces. According to the USGS, this event occurred on December 26, 2005, at 23:15:53.4, 49.1713°N, 49.2201°E, 32 km, $m_b = 5.1$. The epicentral distances and azimuths range from about 130–140 km and 2°–5°, respectively. Example B shows the waveforms of a regional event near Bandar Abbas in Iran, recorded at station KSSS. According to the USGS, this event occurred on November 30, 2005, at 15:19:54, 26.76°N, 55.82°E, $m_b = 6.0$, and it was felt throughout several of the Arabian Gulf countries, including the United Arab Emirates. In this case, the Pn, Sn, and LR phases are pronounced due to their propagation paths, which coincide with the axis of the thick sedimentary column of the Arabian foredeep.

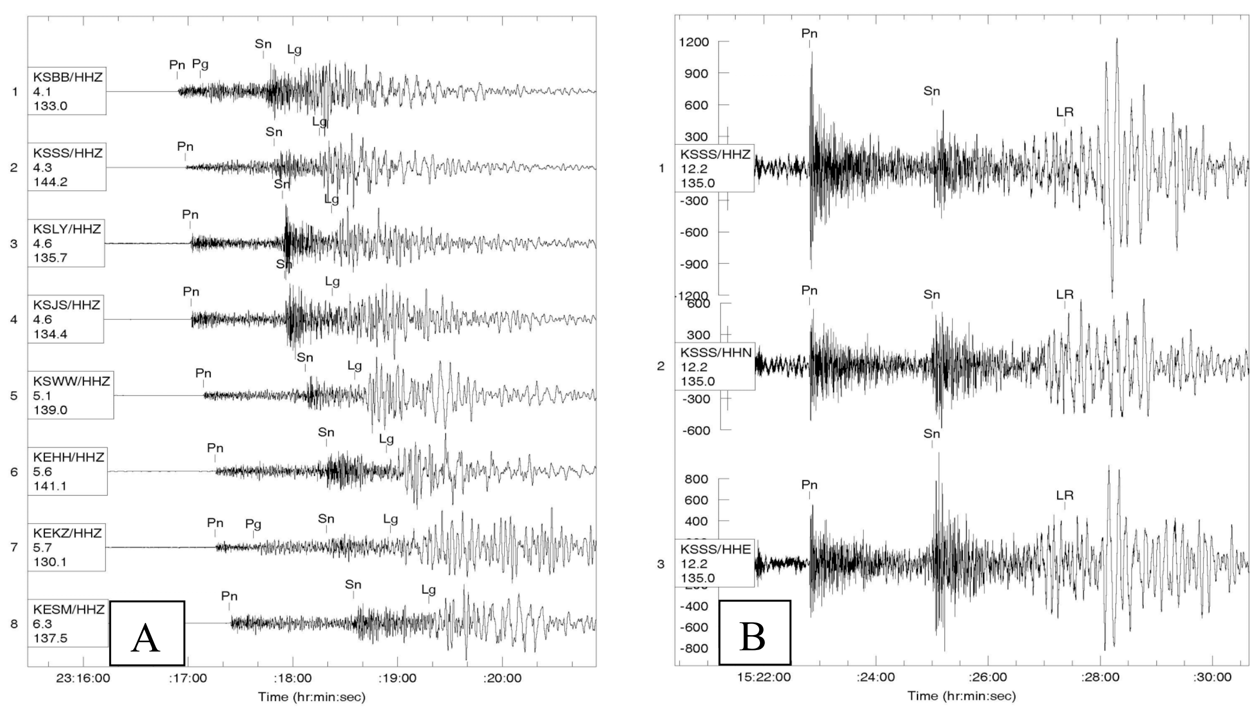

Figure 6. Sample waveforms recorded at eight NISN stations showing the quality of recorded data and pronounced arrival of Pn, Pg, Sn, Lg, and LR phases.

At this stage of the effort, data from all 10 NISN stations (including BHD and MSL) are being analyzed to satisfy the first and subsequent objectives of this project, as stated earlier. The analyses include reformatting the data in accordance with CSS 3.0 and SAC, identifying observed phases, evaluating the path effects on propagating waves from different azimuths, and locating the events using published models for the region.

In the next example (Figure 7), the vertical component waveforms from three events recorded at station KSWW are presented to illustrate the influence of the Zagros tectonic structure on wave propagation. Studies have shown that some of the regional phases (e.g., Sn and Lg) can be attenuated or blocked from propagating across or along the major structural features. In Figure 7, the top waveform, whose backazimuth is about 29^{o}, reveals clear Pn, Pg, and Lg but no clear Sn crossing the Zagros-Bitlis zone, whereas, the second waveform reveals Pn and Sn but no Pg or Lg traveling along the Zagros axis. In contrast, events with a propagation path from west or south (bottom waveform) exhibit unobstructed propagation of Pn, Pg, Sn, and Lg phases.

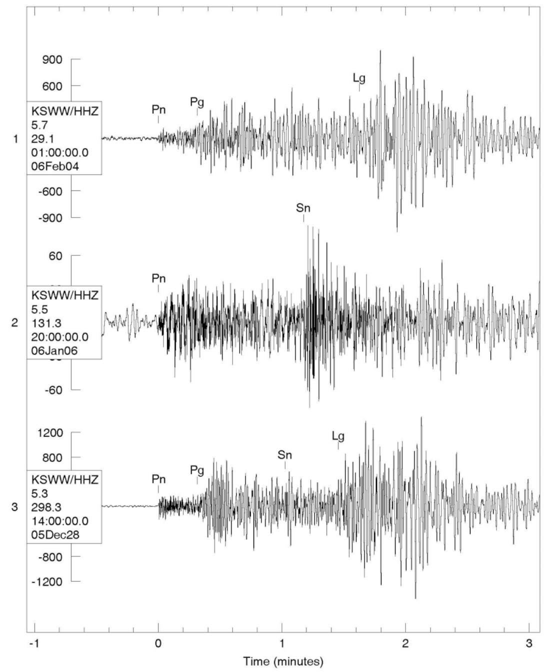

Figure 7. An example showing the impact of tectonic structures (in the form of attenuation or signal blockage) on wave propagation of various azimuths on regional phases Pn, Pg, Sn, and Lg.

Finally, to satisfy the second and third objectives of this effort, preparation to estimate the velocity models along different paths and beneath the 10 NISN station is also underway. Figure 8 shows example of a shear velocity model derived from the inversion of a Rayleigh wave propagating along a path that traverses the region from Bandar Abbas in Iran to station ERBL. Data from many more events along this path will be combined at a later date to provide better estimates and constraints of the dispersion curves and estimated models. Furthermore, joint inversions using the dispersion and receiver functions of observed surface and body waves, respectively, will be attempted to provide more detailed and precise representation of the variation of the velocity model throughout the study area.

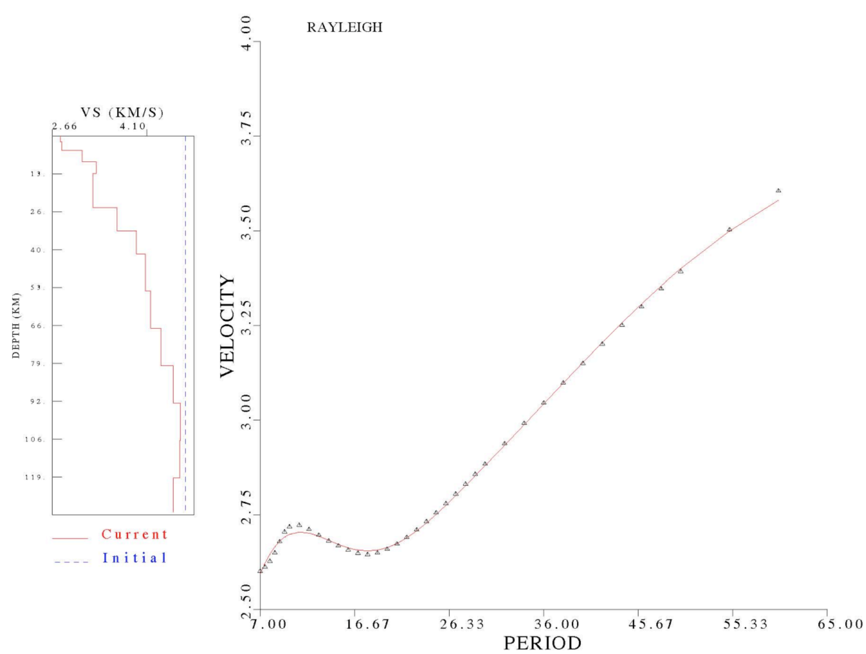

Figure 8. An example of a shear velocity model calculated from the inversion of a Rayleigh wave recorded at station ERBL, whose propagation path traversed the NW-SE trend of the thick sediments of the Arabian plate foredeep.

CONCLUSIONS AND RECOMMENDATIONS

This research effort is in its early stage of accomplishment. To date, the network of 10 NISN stations have been installed and are collecting three-component seismic data. Analyzed waveforms show remarkable quality and a wealth of information about the signal propagation at various azimuths and across major tectonic provinces. Preparations to further exploit these data to estimate the velocity and attenuation models of the study area are underway.

Preliminary evaluation of the data collected to date leads one to recommend expanding the NISN array to cover a larger area of the Zagros and its foothills. This will not only help to draw better three-dimensional models of the physical parameters and properties of the region but will also map the geological and tectonic features for better monitoring of earthquakes throughout the Middle East. Furthermore, it is invaluable to not only continue but also to expand our collaboration with the Iraqi institutions.

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