Improving the level of seismic hazard parameters in Saudi Arabia using earthquake location and magnitude calibration

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key words: Earthquake location, magnitude, Saudi Arabia, seismic hazard,

Abstract

Saudi Arabia is an area, which is characterized very poorly seismically and for which little existing data is available. While for the most parts, particularly, Arabian Shield and Arabian Platform are aseismic, the area is ringed with regional seismic sources in the tectonically active areas of Iran and Turkey to the northeast, the Red Sea Rift bordering the Shield to the southwest, and the Dead Sea Transform fault zone to the north.

Therefore, this paper aims to improve the level of seismic hazard parameters by improving earthquake location and magnitude estimates with the Saudi Arabian National Digital Seismic Network (SANDSN).

We analyzed earthquake data, travel times and seismic waveform data from the SANDSN. KACST operates the 38 station SANDSN, consisting of 27 broadband and 11 short-period stations. The SANDSN has good signal detection capabilities because the sites are relatively quiet. Noise surveys at a few stations indicate that seismic noise levels at SANDSN stations are quite low for frequencies between 0.1 and 1.0 Hz, however cultural noise appears to affect some stations at frequencies above 1.0 Hz.

Locations of regional earthquakes estimated by KACST were compared with locations from global bulletins. Large differences between KACST and global catalog locations are likely the result of inadequacies of the global average earth model (iasp91) used by the KACST system. While this model is probably adequate for locating distant (teleseismic) events in continental regions, it leads to large location errors, as much as 50-100 km, for regional events.

The paper presents detailed analysis of some events and Dead Sea explosions where we found gross errors in estimated locations. Velocity models are presented that should improve estimated locations of regional events in three specific regions: 1. Gulf of Aqabah - Dead Sea region 2. Arabian Shield and 3. Arabian Platform.

Recently, these models are applied to the SANDSN to improve local and teleseismic event locations and to develop an accurate magnitude scale for Saudi Arabia.

Introduction

There has only been a modest amount of earthquake seismological work done in the Arabian Peninsula. Several countries either on or surrounding the Peninsula have seismograph stations, but most stations are equipped with short-period vertical seismometers. In any event, the networks are sparse and often are poorly situated with respect to seismically active areas. Broadband data required for analysis of teleseismic receiver functions are almost wholly lacking. Regional wave propagation from earthquakes and seismic wave attenuation have not been studied. Microseismicity is known to occur in many areas of the Peninsula, but the existing network of stations is inadequate for accurately defining spatial characteristics or determining focal mechanisms.

One of the main objectives of this study was to estimate crustal and upper mantle structure to improve earthquake location and magnitude estimation. While there have been many studies on this topic using a wide variety of techniques, many questions about the structure on the Arabian Peninsula remain unanswered. A thorough understanding of the seismic structure and wave propagation characteristics of the region must be established before proceeding to assess the seismic hazard. Therefore, the objective of the proposed research was to improve assessment of seismic hazard parameters by improving earthquake location and magnitude estimates with the Saudi National Seismic Network (SANDSN).

Seismotectonics & seismic structures

The Arabian Peninsula forms a single tectonic plate, the Arabian Plate. It is surrounded on all sides by active plate boundaries as evidenced by earthquake locations. Figure 1 shows a map of the Arabian Peninsula along with major tectonic features and earthquake locations. Active tectonics of the region is dominated by the collision of the Arabian Plate with the Eurasian Plate along the Zagros and Bitlis Thrust systems, rifting and seafloor spreading in the Red Sea and Gulf of Aden. Strike-slip faulting occurs along the Gulf of Aqabah and Dead Sea Transform fault systems. The great number of earthquakes in the

Gulf of Aqabah pose a significant seismic hazard to Saudi Arabia. Large earthquakes in the Zagros Mountains of southern Iran may lead to long-period ground motion in eastern Saudi Arabia.

The two large regions associated with the presence or absence of sedimentary cover define the large-scale geologic structure of the Arabian Peninsula.The Arabian Platform (eastern Arabia) is covered by sediments that thicken toward the Arabian Gulf. The Arabian Shield has no appreciable sedimentary cover with many outcrops.

The northwestern regions of Saudi Arabia are distinct from the Arabian Shield, as this region is characterized by high seismicity in the Gulf of Aqabah and Dead Sea Rift. Active tectonics in this region is associated with the opening of the northern Red Sea and Gulf of Aqabah as well as a major continental strike-slip plate boundary.

The Dead Sea transform system connects active spreading centers of the Red Sea to the area where the Arabian Plate is converging with Eurasia in southern Turkey. The Gulf of Aqabahh in the southern portion of the rift system has experienced left-lateral strike-slip faulting with a 110 km offset since early Tertiary to the present. The seismicity of the Dead Sea transform is characterized by both swarm and mainshock-aftershock types of earthquake activities.

The Arabian Plate boundary extends east-northeast from the Afar region through the Gulf of Aden and into the Arabian Sea and Zagros fold belt. The boundary is clearly delineated by teleseismic epicenters, although there are fewer epicenters bounding the eastern third of the Arabian Plate south of Oman. Most seismicity occurs in the crustal part of the Arabian Plate beneath the Zagros folded belt (Jackson and Fitch, 1981). The Zagros is a prolific source of large magnitude earthquakes with numerous magnitude 7+ events occurring in the last few decades. The overall lack of seismicity in the interior of

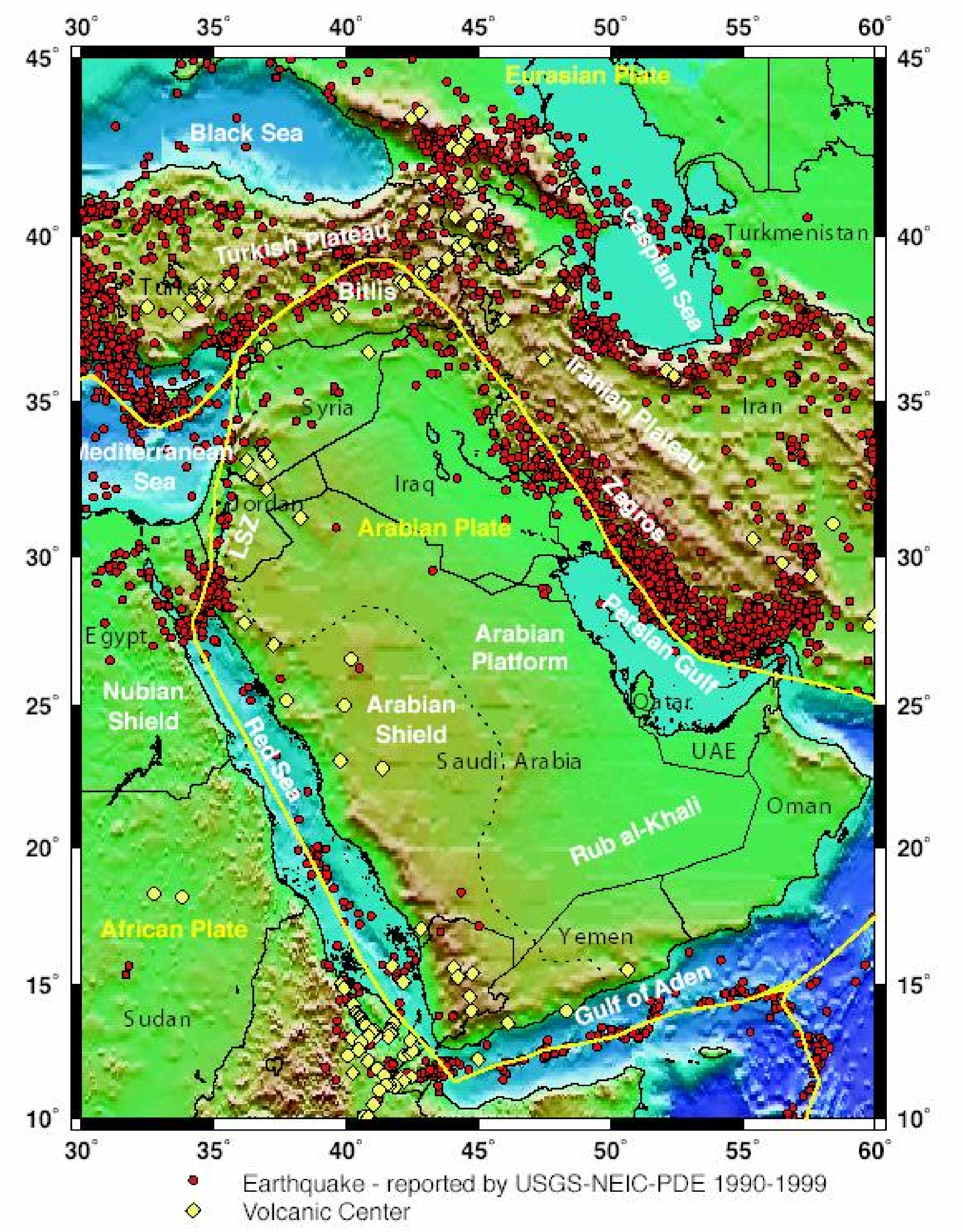

*Figure 1***.** Map of the Arabian Peninsual and surrounding regions. Major geographic and tectonic/geologic features are indicated. Plate boundaries are indicated by yellow lines. Earthquakes and volcanic centers are shown as red circles and yellow diamond, respectively.

the Arabian Peninsula suggests that little internal deformation of the Arabian Plate is presently occurring.

Mooney et al.(1985) suggests that the geology and velocity structure of the Shield can be explained by a model in which the Shield developed in the Precambrian by suturing of island arcs. They interpreted the boundary between the eastern shield and the Arabian Platform as a suture zone between crustal blocks of differing composition.

Surface waves observed at the long-period analog stations RYD (Riyadh), SHI (Shiraz, Iran), TAB (Tabriz, Iran), HLW (Helwan, Egypt), AAE (Addis-Ababa, Ethiopia) and JER (Jerusalem) were used to estimate crustal and upper mantle structure (Seber, D. and B. Mitchell, 1992); (Mokhtar, T. and M. Al-Saeed, 1994) These studies reported faster crustal velocities for the Arabian Shield and slower velocities for the Arabian Platform.

The Saudi Arabian Broadband Deployment (Vernon, F. and J. Berger, 1997; Al-Amri et al.,1999) provided the first data set of broadband recordings of this region. This deployment consisted of 9 broadband three-component seismic stations along a similar transect an early seismic refraction study (Mooney et al., 1985; Gettings et al.,1986). Data from the experiment resulted in several studies and models (Sandvol et al., 1998; Mellors et al., 1999; Rodgers et al.,1999; Benoit et al.,2002). These studies provided new constraints on crustal and upper mantle structure. The crustal model of the western Arabian Platform shows a little higher P-velocity for the upper crust in the Shield than in the Platform and the crustal Platform seems to have a greater thickness than in the Shield by about 3 km. The Moho discontinuity beneath the western Arabian Platform indicates a velocity of 8.2 km/sec of the upper mantle and 42 km depth (Al-Amri, 1998), (Al-Amri, 1999).

Generally, the crustal thickness in the Arabian Shield area varies from 35 to 40 km in the west adjacent to the Red Sea to 45 km in central Arabia (Sandvol et al.,1998; Rodgers et al., 1999). Not surprising the crust thins nears the Red Sea (Vernon, and Berger, 1997; Gettings et al., 1986; Mellors et al.,1999). High-frequency regional S-wave phases are quite different for paths sampling the Arabian Shield than those sampling the

Arabian Platform (Mellors et al., 1999 ; Sandvol et al., 1998). In particular the mantle Sn phase is nearly absent for paths crossing parts of the Arabian Shield, while the crustal Lg phase is extremely large amplitude. This may result from an elastic propagation effect or extremely high mantle attenuation and low crustal attenuation occurring simultaneously, or a combination of both.

Previous reports of large scale seismic structure (Ritsema et al.,1999; Debayle et al., 2001) suggest that a low velocity anomaly in the upper mantle extends laterally beneath the Arabian Shield from the Red Sea in the west to the shield – platform boundary in the east. Additionally, Debayle et al.(2001) observe a narrow region of low velocity beneath the Red Sea and western edge of the Arabian Shield, extending to 650 km depth. A recent tomographic velocity model and receiver function analysis by (Benoit et al., 2002) suggests the upper mantle low velocity anomaly is smaller in extent, laterally and vertically, than imaged in previous studies.

Methodology

The study improved the earthquake location and magnitude estimates using waveform data from the Saudi Arabian National Digital Seismic Network (SANDSN). The proposed research includes standard seismological investigations as well as newly developed techniques as follows:

Data Collection and Validation

In order to validate the station timing and instrument response we performed comparisons of timing and amplitudes of P-waves for large teleseismic events at the SANDSN stations with the Global Seismic Station RAYN. This station has well calibrated timing and instrument response. The relative arrival times of teleseismic P-waves at the SANDSN can be accurately measured by cross-correlating with the observed waveforms at RAYN and correcting for distance effects. Absolute amplitudes of teleseismic P-waves at the SANDSN and RAYN stations were measured by removing the instrument response and gain and band-pass filtering.

This study also considered many events and computed average travel time and amplitude residuals relative to a globally averaged one dimensional earth model, such as iasp9l. Although there were deviations between the timing and amplitudes of SANDSN P-waves from the predictions of the iasp9I model (because of lateral heterogeneity) the tests were useful to identify which stations might have timing and / or instrument calibration problems.

Travel Time Calibration

One of the most fundamental elements of seismological research is earthquake location. In fact the main product of any seismic network is the reporting of earthquake location, origin time and magnitude. The first major element of our proposed research was to improve earthquake locations by developing and improving models of the seismic velocity structure. It is well known that the lithosphere (crust and uppermost mantle) of Saudi Arabia is heterogeneous. Some of the difference in the seismically inferred crustal structure of eastern and western Arabia is due to the thick sediments of the Arabian Platform. However, recent waveform modeling results (Rodgers et al.,1999) suggest that there are also differences in the seismic velocities of the crystalline crust between the Arabian Shield and Platform. These differences result in travel time variations within the Arabian Peninsula, which will bias earthquake locations when a single, one - dimensional velocity model is used.

Similarly, variations in the amplitudes of regional phases, such as those reported by Mellors et al. (1999). That study reported that Pn, Pg and Sn body-waves from the Gulf of Aqabah events to central Arabia are weak, while Lg along is strong. More normal continental energy partitioning of the regional phases is observed for earthquakes from the Zagros. These variations in regional phase propagation characteristics can make it difficult to develop detection algorithms for regional phases, most importantly the first arriving Pn phase. The fundamental travel time and amplitude behavior of regional phases needs to be characterized before the SANDSN can be tuned to provide optimal phase detection, locations and magnitudes.

Accordingly, It improved the earthquake location and origin time estimates by developing and improving models of the regional seismic phases and the seismic velocity structure of the lithosphere. Firstly, data was collected from large well-observed earthquakes with well-constrained locations, depths and origin times. Events with 50 or more observations (stations) and an open-azimuth of less than 90 degrees are typically located to within 20 km of ground truth locations as reported by (Sweeney,1996). The study used similar criteria to select well-located events for travel time analysis. Travel time picks of regional phases Pn, Pg, Sn and Lg were reviewed by an analyst and quality controlled before they are included into the data set. Travel time curves for each phase were generated. As sufficient data are collected, we developed regional travel time models for different paths (e.g. Arabian Shield and Arabian Platform) and for events in different source regions (e.g. Gulf of Aqabah, Red Sea, Zagros Mountains).

Focal mechanism solutions & refinement of velocity models

In order to develop a robust magnitude scale, earthquake moments, focal mechanisms and depths were estimated by modeling observed long-period three-component waveforms (Walter,1993). We modeled the observed waveforms with complete reflectivity synthetic seismograms (Randall,1994) using an appropriate seismic velocity model of the crust and shallow mantle. The current models were validated (Rodgers et al., 1999), possibly refine them or develop new models. Special efforts were spent to define the regions of validity of the velocity models.

The study began by first considering large earthquakes (Mw> 5.0) that are within regional distance (< 1500 km) of Saudi Arabia. Often events of this size have focal parameters from global observations (such the Harvard CMT or USGS-NEIC moment tensor projects).Waveform data for these events were selected and reviewed for signal-to-noise. The data were corrected for instrument response, converted to ground displacement and the horizontals were rotated to radial and transverse components.

Earthquake focal mechanism, depth and seismic moment were estimated by fitting synthetic seismograms to the long-period three-component waveforms. The source parameters are estimated by a grid search method (Walter,1993). For a series of depths, all possible orientations of the double couple focal mechanism (strike, dip and rake) are investigated.

Results & data analysis

Seismic noise measurements

Background seismic noise is an unavoidable problem in earthquake monitoring. The amplitudes of seismic arrivals decrease with distance and seismic magnitude. Path propagation effects, such as attenuation and elastic structure lead to variability in seismic amplitudes. Noise inhibits the detection of weak seismic arrivals (phases) from distant and/or small events. Seismic noise is generated from a variety of sources. These include both man-made (e.g. roads, machinery) and natural sources (e.g. wind, ocean waves, temperature effects). Noise properties can vary between daylight and night hours and between seasons (e.g. summer and winter). Also the geologic character of the seismometer placement has great effect on the noise–hard rock sites typically have lower noise levels than sites on weathered or sedimentary rock or unconsolidated material. Because of the variety of noise sources and the variability of noise, propagation and site characteristics at network sites, the noise properties at seismic stations are frequency dependent and can be highly variable between sites.

Noise spectra were measured at KACST stations (AFFS, HASS, HILS, QURS and TATS). Stations were selected to be distributed around the Kingdom (Figure 2). Event-segmented data were previewed and first-arriving P-waves were picked. Waveforms were instrument corrected to absolute ground motion using the LLNL developed Seismic Analysis Code (SAC). Noise segments were taken as the available waveform before the P-wave pick. Typically for SANDSN data this was 30-60 seconds. For noise spectral measurements we accepted only segments 30 seconds or longer. This limited the low frequency resolution of our noise estimates. Power spectral densities were computed for noise windows by Fast Fourier Transform (FFT) and normalized by the window length. Noise spectra are presented in acceleration in decibels relative 1 $(m/s^2)^2/Hz^2$.

Results for noise at AFFS station are presented in Figure 3. And shown the vertical, north and east component noise acceleration power spectra (in decibels relative to 1 m^2/s^4). Also shown are the average low and high noise spectra of Peterson,1993).

Results showed that stations AFFS, HILS and TATS have the lowest noise levels. Stations HASS and QURS have the highest noise levels of the sites considered. Cultural noise appears as spikes in the power spectra at frequencies above 1 Hz. This is most notable at stations HILS (4 and 8 Hz) and QURS. These sites may be affected by nearby cultural noise sources, such as roads and human activities.

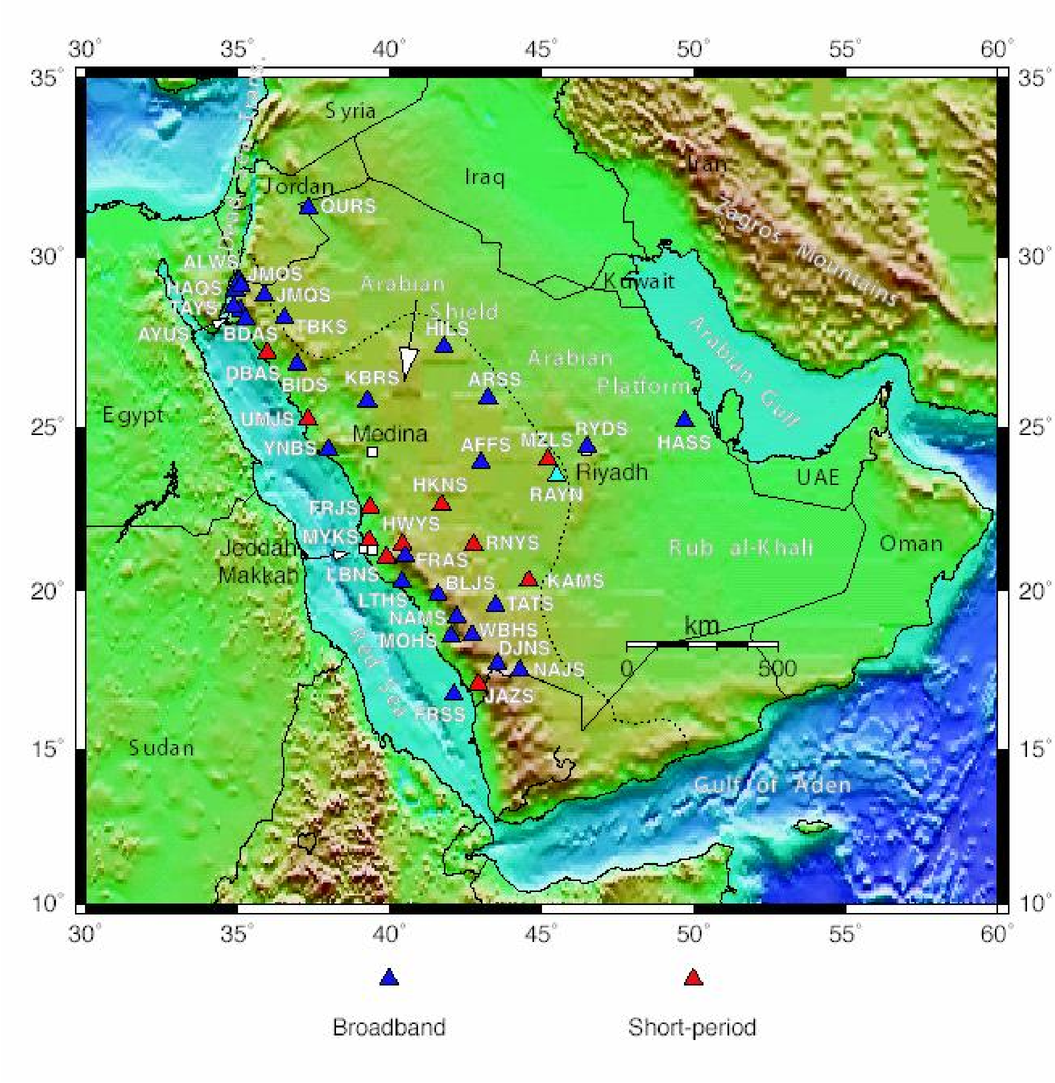

*Figure 2***.** Map of the stations from the Saudi Arabian National Digital Seismic Network (SANDSN).

Generally the noise is relatively low amplitude between 0.1 and 1 Hz, except for station HASS. Detection of energy at frequencies around 1 Hz is most important for P-wave arrivals used in the event location. Higher frequency energy is useful for detecting local and regional events, less than 1000 km away.

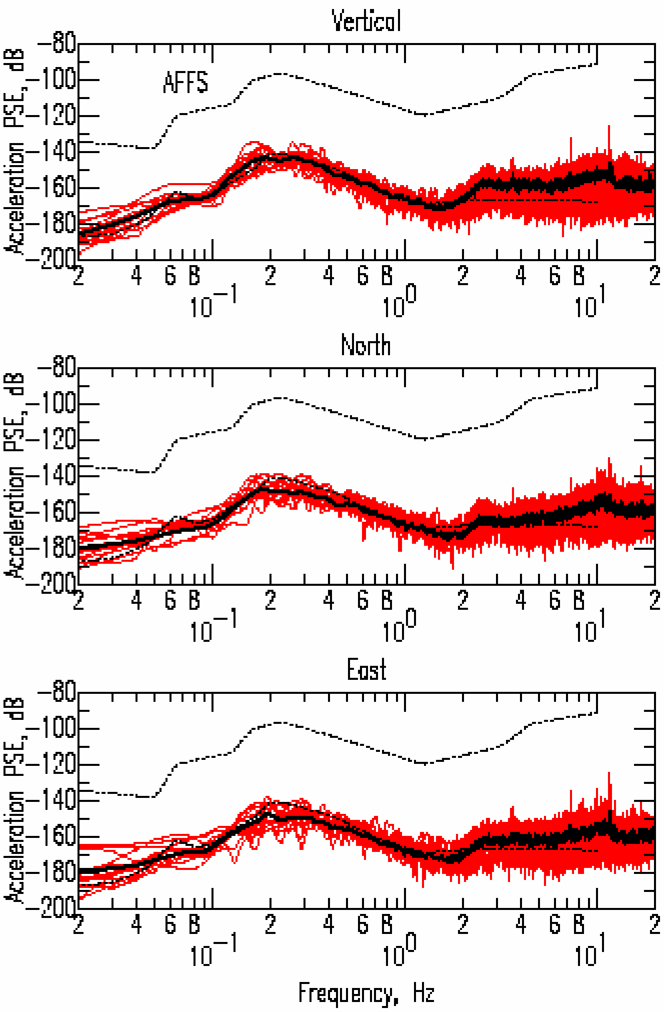

Figure 3. Noise spectra at station AFFS. Acceleration power spectra (in decibels relative to 1 m2/s4) are shown for the vertical, north and east components. Individual spectra are shown in red and the average spectra in black. Also shown are the average low and high noise spectra (dotted line) of Peterson (1993).

SANDSN location performance

The locations of the events outside the network were improved by calibrating the travel time or velocity structure between the event regions and recording stations. The arrival times of moderate-sized events ($m_b \geq 4.5$) can be accurately measured to uncertainties of 1 second or less, if noise levels allow for good signal-to-noise levels. The calibration task is made difficult by the fact that one often does not accurately know the location and origin times of events. Events with accurate locations and origin times, so called ground truth (GT) events, are difficult to obtain. GT events come in various varieties. Man-made explosions with controlled location and detonation time are the best and most difficult to obtain form of ground truth. These events can be located with uncertainties of less than 100 meters and the origin times can be determined to tenths of a second. Mining and civil engineering explosions can be good sources of ground truth, however these events are often too small to be observed beyond 100 km. Earthquakes excite more seismic energy and can be observed at larger distances, however, their locations are poorly more constrained. In some cases where an earthquake is recorded at local distances (< 100 km) with good azimuthal coverage, the locations can be accurate to less than 10-20 km (Sweeney, 1996). This translates to 1-2 seconds of travel time at regional distances.

Comparison with Catalog Locations

Earthquake locations for events in and around Saudi Arabia were then compared with those reported by networks with global station coverage (e.g. REB, USGS-PDE and ISC). The comparison first associates events from each catalog in the LLNL Seismic Research Database. Event locations must occur at nearly the same time and location to be associated with the same event. The global catalogs have the advantage of global azimuthal coverage of each event, while the SANDSN network has observations limited to stations within the Kingdom of Saudi Arabia. Most of the seismicity occurs near or outside the borders of the Kingdom, making location strongly dependent on the assumed seismic velocity model and travel time curve(s).

The SANDSN locations were compared with those reported by: the Provisional Technical Secretariat (PTS) of the Comprehensive Test Ban Treaty Organization (CTBTO) Reviewed Event Bulletin (REB); International Seismological Center (ISC) and the United States Geological Survey (USGS) National Earthquake Information Center (NEIC) Preliminary Determination of Epicenters (PDE). These organizations report seismic event catalogs based on world-wide observations of body-wave arrival times.

We restricted the global catalog event magnitudes to be 4.0 or greater. This reduces small events that might be poorly observed and located by the global network(s).

Figure 4 shows the comparison of event locations from the SANDSN and global network bulletins for the Zagros Mountains region. The map shows that the SANDSN locations were generally to the southwest of the global network locations. The mean location (epicenter) difference is over 50 km. This corresponds to travel time error of as much as 6 seconds. Similar analysis was preformed on a very limited set of Red Sea events. The location differences do not appear to be very large for the events studied. There are not many large events in this area.

These location differences are probably due to the velocity model errors and can be reduced by using more appropriate region-dependent velocity models instead of the *iasp91* model. The *iasp91* model is a global average model for continental regions and is most accurate for predicting teleseismic travel times. At local to regional distances (0-1500 km) travels times are strongly region dependent due to lithospheric structure (i.e. crustal thickness, crustal and uppermost mantle seismic velocities and attenuation). These variations also lead to differences in regional phase amplitudes and propagation characteristics and require detailed study beyond the scope of the current project.

Improved Velocity Models for the Arabian Peninsula

The sensitivity of travel times to one-dimensional (1D) average velocity structure is certainly non-unique and the goal was to find a range of models that fit the data reasonably well and are consistent with what is already known about the region. By using a grid search technique the problems associated with linearizing the dependence of the data on model parameters were, as avoided required by linear inversion methods. The grid search was performed using travel time data sets: (a) Pn and Pg; and (b) Pn, Pg and Sg. Two data sets were considered for two reasons. Firstly, the onset times of Sg are more difficult to pick, so it may not be prudent to include the Sg picks in the estimation of structure.

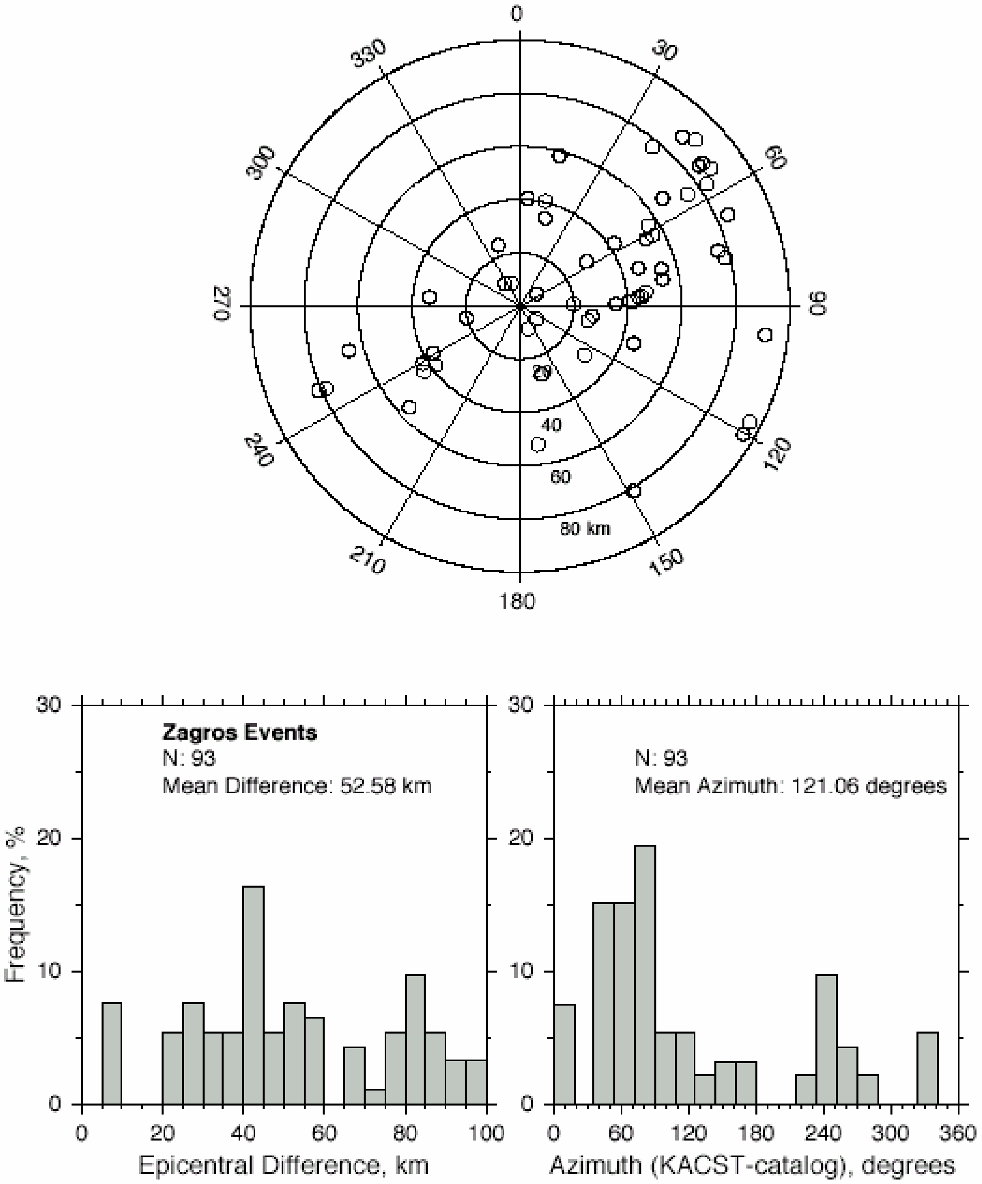

*Figure 4***.** Statistical characterization of location differences between SANDNSN and global network locations for the Zagros Mountains region: (top) azimuth and distance; (left) epicentral difference; (right) directional bias in locations.

Secondly, There is direct solution for the shear wave velocities, but rather scaling shear velocities to compressional velocities with an assumed Poisson's Ratio, so the influence of Sg travel times may bias the model. The optimal model should reduce the scatter in the data (i.e. minimize the rms) and result in zero-mean residuals. The models were chosen that resulted in absolute mean residuals less than 0.5 seconds and minimum rms. The threshold on the absolute mean residual was chosen to be a conservative estimate on the picking error. From the 800 models considered, were chosen. The 20 best fitting models according to the criteria described above. Crustal thicknesses range between 24 and 30 km. The upper crustal velocities are poorly resolved by both data sets. Velocities of the lower crust are 6.0-6.2 km/s.

Discussion & interpretation

Velocity models from surface wave dispersion and waveform modeling

Earlier work with waveform data from the 1995-1997 Saudi Arabian Broadband Deployment by the University of California, San Diego (UCSD) and King Saud University resulted in models for the Arabian Platform and Arabian Shield (Rodgers et al.,1999). In that study, Love and Rayleigh wave group velocities were modeled to estimate average one-dimensional seismic velocity models of the two main geologic/tectonic provinces of Saudi Arabia. A grid search was used to quickly find a range of models that satisfactorily fit the dispersion data, then that range of models was explored to fit the three-component broadband (10-100 seconds) waveforms. The resulting models revealed significant differences between the lithospheric structure of the three regions as shown in tables 1, 2, and 3.

Table 1. Preferred Velocity Model for the Gulf of Aqabah/Dead Sea Region

DEPTH (KM)	THICKNESS(KM)	V_P (KM/S)	V_S (KM/S)
0	2	4.50	2.60
2	5	5.50	3.18
7	10	6.10	3.52

17	11	6.20	3.60
28	∞	7.80	4.37

V_P and V_S are the P- and S-wave velocities, respectively.

Table 2. Preferred Velocity Model for the Arabian Shield Region

DEPTH (KM)	THICKNESS(KM)	V_P (KM/S)	V_S (KM/S)
0	1	4.0	2.31
1	15	6.20	3.58
16	20	6.80	3.93
36	∞	7.90	4.30

V_P and V_S are the P- and S-wave velocities, respectively.

Table 3. Preferred Velocity Model for the Arabian Platform Region

DEPTH (KM)	THICKNESS(KM)	V_P (KM/S)	V_S (KM/S)
0	4	4.00	2.31
4	16	6.20	3.64
20	20	6.4	3.70
40	∞	8.10	4.55

V_P and V_S are the P- and S-wave velocities, respectively.

Surface wave group velocity analysis

To check the validity of our model for the Arabian Platform, Rayleigh and Love wave group velocities were measured for a number of regional events from the Zagros Mountains and Turkish-Iranian Plateau. Paths from these events to the SANDSN stations sample the Arabian Platform. Were also shown the predictions for our Arabian Platform velocity model (*Rodgers et al.*, 1999). Working with Dr. Michael Pasyanos (LLNL) and Ms. Maggie Benoit (Pennsylvania State University), A tomographic model of surface wave group velocities was constructed for the Arabian Peninsula and Africa Rift regions.

Figure 5 shows the resulting tomographic image of 20 second Rayleigh wave group velocities. The image shows slower than average velocities for the Arabian Platform and Rub Al-Khali, probably due to low-velocity sediment cover. The Red Sea is faster than average due to thinner crust. The 20 second group velocities gradually increase from the Eastern Province to the Hejaz and Red Sea. The inclusion of additional surface wave dispersion data could help resolve three-dimensional structure of Saudi Arabia.

Evaluation of sandsn timing with p-wave arrival times

In order to check the timing at the SANDSN stations and to measure relative P-wave arrival times with an accurate cross-correlation method ([21]. This method finds the optimal relative timing of vertical component P-waves at a set of stations. The travel time residuals were then computed relative to a layered earth model, such as *iasp91* (Kennett and Engdahl, 1991). This method was used by Benoit et al. (2002) to image P-wave velocity anomalies beneath the Arabian Shield. Residual uncertainties are typically 0.05-0.1 seconds. The method was to check the relative timing of the SANDSN stations to identify possible timing errors at the stations. Modern seismic recording systems use GPS timing at the site and are less likely to have problems compared with older systems. The residuals were quite small ranging about 1.5 seconds. This range was consistent with that found by Benoit et al. (2002) and is likely related to upper mantle P-wave velocity structure and not due to timing problems at the stations

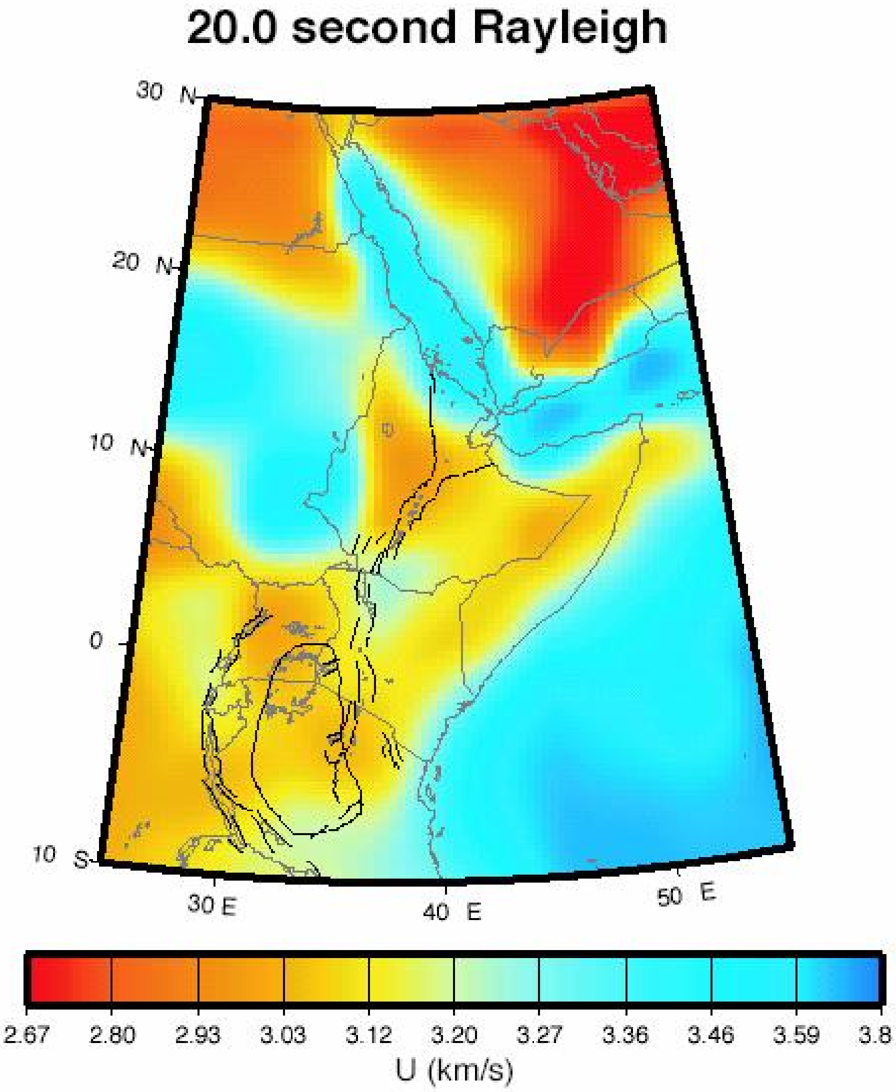

*Figure 5***.** Rayleigh wave group velocities at 20 seconds for the Arabian Peninsula, African Rift and surrounding regions.

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Evaluation of velocity models with sandsn travel times

The seismic velocity models described above are emblematic of the variability in thermal and compositional structure related to complex tectonic processes at work in the Arabian Peninsula. In order to check the validity of travel time predictions from our proposed seismic velocity models, a comparison was made for the observed travel times for well-located earthquakes and chose to use waveforms from the 1995-1997 UCSD-KSU Saudi Arabian Broadband Deployment. It was done this for two reasons. Firstly, The limited KACST waveform data to work with. Secondly, we used the earthquake locations from the International Seismological Center (ISC). These locations rely on arrival time reports from all over the world and are delayed by more than two years after an event occurs. There was little or no overlap between our well-located earthquake catalog and KACST data holdings. The available catalog had events in the Zagros Mountains. This provided paths sampling the Arabian Platform.

Agreement between the observations and the Arabian Platform model predictions is quite good. The paths sample the faster crust of the Arabian Shield and this may be the reason that the arrivals are on average early compared with the model predictions.

Focal mechanisms of regional events

A moderate (M~5) earthquake struck the northeastern United Arab Emirates (UAE) on March 11, 2002. The event was large enough to be detected and located by global networks at teleseismic distances. The region is generally believed to be aseismic, however no regional seismic network exists in the UAE to determine earthquake occurrence. This event served as a test case to illustrate the SANDSN location performance and demonstrated what can be done with broadband waveform data. Local information provided by the United Arab Emirates University (UAEU) Department of Geology, locates this event in or near the town of Masafi, in the Oman Mountains.

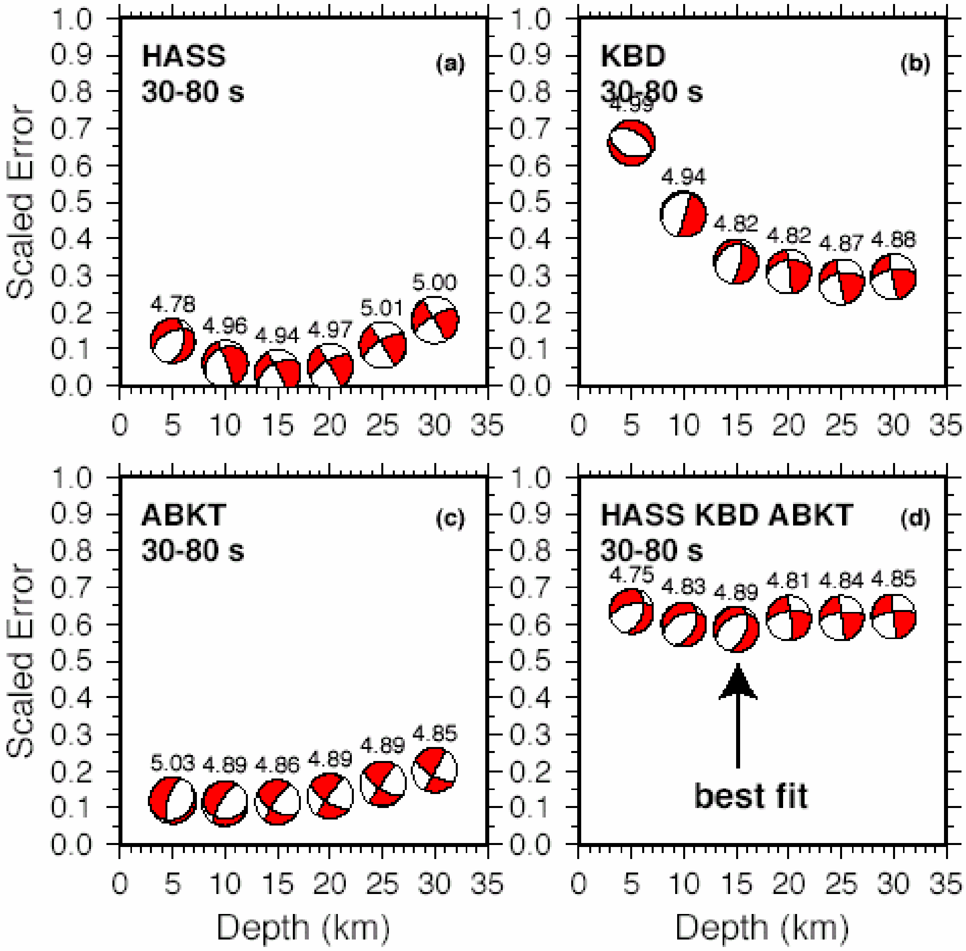

*Figure 6***.** Focal mechanism and scaled error versus depth for the individual three-component station data (a-c, HASS, KBD and ABKT, respectively) and the joint fitting of all three stations (d).

Broadband complete regional waveforms were used to estimate a focal mechanism and depth of the event. Figure 6 shows the misfit (scaled error) and focal mechanism versus depth for the individual stations (HASS, KBD and ABKT) and for the combined three-station fit. The focal mechanism is consistent with the broad-scale tectonics of the Arabian-Eurasian collision. To the west to the Musandam Peninsula, Arabia is under thrusting the southern Eurasian margin along the Zagros Thrust. To the east of the

Musandam Peninsula, convergence is much slower given the seismicity along the Makran coast. Strike-slip motion probably occurs along reactivated thrust planes associated with obduction of the Semail Ophilite (Oman Mountains).

Conclusions & recommendations

1) The Saudi Arabian National Digital Seismic Network (SANDSN) is an excellent, state-of-the-art seismic network. The sites are quiet and noise surveys at a few stations indicated that seismic noise levels at SANDSN stations are quite low for frequencies between 0.1 and 1.0 Hz, however cultural noise appears to affect some stations at frequencies above 1.0 Hz. Broadband waveform data is generally comparable with data from the Global Seismic Network operated by the Incorporated Research Institutions for Seismology (IRIS-GSN).

2) No Evidence was found of timing problems with the data. The sample rate (currently set at 100 samples/second) can be lowered to 50 samples/second without any loss of information. The current high sample rate has several unwanted consequences. Firstly, the high sample rates taxes network communications and computational facilities. Secondly the high sample rate requires additional memory requirements when the data are archived. Reducing the sample rate to 50 would immediately reduce the load on tape and disk memory by 50%.

3) The ANTELOPE system appears to be operating as expected, routinely detecting and locating events. However, the location errors described above are the result of using an inappropriate velocity model. The system uses the *iasp91* model (Kennett and Engdahl, 1991). While this model is probably adequate for locating distant (teleseismic) events in continental regions, it leads to large location errors, as much as 50-100 km, for regional events.

4) Variability of lithospheric structure is revealed by the need for different models for the regions of the northwest of Saudi Arabia (the Gulf of Aqabah / Dead Sea), the Arabian Shield and the Arabian Platform. Travel time analysis and surface wave group velocities confirm the variability in structure and the need for path-dependent models.

5) We measured surface wave group velocities for a number of earthquakes with paths sampling the Arabian Platform. Inclusion of these measurements in a tomography study shows a rich pattern of structure.

Acknowledgments

The authors would like to express their thanks and gratitude to King Abdulaziz City for Science and Technology for funding this project (Grant no. AR-20-68).We extend our sincerest thanks to Moustafa Hameda from KACST and Ahmed R. Khalil from KSU for providing this project with the earthquake data and to Dr. Michael Pasyanos and Ms. Maggie Benoit who performed the surface wave group velocity measurements and tomography.

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