SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

CTBTO
PREPARATORY COMMISSION

National network data contributions to seismic studies in the Kingdom of Saudi Arabia

Rengin Gök, Zaam Otaibi, Yahya Tarabulsi, Ahmed Hosny, Andrea Chiang, Michael Pasyanos

P1.2-94

POSTER

National network data contributions to seismic studies in the Kingdom of Saudi Arabia

Rengin Gök, Andrea Chiang, Michael Pasyanos Lawrence Livermore National Laboratory USA (gok1@llnl.gov)
Zaam Otaibi, Yahya Tarabulsi, Ahmed Hosny National Center for Earthquake and Volcanoes, Saudi Geological Survey KSA

ABSTRACT

- Increased urban development, occasional volcanic swarms, and large earthquakes surrounding the Kingdom of Saudi Arabia (KSA) have contributed to a renewed interest in understanding seismic hazard and risk within the Kingdom.
- In response, the KSA has expanded the national seismic network over the past several decades. Now, a sizable collection of local and regional data provides an opportunity to further develop KSA capabilities in seismology and seismic hazard assessment.
- The Lawrence Livermore National Laboratory (LLNL) and the National Center for Earthquakes and Volcanoes (NCEV) of the Saudi Geological Survey (SGS) started collaborating in 2016, with long-term goals of reducing seismic hazard and risk.
- We began by using time-domain full waveform moment tensor inversion and coda-envelope derived amplitude measurements to solve for earthquake source mechanism, moment magnitudes, and their source-type. We compare the moment magnitudes calculated from the two methods and publicly available earthquake catalogs and discuss the implications of the obtained source parameters. This study supports NCEV operational needs while obtaining stable and robust solutions that give quantitative information about the seismicity needed to better understand potential seismic hazards.
- A parallel collaborative study is focused on improving attenuation models of lithosphere for a broad frequency band using multiple-phase inversion

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

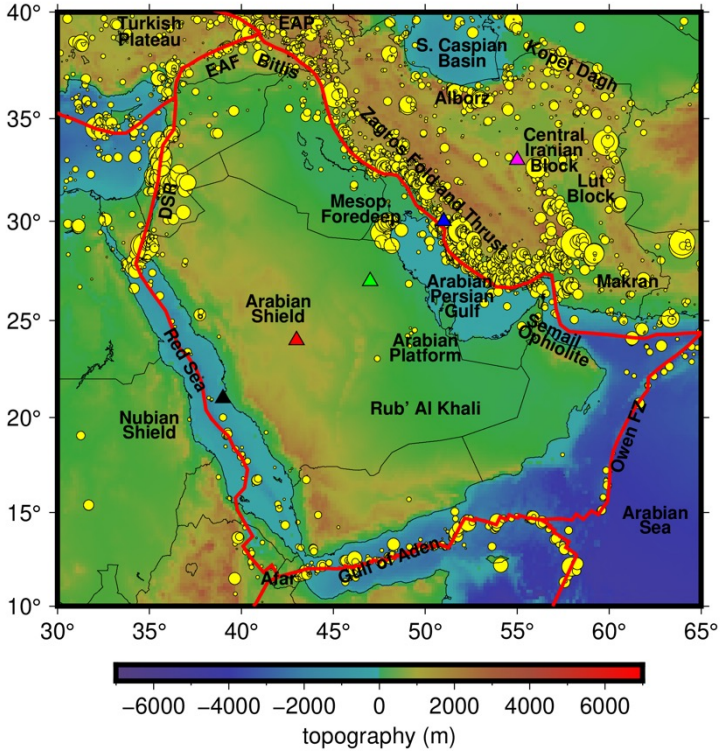
National network data contributions to seismic studies in the Kingdom of Saudi Arabia

Rengin Gök, Andrea Chiang, Michael Pasyanos Lawrence Livermore National Laboratory USA (gok1@llnl.gov)
Zaam Otaibi, Yahya Tarabulsi, Ahmed Hosny National Center for Earthquake and Volcanoes, Saudi Geological Survey KSA

Poster No.: P1.2-094

CTBTO PREPARATORY COMMISSION

INTRODUCTION



- The Middle East is a tectonically diverse region of complex geology due to the presence of all major types of plate boundaries resulting from interactions between five major tectonic plates
- Access to high-quality waveform data from well-calibrated regional seismic stations is fundamental in producing robust and stable estimates of earthquake source parameters, particularly when measurements of absolute ground motion amplitudes are required
- Exploiting the increasing number of high-quality stations in the region we develop a high-resolution broadband attenuation model of the lithosphere for the Arabian Plate. We do this by combining stations from global networks with dense networks from several countries in the region. We then measure regional phase amplitudes and combine them into a multi-phase attenuation tomography
- In the Kingdom of Saudi Arabia there are also renewed public safety concerns near historically inactive lava fields due to a recent 2009 earthquake swarm in northwestern part of the country

Figure 1 Topographic map of the study region indicating tectonic features (black lettering), plate boundaries (red lines), and earthquake sources used in the study scaled by magnitude (yellow circles). DSR = Dead Sea Rift, EAF = East Anatolian Fault, EAP = Eastern Anatolian Plateau, FZ = Fracture Zone. (Pasyanos et al., 2021)

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

National network data contributions to seismic studies in the Kingdom of Saudi Arabia

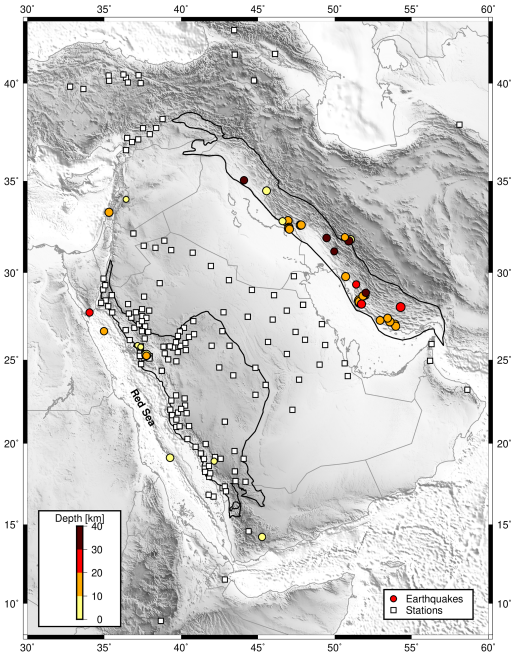
Rengin Gök, Andrea Chiang, Michael Pasyanos Lawrence Livermore National Laboratory USA (gok1@llnl.gov)
Zaam Otaibi, Yahya Tarabulsi, Ahmed Hosny National Center for Earthquake and Volcanoes, Saudi Geological Survey KSA

Poster No.: P1.2-094

CTBTO PREPARATORY COMMISSION

METHODS

Mw and Focal Mechanism Using Moment Tensor Inversion



Chiang et al., 2021

Figure 2. A topographic and bathymetric map showing the Arabian Peninsula and surrounding regions. The black polygons outline two major tectonic features

- We perform three-component, time-domain, full waveform moment tensor inversion to estimate focal mechanism, total seismic moment and source depth
- For this study we use a 1-D Gulf model for earthquakes originating from the Zagros fold-and-thrust belt and a 1-D Arabian Shield model for earthquakes from Western Arabian Peninsula and Red Sea Rift Zone.
- Previous studies found that crustal attenuation does not strongly affect surface wave amplitudes greater than 10 second periods so we fixed the crustal Qs and Qp to 200 and 400, respectively.

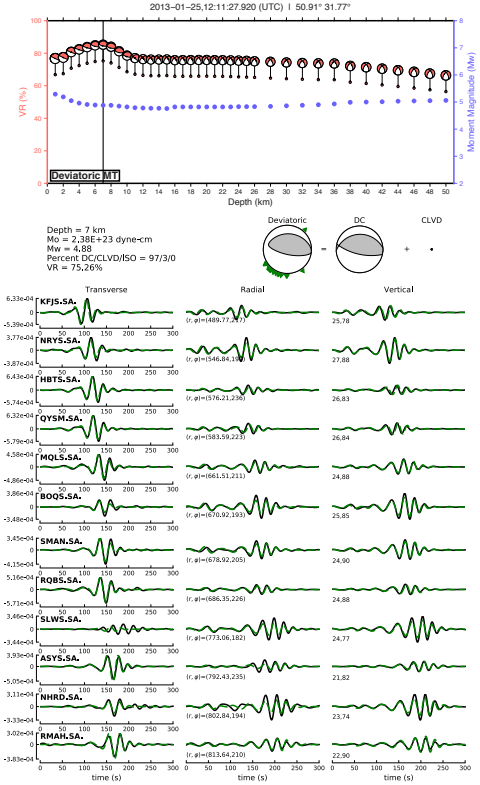


Figure 3. Moment Tensor Solution of an earthquake in the Zagros

Disclaimer: The views expressed on this poster are those of the author and do not necessarily reflect the view of the CTBTO PrepCom

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE
Poster No.: P1.2-094

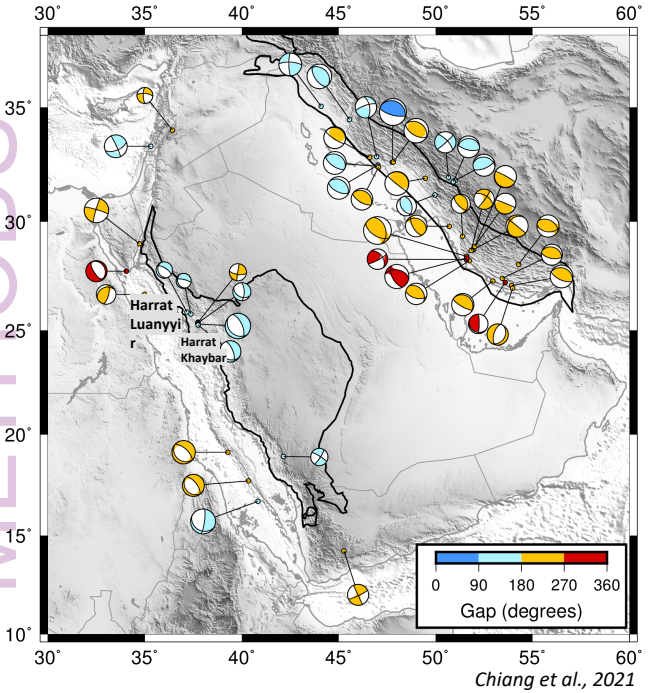
National network data contributions to seismic studies in the Kingdom of Saudi Arabia

Rengin Gök, Andrea Chiang, Michael Pasyanos Lawrence Livermore National Laboratory USA (gok1@llnl.gov)
Zaam Otaibi, Yahya Tarabulsi, Ahmed Hosny National Center for Earthquake and Volcanoes, Saudi Geological Survey KSA

CTBTO PREPARATORY COMMISSION

METHODS

Mw and Focal Mechanism Using Moment Tensor Inversion



- Deviatoric moment tensor solutions for the 46 earthquakes analyzed are shown at Figure 4. The coverage plays an important role when assessing solution uncertainty.
- Within the Zagros fold-and-thrust belt are mostly reverse-faulting earthquakes where the fault planes are oriented along the NW-SE direction.
- Like earthquakes located at Harrat Lunayyir, a few other earthquakes along the western Arabian Shield all have normal and strike-slip mechanisms with little isotropic components.
- Red Sea offshore events have typical normal and strike-slip faulting except one anomalous reverse mechanism at 18km depth.

Figure 4. Focal mechanisms of the 46 earthquakes from deviatoric moment tensor inversion

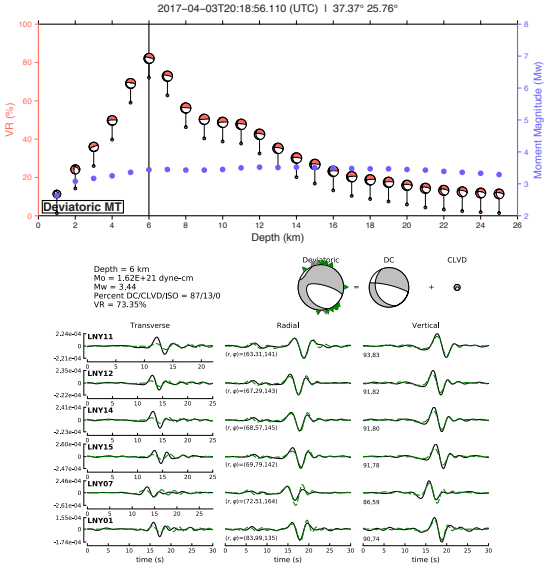


Figure 5. Moment Tensor Solution of an earthquake in Harrat Lunnayir

National network data contributions to seismic studies in the Kingdom of Saudi Arabia

Rengin Gök, Andrea Chiang, Michael Pasyanos Lawrence Livermore National Laboratory USA (gok1@llnl.gov)
Zaam Otaibi, Yahya Tarabulsi, Ahmed Hosny National Center for Earthquake and Volcanoes, Saudi Geological Survey KSA

RESULTS

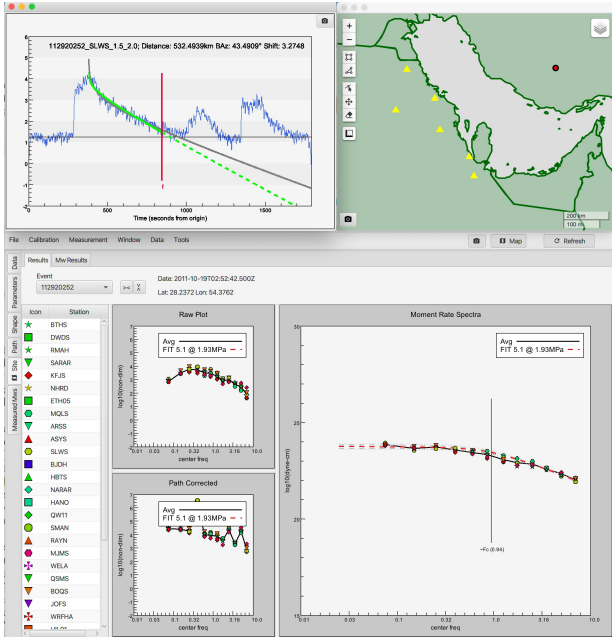


Figure 6 An example source spectra of coda calibration result from the Zagros subregion

Mw using Coda Method

- We use LLNL developed, java-based software application called Coda Calibration Tool (CCT).
- CCT is developed for calibrating 1D shear wave coda envelopes to a small set of reference events and use the calibrated envelopes to estimate Mw (https://github.com/LLNL/coda-calibration-tool).
- We compute the narrowband envelope at each frequency band, ranging from 0.03 to 8 Hz.
- We use large earthquakes from Moment Tensor Inversion study and ground-truth events from Seung Hoon Yoo (personal communication) as reference events for calibration to estimate Mw for the rest of the events.

National network data contributions to seismic studies in the Kingdom of Saudi Arabia

Rengin Gök, Andrea Chiang, Michael Pasyanos Lawrence Livermore National Laboratory USA (gok1@llnl.gov)
Zaam Otaibi, Yahya Tarabulsi, Ahmed Hosny National Center for Earthquake and Volcanoes, Saudi Geological Survey KSA

RESULTS

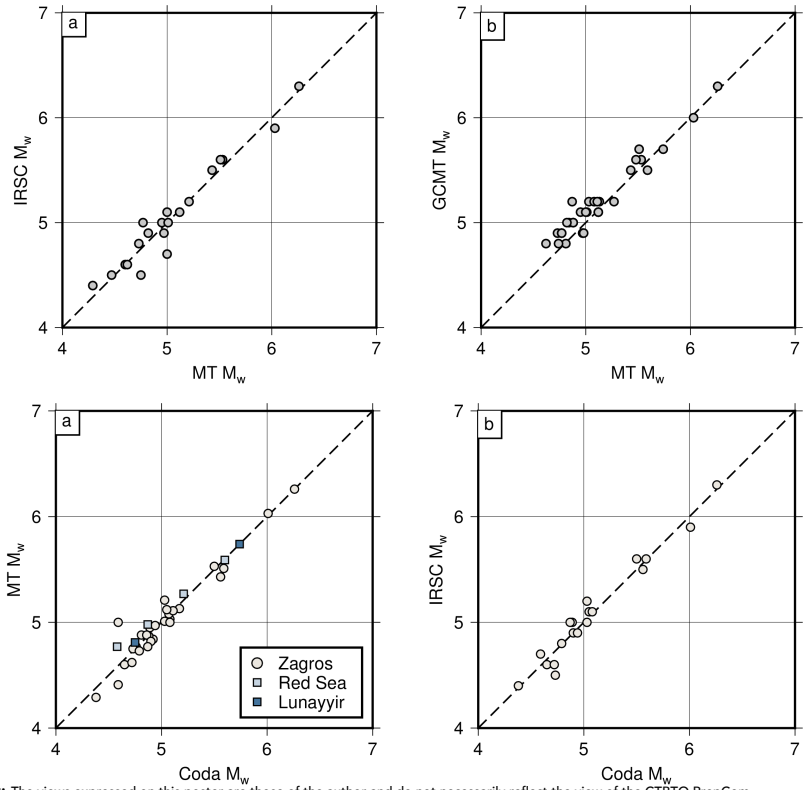


Figure 7
Moment Magnitudes from Waveform Inversion: Comparing moment tensor-derived moment magnitude (MT MW) between this study and (a) Zagros fold-and-thrust belt earthquakes from Iranian Seismological Center (IRSC) and (b) earthquakes from the Global Centroid-Moment-Tensor (GCMT).

Coda Magnitudes: Comparing coda moment magnitude (Coda MW) to moment tensor MW from (a) this study and (b) Iranian Seismological Center (IRSC).

Chiang et al., 2021

Comparison of Mw Results

- The analysis of stable coda-envelope amplitudes compared with regional moment tensor solutions provide an independent check on scalar seismic moment biases, as well as biases in the source mechanism.
- In terms of MW, estimates between our study and the regional solutions from IRSC (left panels) agree much better than compared to GCMT
- The average difference in Mw between the moment tensor Mw and coda Mw is 0.08 with a standard deviation of 0.08.

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE
Poster No.: P1.2-094

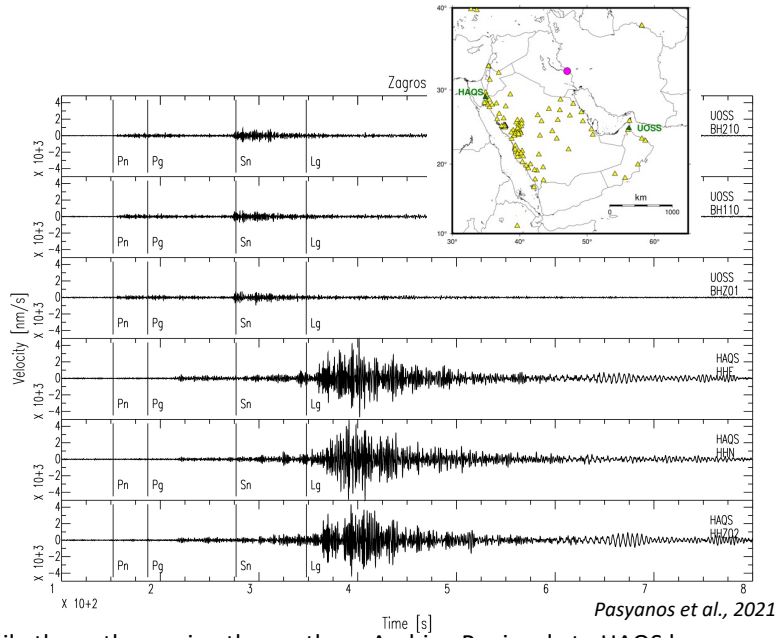
National network data contributions to seismic studies in the Kingdom of Saudi Arabia

Rengin Gök, Andrea Chiang, Michael Pasyanos Lawrence Livermore National Laboratory USA (gok1@llnl.gov)
Zaam Otaibi, Yahya Tarabulsi, Ahmed Hosny National Center for Earthquake and Volcanoes, Saudi Geological Survey KSA

CTBTO PREPARATORY COMMISSION

METHODS

Predicting the amplitudes of regional phases, surface waves, and strong ground motions requires an accurate quantification of seismic attenuation.



Pasyanos et al., 2021

Figure 8. While the path crossing the northern Arabian Peninsula to HAQS has a large Lg phase, it is all but wiped out along the path to UOSS where the Sn phase is actually enhanced.

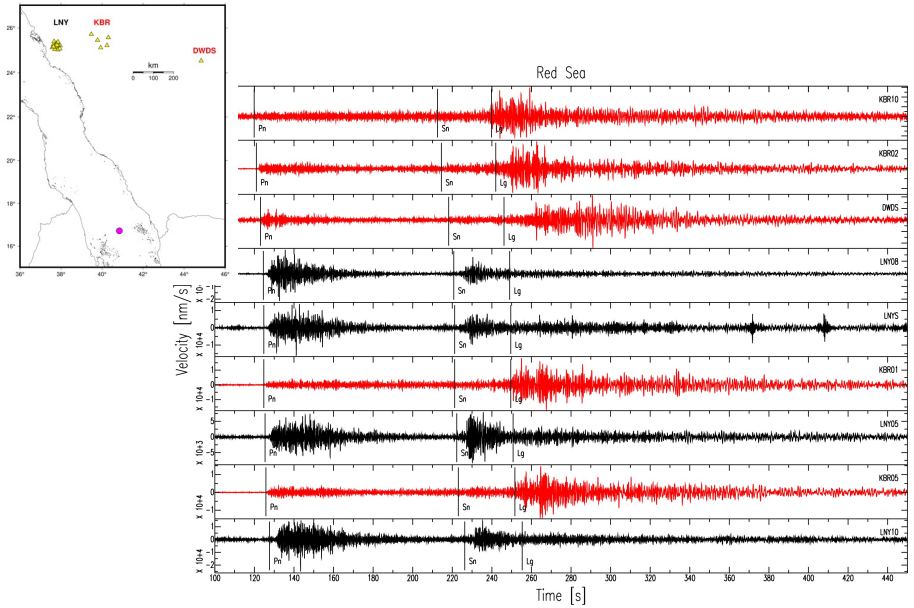


Figure 9. Over the very short azimuthal distances we see a change from efficient Lg propagation to blockage, significantly affecting the observed maximum amplitudes and ground motions.

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

National network data contributions to seismic studies in the Kingdom of Saudi Arabia

Rengin Gök, Andrea Chiang, Michael Pasyanos Lawrence Livermore National Laboratory USA (gok1@llnl.gov)
Zaam Otaibi, Yahya Tarabulsi, Ahmed Hosny National Center for Earthquake and Volcanoes, Saudi Geological Survey KSA

Poster No.: P1.2-094

CTBTO PREPARATORY COMMISSION

RESULTS

Attenuation tomography results

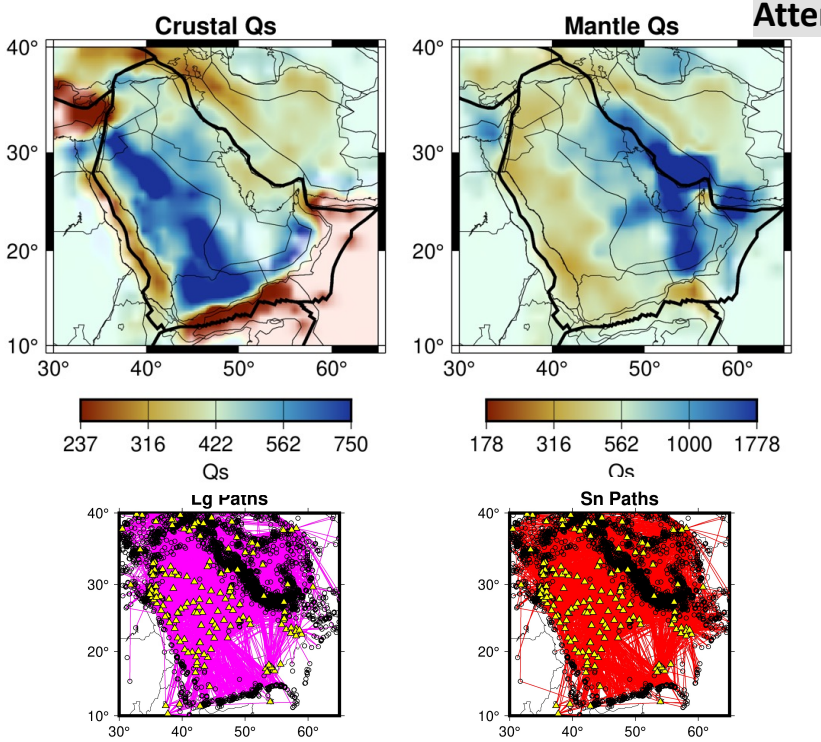


Figure 10 Attenuation maps showing Qs and Qp in the crust and upper mantle for 1–2Hz band

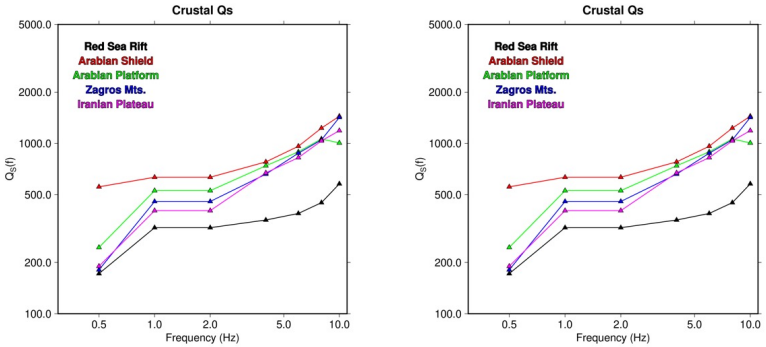


Figure 11 Frequency-dependent attenuation QS(f) in the crust shown for five selected tectonic regions at **Figure 1**.

- While the Arabian Shield might likely be thought to have low attenuation (high Q), the elevated temperatures from the Red Sea rift and recent volcanics lower the effective Q.
- While the thick sediments of the platform and gulf serve to lower the overall crustal Q, the cold temperatures of the region seem to prevail.
- The highest crustal Q in the peninsula is generally found in the Arabian platform and eastern portion of the Arabian Shield relatively unaffected by the elevated temperatures.

National network data contributions to seismic studies in the Kingdom of Saudi Arabia

Rengin Gök, Andrea Chiang, Michael Pasyanos Lawrence Livermore National Laboratory USA (gok1@llnl.gov)
Zaam Otaibi, Yahya Tarabulsi, Ahmed Hosny National Center for Earthquake and Volcanoes, Saudi Geological Survey KSA

CONCLUSIONS

- As a result of collaboration between LLNL and NCEV/SGS we have significantly improved the source and attenuation models with the Arabian Peninsula.
- Moment tensor solutions reveal different mechanisms for different tectonic environments as expected. With a few exceptions, solutions from this study agree with other published solutions even though our study area spans quite a vast and complex tectonic setting.
- Coda magnitudes provided independent validation of the scalar seismic moment with no indication of model bias or relatively unfavorable station coverage
- The results of attenuation tomography could be used in developing better magnitude formulas with the along-path attenuation
- In the Arabian Peninsula, there is not enough strong motion data to empirically derive region-specific GMPEs. Lg attenuation (Q_0) can be used to identify the difference in attenuation characteristics between active tectonic and stable continental regions and adjust the weight of GMPEs considered in the PSHA framework

REFERENCES

Chiang, A., R. Gök, Y. M. Tarabulsi, S, Y. El-Hadidy, W. W. Raddadi, A. D. Mousa, Seismic Source Characterization in the Middle East from Regional Moment Tensor and Coda-Envelopes, submitted to Arabian Journal of Geosciences, doi:10.1007/s12517-020-06266-x

Pasyanos, M. E., Y. M. Tarabulsi, S. Y. Al-Hadidy, W. W. Raddadi, A. D. Mousa, I. El-Hussain, F. Al-Jeri, H. Al-Shukri and R. Gök (2021). Improved Lithospheric Attenuation Structure of the Arabian Peninsula through the Use of National Network Data, Arabian Journal of Geosciences, doi: 10.1007/s12517-021-07294-x