APPLICATION OF TIME-DOMAIN MOMENT TENSOR INVERSION TO WAVEFORM DATA FROM THE NEW SAUDI ARABIA BROADBAND SEISMIC NETWORK

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ABSTRACT

Recently Saudi Geological Survey (SGS) has established a new broadband seismic network. I applied the time domain moment tensor inversion code developed by Dreger (2003) to the waveform data from this new seismic network. I analyzed three earthquakes: the July 2, 2006 event (M_L 4.7) in the Red Sea area, the February 2, 2006 (M_L 5.0) and April 13, 2007 (M_L 4.1) events in the Gulf of Aqaba area. The obtained focal mechanisms are consistent with the tectonic settings, i.e., extension along the spreading centers in Red Sea and strike slip movement along the Dead Sea transform fault, respectively. Also, the focal mechanism of the Red Sea event is partly consistent with that of the Global CMT Catalog. These results suggest that it is possible to monitor and investigate seismic activity by moment tensor determination using data from the new SGS broadband seismic network. I also discussed the issues to be completed before applying the technique used in this study to routine moment tensor determination.

Keywords: Time-Domain Moment Tensor Inversion, Broadband Seismic Network, Focal Mechanism.

INTRODUCTION

Geomorphology and geology of the Saudi Arabia

The Kingdom of Saudi Arabia extends over 1800 km north-south and 1150 km east-west from the Red Sea to the Arabian Gulf (covering an area of approximately 1, 960, 582 sq. km.). The elevations exceed 3000m in the southwest. Sand seas occupy 50% of the country; much of the remainder is rock exposure, and largely lacking soil, laterite cover, grass, and forest. The Arabian plate margins are characterized by:

- extension along spreading centers in the Red Sea and Gulf of Aden in the southwest and south where the plate is spreading from the African plate.
- strike-slip movement along the Dead Sea transform, which marks the northwest margin of the plate along which left-lateral slip is taking place.
- by strike-slip movement along the Owen fracture zone on the southeast, where right lateral displacement of about 300 km has occurred.
- by compression at the Zagros thrust and Bitlis suture in the north and northeast, where the plate is colliding with the Eurasian plate.

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Seismicty of the Saudi Arabia

Saudi Arabia is subject to a range of earthquake activity because it is bounded by the Dead Sea transform on the northwest, the Red Sea spreading center on the west, the Gulf of Aden spreading centre on the south, and the Zagros subduction zone on the northeast.

Currently four institutions are operating seismograph networks: King Abdulaziz Center for Science and Technology, King Saud University in Riyadh, King Abdulaziz University in Jeddah, and the Saudi Earthquake Center at the Saudi Geologic Survey in Jeddah.

Saudi National Seismic Network

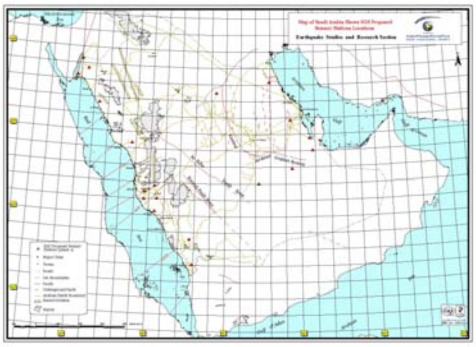

Figure 1. The location of seismic network (Triangles indicate the location of broadband stations).

The Saudi Earthquake Center has deployed broadband seismograph in 2004 and is now running 19 broadband seismic stations. Figure 1 shows the location of these stations. Eight more stations will be installed in the near future. This new network adopts satellite communication and 3 components-broadband digital sensors (Trillium-40).

In this study I apply the time-domain moment tensor inversion code developed by Dreger (2003) to waveform data from this new broadband network. Moment tensor analyses will be useful for monitoring seismic activity and understanding seismotectonics in and around Saudi Arabia.

TIME-DOMAIN MOMENT TENSOR PROCEDURE

In this study, I followed the time–domain inversion procedure (Dreger and Romanowicz, 1994; Pasyanos *et al.* 1996) to determine moment tensors. The software package of this technique has been used at the University of California, Berkeley Seismological Laboratory (BSL) since 1993 to automatically analyze events (M_L>3.5) in northern California (http://seismo.berkeley.edu/~dreger/ mtindex.html).

Also, this package has been implemented at the Japan National Research Institute for Earth Science and Disaster Prevention (NIED) to perform automated seismic moment tensor determination using on-line broadband waveform data from “F-net” (full Range Seismograph Network of Japan) (Fukuyama *et.al* 1998)(http://www.fnet.bosai.go.jp/freesia/index.html).

This software package is available at International Handbook of Earthquake and Engineering Seismology, part B attached Handbook CD, and has been widely used by a number of researchers.

In this technique, linear least squares for deviatoiric moment tensor is preformed for equation of synthetic seismogram for a spatial and temporal point source. Only high frequency location is used. The assumptions for this procedure are as follows: (i) the event location is well represented by the high frequency hypocenter location. Dreger and Helmberger (1993) showed that event mislocation on the order of 15 km can be tolerated. (ii) the source time function may be approximated by a delta function.(iii) the crustal structure is sufficiently well known for low frequency waveform modeling.

The source depth is determined by finding the solution that yields the largest variance reduction:

$$VR = \left[1 - \sum_i \sqrt{(data_i - synth_i)^2} \Big/ \sqrt{data_i^2} \right] * 100 , \qquad ....(1)$$

Where *data* and *synth* are the data and Green's function time series, respectively, and the summation is performed for all the stations and components.
Another useful measure for determining source depth is given by:

$$RES/Pdc = \sum_i \sqrt{(data_i - synth_i)^2} \Big/ Pdc \qquad \ldots\ldots(2)$$

Where, the RES is variance modulate and Pdc is percent double-couple (the ratio of double-couple component to total seismic moment), respectively.

DATA AND CRUSTAL MODEL

I selected three events for my study. Table 1 and Figure 2 show the origin times and hypocenters for these events. The first event is the one that occurred on July 2 in 2006 in Red Sea; USGS determined the hypocenter of this event and the CMT solution determined by the Global CMT project is available. Therefore, it is possible to compare our solution to the Global CMT solution to check whether we performed inversion appropriately. The second event is the one that occurred on February 2 in 2006 in Gulf of Aqaba region. USGS determined the hypocenter of this event, and I use this hypocenter for my analysis. The third event is the one that occurred on April 13 in 2007 in Gulf of Aqaba region The magnitude (M_L) determined by SGS is 4.1 and there is no earthquake information for USGS and Global CMT project. I compared hypocenter determined by SGS to those determined by USGS for some events, and found that the difference between them is relatively small in Gulf of Aqaba region. Therefore, it is likely to be possible to determine moment tensor using the hypocenter determined by SGS.

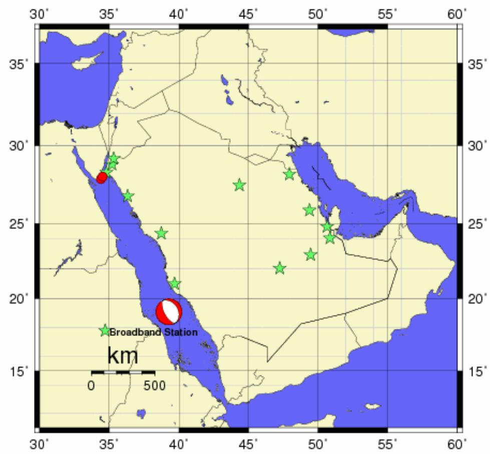

Figure 2. Event locations coverage of my study in Red Sea (focal mechanism solution obtained from Global CMT catalog for Red Sea event) and event February 2 in 2006 in Gulf of Aqaba by SGS and USGS, Event April 13 in 2007 in Gulf of Aqaba was recorder by SGS Network. (The green stars indicate the locations of broadband stations, and the red circles indicate the events location).

TABLE 1. The events information from USGS, M_L from SGS and M_W from the Global CMT catalog.

Date	Time	Epicenter coordinates	Depth	MAG
2006/07/02	23:45:05.30	19.33^0N 38.38^0E	10 km	4.7 M_L and 4.7 M_W(Global CMT Catalog) Red Sea.
2006/02/02	09:49:49.9	27.88^0N 34.41^0E	2 km	5 M_L Gulf of Aqaba.
2007/04/13	22:02:16	28.037^0N 34.522^0E	10 km	4.13 M_L Gulf of Aqaba.

In this study I used the crustal model determined by AL-Amri (1998). He used the spectral analysis of long-period P-wave amplitude ratios to determine the thickness, seismic velocities, and density in the crustal and the uppermost upper mantle. I set Qα and Qβ to 600 and 300, respectively. I prepared model files for this crust model for different depth following the instruction of Dreger (2003).

RESULTS

The July 2, 2006 Red Sea event

First, I analyzed the July 2, 2006 Red Sea event. I extract the SEED file of this event to obtain the SAC wave form data and the instrumental response files. The nearest station is SGS09 and I used the data from this station. I calculated the observed spectra used for moment tensor inversion. I adopted the epicenter determined by USGS, and the epicenter distance is 201 km. Figurer 3 show the result for this event. The variance reduction increases and the variance divided by the percent double couple decreases, respectively, as the depth decreases (Figure 4 and Figure 5), which suggests that the focal depth is shallow. The determined focal mechanism is normal fault, which is partly consistent with the Global CMT Solution shown in Figure 2. The normal fault is consistent with the tectonics setting explained in Introduction (i, e., extension along spreading centers in the Red Sea and Gulf of Aden). The difference between the two solutions is likely to be due to weak constraint of the data used in this study (from the single station) on focal mechanism.

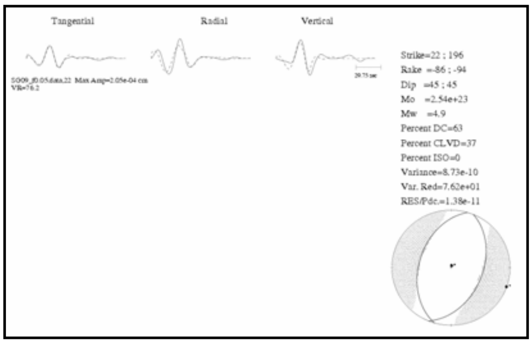

Figure 3. Result of the Red Sea event.

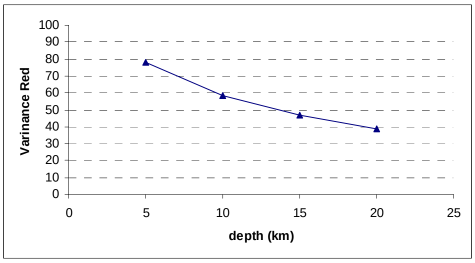

Figure 4. Change of variance reduction with respect to depth for the Red Sea July 2, 2006 event.

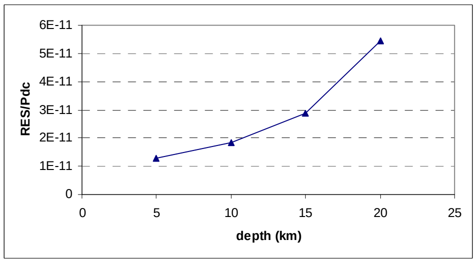

Figure 5. Change of variance divided by the percent double-couple with respect to depth for the Red Sea event**.**

The February 2, 2006 Gulf of Aqaba event

Then, I analyzed the February 2, 2006 Gulf of Aqaba event. The nearest station is SGS25; I used the data from this station. I adopted the epicenter determined by USGS and the epicenter distance is 60 km. Figure 6 show the result for this event. The variance reduction does not change significantly for changes of depth (Figure 7). Based on the variance divided by the percent double couple, 10 km is the optimal estimate (Figure 8). These results suggest the focal depth is shallow. The obtained focal mechanism is oblique strike slip. The strike slip component is consistent with the strike slip movement along the Dead Sea transform fault.

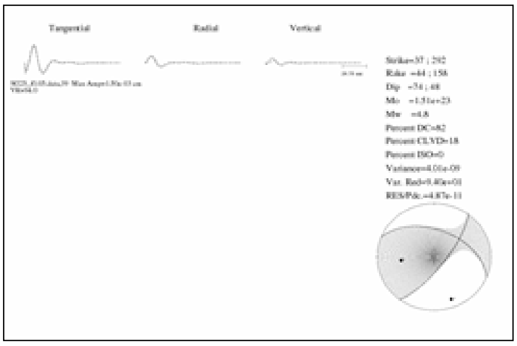

Figure 16. Result of February 2, 2006 Gulf of Aqaba event.

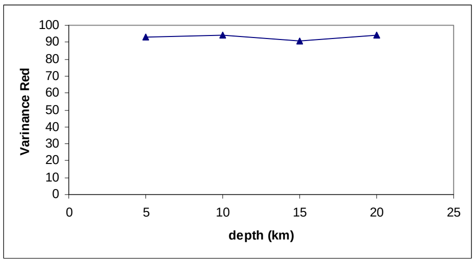

Figure 7. Change of variance reduction with respect to depth for the February 2, 2006 Gulf of Aqaba event.

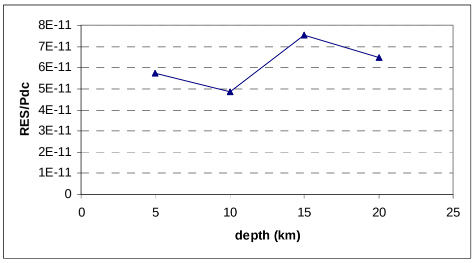

Figure 8. Change of variance divided by the percent double-couple with respect to depth for the February 2, 2006 Gulf of Aqaba event**.**

The April 13, 2007 Gulf of Aqaba event

Finally, I analyzed the April 13, 2007 Gulf of Aqaba event. For this event, data from SGS25, SGS26, and SGS27 are available. I used the data from SGS27, because the noise was lowest for this station. I used the epicenter determined by SGS and the epicenter distance is 149km from SGS27 station. Figure 9 show the result for this event. The slight increase of the variance reduction for shallower depth (Figure 10), and the small value of the variance divided by the percent double couple at a depth of 5 km suggest that the focal depth is shallow (Figure 11). The obtained focal mechanism is oblique strike slip. The strike slip component is consistent with the strike slip movement along the Dead Sea transform fault.

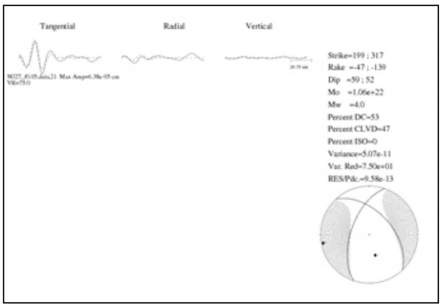

Figure 9. Result of April 13, 2007 Gulf of Aqaba event .

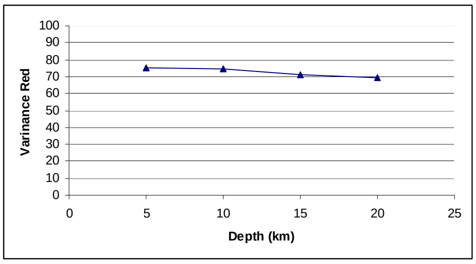

Figure 10. Change of variance reduction with different depths for Gulf of April 13, 2007 Gulf of Aqaba event.

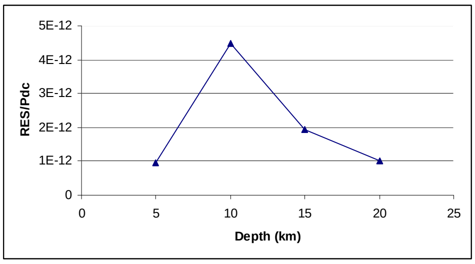

Figure 11. Change of variance divided by the percent double-couple with different depths for April 13, 2007 Gulf of Aqaba event.

DISCUSSION

I showed above that it is possible to determine moment tensor solutions which are consistent with tectonic settings. Hurukawa *et al.* (2001) obtained a variety of focal mechanisms (normal, thrust, and strike slip) in the Gulf of Aqaba region, where further investigation will be necessary. Also, data exchange among neighboring countries will be effective to improve accuracy of earthquake source parameters.

Before applying the technique used in this study to routine moment tensor determination, there are several issues to be investigated. I compared the hypocenter determined by SGS to those determined by USGS for same events and there are significant differences. Therefore, intensive evaluation on accuracy of SGS earthquake catalogs should be carried out; then based on that result, it will be necessary to investigate the ways to improve them. Data exchange with neighboring countries may be effective.

Also, it will be necessary to study crustal structures. Although several studies have been carried out (e.g., AL-Amri 1998), waveform modeling such as studies by Dreger and Helmberger (1991) and Zhao and Helmberger (1991) have been done only for the limited path (Rodgers *et al.* 1999).

CONCLUSION

In this study, I applied the time domain moment tensor inversion code developed by Dreger (2003) to the waveform data from the broadband seismic network that has been newly deployed by Saudi Geological Survey (SGS). Considering the high seismic activities and data availability, I analyzed three events: the July 2, 2006 event in Red Sea area, the February 2, 2006 and April 13, 2007 events in the Gulf of Aqaba area. I obtained the normal fault mechanism for the Red Sea event, which is partly consistent with the Global CMT solution and consistent with the tectonic movement. The strike slip components of the focal mechanisms determined for two events in Gulf of Aqaba were compatible with the tectonic movement. These results suggest that it is useful to monitor and investigate seismic activity by moment tensor analyses using broadband waveform data from the new SGS seismic network.

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