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DETERMINATION OF MOMENT TENSOR SOLUTION IN THE FIJI REGION USING THE WAVEFORM INVERSION TECHNIQUE

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ABSTRACT

We conducted moment tensor determination for 27 events that occurred in the North Fiji Basin from 2015 – 2022 with a magnitude of Mw > 4.0 and depths less than 350 km. We used seismograms from seismograph stations in Fiji and the neighboring countries. We used a regional velocity model with a 10-km thick crust by Xu and Wiens (1997) to compute Green's functions. Focal mechanism solutions were then validated in reference to the Global Centroid Moment Tensor (GCMT) solutions. We found that the solutions obtained by the present study are generally consistent with the GCMT solutions in terms of focal mechanism and moment magnitude. Stress axes of the focal mechanisms are consistent with tectonic process reported by previous studies. Focal depths were shallower than the GCMT centroid depths by 1.4 km in average. We also evaluated an effect of velocity model on focal mechanism solutions by comparing waveform fitting and similarity to GCMT. We performed the moment tensor inversion for events with Mw > 5.0 using the original regional model, its modified model with a 20-km thick crust, and a global standard model. For most of the events used for comparison, the waveform fitting is best for the original regional model with a 10-km thick crust than the other two velocity models. We compared focal mechanisms determined from data including and excluding stations from the neighboring countries. The comparison shows that the mechanisms are closer to the GCMT by including data from neighboring countries, suggesting the importance of international data exchange.

Keywords: Moment Tensor, Fiji, velocity model.

1. INTRODUCTION

Fiji is in the southwest Pacific, an archipelago consisting of 332 islands, of which only 106 are inhabited; the total land size is 18300km2. Fiji sits on the converging zone of the Pacific Plate and Indo-Australian Plate. It is a remnant arc in a broad, complex, highly deformed area between the two opposing subduction zones. Although most of the Fiji Islands are not in the vicinity of a trench of subduction zones, it is still tectonically active due to the movement of the major plate boundaries. It is subject to an impact from intraplate seismicity and subduction zone seismicity. The present study highlights a critical area needed for the Fiji seismology unit in terms of disaster risk reduction: The determination of moment tensors in and around the Fiji region. The Mineral Resources department of Fiji established its seismic network in 1979, but the earthquake focal mechanisms were not evaluated routinely. The main objective of this study is to determine the focal mechanisms around the Fiji region and to determine the lower limit of an earthquake whose moment tensors can be determined reliably. The present study should contribute to resolving this vital earthquake parameter using the Fiji seismic stations on a routine basis in the future.

2. DATA

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We analyzed seismograms recorded at seismic networks of Fiji, New Caledonia, Geoscope, and Global Seismograph Network (GSN) in the studied region. The data were retrieved from the Data Center of the Oceania Regional Seismic Network (ORSNET). The target earthquakes are ones in the Fiji region with a magnitude less than 6 with a depth ranging from 0 to 350 km. Broadband sensors are used for moment tensor inversion. Moment tensor determination was performed on 27 earthquakes (M < 6) from 2015 to 2019 and in 2022 (from May to June) as illustrated in Figure 1a, which are in the North Fiji Basin. We used hypocenter parameters determined by United States Geological Services (USGS) and ORSNET.

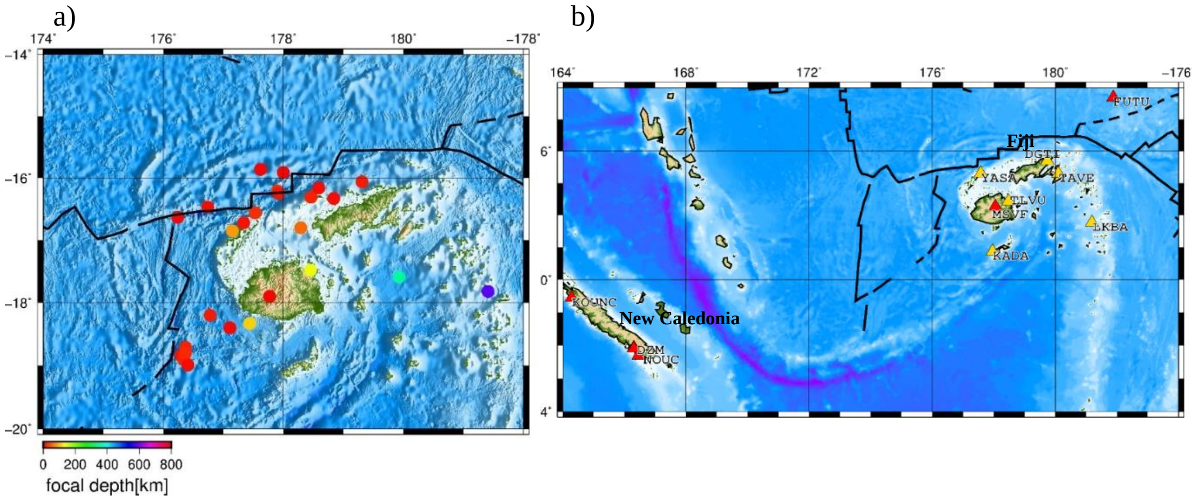

Figure 1. Seismicity(a) and station distribution(b) used in this study. The yellow triangles are the Fiji network stations and the red triangles are from the Global Seismic Network (GSN) and New Caledonia Seismic Network.

Most of the earthquakes in the North Fiji Basin analyzed in the present study are shallow in depth. Regarding disaster mitigation, shallow events are more hazardous than deeper earthquakes because of the risk of tsunami and strong ground motion.

3. METHODOLOGY

3.1. Theory of moment tensor

The simplified representation of a seismic source with moment tensors, either the spatial or the temporal point source, is shown by the formula below.

$$U_n(x,t) = M_{ij} \,.\, G_{ni,j}(x,z,t), \qquad (1)$$

where U_n is the observed *n-th* component of displacement, G_{ni},j is the nth component of Green’s function for specific force-couple orientations and M_{ij} is the *ij-th* component of a seismic moment tensor, where indices i and j are the geographical directions. The above equation is solved using the linear least square method for a specified depth, where moment tensors are the only parameters to be determined. The moment tensors are decomposed into double couple (DC) and compensated linear vector dipole (CLVD) components. The shear faulting has only DC component, which will be used as one of indices of solution’s reliability.

Expressing Eq. (1) in vector and matrix form, we have

$$U = GM, \tag{2}$$

where U is the matrix of the observed ground motions, G is the matrix of Green's functions and M is the vector of the moment tensor component. The Green's function is computed using the wavenumber integration method (Saikia, 1994) and depends on the seismic structure model (P and S velocities, density, Qp and Qs), focal depth, azimuth, and distance between hypocenter and station. We used a velocity model for the North Fiji Basin (Figure 4), which was determined from surface wave analysis by Xu and Wiens (1997), which has a 10-km thick crust. The density and quality factors are taken from the PREM model (Dziewonski & Anderson, 1981). We also used two other velocity structures, one is the iasp91 model (Engdahl et al., 1991) and the other is a modified Xu and Wiens model with 20-km thick crust. These two velocity models are used to know the effects of a velocity model on a moment tensor solution. The moment tensor is obtained by applying a linear least square method

$$M = (G^T G)^{-1} G^T U, \tag{3}$$

Regarding the focal depth determination, we assume that the greater variance reduction is achieved for the best reliable depth, where a variance reduction (VR) is defined by the following formula.

$$VR = \left[1 - \Sigma_i \frac{\sqrt{(data_i - synth_i)^2}}{\sqrt{data_i^2}} \right] * 100, \tag{4}$$

where *synth* and *data* represent synthetic and observed seismograms, respectively. The synthetic seismogram is computed by a multiplication of the moment tensor and Green's function. This computation is made for all stations. The greater VR means the better waveform fitting, which will be used as an index of solution's reliability.

3.2. Computer codes

We used the code TDMT_INVC (time-domain moment tensor inversion code) developed by Dreger (2003). The code is implemented on SEISAN (earthquake analysis software) (Havskov and Ottemoller, 2020), which is widely used in the seismological community. This program can be used to compute several earthquake parameters. This tool also contains different codes to enable us to analyze earthquakes for research purposes.

4. RESULTS AND DISCUSSION

We obtained moment tensor solutions for 27 earthquakes in the North Fiji Basin. The magnitude range is from 4.0 to 5.8 and the depth range is from 0 to 350km. We examined the quality of the obtained focal mechanisms based on the similarity to the corresponding solutions in the Global Centroid Moment Tensor (GCMT) catalog (http://www.globalcmt.org/; Ekström et al., 2012) in case solutions are available in the catalog. The similarities were represented by the rotation angle calculated using the method developed by Kagan (2007), which is also used as an index of solution's reliability. We choose 55 ° for the threshold of 'similarity of focal mechanisms.' Among the 27 events (Table 1), the solutions for 12 events are available in the GCMT catalog. The rotation angles are less than 55° for all of the 12 solutions (Figure 2a), which is regarded as reliable (Group A).

For the other 15 solutions, we classified 'reliable' for focal mechanism solutions with DC components greater than 70%, VR greater than 35%. Among the 15 events with GCMT unavailable, 9 events are classified as reliable (Group B) (Figure 2b) (Table 1). In summary, 21 of a total of 27 solutions were reliably determined, which is encouraging for reliable determination of focal mechanisms and moment magnitude in the future, since GCMT solutions are not always available. The rest of the solutions are regarded as unreliable and classified as Group C (Table 1).

Table 1. Categorization of results in magnitude ranges see definition in text for Group A, B, and C.

Group	2.9 ≤ Mw ≤ 4.5	4.6 ≤ Mw ≤ 4.9	Mw ≥ 5.0
A	1	3	8
B	3	4	2
C	6	0	0
Total	10	7	10

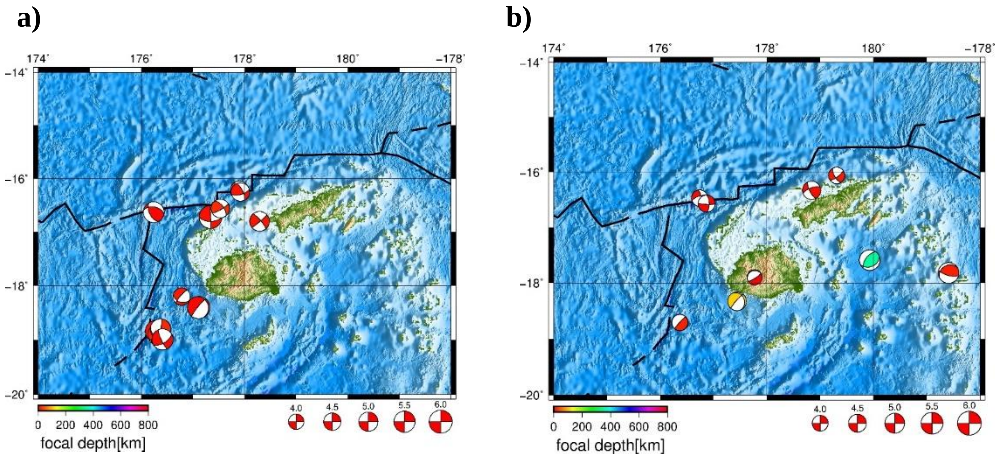

Figure 2. Distribution of Group A (4.5 ≤ Mw ≤ 5. 9) focal mechanism and Group B (4.1 ≤ Mw ≤ 5. 2) solutions. (a) Group A Focal mechanisms solution, (b) Group B solutions. The color of the mechanism represents the focal depth.

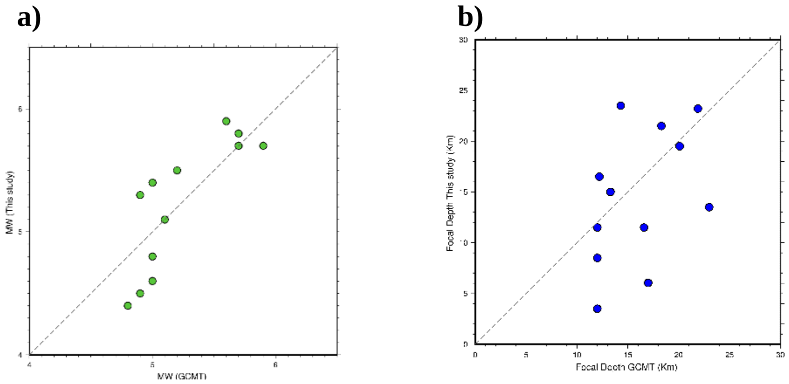

Figure3. a) Comparison of Mw determined by this study and those from the GCMT catalog. b) Comparison of the focal depth determined in this study and those from the GCMT catalog.

We compared moment magnitude (Mw) and the Mw of GCMT as shown in Figure 3a. Comparing the moment magnitude determined in this study and the Mw determined by GCMT, we obtained a root mean square of the difference between the two Mw to be 0.26, which indicates that the Mw in our solutions is consistent with that of GCMT. We also compared the focal depth of our solutions (Figure 3b) to GCMT focal depth. The depths obtained in this study are shallower compared to GCMT, with an average difference of 1.4km. The difference could be due to the difference in velocity structure used in this study, which is more specific to the region, and the stations used for moment tensor inversion. The minor differences from GCMT are encouraging from the viewpoint of disaster mitigation since the precise determination of moment magnitude and the focal depth is directly related to tsunami potential.

Figure 4 illustrates tensional axes of 19 reliable events with shallower than 50 km (Groups A and B). The red rectangle in Figure 4 is the strike-slip zone due to the movement along the Fiji fracture zone. The tensional stress in the green rectangle depicts normal fault earthquakes with WNW-ESE tension axes, which are associated with spreading motion along the NNE-SSW ridge. The North Fiji Basin has spreading ridges, which could be clearly identified by the direction of the tensional stress.

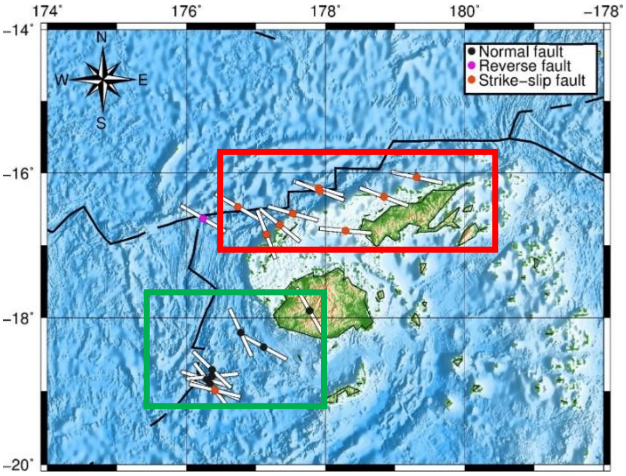

Figure 4. Map of tensional axes. Events are shallower than 50 km. The white rectangles depict the direction of the stress on the focal mechanism determined by this study.

We examined the effect of the velocity model on moment tensor solutions using three different velocity models, as mentioned in section 3.1. We selected six well-constrained solutions with relatively large VR and small Kagan angles (Figure 5). The VR for the Xu and Wiens model is larger than those obtained from the other models for five events (Figure 5). For event 4, the variance reduction is comparable. We also compared the rotation angle and found that the original Xu and Wiens model with a 10-km thick crust is better than the other models in representing a velocity structure of the Fiji region. The other models, particularly the iasp91 model, give different focal mechanisms from GCMT. Since Green's function strongly depends on the velocity model, it is vital to use the appropriate velocity model for reliable determination of focal mechanism and moment magnitude.

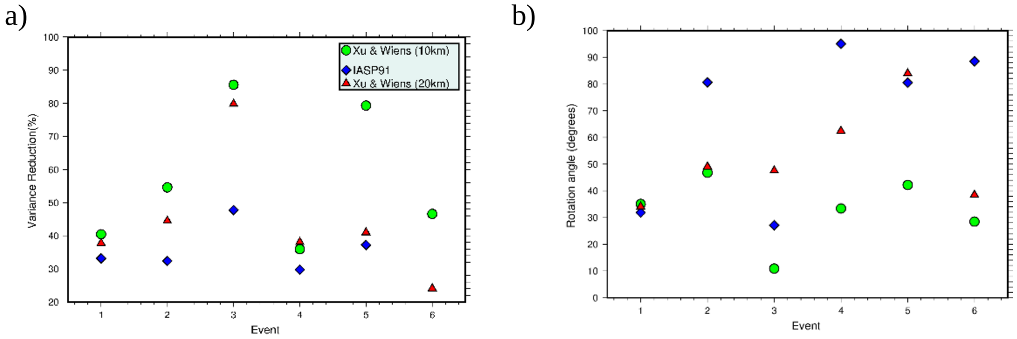

Figure. 5. Effects of velocity model. Comparison of VR(a) and Rotation angle(b)for three velocity models of Xu and Wiens (1997) with a 10km-thick crust (green circle), Xu and Wiens (1997) with crustal thickness modified to 20 km (red triangle), and the iasp91 model (blue square) are shown.

We examined the results of the moment tensor inversion concerning the station coverage of the inversion. We show the effects of station coverage by comparing moment magnitude and rotation angle determined from stations including neighboring countries (New Caledonia and Futuna). The result shows that the moment tensor inversion using stations including neighboring countries provides Mw and the focal mechanism consistent with GCMT. It may be because neighboring stations improved the number of stations and azimuthal coverage from the events. It is essential to make international data exchange for reliable determination of moment tensors.

5. CONCLUSIONS

In this study, we determined moment tensor solutions for 27 events in the Fiji region using the seismic networks in Fiji and neighboring countries. For 12 events for which GCMT solutions are available, we compared our solutions with the corresponding GCMT solutions. Mw of 4.6 is a lower-limit of magnitude whose moment tensor solutions could be reliably determined from stations in Fiji and nonboring countries. Moment magnitudes are determined within the difference of 0.3 from the moment magnitude of GCMT. The focal depths of the present study are shallower than those of GCMT by 1.4 km on average. Among 15 events for which no GCMT solutions were available, we regarded 9 events as reliable from a degree of waveform fitting and consistency of focal mechanism with GCMT for events nearby. For 21 of the 27 events, focal mechanism and moment magnitude are considered reliable. Events near the Fiji fracture zone have a left-lateral strike-slip mechanism. Normal fault mechanisms were obtained in the west of Fiji islands, which suggests active spreading ridges in the region.

We examined effect of velocity models on resultant moment tensors. Different velocity model resulted in substantially different moment tensors. We conclude that the Xu and Wiens (1997) model with a 10-km thick crust provides better solutions of moment tensors as compared with a thickened crust model and a global standard model in terms of waveform fitting and similarity to GCMT.

We also examined the effects of station coverage on moment tensor determination and show the importance of stations in neighboring countries along with Fiji stations for reliable determination of moment tensors.

The present study is encouraging for reliable determination of focal mechanism and moment magnitude using local and regional data. Understanding earthquake mechanisms is a fundamental step needed for earthquake disaster mitigation. The compilation of moment tensor solutions for the Fiji region will be the first step in creating a seismotectonic model for the Fiji region.

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