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Source process and tectonic implication of the January 20, 2007 Odaesan earthquake, South Korea

Ali K. Abdel-Fattah [a,c,*], K.Y. Kim [b], M.S. Fnais [a], A.M. Al-Amri [a]

[a] *King Saud University, Faculty of Science, Geology and Geophysics Department, Riyadh, Saudi Arabia*
[b] *Department of Geophysics, Kangwon National University, Chunchon, Republic of Korea*
[c] *Department of Seismology, National Research Institute of Astronomy and Geophysics, 11421 Helwan, Cairo, Egypt*

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ABSTRACT

The source process for the 20th of January 2007, *Mw* 4.5 Odaesan earthquake in South Korea is investigated in the low- and high-frequency bands, using velocity and acceleration waveform data recorded by the Korea Meteorological Administration Seismographic Network at distances less than 70 km from the epicenter. Synthetic Green functions are adopted for the low-frequency band of 0.1–0.3 Hz by using the wave-number integration technique and the one dimensional velocity model beneath the epicentral area. An iterative technique was performed by a grid search across the strike, dip, rake, and focal depth of rupture nucleation parameters to find the best-fit double-couple mechanism. To resolve the nodal plane ambiguity, the spatiotemporal slip distribution on the fault surface was recovered using a non-negative least-square algorithm for each set of the grid-searched parameters. The focal depth of 10 km was determined through the grid search for depths in the range of 6–14 km. The best-fit double-couple mechanism obtained from the finite-source model indicates a vertical strike-slip faulting mechanism. The NW faulting plane gives comparatively smaller root-mean-squares (RMS) error than its auxiliary plane. Slip pattern event provides simple source process due to the effect of Low-frequency that acted as a point source model. Three empirical Green functions are adopted to investigate the source process in the high-frequency band. A set of slip models was recovered on both nodal planes of the focal mechanism with various rupture velocities in the range of 2.0–4.0 km/s. Although there is a small difference between the RMS errors produced by the two orthogonal nodal planes, the SW dipping plane gives a smaller RMS error than its auxiliary plane. The slip distribution is relatively assessable by the oblique pattern recovered around the hypocenter in the high-frequency analysis; indicating a complex rupture scenario for such moderate-sized earthquake, similar to those reported for large earthquakes.

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1. Introduction

Southern part of the Korean Peninsula (SKP) is tectonically controlled by the relative motions between the Pacific, Philippine and Eurasian plates (Fig. 1; Molnar and Tapponnier, 1975; Kato et al., 1998; Kogan et al., 2000). These relative motions might be responsible for the occurrence of intraplate earthquakes in the SKP with strike-slip faulting mechanisms and minor dip- or reverse-slip components (June, 1990; Kim, 1993; Kim et al., 2004). Park et al. (2007) indicated that strike-slip faulting with a reverse-slip component is the dominant mechanism in the SKP and suggested that NNW- to NE-striking faults are most likely to generate earthquakes in the SKP. The SKP is characterized by relatively low seismic activities with small- to moderate-size earthquakes that do not produce surface ruptures and relatively few aftershocks following the mainshock events. Moreover, the seismicity is randomly distributed and no tectonic trends are clearly traced. Therefore, identification of active fault planes is generally a difficult issue in this region.

Since local tectonics and occurrence of intraplate earthquakes are not understood well in the Korean peninsula, it is important to depict in detail the rupture processes of small- to moderate-size earthquakes. This may help to identify the active faults in this region. At 11:56:53.48 on January 20, 2007 an *Mw* 4.5 earthquake struck Gangwon province of South Korea (Fig. 2). The earthquake felt widely over the SKP attracted public attention although no damage was reported. Four aftershocks with magnitudes in the range of 2.5–2.8 occurred, three on the same day, with the fourth and smallest occurring one day later.

In the present study, we aim to investigate the spatial and temporal slip distribution of the Odaesan earthquake in both low- and

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* Corresponding author at: King Saud University, Faculty of Science, Geology and Geophysics Department, Riyadh, Saudi Arabia. Tel.: +20 507433140.
E-mail addresses: ali_kamel100@yahoo.co.uk, ali_kamel@yahoo.com (A.K. Abdel-Fattah).

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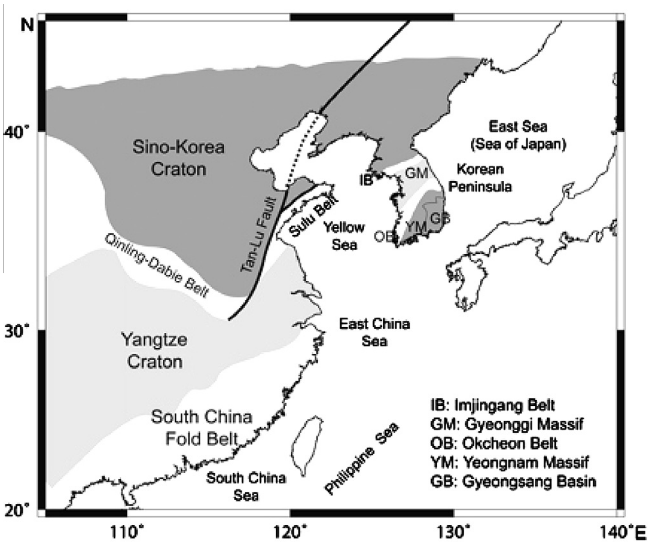

Fig. 1. Simplified tectonic map of East Asia. Folded belt areas are illustrated in white, and cartons and massifs are depicted in gray. Faults are represented by thick solid lines (from Chang and Baag, 2007).

high- frequency bands. Synthetic Green functions (SGF) and empirical Green functions (EGF) are adopted for the low-frequency and the high-frequency bands, respectively. A grid search method is applied to four parameters: the strike, dip, rake, and focal depth of rupture nucleation. For each set of grid-searched parameters, the spatial and temporal slip distribution was recovered on the two nodal planes of the focal mechanism using a least squares waveform inversion technique. We compare the obtained results in both low- and high- frequency bands. The results contribute to the tectonic implication of the eastern part of the Gyeonggi Massif (Fig. 1).

2. Tectonic settings

The SKP is located in the northeastern Asia margin, a convergent region of the China continent and the Japanese Island Arc. This arc is characterized by the subduction of the Philippine Sea plate and the southeastward expulsion of the Eurasian plate (Molnar and Tapponnier, 1975; Zonenshain and Savostin, 1981; Kato et al., 1998; Kogan et al., 2000; Jin and Zhu, 2003; Jin and Park, 2006; Jin et al., 2007). The focal mechanisms for intraplate earthquakes in the SKP show predominant strike-slip faults with minor reverse or normal components (June, 1990; Kim, 1993; Kim et al., 2004; Park et al., 2007).

The geology of the SKP mainly consists of four tectonic provinces: running from northwest to southeast, the Imjingang belt, the Gyeonggi massif, the Okcheon belt, and the Yeongnam massif (Fig. 1). The Imjingang belt is an east–west- trending fold and thrust zone consisting of metasedimentary rocks and volcaniclastics (Devonian–Carboniferous), underlain unconformably by Proterozoic basement rocks (Chough et al., 2000). Two Precambrian metamorphic massifs, the Gyeonggi and the Yeongnam massifs, separated by the Phanerozoic Okcheon belt, which consists of high-grade schists and gneisses (Sagong et al., 2005). A Cretaceous sedimentary basin named the Gyeongsang basin lies on the southeastern part of the Yeongnam massif.

The epicenter of the Odaesan earthquake is located in the eastern part of the Gyeonggi Massif. The geology of the source region is composed mainly of Jurassic granite, porphyroblastic gneiss, migmatitic gneiss, and Cretaceous sedimentary rocks. The area has been intruded by Jurassic granite and is partly blanketed with Cretaceous sediments. Two dominant fault trends are known in the epicentral area. The first is the Woljeongsa fault that runs N10°E along a small river, Odaecheon, at distance of 1 km to the east of the epicenter in the area of Jurassic granite (Jo and Baag, 2007). The second is the South Korean Tectonic Line (SKTL) and represents the major tectonic boundary between the Gyeonggi Massif and the Yeongnam Massif (Chough et al., 2000).

3. Data analysis

3.1. Data used

Waveform data used in the present study were recorded by the digital seismographic networks operated by the Korean Meteorological Administration (KMA). The January 2007 Odaesan earthquake sequence started on 17 January 2007 at 16:03:02, which was followed by over 45 microearthquakes as observed by Kim et al. (2010) through scanning continuous waveform data recorded at the nearest station DGY. Only nine foreshocks and nine aftershocks were locatable by Kim et al. (2010) with coda-duration magnitudes (M_D) larger than 1.0 based on the formula given by Tsumura (1967). The Odaesan earthquake triggered almost all broadband and short-period stations in the SKP, as well as a dense network of accelerometers. Based on the double-couple point source assumption, two fault-plane solutions have been reported for the Odaesan earthquake: one solution (strike = 20°, dip = 70°, rake = −165°) was retrieved from the polarities of P_g, P_n and SH waves (Jo and Baag, 2007), and the other solution (strike = 115°, dip = 85°, rake = −5°) was determined from the waveform modeling done by Herrmann (2007). The solution (strike = 115°, dip = 88°, rake = −6°) was obtained by Kim (2007) from the moment tensor inversion.

To investigate the finite source model of the Odaesan earthquake in both low- and high- frequency bands, we used the waveform data recorded by the stations within an epicentral distance of less than 70 km. The selected stations consisted of two broadband stations, three short-period stations and two force-balance accelerometers (ES-T). The sampling intervals of these instruments are all 100 samples per second. The earthquake locations used in the present study and the seismic stations are shown in Fig. 2. The spatial distribution of stations around the epicenter is satisfactory and helps in better constraining the solution.

The focal mechanisms of the foreshocks and aftershocks were determined using the amplitude spectra and *P*-wave polarities. A computer program developed by Zahradnik et al. (2001) was used to determine the fault plane solutions. The focal and fault plane parameters of the mainshock, foreshocks, and aftershocks are listed in Table 1. For the mainshock analysis, the waveform data were analyzed in low- and high-frequency bands. The waveform data were filtered with frequency bands of 0.1–0.3 and 1.0–3.0 Hz for the low- and high-frequency bands, respectively. A linear trend was removed and the data were corrected to ground velocity. The velocity model used in the present study to calculate synthetic Green functions is listed in Table 2.

3.2. Analysis of foreshocks and aftershocks

To use a small event as an empirical Green function (EGF), its magnitude should be small enough to be considered as a delta function in space and time, and large enough to be recorded with good signal-to-noise ratios at all the relevant stations. In addition, both the large and small events should have similar focal mechanisms and hypocenters. We relocated the hypocenters using *P*- and *S*-wave arrival times and the iterative technique based on Geiger's method. The epicenters of relocated events cluster around the mainshock location (Fig. 2).

Focal mechanisms of the available foreshocks and aftershocks were calculated using a recently developed method by Zahradnik

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