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Estimation of possible maximum earthquake magnitudes of Quaternary faults in the southern Korean Peninsula

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ABSTRACT

The Korean Peninsula is located in the intraplate regime of the Eurasian plate, and numerous historical and instrumental earthquakes have been recorded. Among these, the largest earthquakes were recorded in and around the Gyeongju and Ulsan areas in the southeastern part of the Korean Peninsula. We recently reexamined faults in Jinhyun and Jintee, part of the Ulsan fault swarm, to clarify the average slip rate and the maximum potential magnitude of future earthquakes. The Jinhyun fault extends to the Tabgol fault (J-T fault), and the Jintee fault extends to the Singye (S-J fault). The faults cut through alluvial fans and are covered by unconsolidated granite washes on Tertiary granite. All of these faults show reverse sense of motion such that the Tertiary granite has been moved upward with a high angle relative to the Quaternary sediments. Most sediment samples from the Jinhyun and Jintee faults showed quartz OSL ages of ca. 40–60 ka. The calculated vertical slip rate for the Jinhyun and Jintee faults is in the range of 0.18–0.28 mm/y. Based on maximum earthquake magnitudes calculated from geological survey results as well as historical and instrumental earthquake information, the maximum potential magnitudes of future earthquakes in the Gyeongju area are estimated to range from 4.6 to 5.6. This suggests that the potential maximum magnitude in the southern Korean Peninsula is presumably not more than 6.

1. Introduction

The Korean Peninsula, located in the eastern part of the Eurasian plate, has traditionally been regarded as a seismically stable region (Fig. 1). However, according to the historical literature, more than 1900 earthquakes have occurred in the Korean Peninsula (Lee and Yang, 2006). In addition, there is a similarity in tectonic environment between the seismic activity that occurred in Korea and in northeast China during the 16th–18th centuries. Korean historical and instrumental records for the past 2000 years highlight seismic activities in specific locations, such as Gyeongju, Ulsan, Pyeongyang, and Hongsung (Fig. 1). For instance, earthquakes of seismic intensity MMI VIII have occurred more than 10 times in and around the Gyeongju area of the southeastern Korean Peninsula. The largest recorded earthquake (MMI IX) occurred in the Ulsan area adjacent to the Ulsan fault belt in the year 1643 (Lee and Yang, 2006).

Most active faults in the peninsula are observed in its southeastern part, and these typically occur as swarms at and around the Yangsan and Ulsan fault belts (Fig. 1). The Suryum fault along the East Sea coast, which separates an MIS 5e marine terrace, has twice shown reverse movement and might be related to Mw ~6–7 late Pleistocene earthquakes (Choi et al., 2010). Recently, Kyung (2010) compiled late Quaternary fault characteristics and suggested maximum earthquake magnitudes of 6.8–7.0. However, timing of the last faulting episode remains unclear because of an absence of effective dating materials.

This work is based on interpretation of aerial photographs (scale 1:20,000), examination of shaded-relief maps constructed from a 5-m-resolution digital elevation model (DEM), field observations, and optically stimulated luminescence (OSL) ages on the unconsolidated sediments. In this study, we focus on the Jinhyun fault of the Ulsan fault belt because this site reveals a good stratigraphic

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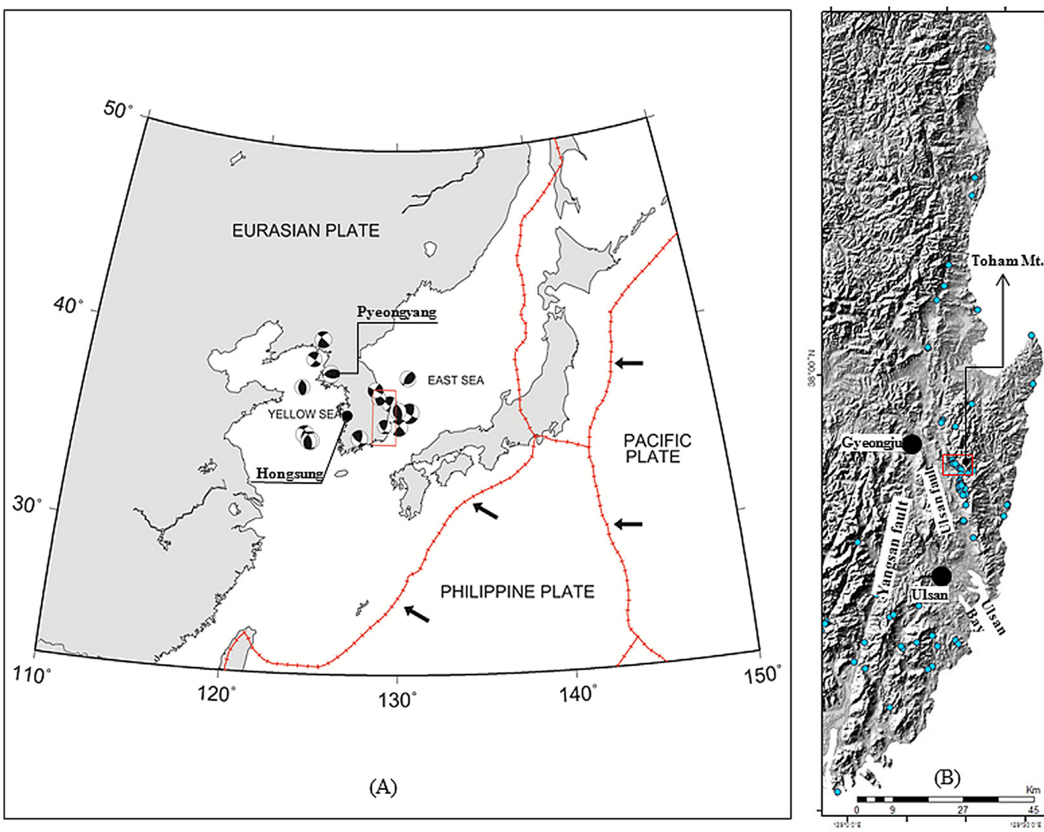

Fig. 1. (A) Focal mechanism solutions of earthquakes near the Korean Peninsula indicating a present E–W compressional stress system in the East Sea (Jun and Jeon, 2010). (B) Circles are locations of Quaternary faults in the Yangsan and Ulsan fault belts. The box shows the study area.

profile that is representative of the Quaternary sediments and also because previous scientific results such as OSL ages and sedimentological interpretations are relatively well documented there. Other fault exposures, such as the Tabgol, Jintee, and Singye, are described here to support the results. Based on various new data, we here evaluate the maximum earthquake of the Ulsan fault belt and suggest the potential maximum magnitude that could occur in the southern Korean Peninsula.

2. Geologic background

2.1. Tectonic overview

Stress generates tectonic activity between plates, and its distribution and intensity can provoke earthquakes. The Korean Peninsula at the eastern margin of the Eurasian plate is controlled by the subducting Pacific and Philippine plates, and it is also affected by the collision of the Indian plate with the Eurasian continent. After opening of the East Sea, induced by the Eurasia–India collision, the tectonic stress field of the eastern margin of Asia changed from extensional (Yin, 2010). According to Global Positioning System (GPS) network data and analysis of focal mechanisms in the Korean Peninsula, compressional stresses are oriented ENE–WSW or E–W (Park et al., 2001; Hamdy et al., 2005; Jin and Park, 2006, 2007; Kim et al., 2006; Park et al., 2007; Choi et al., 2008; Hong and Choi, 2012).

Neotectonic events in the Korean Peninsula are characterized by more than 50 Quaternary faults (Fig. 1). Most of these faults occur along the Yangsan (YF) and Ulsan fault (UF) belts in the southeastern Korean Peninsula (Okada et al., 1994, 1998, 2001; Kyung et al., 1999; Chang, 2001; Kyung and Chang, 2001; Kyung and Lee, 2006; Park et al., 2006; Choi et al., 2010). Ree et al. (2003) suggested that maximum horizontal ENE compression had resulted in the formation of Quaternary reverse faults as well as dextral strike-slip faults in southeastern Korea. The Quaternary faults striking from NNW to NE are the most likely cause of earthquakes in South Korea (Park et al., 2006). Focal mechanisms of earthquakes that occurred in South Korea between 1999 and 2004 indicate NNW- to NE-striking strike-slip faults with reverse sense (Park et al., 2006).

2.2. Topography and stratigraphy

The NNW-trending UF belt extends up to ~50 km from Gyeongju to Ulsan Bay. It is recognized as a prominent wide and linear valley containing a thick accumulation of alluvium but lacking distinct fault exposures. Most Quaternary faults are observed at the piedmont of the Toham Mountain Range (el. 745.1 m) to the east of the valley. These are generally reverse faults dipping toward the east. Thus, the east block has been lifted toward the west.

The NNW-trending UF valley is composed of alluvial fans less than 250 m in height along a stream originating from the Toham Range and joining the EW-trending Nam stream. The fans are developed in a straight line in and around the fault valley and dip toward the west or southwest with an angle of 5°. These compound alluvial fans (Yoon and Hwang, 1999) with slopes of 4–8° are classified into two levels, middle and lower surface, based on elevation, continuity, sediments, degree of weathering, and paleosols. The middle surface (M1 and M2) ranges from 140 to 250 m in height, and the lower surface (L) ranges from 95 to 160 m (Fig. 2A and B). The middle surface is divided into the upper surface (M1), from 160 to 250 m, and the lower surface (M2), from 140 to 170 m, by a step-like scarp. The middle upper surface begins at the end of