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Evidence for significant clockwise rotations of the Korean Peninsula during Cretaceous

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ABSTRACT

In an effort to evaluate the Cretaceous magnetostratigraphy for the Korean Peninsula and to establish the tectonic coherence of its various elements, we collected paleomagnetic data from 121 samples from 20 sites within the Chilgok Formation (108.3–109.9 Ma) in the Gyeongsang Basin. Together with previously published data, we evaluate the results from a total of 163 sites in the basin.

We combine our age model with results from recent stratigraphic, paleomagnetic and radiometric geochemical studies. In this study, we found that two distinct declination shifts decrease with younging direction, indicating two clockwise rotational events of the Korean Peninsula with respect to the Eurasia continent. The earlier event took place during 130–100 Ma (Phase I, newly termed "Goguryeo Disturbance") and a later one during 80–50 Ma (Phase III, belonging to "Bulguksa Orogeny"). The mean rotation rate in the interval from 115.2 to 103.8 Ma (Phase I) is about 0.74°/Ma, while the rate from 90.9 to 79.8 Ma (Phase II) is 0.19°/Ma. Based on paleolatitude change during Phase I, we infer that the Korean Peninsula (eastern part of the Sino-Korea Block) migrated southward about 300 km after the complete amalgamation of the Sino-Korea Block into the Eurasian continent resulting in N–S compression within the Korean peninsula and Manchuria. Large-scale strike-slip faults (e.g., Tan-Lu Fault, Okcheon Boundary Fault) were probably rejuvenated in the Sino-Korea Block during Phase I.

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1. Introduction

The Gyeongsang Basin is located in the southeastern part of the Korean Peninsula and is composed of the Milyang, Uiseong, and Yeongyang sub-basins (Fig. 1). Previous paleomagnetic analysis of the Yeongyang sub-basin (Park et al., 2005) led to the suggestion that this sub-basin underwent a counterclockwise rotation by $16.3° \pm 4.6°$ with respect to the other two sub-basins. Park et al. (2005) proposed that the rotation of the Yeongyang sub-basin was caused by the sinistral movement of the basin-bounding fault during the latest Cretaceous to Paleogene.

The previous studies lumped both the magnetite-carried and hematite-carried directions together and lacked any detailed field tests to distinguish between primary and secondary magnetizations. In addition, the full scale magnetostratigraphy has not been reported in the Cretaceous sequence, which is essential to evaluate the tectonic evolution of the Korean Peninsula (Kim et al., 1993a; Zhao et al., 1999; Park et al., 2005). In order to address these problems, a paleomagnetic analysis of the Milyang and Uiseong sub-basins is critical so as to obtain a reliable and representative Cretaceous paleopole for the Korean Peninsula. Furthermore, a detailed paleomagnetic study of the formations in the Gyeongsang Supergroup is essential to constrain the direction and timing of magnetization of the Gyeongsang Basin.

The magnetostratigraphy of the Gyeongsang basin is poorly constrained in part due to poor age constraints. Recently, reliable U–Pb radiometric age data from zircon grains in the sedimentary and volcanic rocks were obtained (e.g. Jwa et al., 2009; Lee et al., 2010b). Using this new age control and the sequential stratigraphic interpretation of the Gyeongsang Basin (Chough and Sohn, 2010), we perform a reconnaissance paleomagnetic study of the Chilgok Formation, which unconformably overlies the Precambrian crystalline basement.

2. Geologic setting of the Gyeongsang Basin

The Cretaceous Gyeongsang Supergroup, the largest supracrustal belt in the Korean Peninsula, is composed of three groups: the Shindong (characterized by little or very small amount of volcanic rock fragments), the Hayang (containing volcanic rocks and rock fragments), and the Yucheon (mainly consisting of intrusive and extrusive rocks) Groups in stratigraphically ascending order. The sedimentary sequences generally dip eastward with dip angles between 0° and 30° (Fig. 1).

The Shindong Group is considered to have formed in an extensional backarc trough (Chough and Sohn, 2010) and consists of the Nakdong Formation (conglomerate intercalated with sandstone and mudstone), Hasandong Formation (combination of red to pale green sandstone and shale), and Jinju Formation (gray to dark gray

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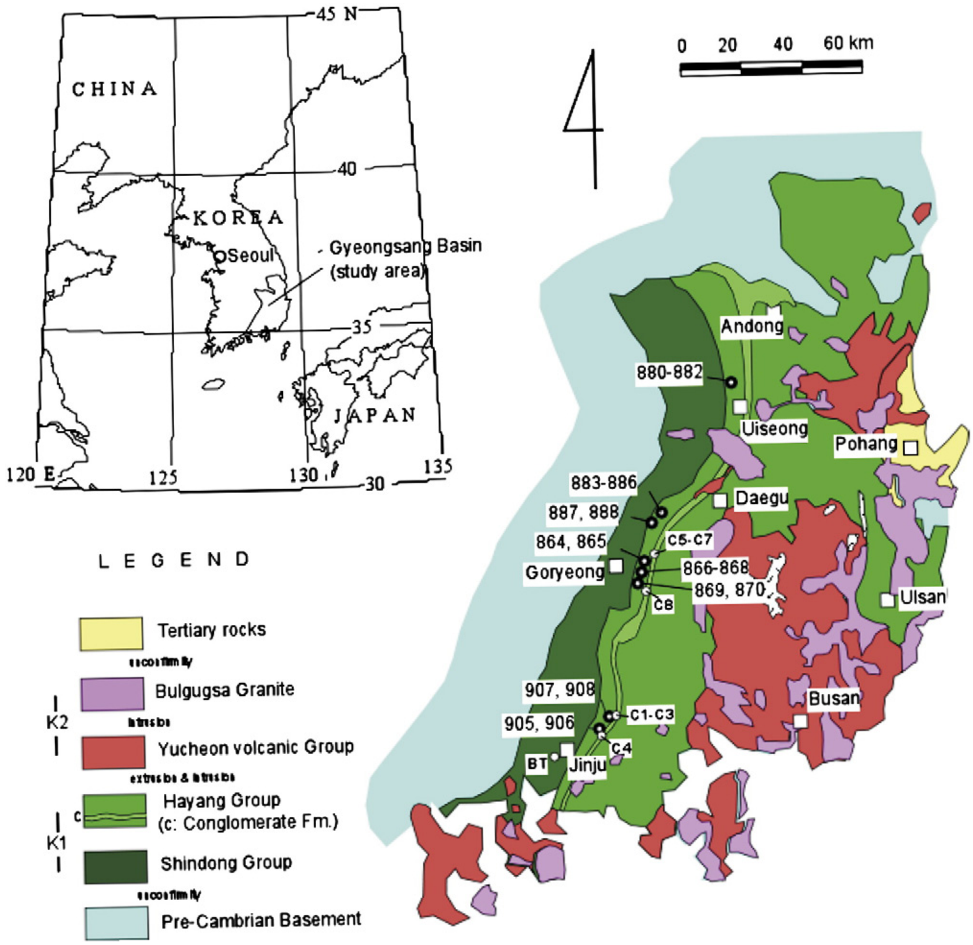

Fig. 1. Geologic map with paleomagnetic sampling sites (Sites 864 to 908). Labels of 'C1 to C8' and 'BT' denote sites of conglomerate test (Kim et al., 1998) and baked test (Jeon et al., 1998).

shale and sandstone). The total thickness of the Shindong Group is about 2000–4000 m (Lee, 1987).

The Hayang Group (Fig. 1) varies in thickness from about 2000 to 5000 m (Lee, 1987), and consists of sandstone, shale, conglomerate, marl and tuff (Lee, 1987). The timing of deposition of this group is debated due partly to a poor fossil record.

The red beds of the Gyeongsang Supergroup contain abundant volcanic rock fragments. The Chilgok Formation, the lowest part of the Hayang Group, is red in color and contains a variety of mafic to felsic volcanic rock fragments (>33%) as well as granite and quartzite fragments (Lee, 1987).

3. Reconnaissance paleomagnetic study of the Chilgok Formation

3.1. Sampling and laboratory procedures

The Chilgok Formation is intercalated in the middle part of the Gyeongsang Supergroup, and is well recognized in the field. Samples for the pilot study were mostly collected from the red beds. Rocks in the vicinity of intrusive dikes or in hydrothermal alteration zones were avoided because they might have been affected by heating and thermochemical transformations. Five to nine samples were collected at each sampling site, covering 1–3 m stratigraphic thickness. The core samples were later cut in the laboratory to obtain standard specimens of 24 mm diameter, and then sliced to 23 mm length to prepare for measurements. A total of 121 paleomagnetic samples were collected from 20 sites.

Natural remanent magnetization (NRM) was measured using a cryogenic SQUID rock magnetometer and a spinner rock magnetometer. All specimens were demagnetized by stepwise heating in a non-inductive electric furnace enclosed in four nested shields. The residual field in the furnace during cooling cycle was about 5 nT. Low-field susceptibility was measured using a Bartington MS2 susceptibility meter after each step of the progressive thermal demagnetization in order to detect chemical changes due to heating. The progressive thermal demagnetization data were analyzed using the principal component analysis (PCA) method (Kirschvink, 1980), and site means were calculated using Fisher's statistics (Fisher, 1953). Thermomagnetic analysis and isothermal remanent magnetization (IRM) acquisition were applied to representative samples to study magnetic minerals that carry the remanent magnetization. Thermomagnetic analysis was performed by using an automatic recording semi-horizontal thermobalance. Petrographic inspection of polished surfaces and thin-sections of selected specimens was also carried out under reflected and transmitted light.

3.2. Results

One of the main objectives of this study is to reveal the characteristic magnetization in the red beds of the Chilgok Formation. Typical thermomagnetic results in this study suggest magnetite and hematite to be the predominant magnetic minerals in the samples. The unblocking temperatures of about 570°–575 °C and 675°–680 °C confirm the presence of magnetite and hematite, respectively. The irreversible portion of the cooling cycle may result from the creation of new ferromagnetic minerals from the paramagnetic and superparamagnetic materials due to recrystallization during heating (Fig. A1).

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