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Depositional history, tectonics, and provenance of the Cambrian-Ordovician boundary interval in the western margin of the North China block: Comment

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INTRODUCTION

Myrow et al. (2015) detailed the sedimentology, biostratigraphy, and chemostratigraphy of the Cambrian-Ordovician succession in the western North China block (or Sino-Korean block) at Wuhai, Inner Mongolia, China, and recorded an ~30 m.y. unconformity that formed during the upper Cambrian Series 3–upper Middle Ordovician. They provided a valuable description of the succession accompanied by excellent illustrations of sedimentary facies as well as detailed data on chemostratigraphy, thus providing an important basis for further geologic studies in the region. In addition, they presented a discussion on the origin of the ~30 m.y. unconformity and suggested that the western Sino-Korean block would have been placed near the western Himalaya during the early Paleozoic, where a hiatus of similar magnitude has been reported (Myrow et al., 2006, 2016). This result seems to support the theory of McKenzie et al. (2011), who first suggested a close paleogeographic affinity between the Sino-Korean block and Himalaya based on detrital zircons and trilobites. However, the paleogeographic interpretation of Myrow et al. (2015) requires further discussion because of the following reasons: (1) incorrect description of the "unconformities" in other localities of the Sino-Korean block, and (2) presence of other potential options on the formative mechanism of this unconformity, including tectonic tilting and eustatic sea-level change. In the following section, we describe each topic in detail and discuss the nature and implication of this unconformity.

CAMBRIAN-ORDOVICIAN UNCONFORMITIES ON THE SINO-KOREAN BLOCK

At the Subaiyingou (or Subeigou) section where the study was conducted, the Cambrian-Ordovician boundary occurs ~360 m above the Precambrian-Cambrian unconformity (Lee et al., 2016). Myrow et al. (2015) focused on the upper part of this succession, consisting of fine-grained sedimentary facies such as lime mudstone and marlstone alternations, and they reported that trilobites belonging to the *Blackwelderia* zone, indicating the middle Guzhangian Stage of Cambrian Series 3 (Park et al., 2013), occur 18.51 m below the Cambrian-Ordovician boundary. Lee et al. (2016) reported trilobite *Jiulongshania rotundata* from strata 16.4 m below the boundary, which also occurs within the *Blackwelderia* zone of Myrow et al. (2015). Sedimentary facies as well as trilobite occurrences collectively suggest a relatively slow sedimentation rate, indicating that the uppermost part of the Cambrian succession in Wuhai area would not exceed the Guzhangian Stage (Myrow et al., 2015; Lee et al., 2016). The lower part of the Sandaokan Formation unconformably overlying the Cambrian succession was correlated to the conodont biozone *Histiodella holodentata* of the middle to upper middle Darriwilian Stage, Middle Ordovician (Myrow et al., 2015). Therefore, the Cambrian-Ordovician unconformity developed in the Wuhai area of the western Sino-Korean block indicates a hiatus of ~30 m.y. or more (Myrow et al., 2015).

Myrow et al. (2015) compared another hiatus in the western Himalaya with that of the western Sino-Korean block, which lasted from the latest Cambrian Series 3 or earliest Furongian to approximately the early Middle Ordovician. Chronostratigraphic control on the western Himalayan succession is poor, and therefore the exact duration of this hiatus remains under question (Myrow et al., 2006), although a duration of ~22–36 m.y. has been recently suggested for this hiatus (Myrow et al., 2016). Myrow et al. (2015) suggested that since the durations of the hiatuses in the western Sino-Korean block and the western Himalaya are similar, these two regions could have been connected during the early Paleozoic. Supposed sediment provenance changes across the Cambrian-Ordovician boundary in the western Sino-Korean block (cf. Darby and Gehrels, 2006) have been suggested to indicate tectonic uplift that might have formed this unconformity (Myrow et al., 2015; further discussed in next section).

In addition to the unconformity in the western Sino-Korean block, Myrow et al. (2015) reported three additional localities in the block with evidence of unconformities across the Cambrian-Ordovician boundary. These include the eastern (Taebaek, South Korea), northeastern (Baishan, Jilin, China), and northern (Baotou, Inner Mongolia, China) margins of the Sino-Korean block. These localities display sedimentologic features that would suggest a break in sedimentation, including sandstone overlying carbonate (Taebaek), subaerial exposure and an erosion surface (Baishan), and conglomerate and sandstone on a paleokarst surface (Baotou; Myrow et al., 2015, their table 1). However, some of these features are not related to an unconformity (Taebaek) or are not correctly quoted (Baishan).

In the Taebaek area of Korea (Taebaeksan Basin), an ~1200-m-thick mixed carbonate-siliciclastic sequence was deposited from the Cambrian Series 2 to the Middle Ordovician (Kwon et al., 2006). The Cambrian-Ordovician boundary lies in the basal part of the Dongjeom Formation, which conformably overlies the Hwajeol Formation (Choi et al., 2016). Evidence of a time gap or sedimentary hiatus across the Cambrian-Ordovician boundary is not recognized in this area, which can be noted from detailed sedimentological and paleontological studies performed in the area over the past 30 yr (e.g., Woo and Park, 1989; Choi et al., 2003, 2016; Choi and Chough, 2005; Kwon et al., 2006; Lee and Choi, 2007, 2011). There is an increase in input of sandstone around this boundary, indicating a gradual transition from a shale-carbonate–dominant environment to a siliciclastic-dominant environment without a significant hiatus (Choi et al., 2004; Kwon et al., 2006). Late Furongian to earliest Tremadocian trilobite biozones successively

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GSA Bulletin; July/August 2017; v. 129; no. 7/8; p. 1019–1021; https://doi.org/10.1130/B31806.1; published online 22 May 2017.

occur across the Hwajeol and Dongjeom formations, which are well correlated to those of North China and other parts of the world (Choi and Chough, 2005; Choi et al., 2016).

The Cambrian-Ordovician boundary interval at Dayangcha section, Jilin, northeastern China (Baishan, Jilin in table 1 of Myrow et al., 2015), has been intensively studied in terms of sedimentology, paleontology, and sequence stratigraphy (Chen et al., 1988, and references therein; Ripperdan et al., 1993; Zhang et al., 1999; Zhang and Erdtmann, 2004). Although Myrow et al. (2015, their table 1) added the section as an unconformity-bearing locality in North China with geological features of "subaerial exposure," the Cambrian-Ordovician succession in the Dayangcha section was in fact described as "rhythmical sequence of lime mudstone and shales" deposited along the outer shelf of the platform (Chen et al., 1988, p. 415). Ripperdan et al. (1993) pointed out that the section shows several depositional breaks or "condensed sections," which can be correlated with global sea-level changes across the Cambrian-Ordovician boundary interval. Zhang et al. (1999) also noted the glauconitic condensed section of a maximum marine flooding event near the Cambrian-Ordovician boundary. Those studies question the occurrence of a "subaerial" unconformity in the area, and therefore careful comparison is required to understand the Cambrian-Ordovician unconformities within the Sino-Korean block.

FORMATIVE MECHANISMS OF THE UNCONFORMITY

The Cambrian-Ordovician unconformity in the Wuhai area was well documented compared with examples in other places of the Sino-Korean block, as noted earlier herein. However, the unconformity-forming mechanism is still under question. Myrow et al. (2015) suggested a tectonic uplift event across the Cambrian-Ordovician boundary that would have caused formation of the unconformity, based on "changes in provenance" indicated by different detrital zircon age spectra from the Cambrian and Ordovician successions in the Wuhai area (Darby and Gehrels, 2006). However, Proterozoic, Cambrian, and Ordovician detrital zircon spectra presented by Darby and Gehrels (2006) are all distributed between 1800 Ma and 2800 Ma, with two major peaks around 2000 Ma and 2700 Ma. Although there are higher age probabilities for the 2600 and 2700 Ma peaks in the Ordovician spectrum compared with other spectra, these detrital zircon spectra are based on a small number of samples (e.g., Ordovician: 32 zircons) and therefore are statistically less reliable (Darby and Gehrels, 2006, their fig. 4). Such differences in age probability can even occur within the same lithologic units without any significant provenance changes (e.g., Lee et al., 2012).

Previous studies have noted a major shift in the sedimentary succession on the Sino-Korean block during the late Cambrian Series 3, where a major drowning unconformity formed in the eastern to northeastern part of the block (Meng et al., 1997; Kwon et al., 2006; Chen et al., 2011). Meng et al. (1997) noted the disparity in sedimentary environmental changes recognized throughout the block during this time interval (late Cambrian Series 3–Furongian); there is a transition from shallow- to deep-water facies (drowning unconformities of Kwon et al., 2006; Chen et al., 2011) in the northern (to northeastern) part of the platform, whereas supratidal to subaerial facies occur in the southern (to southwestern) part of the platform. Classically, this has been explained by a tectonic tilting event that occurred across the Sino-Korean block, although the causes for this event were only briefly presented as "the result of collision with a marginal basin to the north" (Meng et al., 1997, p. 219). It is noteworthy that the unconformity in the Wuhai area initiated during the late Cambrian Series 3, coinciding with this "tilting" event. The tilting event could have been responsible for the formation of the long-lasting unconformity, and discussion on this idea would be necessary.

Last, it is necessary to discuss eustatic sea-level change as a significant mechanism for long-ranging hiatus formation, although Myrow et al. (2015) pointed out that the Cambrian-Ordovician unconformities elsewhere, which may have been caused by eustatic sea-level fall events, are relatively brief in time span in comparison with that of Wuhai. There are at least two eustatic sea-level fall events recorded within the time span represented by this unconformity: Cambrian Series 3–Furongian boundary sea-level fall event (Saltzman et al., 2004; Lee et al., 2015) and earliest Middle Ordovician sea-level fall event (Meng et al., 1997; Kwon et al., 2006; Morgan, 2012). Among these two events, the former corresponds to a third-order sea-level fall (Sauk II–III sequence boundary in Laurentia; Lee et al., 2015), whereas the latter is a second-order sea-level fall event (Sauk–Tippicanoe sequence boundary) that has been known since the initial report of Sloss et al. (1949). In addition, unconformities are recognized across the Cambrian-Ordovician boundary in Laurentia (Sauk IIIA–IIIB sequence boundary), which also could have been induced by eustatic sea-level fall event(s) (cf. fig. 4 *in* Morgan, 2012).

Combination of these sea-level fall events could have resulted in an ~30 m.y. hiatus by overprinting preexisting unconformities. For example, the Upper Ordovician Montoya Group in New Mexico and western Texas of the United States unconformably overlies the Cambrian Series 3 Abrigo Limestone (Morgan, 2012). The duration of this unconformity is similar to those of Wuhai and western Himalaya, but it does not mean that these three localities would have been connected to one another. Laurentia, a large paleocontinent containing present-day North America, was completely separated from Gondwana and the Sino-Korean block during the early Paleozoic (Li and Powell, 2001). Instead, it is more likely to infer that a combination of several sea-level fall events that occurred throughout this time interval resulted in several large hiatuses of similar duration in various localities of the world. Durations and effects of unconformity-forming sea-level fall events would have been different in various localities, due to several factors, including topography, sedimentation pattern, climate, and local tectonics. Further detailed sedimentologic as well as sequence stratigraphic studies throughout the Sino-Korean block are required to fully understand the origin of the unconformity.

SUMMARY

The report of a major unconformity that lasted for ~30 m.y. from the western Sino-Korean block using various evidence, including sedimentology, biostratigraphy, and geochemistry, is an important contribution with regard to understanding the geologic history of the Sino-Korean block and related geologic areas (Myrow et al., 2015). Paleogeographic correlation using the unconformity is an intriguing and plausible idea that needs to be tested. However, we think that further discussion on this idea is necessary, especially on the traditional "tectonic tilting" idea and eustatic sea-level change. In addition, there are several mistakes in terms of summarizing previous works in other localities, which call into question the reliability of their discussion. The work by Myrow et al. (2015) lays an important foundation stone for further studies in the western Sino-Korean block, and we hope our discussion may also be helpful.

ACKNOWLEDGMENTS

We would like to thank the editor Brad Singer for careful handling of the manuscript. This article is a contribution by J.-H. Lee to the National Research Foundation of Korea (2016R1C1B1012104) and S.-b. Lee to the Basic Research Project (GP2017-002) of the Korea Institute of Geoscience and Mineral Resources in relation to the revision of the 1:1,000,000 scale geologic map of Korea based on the correlation between Korea and China.

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SCIENCE EDITOR: BRADLEY S. SINGER

MANUSCRIPT RECEIVED 16 MARCH 2017
MANUSCRIPT ACCEPTED 12 MAY 2017

Printed in the USA