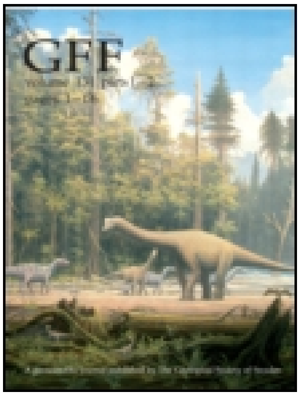

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The eastern extension of Paleozoic South China in NE Japan evidenced by detrital zircon

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Note

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Abstract: The South Kitakami belt is unique in exposing a thick, well-preserved Paleozoic shelf sequence in Japan in which Phanerozoic accretionary complexes dominate. Its origin with respect to continental blocks has been debated in regard of two options, i.e., as belonging to the margin of North China or South China. Present work on U–Pb detrital zircon dating has identified Neoproterozoic mineral grains from the Silurian and Carboniferous sandstones in the S. Kitakami belt, and proved the link between Paleozoic Japan and South China with dominant Proterozoic basements. South China likely extended further to the east from the mainland China.

Keywords: detrital zircon; U–Pb age; Silurian; Carboniferous; South Kitakami belt; South China.

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Introduction

The Paleozoic tectonic evolution of Japan still remains enigmatic in comparison with its Mesozoic–Cenozoic history, mainly because of the scarce occurrence of the Paleozoic rocks. The distribution of pre-Permian units is highly limited in Japan, particularly to several narrow zones often characterized by serpentinite mélange, such as the Kurosegawa belt and Nagato-Hida marginal belt in SW Japan (e.g., Isozaki 1996; Isozaki et al. 2010). Heretofore, the oldest nonmetamorphosed, fossil-dated sedimentary unit known from Japan was the lower Upper Ordovician (Sandbian; 453–458 Ma) in the Hida marginal belt that yielded conodonts from siliceous mudstone (Hitoegane Fm; Tsukada & Koike 1997). "The oldest strata in Japan" in fact occurs as a small exotic block within the chaotically deformed serpentinite mélange (Nakama et al. 2010; Isozaki 2011).

In this regard, the South Kitakami belt in NE Japan is exceptional in Japan on account of the nondisturbed/nonmetamorphosed thick Paleozoic sequence of continental shelf facies preserved, therein. The Paleozoic strata in this belt consist of shallow marine carbonates interbedded with terrigenous clastics of the Silurian, Devonian, Carboniferous and Permian age, which were punctuated by several unconformities but still retain the primary stratigraphic relationships intact (e.g., Kawamura & Kato 1990). Except for the Ordovician ophiolite and the overlying volcaniclastics (Ozawa 1988; Shimojo et al. 2010), the nature and origin of the pre-Silurian basement are not well identified with respect to the major continental blocks in East Asia (Fig. 1A). Two options were proposed for the origin of Japan: i.e., physiographically closer to North China (e.g., Tazawa 1998) or South China with similar "Tethyan" Paleozoic faunas (e.g., Kato 1990; Ehiro 2001). After their mutual collision during the mid-Triassic, the North and South China blocks were incorporated into a much larger continental framework called Asia (e.g., Maruyama et al. 1989; Fig. 1A). The pre-Triassic position of Japan with respect to these continental blocks remains uncertain.

In order to decipher the origin of the South Kitakami belt and also of Japan, this study utilized single-grain dating of detrital zircon from the Paleozoic sandstones of the South Kitakami belt using a laser-ablation induced-coupled-plasma mass spectrometer (LA-ICP-MS) (See Supplement for details). This short article reports a preliminary result of single zircon U–Pb dating for the Silurian and Carboniferous sandstones, and discusses their geotectonic implications.

Samples

We dated two nonmetamorphosed sandstones from the South Kitakami belt in NE Japan; one sample coming from the Silurian strata in the O-hasama area in central Iwate prefecture (OR), and the other from the Carboniferous strata in the Hikoroichi area in southern Iwate prefecture (HK) (Fig. 1B). The sample OR is a fine-grained arkosic sandstone in the middle part of the Silurian Orikabe-toge Formation (Yamazaki et al. 1984) collected along a forest road in the northwest of Mt. Jitake (39, 31′, 43.07″N, 141, 23′, 7.79″E). On the basis of the trilobites (*Encrinurus*) and corals (*Halysites*), this formation has a Wenlockian correlation

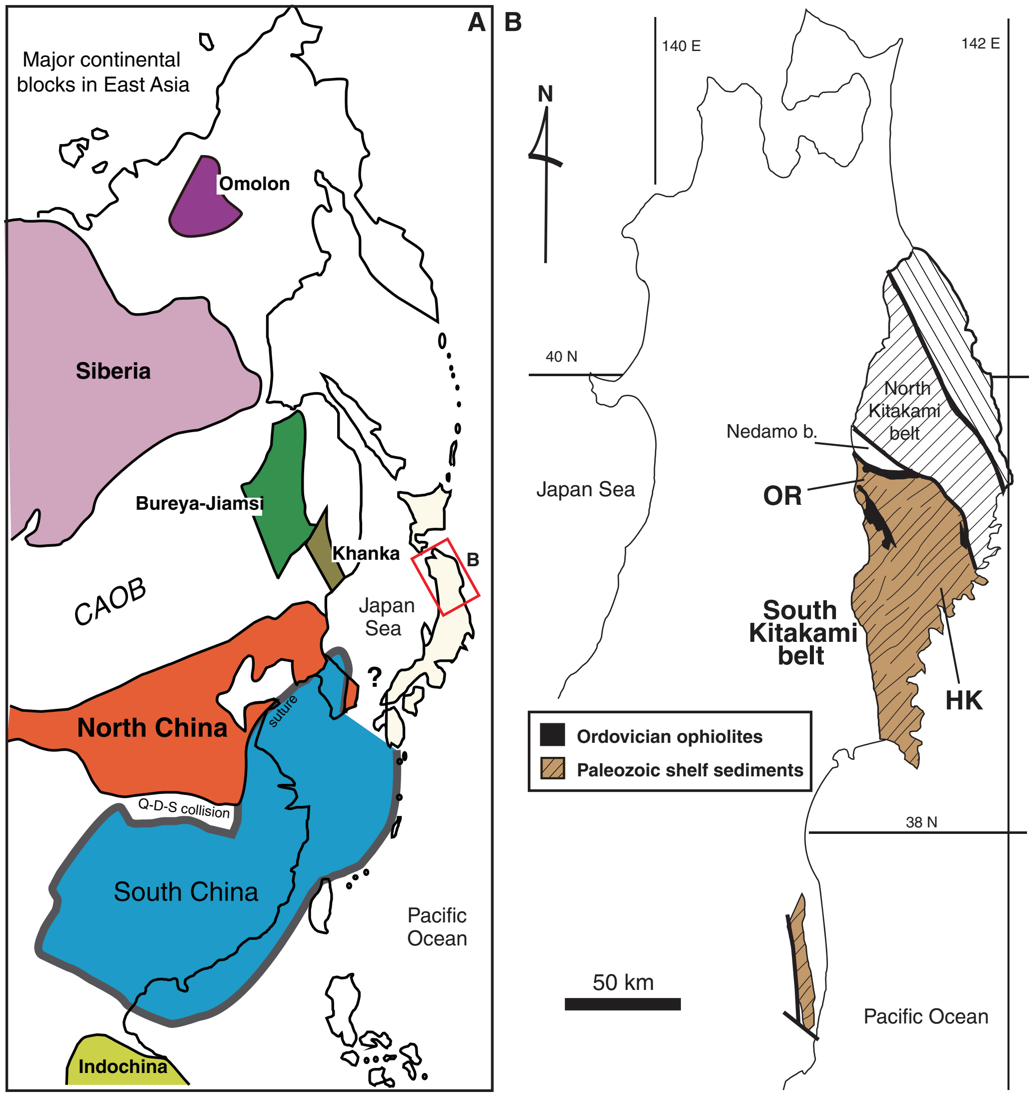

Fig. 1. Tectonic sketch map of major continental blocks in East Asia **(A)** and index map of the South Kitakami belt in NE Japan **(B)**. Sample localities of the analyzed sandstones are shown (OR: Silurian Orikabe-toge Fm; HK: Carboniferous Hikoroichi Fm).

(433.4–427.4 Ma according to Melchin et al. 2012). The sample HK is a calcarenaceous sandstone with abundant lithic grains belonging to the Lower Carboniferous Hikoroichi Fm (H1 Member; Kawamura 1983, 1984) collected from an outcrop along the river at the entrance of the Sakamotozawa creek in Ofunato city (39, 7′, 46.78″N, 141, 39′, 40.19″E). On the basis of corals, this member was correlated with the upper part of the Tournaisian (358.9–346.7 Ma according to Davydov et al. 2012).

Individual zircon grains were hand-picked after crushing and panning. By cathodoluminescence visual imaging, we selected micro-domains of zircon crystals with oscillatory zoning that is unique to igneous zircon (Corfu et al. 2003). Details of analytical procedures are explained in "Analytical" of the supplement (see Supplementary material for details). The U–Pb ages were measured at laser-abladed spots on 60 single zircon grains from OR and 60 grains from HK, respectively. Among these, 54 grains from OR and 55 grains from HK were plotted on the concordia line of U–Pb isotopic systematics (see DD-Tables 1, 2 and DD-Figs. 1, 2 in Supplementary material). In order to avoid analytical bias owing to Pb loss and common Pb contamination, six grains in OR and five grains in HK which obviously represent discordant measurements (over 10% discordance) were eliminated from the following discussion.

Data

Figure 2 summarizes the $^{206}Pb/^{238}U$ age populations of the detrital zircon grains, as histogram and probability age frequency curves according to the *Isoplot/Ex 3* (Ludwig 2003), using solely the ages on the concordia.

The sample OR has two zircon grains with the youngest age; i.e., 419.4 ± 10.2 Ma and 419.8 ± 16.5 (the latest Silurian almost close to the Silurian–Devonian boundary at 419.2 Ma according to Melchin et al. 2012). Most zircons (43 grains) are clustered into the age range of 433–466 Ma (Middle Ordovician to Early Silurian). On the other hand, there are six zircon grains with much older Precambrian ages; i.e., 627.1 and 916.5 Ma (Neoproterozoic), 1070.4, 1116.2, 1204.1 and 1993.1 Ma (Mesoproterozoic).

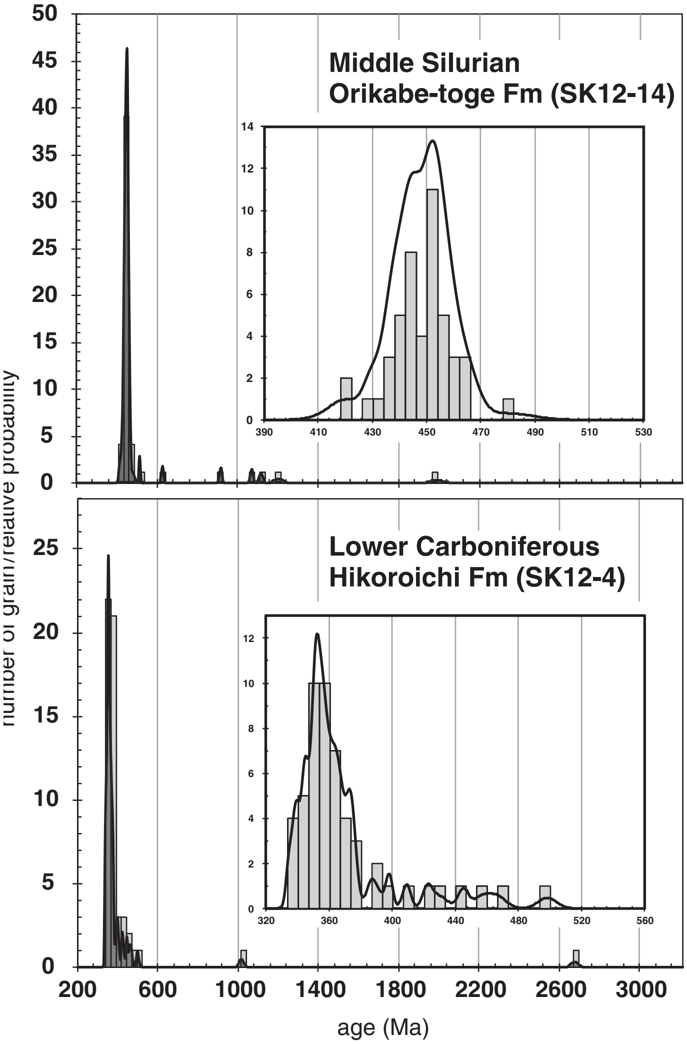

Fig. 2. U–Pb age spectra in histogram and probability curve of detrital zircon grains from sandstones of the Silurian Orikabe-toge Fm and Carboniferous Hikoroichi Fm in the South Kitakami belt. Insets show the enlargement for the younger population.

The sample HK has two zircon grains with the youngest age of ca. 335 Ma (Visean; Davydov et al., 2012). Most zircon grains are clustered within the range of 335–384 Ma (Late Devonian–Earliest Carboniferous). There are two distinctly older grains with ages of 1015.6 Ma (Mesoproterozoic) and 2679.4 Ma (Archean).

Discussion

The new zircon ages provide fresh constraints on the depositional age of the analyzed Silurian and Carboniferous sandstones. The two analyzed sandstones have a strong age peak; i.e., Sample OR with the peak at ca. 450 Ma (Late Ordovician) and Sample HK at ca. 350 Ma (Early Carboniferous), respectively. These age spectra are concordant with the petrography of sandstone, in particular, with that of the Lower Carboniferous Hikoroichi Fm. By analyzing sandstone composition, Kawamura (1984) clarified the arc-derived nature of the Hikoroichi clastics, and the possible provenance dominated by subduction-related calc-alkaline batholith belt. The present data confirm that the mid-Paleozoic Japan had extensive exposures of the Early–Middle Paleozoic arc-batholith belt(s) in the main terrigenous clastic provenance. However, there are no examples of the corresponding large batholith belts currently exposed in Japan except for a fairly minor remnant distribution less than 10 km in diameter. This indicates that pre-existing Paleozoic large batholith belts were destroyed/consumed almost completely by episodes of successive "tectonic erosion" as speculated by Isozaki et al. (2010).

The sample OR has two detrital zircon grains with the youngest age of ca. 419.8 ± 16.5 and 419.4 ± 10.2 Ma, suggesting the depositional age of the formation to range up possibly to the Silurian–Devonian boundary. These ages are younger than the previously reported Wenlockian fossil age from the middle Orikabe-toge Fm, although they have large error bars. The sample HK also yielded younger zircon grains than previously expected. Two of the youngest ages of 334.5 ± 3.5 and 337.8 ± 4.2 Ma imply a Visean age for the deposition of the H1 Mb of the Hikoroichi Fm, slightly younger than the late Tournaisian fossil age (ca. 352–347 Ma), suggesting the possibility for the younger extension in age of this unit.

The most noteworthy implications derive from much older grains of detrital zircon found in both samples. In particular, from OR, we detected six grains with Precambrian ages of 627.1, 916.5 (Neoproterozoic), 1070.4, 1116.2, 1204.1 and 1993.1 Ma (Mesoproterozoic), and from HK, two grains of

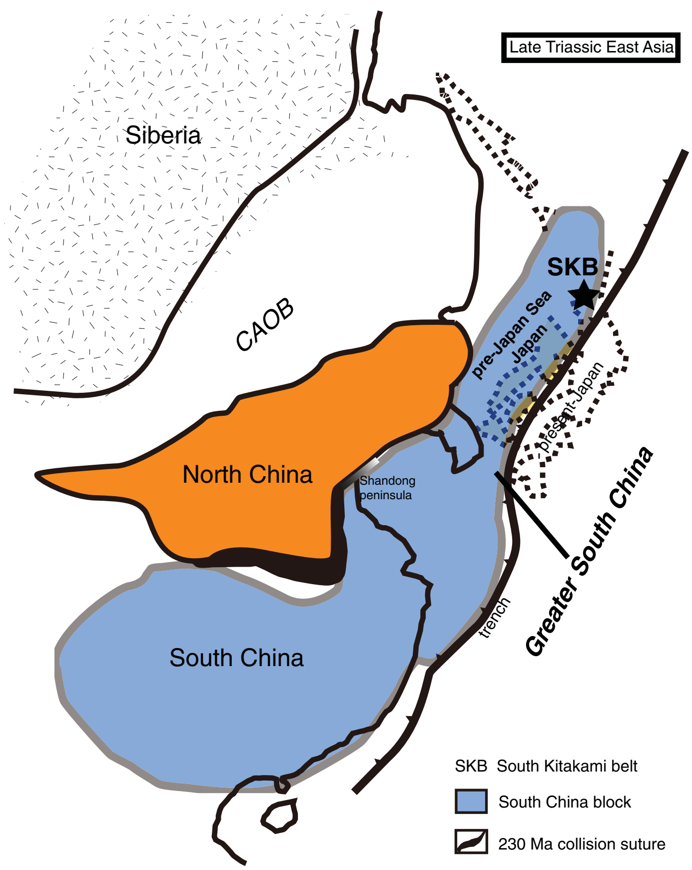

Fig. 3. Reconstruction of Late Triassic East Asia immediately after the continental collision of the North and South China blocks. The detrital zircon ages suggest that the South Kitakami belt have had an intimate link to South China. Note that the eastern extension of the South China continental crust likely reaches the South Kitakami belt (SKB) in NE Japan. This continental entity, twice larger than previously believed, is newly named "Greater South China".

1015.6 (Mesoproterozoic) and 2679.4 Ma (Archean). These indicate that the Middle–Late Paleozoic South Kitakami belt clearly picked up sedimentary influence from the Precambrian crust that cannot be found in modern Japan. In the vicinity of modern Japan, two continental blocks in mainland Asia, i.e., the North and South China blocks, likely appear as possible provenances of the Precambrian clastics, as these two have extensive Precambrian basements.

In particular, the late Meso- and Neoproterozoic grains (five grains from OR and one from HK) are geologically significant because the occurrence of Precambrian basements with these ages is restricted solely to the South China block (e.g., Liu et al. 2008). The new detrital zircon ages from the two sandstone samples from the South Kitakami belt suggest a more intimate tectono-sedimentary relationship with the South China block (Fig. 3), even though we need to consider other aspects of sedimentary recycling in order to interpret a more detailed delivery history. On the other hand, Neoarchean to early Meoproterozoic basements exist in both blocks (e.g., Liu et al. 2008), although the older zircon grains from the South Kitakami belt, such as 1993.1 Ma from OR and 2679.4 Ma from HK, are not diagnostic in identifying the provenance.

The Japanese Islands have a nearly 700 million-year-old history that started with the breakup of the Rodinia supercontinent (Isozaki et al. 2010). Proto-Japan originally developed from a passive continental margin detached from Rodinia and was later converted tectonically into an active continental margin along the western Pacific (Panthalassa) around ca. 520 Ma (Middle Cambrian) as marked by the oldest arc-granite and the oldest high-P/T metamorphic rocks in Japan. The present data positively confirmed that Paleozoic Japan grew along the Pacific margin of South China in accordance with faunal similarity. This further suggests that the pre-collision Paleozoic South China crust likely extended eastward up to NE Japan (the South Kitakami belt), for more than 1500 km further to the east from the modern eastern margin of the conterminous South China block around the Shandong peninsula on mainland China (Fig. 3). Accordingly, the size of South China appears twice larger than previously believed, thus providing a significant constraint in reconstructing the paleo-position of Paleozoic South China in the framework of the Proterozoic supercontinent Rodinia. Here, we name the "Greater South China" for this larger continental entity that includes the South China block proper and the Japan segment up to the South Kitakami belt to the northeast.

Supplementary material

Supplementary material for this article is available via the supplementary tab on the article's online page at http://dx.doi.org/10.1080/11035897.2014.893254

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