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Qi-Qin Accretionary Belt in Central China Orogen: Accretion by trench jam of oceanic plateau and formation of intra-oceanic arc in the Early Paleozoic Qin-Qi-Kun Ocean

Shuguang Song [a], Liming Yang [a], Yuqi Zhang [a], Yaoling Niu [b,c], Chao Wang [a], Li Su [d], Yanlin Gao [e]

[a] *MOE key Laboratory of Orogenic Belt and Crustal Evolution, School of Earth and Space Sciences, Peking University, Beijing 100871, China*

[b] *Department of Earth Sciences, Durham University, Durham DH1 3LE, UK*

[c] *Institute of Oceanology, Chinese Academy of Science, Qingdao 266071, China*

[d] *School of Scientific Research and State Key Laboratory of Geological Processes and Mineral Resources, Chinese University of Geosciences, Beijing 100083, China*

[e] *Qinghai Science & Technology Department, Xining 810000, China*

Correspond author:

Shuguang Shuguang (sgsong@pku.edu.cn)

Most orogenic belts have experienced a complex accretionary process with multiple episodes of seafloor subduction and trench retreat. This accretionary process is important in continental development and growth [1, 2].

Three giant orogens extend in China, e.g., the Central Asian Orogen in the north, the Central China Orogen in the middle and the Himalayan Orogen in the southwest. They are keys for the formation of the Eurasian continent (Fig. 1A). The Central China Orogen is one of the three major orogens in China [3] and has experienced a long and complicated orogenic history [4-6]. It consists of the Qinling-Tongbei-Dabie orogenic belt in the east, the West Qinling orogenic belt, in the middle and Qilian and Kunlun orogens in the middle-west and the West Kunlun orogen in the west (Fig. 1A). The Qi-Qin Accretionary Belt (QQAB) extends discontinuously from the South Qilian Accretionary Belt in the northwest to the Tianshui-Wushan Accretionary Belt (TWAB), and further to the East Qinling Orogen in the southeast (Fig. 1B) for ~2000 km, which stretches across much of the Central China Orogen (CCO). This giant accretionary belt was formed during the evolution and closure of the Qin-Qi-Kun Ocean (Proto-Tethys Ocean (?) or Paleo Pacific Ocean (?)), which played important roles in the amalgamation of continental China and Pangea [7].

Here we report research progresses of a newly recognized oceanic accretionary belt in the Central China Orogen, namely the “Qi-Qin Accretionary Belt” (QQAB) that formed in the Early Paleozoic. It extends discontinuously for ~2000 km from the south Qilian Orogen in the northwest to the West Qinling Orogen in the east, and

43 further to the East Qinling Orogen in the southeast (Fig. 1B). This accretionary belt
44 consists of two major components: (1) the Cambrian (525-500 Ma) plume-type
45 ophiolite complexes and (2) the Ordovician intra-oceanic island arc complexes, based
46 on detailed studies of petrology, geochemistry and geochronology. They accompany
47 closely together in each of the terranes along the QQAB (Fig. 1B). Trench jam of an
48 oceanic plateau during seafloor subduction is likely the major mechanism for the
49 generation of the QQAB. This mode of accretion may be important in Earth's history.
50

51 **Fig. 1.** (A) Skeleton map showing the three giant orogens in continental China: the
52 Central Asian Orogen in the north, the Central China Orogen in the middle and
53 Himalayan Orogen in the Southwest. (B) Skeleton map of Qinling-Qilian-Kunlun
54 orogenic belt showing the spatial stretch of the Qi(lian)-Qin(ling) Accretionary belt
55 (QQAB). All terranes in the QQAB consists of Cambrian Plume-type ophiolites and
56 Ordovician IBM (Izu-Bonin-Mariana)-type island arc complexes. The TWAB
57 (Tianshui-Wushan Accretionary Belt) in the West Qinling Orogen consists of Wushan,
58 Guanzizhen and Liziyuan terranes. The QQAB in the East Qinling Orogen is
59 composed of ophiolites and arc volcanic rocks as a result of the Shangdan Ocean floor
60 subduction [6].

61 Determination of a Cambrian oceanic plateau

62 Ophiolites occur as scattered blocks along the QQAB. In the south Qilian

accretionary belt (SQAB) of the Qilian Orogen, the western segment of the QQAB, the Lajishan-Yongjing ophiolite blocks, separated by Cretaceous/Cenozoic sedimentary covers, are well preserved [8]. These ophiolite blocks consist predominantly of thick massive and pillow basalts with minor ultramafic and gabbroic bodies. Three groups of basaltic rocks have been recognized: (1) the subalkaline group with enriched mid-ocean-ridge-basalt (E-MORB) compositions, (2) the alkaline group with intra-plate ocean-island-basalt (OIB) compositions, and (3) picrite group. The picrites occur both as massive flows and pillow lavas. These rocks have high MgO (18-22 wt%) with 48–52 wt% SiO_2. Most of the samples have TiO_2 (> 1 wt%) except for the massive basalt. They show major element compositions resembling komatiites (TiO_2 < 1 wt%) and memeichite (TiO_2 > 1 wt%) classified by Le Bas (2000) despite lacking the spinifex texture. Cr-numbers [$Cr^{\#}$=Cr/(Cr+Al)] of spinels from the picrites suggest 18–21% degree of partial melting at the estimated mantle potential temperature (Tp) of 1489–1600 °C, equivalent to values of Cenozoic Hawaiian picrites (1500–1600 °C [9]). The rock association and the geochemistry suggest this P-type ophiolite may be fragment of an ocean plateau of mantle plume origin. Zircons from gabbro samples yielded U–Pb Concordia age of 525-500 Ma [8], suggesting the timing of oceanic plateau formation in the Cambrian.

Ophiolites from the TWAB of the West Qinling Orogen, the middle segment of the Qin-Qi-Kun orogenic belt (Fig. 1), mainly consist of gabbros, and massive and pillow basalts. The basalts in this ophiolite complex show affinity of enriched MORB

[10,11]. Zircon U-Pb dating (530-500 Ma) indicates the ophiolite formed in the Cambrian [12], as are the P-type ophiolites in the SQAB. Therefore, ophiolites from the TWAB of the West Qinling Orogen may represent the eastern extension of the Cambrian oceanic plateau.

IBM-type intra-oceanic arc volcanic complex with boninite and sanukite in Late Ordovician

An arc volcanic complex crops out in the south relative to the ophiolite complex in all the accretionary terranes, and extends from Subei (the Yanchiwan Terrane) in the northwest, via Lajishan, Yongjing to west Qinling, and to east Qinling in the southeast (Fig. 1). The arc-volcanic complex consists predominantly of basalt, basaltic andesite and andesite with minor dacite and rare rhyolite. Boninite, most probably emplaced in forearc settings, has been recognized at all outcrops of these terranes along the accretionary belt, including Yanchiwan, Lajishan [12], Yongjing and Guanzizhen terranes. They show geochemical characteristics of boninite from the Izu-Bonin-Mariana (IBM) intra-oceanic island arc, e.g., low TiO_2 (< 0.5 wt%), high MgO (8-22 wt%), high Cr (500-1300 ppm) and Ni (150-300 ppm). Sanukites (high-magnesian andesite) are also found in the Lajishan area. They are characterized by porphyritic crystals of orthopyroxene and plagioclase in a glassy groundmass with typical compositions of high $Mg^{\#}$ ([Mg/(Mg+Fe)] > 0.6), Ni (>100 ppm), Cr (>200 ppm), K_2O >1 wt%), and high concentrations of large ion lithophile elements and

light rare earth elements.

Zircons from the andesite and sanukite from Yanchiwan, Lajishan and west Qinling yield Ordovician ages from 460 Ma to 440 Ma [8, 10-12]. The rock association, geochemical data and age data suggest the 1200-km-long volcanic belt from the SQAB to TWAB is a newly generated, IBM-type intra-oceanic island arc, much later than the Andean-type continental arc (~520-445 Ma) in the North Qilian Accretionary Belt [4].

Trench jam, trench retreat and new intra-oceanic arc generation

When a subducting ocean plate carries a volumetrically massive body that is too buoyant to subduct, the phenomenon of “trench jam” can occur [13-15], resulting in the cessation of the existing subduction and initiation of a new subduction zone. Oceanic plateaus are the best candidates for such a buoyant and unsubductable mass. This is because oceanic plateaus have thickened bulk crust and thickened residual mantle lithosphere that are both less dense (hence more buoyant) than the adjacent normal oceanic lithosphere and the subjacent asthenosphere [14].

As described above, the high-Mg picrite and OIB- and E-MORB-type basalts in South Qilian (SQAB) and West Qinling (TWAB) are best interpreted as products of mantle plume magmatism, obducted as ophiolitic fragments in the QQAB. The age data (534-500 Ma) indicate that the oceanic plateau and seamounts formed in the

Cambrian. More importantly, the QQAB has also incorporated intra-oceanic arc volcanic rocks, which laterally extends for more than 1200 km (Fig. 1), and formed in a narrow time period of ~ 470 to 440 Ma, much younger in age and shorter in duration than the arc volcanism in the North Qilian Accretionary Belt (~520-440 Ma [4]). Such lithological association in space and time is informative and points to the two major events of (1) trench jam and subduction cessation caused by the arrival of an oceanic plateau (~ 470 Ma), and (2) initiation of a new subduction zone with the development of younger volcanic sequence (~ 460-440 Ma). This scenario is illustrated in Fig. 2.

Fig. 2. Cartoons showing the tectono-magmatic evolution for the Lajishan-Yongjing P-type ophiolite complex for the Early Cambrian. (A) Plume origin for an oceanic plateau at 535-500 Ma. (B) The buoyant plateau reached and jammed the trench, stopped subduction and became a part of newly accreted continent at about 470 Ma. (C) A new subduction zone was initiated at the younger seafloor side of the plateau with the new volcanic arc developed soon afterwards at ~460-440 Ma. Modified after Ref. [8].

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