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The Neoproterozoic magmatisms along the northern margin of the Yangtze craton: implications for a tectonic link between the Qinling and Dabie-Sulu Orogens and a geochemical constraint on the Rodinia reconstruction

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Introduction

The South China block and the North China craton are two major tectonic units in eastern China. They were finally coalesced with the formation of the Qinling-Dabie-Sulu ultrahigh pressure metamorphic belt in Triassic times. South China consists of the Yangtze craton in the northwest and the Cathaysia block in the southeast. They were coalesced through a Neoproterozoic collision belt. Geochronological and geochemical studies indicate that a number of the Yangtze crustal fragments were formed around 1000-800 Ma. For example, depleted mantle Nd model ages (T_{DM}) of the Yangtze sedimentary sequences cluster around 0.8 Ga. This period is also highlighted by eclogites and their host gneisses from the Qinling-Dabie-Sulu ultrahigh pressure metamorphic belt, which are product of Triassic continental subduction of the Yangtze craton beneath the North China craton. The eclogites and gneisses frequently show zircon U-Pb upper intercept ages of ca. 950-750 Ma, which are interpreted to represent the ages of their protolith.

It is generally accepted that the generation of the Qinling-Dabie-Sulu belt represents the finally amalgamation of the Yangtze and China-Korea cratons in Triassic times. In the Qinling Orogen, the South and North Qinling are counted as the collision placements contacting by a fault belt between the two cratons, respectively. In the Dabie-Sulu Orogen, however, the boundary between the two cratons is the subject of controversy. For instance, studies of Pb isotopic mapping suggest the Dabie-Sulu Orogen shows an affinity of the China-Korea craton, but regions in the Yangtze craton with akin Pb isotopic composotions are also recognized. This situation results in answers are unclear to the questions: if the Qinling and Dabie-Sulu orogens were formed during a uniform orogeny; what is the tectonic background of the amalgamation; whether the collision indicates a continental dynamic signature related to formation of the proposed China Super continent (coalesced by the Yangtze, the China-Korea, the Trim and the Chaidamu blocks) and even the Pangea globe wide. A conventional comparison between the Qinling and Dabie orogens is blocked due partly to their difference in unroofed level, deformation degree and metamorphic facies during and post the collision, and partly to the geographic separation by the Nanyang Basin between them. Therefore, comprehensive geochemistry studies are critical to make the comparison available.

The Qinling Orogen is divided into four units, namely southern margin of the China-Korea carton, the North Qinling, the South Qinling and the northern margin of

the Yangtze craton, respectively from north to south. These units are separated by fault belts. The North- and the South Qinling are regarded as the regions of the China-Korea craton and Yangtze craton, respectively, involved in the Qinling Orogen. Tectostratigraphically, the North-, South Qinling and the northern margin of Yangtze craton show essentially analogous unit construction, i.e. Archean crystal basement, the overlain Neoproterozoic dominated volcanic and plutonic suites and Sinian (750-540 Ma)-Phanerozoic covers. As most of the eclogites and their host gneisses in Dabie-Sulu Orogen display Neoproterozoic ages for their protolith, the timing and affinity of tectonic settings revealed by the geochronology and geochemistry, respectively, of the Neoproterozoic suites are consequently to be used as key clues for comparison for a tectonic link between the Qinling and the Dabie-Sulu Orogens.

Neoproterozoic igneous suite in northern Yangtze and South-, North Qinling units

Three representative Neoproterozoic suites occurred along the northern margin of the Yangtze craton are investigated. The Xixiang Group is an arc-related volcanic succession. Its lower and upper units are dated at 950±12 and 895±8 Ma old, respectively by single-grain zircon U-Pb TIMS dating. The Tiechuanshan Formation is a bimodal basalt-rhyolite/dacite suite with a silica gap between 49.8 and 66.3 wt%, which is 806±14 Ma old. The Wangjiangshan Gabbro, emplaced into the former volcanic suites, yields a mineral-whole rock Sm-Nd isochron age of 785±88 Ma.

The lower Xixiang unit is dominated by high-Mg andesite and low-Ti tholeiite. These rocks are characterized by large Mg number (69-73), high Cr (209-621 ppm) and Ni (98-171 ppm), low TiO_2 (0.47-0.69 wt%), depletion in LREE (La_N/Yb_N=0.4-1.1) and variable negative anomalies of high strength field elements HFSE (Th, Nb, Ta Zr, Hf, P and Ti). Together with high positive ε_{Nd} (950 Ma) values (+6.0 to +8.8), these features show an affinity of boninitic associations, which are usually found in fore-arc settings. The upper Xixiang unit ranges in lithology from basalt through andesite to dacite-rhyolite with stratigraphic height. They are characterized by enrichment in LREE (La_N/Yb_N=1.70-7.75) and large ion lithophile elements (LILE) and having pronounced negative Nb, Ta, Ti and Eu anomalies. Their ε_{Nd} (895 Ma) values range from +2.0 to +6.8. These features characterize modern arc volcanic suites. Rhyolite from the top of the Xixiang Group has a back-arc affinity as indicated by their high Na_2O and K_2O contents and LILE/HFSE ratio.

The Tiechuanshan basalt shows variable negative Nb and Ta anomalies, and can be divided into tholeiitic and alkaline members with ε_{Nd} (806 Ma) being +4.6 to +5.3 and +0.1 to +3.9, respectively. The tholeiites exhibit primitive mantle normalized incompatible element patterns resembling that of E-MORB along with high Cr (190-291 ppm) and Ni (65-93 ppm) and large Mg numbers (69-54). The alkaline basalts, on the other hand, display OIB-like incompatible element distributions characterized by enrichment in LILE and TiO_2 (2.59-1.91 wt%) together with small Mg numbers (46-17). The Tiechuanshan rhyolites and dacites are characterized by remarkable negative Eu (Eu/Eu*=0.37-0.73), Nb, Ta and Ti anomalies, high La_N/Yb_N (10.9-16.7), negative ε_{Nd} (806 Ma) (-2.7 to -5.1) and high initial $^{87}Sr/^{86}Sr$ (806 Ma) ratios (0.7054-0.7106). These characteristics

indicate significant contributions of crustal components. The Tiechuanshan assemblage is similar to volcanic rocks developed in continental rifts and continental flood basalt provinces, which are considered to be plume-related.

The Wangjiangshan Gabbro is tholeiitic and has low Rb, U, Th, Nb, Ta, Zr and Hf concentrations along with positive ε_{Nd} (785 Ma), which implies derivation from a previously depleted mantle source. The less fractionated samples show high MgO (9.34-8.96 wt%), Cr (368-312 ppm) and Ni (201-185 ppm) and positive ε_{Nd} (785 Ma) (+5.4 to +3.6). They suggest high degree partial melting of the source mantle under a relatively high geotherm compared to the coeval southeastern Australian Gairdner Dyke.

The 90 Ma age difference, contrasting rock associations and distinct geochemical and isotopic compositions of felsic rocks between the upper Xixiang Group and the Tiechuanshan Formation suggest their diverse tectonic settings of formation. It is thus inferred that the lower and upper units of the Xixiang Group were formed in fore-arc and back-arc settings, respectively, whereas the Tiechuanshan volcanic suite and the Wangjiangshan Gabbro were developed in a plume-related intra-continental rift setting.

In the South Qinling, the Neoproterozoic igneous rocks are dominated by the Wudang and the Yaolinghe Groups of volcanic suites and its plutonic equivalent (mafic dyke swarm). The Wudang volcanic suite resembles the Xixiang Group in lithological association ranging from basalt through andesite to dacite/rhyolite. Chronological study reveals an age period of 1.0-0.9 Ga, which is undistinguished from those of the Xixiang Group. Basalt and andesite of the Wudang Group are characterized by the depletion in Nb, Ta, Ti and P and enrichment in LILE, which is indicative of a genesis of arc-related magmatism. Whereas the Wudang felsic rocks are highly evolved, they also show similar geochemical features with interbedded mafic rocks. Along with positive ε_{Nd} values of ~ +3 to +5 for all lithologies of the Wudang suite, they are interpreted as co-magmatic in genesis.

The Yaolinghe Group and its plutonic equivalent, the Wudang mafic dyke, are alkaline with high TiO_2 of 4.0-1.5 wt%. Interbedded felsic volcanic rocks show an affinity of within-plate or A-type granite. Coupled with positive ε_{Nd} values of ~ +3 to +6 and eruption/emplacement ages of 0.82-0.78 Ga, the association is argued for a genesis of rift-related setting, which is analogues to that of the coeval Tiechuanshan Formation and Wangjiangshan Gabbro occurred in the northern Yangtze craton.

Kuanping Group occurred along northern margin of the North Qinling is the largest Neoproterozoic suite with an extending length of ~1000 km, and has been dated at 975 $\pm$39 to 920$\pm$59 Ma by whole rock Sm-Nd isochrons. The Kuanping Group is a metasedimentary-volcanic succession. The volcanics is dominated by tholeiites with a narrow SiO_2 range of ~44-48 wt%. These basalts are characterized by depletion in LILE and LREE, high positive ε_{Nd} of +8 to +4, absence of Nb-Ta anomalies, which are typical of MORB. Therefore, the contrast geochemical characteristics and affinities of tectonic settings between the coeval igneous suites of ~950 Ma from the Yangtze-South Qinling and the North Qinling suggest that they were generated in distinct tectonic environments.

Geochemical comparisons between the Qinling and the Dabie-Sulu Orogens

The Dabie-Sulu Orogen is located between the China-Korea and Yangtze cratons. Whereas two diverse metamorphic facieses have been identified in the Dabie area, namely the UHP-HP metamorphic association in the south (South Dabie unit) and the granulite-amphibolite association (North Dabie unit) in the north, respectively, there is not a consensus yet on the corresponding tectonic relations between the North-, South Qinling and North-, South Dabie units. Interpretation of the boundary between the North- and South Dabie units in term of tectonic significance becomes the focus of debate, i.e. if the contact belt stands for a collision boundary between the China-Korea and Yangtze cratons.

Since the eclogites have experienced complex history of HP-UHP metamorphism, exhumation and deformation, these rocks are fragmental occurred in forms of lens and bean-pods and small in size. Therefore, systematic sampling along or across their trends analogues to that of volcanic successions in the Qinling Orogen and the northern margin of the Yangtze craton is not practicable.

Comprehensive geochemical studies for individual eclogite blocks distinguish two types of basaltic eclogites. The first type displays trace elemental features of depletion in HFSE (Nb, Ta, Zr, Hf, P and Ti) and enrichment in LILE, which are similar to those of the Xixiang basalts from the Yangtze and the Wudang basalts from the South Qinling. The second type illustrates elemental patterns of enrichment in LILE, TiO_2 and high LILE/HFSE ratios, which are indistinct from those of the alkaline basalts from the bimodal Tiechuanshan Formation of the Yangtze craton and the Yaolinghe Group of the South Qinling. In addition, ortho-gneisses of eclogite hosts show highly fractional elemental patterns characterized by depletion in HFSE and negative Eu anomaly, which resemble those of rhyolites and dacites found in the Xixiang and the Wudang Groups.

In the North Dabie, corresponding studies show that two types of mafic rocks among the granulite-amphibolite suites can be divided in term of trace elemental geochemistry. One type displays patterns analogues to that of the first type eclogite, i.e. depletion in HFSE and high LILE/HFSE ratios. The others, however, demonstrate patterns similar to those of boninitic andesite and low-Ti basalts characterized by low incompatible elemental concentrations and depletion in Ti. This lithological association resembles that found in the lower Xixiang Group.

Based on the discussions above, two essential conclusions are inferred: both the South- and North Dabie units are comparable with the South Qinling unit in terms of protolith timing, elemental geochemistry and indicated tectonic settings of formation; the contact belt between South and North Dabie units is unlikely to represent a collision boundary. Alternately, the South- and North Dabie units may reflects different levers of the subducted Yangtze Neoproterozoic suites, in which the North Dabie unit may be correspond with the lower Xixiang volcanic unit.

Constraint on Rodinia reconstruction

The Xixiang and Tiechuanshan volcanic suites and the Wangjiangshan Gabbro reflect a tectonic evolution from arc to intra-continental rift in the Neoproterozoic along the northwestern margin of the Yangtze craton. The transition occurred at ca. 800-820 Ma. The Tiechuanshan mafic rocks are geochronologically and geochemically indistinguishable from the Gairdner Dyke and its volcanic equivalents from southeastern Australia. Coeval mafic-ultramafic and granitic plutons in southern South China and bimodal volcanic suites along the western margin of the Yangtze craton have been also documented, which are interpreted to be plume-related in genesis as well. Accordingly, the Neoproterozoic tectonic evolution in the Hannan area, elsewhere in South China and in South Qinling supports a Rodinia Supercontinent reconstruction model, in which an ascending superplume centered beneath South China and triggered the break-up of the Rodinia Supercontinent onset ~820 Ma involving the separation of South China from southeastern Australia. Whereas ~950 Ma magmatism is also recorded along the northern margin of the North Qinling, its MORB affinity disapproves a collision connection between the North Qinling and the northern Yangtze/ South Qinling during that period.