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Building of Arc Crust during Closure of the Paleo Asian Ocean, Implications from Arc-root Mafic-Ultramafic Suite in the East Tianshan, NW China

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The Central Asian Orogenic Belt (CAOB) is a major site of juvenile continental growth (Sengör et al., 1993). This belt incorporates oceanic, intraoceanic and continental margin arc terranes as well as numerous fragments of Precambrian microcontinents and collisional and post-collisional complexes (Kröner et al., 2017). The formation of arcs, the major components of the CAOB continents, was relevant to the evolution and closure of the Paleo Asian Ocean (PAO), which was dominated by intraoceanic subductions. Twenty-one intraoceanic arcs (IOAs) were recognized in the CAOB on the basis of the preserved arc fragments, including boninites, island arc basalts, calc-alkaline basalts, high alumina basalts and super subduction zone ophiolites (Safonova et al., 2017). Based on analysis of these volcanic rocks, Safonova et al. (2017) proposed that these fossil IOAs have similar magmatic evolution paths to the present-day IOAs along the Pacific convergent margins. However, few true arc crustal magmatic rocks, especially lower arc crustal or arc-root magmatic rocks were identified or exposed in the CAOB. In fact, the paucity of lower arc crustal or arc-root magmatic samples exist all over the world except the fossil Talkeetna (south-central Alaska) and Kohistan (NW Pakistan) arc crustal sections as well as some crustal xenoliths (Greene et al., 2006; Tollan et al., 2012; Cooper et al., 2019). The Silurian arc-root mafic-ultramafic rocks in the Chinese East Tianshan are precious arc crustal samples in the CAOB, and by studying these samples we can know the true components of the deep arc crust and understand arc-root magmatic evolution during intraoceanic subductions in the PAO.

The Silurian mafic-ultramafic rocks are located in the westernmost of the Chinese East Tianshan, outcropping within an area of ~50 km^2. This region is covered by Carboniferous volcanic rocks intruded by early Permian diorite-granodiorite-granite intrusions. These Silurian mafic-ultramafic rocks occur as variable-sized enclaves with areas spanning 0.03–6 km^2. These enclaves do not have intrusive contacts against the country rocks, but generally overlie the Early Permian granodiorites or ultramafic rocks with sharp contacts (Fig. 1a). These rocks are composed of deformed peridotite, olivine websterite (ol-websterite), olivine clinopyroxenite (ol-clinopyroxenite), plagioclase clinopyroxenite (pl-clinopyroxenite), troctolite, hornblende troctolite (hbl-troctolite), gabbro, and hornblende gabbro (hbl-gabbro). In the field, deformed peridotite shows significant deformation fabrics (Fig. 1b), differing from other lithologies. After detailed microscopic observations of these lithologies, we try to divide these rocks into two categories, one is pyroxenitic-gabbroic series composed of ol-websterite, ol-clinopyroxenite, pl-clinopyroxenite, gabbro and hbl-gabbro, and the other is troctolitic series composed of deformed peridotite, troctolite and hbl-troctolite for the following reasons. Deformed peridotite contains deformed olivine crystals and a few troctolitic masses composed of skeletal olivine intergrown with plagioclase (Fig. 1c). Troctolite has similar components to the deformed peridotite but is dominated by troctolitic masses (Fig. 1d). These petrological characteristics suggest that troctolite comes from the transformation of deformed peridotite through a magmatic process. Troctolite grades into hbl-troctolite with increasing hornblendes. The ol-websterite, ol-clinopyroxenite, pl-clinopyroxenite, gabbro and hbl-gabbro do not show any deformation fabrics, and are arbitrarily classified as one lithological category.

The pyroxenitic-gabbroic rocks are dominated by adcumulate textures. The ol-websterite is composed of >50 vol% clinopyroxenes, 20%–25% orthopyroxenes, 15%–20% hornblendes and 5%–10% olivines (Fig. 1e). The ol-clinopyroxenite is dominated by anhedral clinopyroxenes with variable crystal sizes spanning 0.5–6 cm (Fig. 1f). Olivine crystal fragments occurs interstitially within clinopyroxenes, and hornblende rims clinopyroxene. The pl-clinopyroxenite is composed of 40%–70% clinopyroxenes and 30%–40% plagioclases. Clinopyroxenes in this rock form adcumulate textures and have perfect 120° grain boundaries. This rock is different from gabbros in that plagioclase occurs as veinlets or masses cutting through clinopyroxene cumulates rather than occurs as a cumulus or intercumulus phase as

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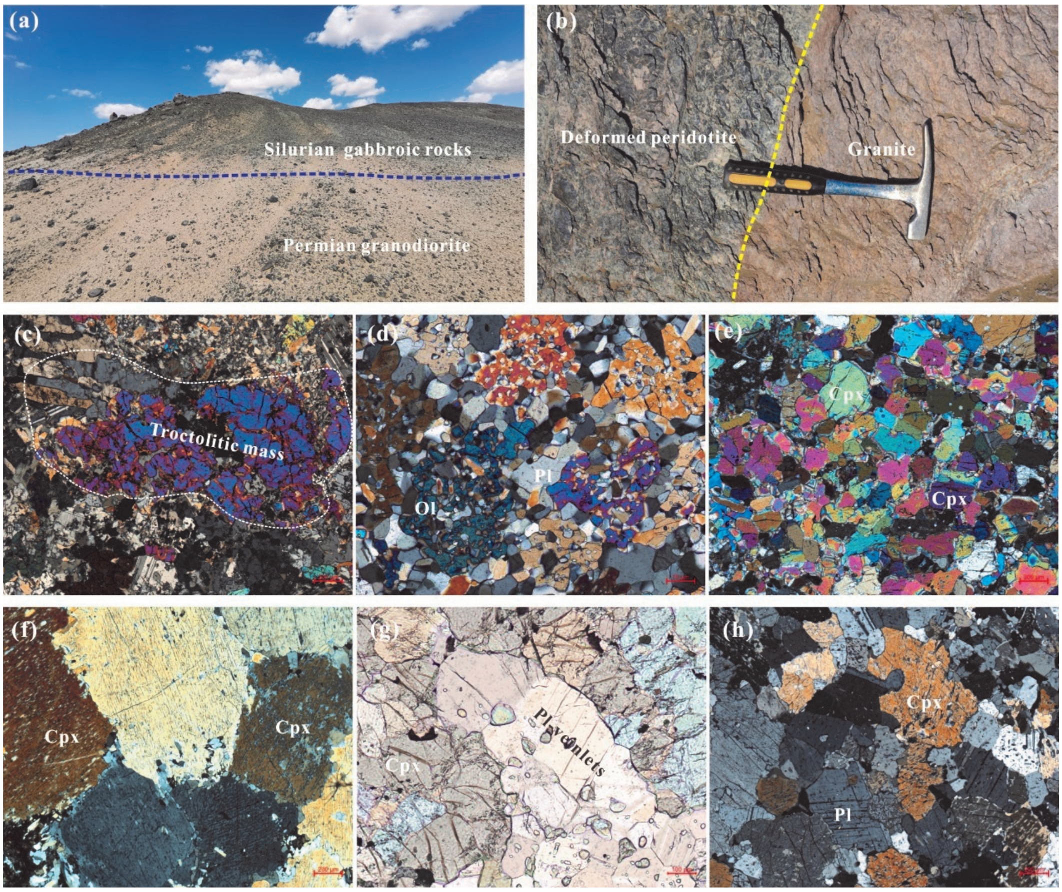

Fig. 1. Photographs and photomicrographs showing (a) Silurian gabbro rocks overlying early Permian granodiorite; (b) deformed peridotite in sharp contact with granite; (c) troctolitic masses in deformed peridotite; (d) troctolite; (e) ol-websterite; (f) ol-clinopyroxenite; (g) pl-veinlets cutting clinopyroxene cumulates in the pl-clinopyroxenite; (h) gabbro. Picture (g) was taken under plane-polarized light while others taken under cross-polarized light.

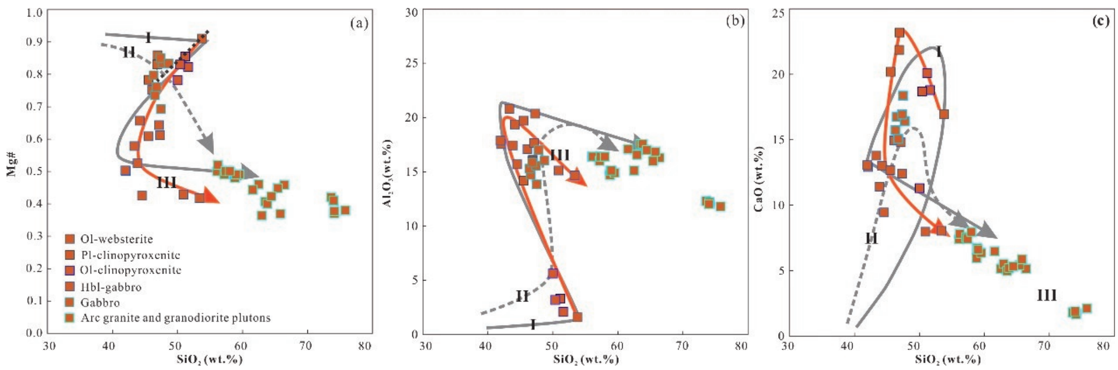

Fig. 2. Harker diagrams of SiO_2 versus $Mg^{\#}$ (a), Al_2O_3 (b) and CaO (c) illustrating the bulk-rock evolution of the Silurian pyroxenitic-gabbroic rocks.

I: Experimentally-derived z-shaped, s-shaped and anticlockwise loop-like CLDs of hydrous basaltic-andesitic melts in the Harker diagrams of SiO_2 versus $Mg^{\#}$ (a), Al_2O_3 (b) and CaO (c) following fractional crystallization under lower arc crustal pressures (0.7–1.2 Gpa, Müntener and Ulmer, 2018), and representing the bulk-rock evolution of the natural Kohistan and Talkeetna arc-root magmatic rocks as well. II: CLDs of damp or dry basaltic magmas showing a continuous decrease of $Mg^{\#}$ with increasing SiO_2, a clockwise evolution at overall lower CaO, along the CLD, and a S-shaped trend of Al_2O_3 with SiO_2, strikingly different from those of hydrous melts. Arc granite and granodiorite plutons are from Du et al. (2018)

observed in gabbros although this rock contains high volumes of plagioclases (Fig. 1g). The gabbro is composed of 40%–60% clinopyroxenes, 10%–15% hornblendes and 40%–50% plagioclases (Fig. 1h). Hornblende occurs as rims of clinopyroxene. The hbl-gabbro is composed of 20%–80% hornblendes, 15%–40% plagioclases and 5%–20% clinopyroxenes. Hornblende can form adcumulate textures when their volumes exceed 40% in the hbl-gabbro. Sometimes, the hbl-gabbro is only composed of hornblende and plagioclase without clinopyroxene.

The adcumulate textures of the pyroxenitic-gabbroic rocks suggest these rocks are cumulates resulted from fractional crystallization of basaltic magmas, whereas the troctolitic rocks are possibly hybrid rocks resulted from melt-rock reactions between late infiltrated melts and preformed ultramafic rocks. The samples of the pyroxenitic-gabbroic rocks form a z-shaped, a s-shaped and an anticlockwise loop-like bulk-rock evolution trend in the diagrams of SiO_2 versus $Mg^{\#}$, Al_2O_3 and CaO (Fig. 2), consistent with the evolution trends delineated by IOA arc-root crustal cumulates and experimental results derived from experiments on hydrous Mg-basalt or basaltic andesite under lower arc crustal conditions (0.7–1.2 Gpa, Müntener and Ulmer, 2018), revealing the Silurian pyroxenitic-gabbroic rocks are actually arc-root cumulates. The pyroxenitic portions of the arc-root pyroxenitic-gabbroic suite were estimated to have denser properties than underlying mantle peridotite at the same temperature and pressure (Jagoutz and Behn, 2013), and were readily delaminated into underlying mantle. The onset of intraoceanic arc magmatism was progressed from the late Neoproterozoic to the early Permian whereby substantial pyroxenitic cumulates must have been generated in the arc roots during the closure of the PAO by intraoceanic subductions. By delamination of these denser pyroxenitic cumulates, the ultramafic components of the primary arc magmas are removed, and the residual portions evolved to form true arc crusts which will be finally transformed into andesitic continental crust by further magmatic processes. Magmatic differentiation by fractional crystallization in the arc roots and delamination of fractionated denser pyroxenitic rocks may be the major regime in building of the arc crusts during the closure of the PAO, which is the early stage of the juvenile continental growth of the CAOB.

Key words: intraoceanic arc, building of arc crust, continental growth, delamination, CAOB

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