Tarim Craton is less well studied, and thus far no Palaeoproterozoic high-pressure granulite has been recognized in the Tarim Craton. This scarcity of investigation has hampered our understanding of the tectonic relationship between the Tarim Craton and the other two cratons in China. The objectives of this contribution are (1) to present the first mineralogical and petrological data from the newly discovered HP mafic granulites in the Dunhuang block of the Tarim Craton, (2) to date the HP granulites, and (3) to document the tectonic implications of these data by comparison with the other Palaeoproterozoic orogenic events in the Tarim Craton and North China Craton.

Geological setting. The central section of the Tarim Craton is occupied by desert and is surrounded by the Panerozoic orogenes. The outcrops of Precambrian basement are present only along its margins (Fig. 1a). In recent years, several studies focused on the Kuluketage area of the northeastern Tarim Craton (Fig. 1). Zircon U–Pb dating of TTGs (tonalite–trondhjemite–granodiorite) from the Kuluketage area yielded late Neoarchaean and early Palaeoproterozoic ages, which were interpreted to be the crystallization ages of these basement rocks (Long et al. 2010, 2011). U–Pb zircon dating indicates that TTG gneisses and paragneisses underwent amphibolite- to granulite-facies metamorphism at 1.85–1.80 Ga (Zhang et al. 2011). For monzonitic gneisses from the north Altyt Tagh Mountains, southern Tarim Craton, Lu et al. (2008) presented a sensitive high-resolution ion microprobe (SHRIMP) U–Pb age of 2830 ± 45 Ma. An age of 1896 ± 29 Ma from a metasedimentary rock sample was interpreted as the metamorphic age (Lu et al. 2008). The metamorphic basement of the Dunhuang block in the eastern Tarim Craton (the Dunhuang Complex, the focus of this study) was traditionally assigned to the Archaean–Palaeoproterozoic, although the available isotopic data are notably limited (Bureau of Geology and Mineral Resources of Gansu Province (BGMG) 1989; Mei et al. 1998). To date, only one thermal ionization mass spectrometry (TIMS) U–Pb zircon age of 2670 ± 12 Ma has been reported from a tonalitic gneiss sample at the Shibaoceng location (Fig. 1b; Mei et al. 1998).

Sample petrography and P–T conditions. More than 15 samples of mafic granulite were collected at Shibaoceng, which is near the Altyt Tagh fault (Fig. 1). Two mafic granulite samples, AQ10-4-2.3 (39°51.01′N, 95°59.21′E) and AQ10-4-4.1 (39°51.15′N, 95°58.74′E), which were selected for U–Pb dating, are described below. Mineral abbreviations are based on Kretz (1983).

Mafic granulites occur as sheet-like and lenticular bodies in tonalitic gneisses (Fig. 1b). The peak mineral assemblage consists of Grt + Cpx + Pl + Qtz (Fig. 2a). This is a common HP granulite mineral assemblage. Rare Amp and Pl inclusions occur in the core of Grt porphyroblasts, suggesting a possible prograde assemblage. In addition to rare Amp inclusions in Grt, two stages of Amp crystallization are recognized: brown AmpI occurs as porphyroblasts coexisting with Cpx (Fig. 2a) and green AmpII grows around AmpI (Fig. 2a). Opx occurs as isolated tiny grains around Cpx and brown Amp (Fig. 2b and c) or as coronas on Qtz adjacent to Grt (Fig. 2d). Such textures indicate decompression following peak HP granulite-facies metamorphism.

Most Grt grains are unzoned or weakly zoned with a narrow rim characterized by slightly decreasing Prp and increasing Alm. Rare Grt porphyroblasts show slightly increasing Prp and slightly decreasing Alm and Spms from core to mantle (highest Prp content), suggesting a weak prograde zoning. Cpx is almost pure Di with Jd contents of 3–5 mol%. Brown AmpI is pargasite or magnesiohastingsite with 1.6–2.2 wt% TiO₂. Green AmpII rimming Cpx is magnesiohornblende or ferrohornblende with lower TiO₂ (0.5–1.0 wt%).

Metamorphism at conditions of (ultra)high-pressure, high-pressure (HP) granulite facies and ultrahigh temperature is sparsely perceived but widely distributed in Phanerozoic orogenic belts and the Palaeoproterozoic (HP) granulite facies metamorphism. Although the available isotopic data are notably limited, metamorphism of these rocks was traditionally assigned to the Archaean–Palaeoproterozoic, although the available isotopic data are notably limited (Bureau of Geology and Mineral Resources of Gansu Province (BGMG) 1989; Mei et al. 1998). To date, only one thermal ionization mass spectrometry (TIMS) U–Pb zircon age of 2670 ± 12 Ma has been reported from a tonalitic gneiss sample at the Shibaoceng location (Fig. 1b; Mei et al. 1998).

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Metamorphism at conditions of (ultra) high-pressure, high-pressure (HP) granulite facies and ultrahigh temperature is sparsely preserved but widely distributed in Phanerzoic orogenic belts and Precambrian cratons (e.g. Santosh & Kusky 2010; Santosh et al. 2012; and references therein). This metamorphism preserves important records of the tectonic history of orogenic belts and the formation of cratons. High-pressure granulite is typically inferred to record subduction-to-collision orogenesis, and studies of high-pressure granulite in the Precambrian cratons can provide crucial constraints on the evolution of early continental assembly and crust evolution.

China consists mainly of three Precambrian cratons (the North China Craton, the South China Craton and the Tarim Craton) that amalgamated during Phanerzoic orogenic processes (e.g. Zhao et al. 2005; Zhai & Santosh 2011). Palaeoproterozoic high-pressure granulite has been recognized in the North China Craton and has attracted global attention in recent years, particularly in relation to Palaeoproterozoic subduction–collision and the assembly of the Palaeoproterozoic supercontinent Columbia. However, compared with the North China and South China Cratons, the Tarim Craton is less well studied, and thus far no Palaeoproterozoic high-pressure granulite has been recognized in the Tarim Craton.
Pl coexisting with Cpx has An = 22–28 mol%, whereas Pl coexisting with Opx has a higher An content (An = 50–57 mol%).

Grt–Amp–Pl–Qtz thermobarometry (Graham & Powell 1984; Kohn & Spear 1990) yields 0.85–0.92 GPa and 660–700 °C for a prograde assemblage enclosed in a garnet core. Grt–Cpx–Pl–Qtz thermobarometry (Newton & Perkins 1982; Powell 1985; Krogh 1988) yields 760–820 °C and 1.10–1.25 GPa for the peak assemblage, suggesting HP granulite-facies metamorphism. Using the multi-equilibrium approach, the average P–T mode of THERMOLCALC 3.1 (Powell et al. 1998) yields similar peak P conditions (1.16 ± 0.18 GPa) and a slightly higher peak temperature condition (858 ± 109 °C).
Later metamorphic reactions led to the growth of Opx. Using Grt–Opx–Pl–Qtz thermobarometry yields 0.6–0.7 GPa and 700–770°C (Newton & Perkins 1982; Harley 1984), indicating a significant drop in pressure for similar temperatures. Combining petrographic observations with P–T estimates from two mafic granulite samples suggests a clockwise loop with inferred prograde amphibolite-facies conditions, peak conditions in the HP granulite facies and nearly isothermal decompression through medium- to low-pressure granulite facies to amphibolite facies (Fig. 3).

Analytical procedures and U–Pb results. The zircons were mounted in epoxy resin and were polished to expose the cores of the grains for cathodoluminescence (CL) and U–Pb analyses. Prior to analysis, the mineral inclusions in zircons were identified by laser Raman spectrophotometry. The U–Pb analyses were performed at the Institute of Mineral Resources, Chinese Academy of Geological Sciences using the multicollector laser ablation inductively coupled plasma mass spectrometry facility. Detailed analytical procedures have been given by Hou et al. (2009) and Liu et al. (2010).

All zircons from the two mafic granulite samples show similar characteristics. These zircons are clear, and form spherical, oval or irregular crystals (Fig. 3). In the CL images, most of the zircon grains show low to medium luminescence with fr-tree sector zoning or are unzoned. These morphology and CL features are characteristic of metamorphic zircon grains. Minor mineral inclusions of Grt, Cpx, Pl and Qtz in zircons indicate that these zircons grew under high-pressure granulite-facies conditions (Fig. 3). A narrow CL-bright rim was also observed for most zircon grains, probably implying a later metamorphic overprint or fluid modification.

A total of 68 spots were analysed on 68 grains for sample AQ10-4-2.3, and 63 spots were analysed on 63 grains for AQ10-4-4.1. Most of these analyses produced discordant ages, resulting from a marked loss of radiogenic Pb. For sample AQ10-4-2.3, a few analyses are concordant with 207Pb/206Pb ages ranging from 1805 ± 19 Ma to 1859 ± 29 Ma and give a weighted mean age of 1822 ± 14 Ma (MSWD = 1.8). The upper intercept age of the discordia line defined by all analyses is at 1834 ± 12 Ma (MSWD = 2.8) (Fig. 4a). We interpret the 1834 ± 12 Ma age as the time of granulite-facies metamorphism. For sample AQ10-4-4.1, all analyses are discordant and yield a concordia upper intercept age of 1842 ± 5 Ma and a lower intercept age of 442 ± 11 Ma (MSWD = 1.15, Fig. 4b).

Discussion and conclusions. The ages from the two samples are identical within uncertainty, and on the basis of the mineral inclusions in zircon we suggest that 1.83–1.84 Ga represents the age of the high-pressure granulite-facies metamorphism determined from thermobarometry. The relatively high P/T of peak metamorphism and the clockwise P–T path suggest that these HP rocks are the products of collisional orogenesis. This paper presents the first evidence of Palaeoproterozoic HP granulite in the Tarim Craton. However, HP granulites with ages of c. 1.85 Ga have been commonly reported in the Central Zone of the North China Craton (also named the Trans-North China Orogen) and are considered to be key evidence of collisional orogeny between the western continental block and the eastern continental block, resulting in final accretion of the North China Craton (Zhao et al. 2005, and references therein). Moreover, c. 1.85 Ga high-pressure granulite-facies metamorphism in the North China Craton is not restricted to the ‘Trans-North China Orogen’ (e.g. Kusky et al. 2007; Kusky 2011), and several workers have suggested that the distribution of 1.85 Ga metamorphic rocks in the North China Craton is more complex than originally proposed by Zhao et al. (2005) (e.g. Wan et al. 2006). This necessitates a re-evaluation of the Palaeoproterozoic tectonic models of the North China Craton.

For the Tarim Craton, recently reported 1.85–1.80 Ga metamorphism in the Kuluketage was interpreted as a production of Palaeoproterozoic orogeny, although its metamorphic conditions and P–T path have not been constrained (Zhang et al. 2011). Therefore, similar to the North China Craton, a c. 1.85 Ma tectonothermal event probably also represents a major orogenic event in the Tarim Craton and is broadly coeval with the late Palaeoproterozoic global orogenic event recorded from many other continental fragments, including Laurentia, Baltica, Amazonia and India, which has been correlated with the time of assembly of the Palaeoproterozoic supercontinent Columbia (Rogers & Santosh 2002, 2009; Zhao et al. 2002, 2004, 2010; Santosh et al. 2009; Condie & Astar 2010; Santosh 2010; Meert 2012). Recent models suggest that the assembly of Columbia at c. 1.90–1.85 Ga coincided with major geological events that affected the entire globe (Zhang et al. 2011, and references therein). These observations suggest that the Tarim Craton is part of the Palaeoproterozoic Columbia supercontinent.

Our new data support a hypothesis that the Dunhuang block is the western extension of the Alxa block as result of the sinistral...
displacement of the Altyn Tagh fault (Xu et al. 1999; Yang et al. 2001) (see Fig. 1). The Altyn block is the westernmost part of the North China Craton, and has been traditionally considered to be Archean. However, recent studies indicate that the eastern Altyn block was subjected to high-grade metamorphic events c. 1.89 Ga and c. 1.79 Ga (Dan et al. 2012). We speculate that the c. 1.89 Ga metamorphic event may be related to continental collision, whereas the c. 1.79 Ga event is probably a result of terrane uplift and/or regional extension. Also, a U–Pb zircon age of 1856 ± 6 Ma from an amphibolite sample from Longshougun (near Jinchang city) in the western Altyn block (see Fig. 1; Gong et al. 2011) was interpreted as the age of high-grade metamorphism, although the metamorphic conditions have not been constrained. The age similarity of high-grade metamorphic events in the Tarim Craton and North China Craton suggests that they experienced a similar Palaeoproterozoic collisional orogeny c. 1.90–1.80 Ga.

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