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Age, geochemistry, and tectonic implications of a late Paleozoic stitching pluton in the North Tian Shan suture zone, western China

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ABSTRACT

The Central Asian orogenic belt is the largest tectonic assembly of continental and oceanic terranes on Earth due to closure of the paleo–Asian Ocean in the Phanerozoic. Among major suture zones in the North Xinjiang region of western China, the North Tian Shan suture zone, because of collision between the Yili terrane in the south and the Junggar terrane in the north, contains the youngest ophiolitic rocks and may represent the terminal stage of development of the Central Asian orogenic belt in western China, but the timing of the suture zone remains poorly constrained. A sensitive high-resolution ion microprobe (SHRIMP) zircon U-Pb age of 316 ± 3 Ma (i.e., the beginning of the late Carboniferous) from the undeformed Sikeshu pluton, which crosscuts the suture zone, places a crucial upper-age bound for the time of collision between the Yili and Junggar terranes. This event occurred later than, or nearly concurrent with, other accretion-collision events in the North Xinjiang region, implying that final terrane amalgamation was completed in the late Carboniferous. The Sikeshu pluton shares geochemical characteristics of the widespread late Carboniferous to Permian postcollisional A-type and I-type granitoids with depleted-mantle–like Sr-Nd isotopic signatures in the North Xinjiang region. They all occurred during a protracted (ca. 320–270 Ma) episode of postcollisional magmatism that may have been induced by basaltic underplating due to either slab breakoff or delamination of thickened mantle lithosphere beneath the Central Asian orogenic belt. The same postcollisional magmatism also generated Cu-Ni-sulfide–bearing, mafic-ultramafic magmatic complexes, adakites, and porphyry-type copper-molybdenum–bearing magmatic rocks in the North Xinjiang region.

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INTRODUCTION

The Central Asian orogenic belt, which exhibits an arcuate geometry, is bounded by the European craton in the west, Siberian craton in the east, and Tarim and North China cratons in the south (Fig. 1). It is the largest Phanerozoic accretionary orogen in the world, and it is the most significant area of Phanerozoic continental growth (Zonenshain et al., 1990; Mossakovsky et al., 1993; Sengör et al., 1993; Sengör and Natal'in, 1996; Jahn et al., 2000; Kovalenko et al., 2004; Windley et al., 2007). The Central Asian orogenic belt may have resulted from accretion and collision of a variety of terranes, including oceanic plateaus, accretionary complexes, oceanic-island arcs, seamounts, and Precambrian microcontinents. The accretionary processes may have resulted from (1) progressive duplication of a single and long-evolving island-arc system (Sengör et al., 1993; Sengör and Natal'in, 1996), (2) accretion of large flysch complexes deposited along continental margins or within oceanic domains (Zonenshain et al., 1990; Mossakovsky et al., 1993; Fedorovskii et al., 1995; Buslov et al., 2001, 2004; Khain et al., 2002, 2003; Kheraskova et al., 2003), or (3) collision of several island arcs and microcontinental blocks with Siberia in the north and Tarim–North China in the south (Badarch et al., 2002; Yakubchuk, 2004; Xiao et al., 2003, 2004a, 2004b, 2008; Briggs et al., 2007; Windley et al., 2007; Kelty et al., 2008). The microcontinents within the Central Asian orogenic belt may have originated either from Siberian and European Cratons in the north (Sengör et al., 1993; Sengör and Natal'in, 1996) or from Gondwana in the south (e.g., Dobretsov et al., 1996). Some workers envision the paleogeography of the paleo–Asian Ocean in the early Paleozoic to have been similar to the complex archipelago systems of the southwestern Pacific, which are composed of multiple island systems and strips of continental blocks (Filippova et al., 2001; Windley et al., 2007; Xiao et al., 2008). An understanding of the timing of terrane amalgamation and eventual assembly is critical to deciphering the geological history of the Central Asian orogenic belt, and it has important implications for the growth history of continental crust in Earth's history. In this respect, it is extremely important to determine the timing of suture zone formation across the Central Asian orogenic belt.

The North Xinjiang region of western China is located in the southwestern corner of the Central Asian orogenic belt (Fig. 1), and its geology records a progressive southward amalgamation history of the Central Asian orogenic belt through multiple collisions of Precambrian microcontinents, Paleozoic accretionary complexes, oceanic-island arcs, and seamounts (Coleman, 1989; Sengör et al., 1993; Sengör and Natal'in, 1996; Windley et al., 2007; Xiao et al., 2008). The multiple collisional events are best expressed by the development of a series of suture zones marked by the occurrence of ophiolite complexes and highly deformed flysch and volcanic complexes. Narrow upper-age bounds for the times of these suture zones are essential to determining when each collisional event occurred and when the final terrane amalgamation was completed in the North Xinjiang region. Combined with a summary of other suture zones, this study is mainly focused on the North Tian Shan suture zone. Because the suture zone is considered to have resulted from the youngest collisional event in the North Xinjiang region (e.g., Xiao et al., 1992; C.M. Han et al., 2006; Charvet et al., 2007), a narrow constraint on the timing of the North Tian Shan suture zone can provide a crucial upper-age bound for the final closure of the paleo–Asian Ocean in this region and has important implications for tectonic setting of magmatism after ocean closure.

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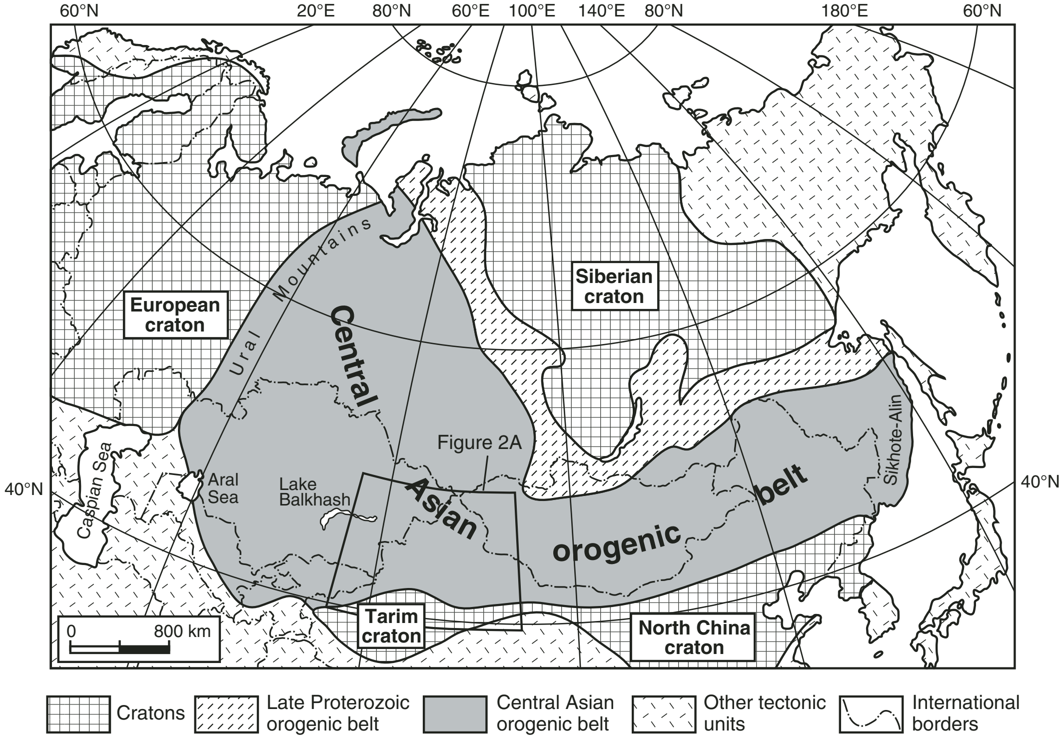

Figure 1. The Central Asian orogenic belt is situated between the European craton in the west, the Siberian craton in the east, and the North China and Tarim cratons in the south (modified from Sengör et al., 1993; Jahn et al., 2000). The approximate location of Figure 2 is shown with a box.

Major Suture Zones in the North Xinjiang Region

The North Xinjiang region encompasses the Chinese Altai, the triangular Junggar Basin, and the Chinese Tian Shan (Fig. 2A); all of these features were created as physiographic provinces by the Cenozoic Indian-Asian collision (e.g., Hendrix et al., 1994; Yin et al., 1998; Bullen et al., 2003; De Grave et al., 2007). However, the development of a series of major suture zones in the North Xinjiang region was related to closure of the paleo–Asian Ocean in the Paleozoic, and thus a brief review of the age constraints on the suture zones is essential to our study and its regional context.

In general, the suture zones in the North Xinjiang region trend in the northwest to west-northwest directions (Fig. 2B). They occur in the surroundings of the Junggar Basin and are marked by ophiolites that, in places, are associated with accretionary complexes. From northeast to southwest, they are the Irtysh-Zaysan suture zone along the southwestern edge of the Altai Mountains, the Kujibai-Hongguleleng suture zone along the southern edge of the Tarbgatay and Saur Mountains, the Western Junggar suture zone on the west side of the Junggar Basin, the Zhaheba-Armantai and Kalamaili suture zones on the east side of the Junggar Basin, and the North Tian Shan suture zone along the northern edge of the Chinese Tian Shan (Fig. 2).

The Irtysh-Zaysan suture zone separates the Altai terrane in the north from the early Carboniferous Zharma-Saur arc and Silurian to early Carboniferous Dulate-Baytag arc in the south (Fig. 2B). The Altai terrane is dominated by early to middle Paleozoic gneisses, schists, and granitoids (e.g., Windley et al., 2002; T. Wang et al., 2006, 2009; Wei et al., 2007; Briggs et al., 2007; Yuan et al., 2007; Sun et al., 2008). The Irtysh-Zaysan suture zone in the Chinese Altai has been modified by large-scale, strike-slip faulting (Laurent-Charvet et al., 2003; Charvet et al., 2007) and a major postcollisional thrust that places amphibolite-facies metasedimentary and metagranites of early Paleozoic ages over a lower-greenschist-facies Devonian-Carboniferous arc sequence (Briggs et al., 2007).

The Kujibai-Hongguleleng suture zone separates the Zharma-Saur arc in the north from the Silurian Boshchekule-Chingiz arc in the south (Fig. 2B). The latter is composed mainly of Silurian volcanic and siliciclastic sequences intruded by late Silurian to early Devonian plutons in the southern part of the arc terrane.

The Western Junggar suture zone, which mainly consists of Ordovician to early Carboniferous arc-accretionary complexes (e.g., Windley et al., 2007; Xiao et al., 2008), separates the Boshchekule-Chingiz arc in the north from the Junggar terrane in the south (Fig. 2B). The Junggar terrane is largely buried below Cenozoic basin sediments, but it possibly contains a collage of early Paleozoic arcs, accretionary complexes, trapped oceanic crust, and continental fragments (Xiao et al., 1992; Li et al., 2000; Chen and Jahn, 2004; Zheng et al., 2007; Xiao et al., 2008). The Bogda intracontinental rift within the Junggar terrane developed during the Carboniferous and early Permian (Gu et al., 2000; Shu et al., 2005; Y.X. Wang et al., 2006).

In the East Junggar (Fig. 2A), the Zhaheba-Armantai suture zone separates the Silurian to early Devonian Dulate-Baytag arc in the north from the Devonian to early Carboniferous Yemaquan arc in the south (Fig. 2B). In the Dulate-Baytag arc, fossil-dated Upper Ordovician strata (BGMRXUAR, 1993) are unconformably overlain by early Silurian adakites (zircon U-Pb age of 441 Ma; Zhang et al., 2008) and Devonian volcano-sedimentary strata. The latter are in turn unconformably overlain by early Carboniferous strata. The oldest rocks in the Yemaquan arc are represented by Silurian granites, which are unconformably overlain by Devonian to early Carboniferous volcano-sedimentary strata. The Yemaquan arc is separated by the Kalamaili suture zone from the Junggar terrane in the south (Fig. 2B).

Finally, the North Tian Shan suture zone separates the Junggar terrane in the north from the Yili terrane in the south (Fig. 2B). The Yili terrane consists of Neoproterozoic basement with zircon U-Pb ages of 882 and 798 Ma (Chen et al., 1999, 2000), late Ordovician amphibolites

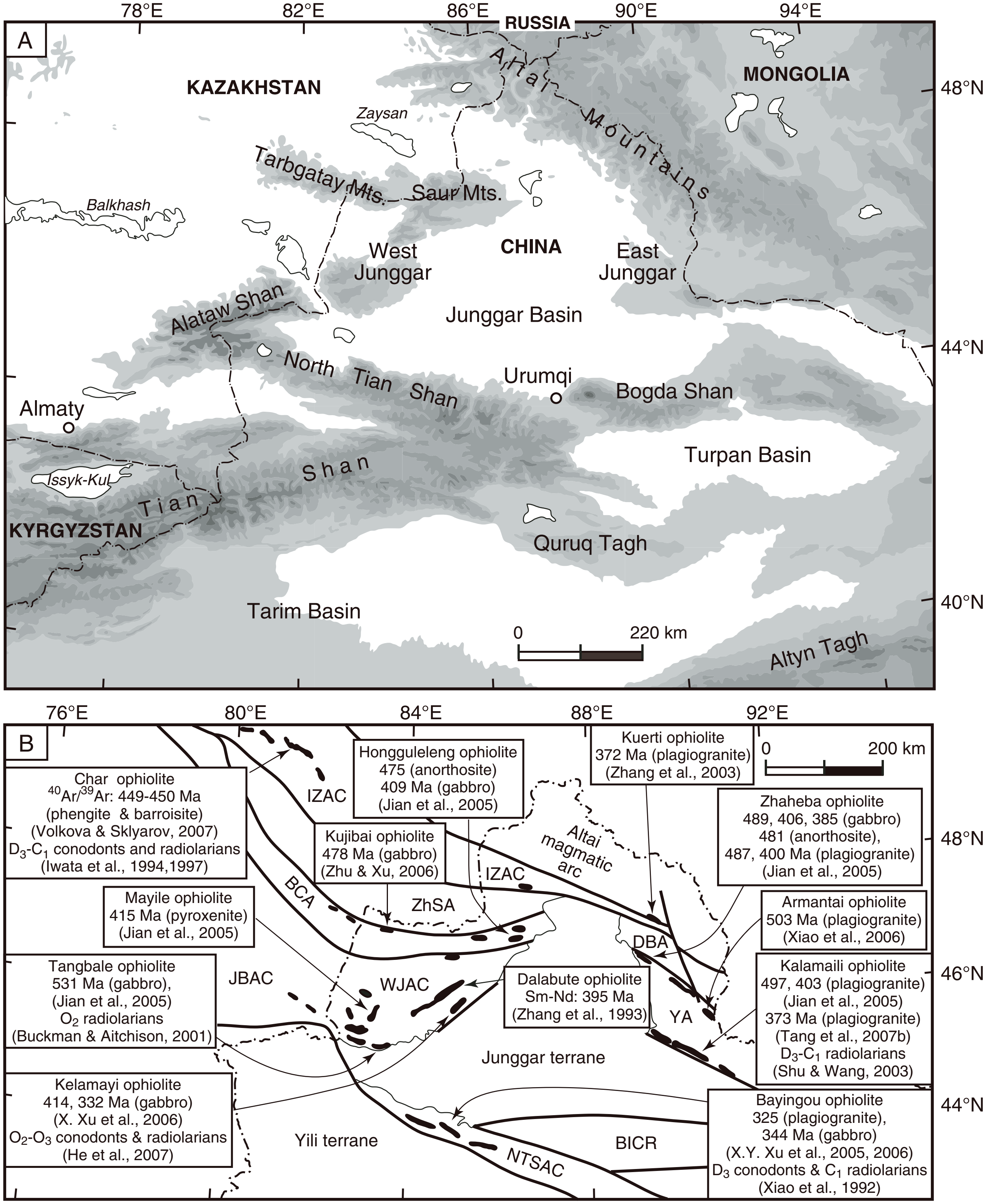

Figure 2. (A) Topographic map showing the locations of the Altai Range, the Junggar Basin, and the Tian Shan in Central Asia. (B) Tectonic map showing the terranes separated by major suture zones (or accretionary complexes) in North Xinjiang region and eastern Kazakhstan, ophiolitic fragments, and their zircon U-Pb (except where specifically noted) and microfossil ages (modified from Xiao et al., 2008; Windley et al., 2007). IZAC—Irtysh-Zaysan accretionary complex, ZhSA—Zharma-Saur arc, BCA—Boshchekule-Chengiz arc, JBAC—Junggar-Balkhash accretionary complex, WJAC—western Junggar accretionary complex, DBA—Dulate-Baytag arc, YA—Yemaquan arc, NTSAC—North Tian Shan accretionary complex, BICR—Bogda intracontinental rift (see text for details).

with zircon U-Pb ages of 455 and 451 Ma (Hu et al., 2008), and Paleozoic volcano-sedimentary rocks (BGMRXUAR, 1993).

In West Junggar (Fig. 2A), the suture zones are dominated by middle Devonian and older ophiolites (Zhang et al., 1993; Jian et al., 2005; Xu et al., 2006b; Zhu and Xu, 2006; Fig. 2B). The Kujibai-Hongguleleng suture zone formed prior to the early Carboniferous, because the inclusions of various ophiolite fragments are present in the Lower Carboniferous molasse beside the Kujibai ophiolite (Zhu and Xu, 2006). A few ophiolites occur in the Western Junggar accretionary complex (Fig. 2B). The Dalabute ophiolite, which has a Sm-Nd isochron age of 395 ± 12 Ma (Zhang et al., 1993), is unconformably covered by Lower Carboniferous marine strata with interbeds of andesite that has yielded a U-Pb zircon age of 336 ± 5 Ma (X. Xu et al., 2006). The Kelamayi ophiolite is strongly deformed, and its associated siliceous rocks have yielded middle and late Ordovician conodonts and radiolarians (He et al., 2007). In addition, an altered gabbro in the ophiolite yielded two U-Pb zircon ages of 414 ± 9 Ma and 332 ± 14 Ma (X. Xu et al., 2006); the former is possibly the crystallization age, and the latter age may be related to exhumation of the spinel-bearing dolomitic marble and garnet amphibolite (Zhu et al., 2008). Furthermore, the Kelamayi ophiolite is unconformably overlain by Upper Carboniferous and Lower Permian sequences (X. Xu et al., 2006). The Tangbale ophiolite occurs together with middle Ordovician radiolarian cherts (Buckman and Aitchison, 2001) and Silurian blueschists (Zhang, 1997). All of these observations indicate that the suture zones in West Junggar were developed before the late Carboniferous, and, subsequently, all of the terranes were intruded by late Carboniferous to Permian granitoids (Chen and Jahn, 2004; Chen and Arakawa, 2005; B.F. Han et al., 2006; Zhou et al., 2006; Y.P. Su et al., 2006a).

In East Junggar (Fig. 2A), the ophiolites have zircon U-Pb ages of 503–373 Ma (Jian et al., 2005; Xiao et al., 2006; Tang et al., 2007b; Fig. 2B). It is generally accepted that the Zhaheba-Armantai suture zone formed earlier than the Kalamaili suture zone (e.g., Xiao et al., 1992; Xiao et al., 2008). For the development of the Kalamaili suture zone, the upper-age bound can be constrained by Visean sediments that unconformably overlie the ophiolite (Li et al., 1989) and early Carboniferous molasse deposits, and the lower-age bound may be defined by a U-Pb zircon age of 373 ± 10 Ma for a plagiogranite of the Kalamaili ophiolite (Tang et al., 2007b), and Famennian to Tournaisian radiolarian cherts associated with the ophiolite (Li et al., 1990; Shu and Wang, 2003). The suturing event was related to the late Tournaisian to early Visean collision between the Junggar terrane and the Yemaquan arc, after which all of the terranes were intruded by late Carboniferous to Permian granitoids and Cu-Ni-sulfide–bearing, mafic-ultramafic magmatic complexes (B.F. Han et al., 1997, 2004, 2006; Chen and Jahn, 2004; Y.P. Su et al., 2006b, 2008; Tang et al., 2007a).

The data summarized here convincingly indicate that the Junggar terrane (Fig. 2B) and the terranes in West and East Junggar (Fig. 2A) were amalgamated together in the early Carboniferous. It is noteworthy that the terranes in West Junggar are the eastward extensions of those in eastern Kazakhstan (Fig. 2B), and all of them, together with those in East Junggar, might have occurred as the Kazakhstan-Junggar composite terrane since the beginning of the late Carboniferous.

The west-northwest–striking Irtysh-Zaysan suture zone extends from China to eastern Kazakhstan and is intruded extensively by early Permian granitic plutons (Tong et al., 2006; Figure 1 *in* Vladimirov et al., 2008). This crosscutting relationship, combined with $^{40}Ar/^{39}Ar$ ages of 450–449 Ma from blueschists of the Char ophiolite (Volkava and Sklyarov, 2007) and abundant late Devonian and early Carboniferous conodonts and radiolarians (Iwata et al., 1994, 1997) from the siliceous rocks associated with the ophiolite, suggests that the development of the Irtysh-Zaysan suture zone occurred in the late Carboniferous (Buslov et al., 2001, 2004; Vladimirov et al., 2001, 2003, 2008), probably between 321 and 303 Ma, resulting from the collision between the Altai terrane and the Kazakhstan-Junggar composite terrane, and followed by early Permian molasse deposits in the north slope of the Saur Mountains and within the eastern segment of the Irtysh-Zaysan suture zone (BGMRXUAR, 1993).

The North Tian Shan suture zone between the Junggar and the Yili terranes is marked by an accretionary-complex belt extending over 300 km along the northern edge of the North Tian Shan (Fig. 2B). It is bounded by the west-northwest–striking North Tian Shan fault in the south and a north-directed thrust in the north that juxtaposes the accretionary complex over the Permian to Cretaceous sequences (Fig. 3A).

The accretionary complex in the suture zone is principally composed of two lithologies: one is the Devonian-Carboniferous volcano-sedimentary rocks widely accepted as an accretionary complex (e.g., Xiao et al., 2008; B. Wang et al., 2006; Windley et al., 2007), and the other is ophiolite remnants of the North Tian Shan oceanic crust (Xiao et al., 1992; Gao et al., 1998; B. Wang et al., 2006). The ophiolite consists of fragments of strongly serpentinized peridotites (Figs. 4A and 4B), gabbros, plagiogranite, pillow lavas, and siliceous-pelagic sedimentary rocks (Figs. 4C–4E). These ophiolitic fragments are tectonically mixed within the Devonian-Carboniferous volcaniclastic rocks, calcareous rocks, and turbiditic flysch deposits (BGMRXUAR, 1993; Figs. 4F–4H). The siliceous rocks in the accretionary complex yielded Famennian conodonts (e.g., *Palmatolepis* sp. and *Polygnathus* sp.) and Lower Carboniferous radiolarians (e.g., *Ceratoikicum* sp.) (Xiao et al., 1992), while plagiogranite and gabbro from the Bayingou ophiolite yielded sensitive high-resolution ion microprobe (SHRIMP) zircon U-Pb ages of 325 ± 7 Ma (Xu et al., 2005) and 344 ± 3 Ma (X.Y. Xu et al., 2006), respectively. The late Permian strata that unconformably overlie the accretionary complex within the suture zone were deposited at ca. 260 Ma (Yang et al., 2006b; C.Q. Su et al., 2006; H.L. Wang et al., 2007).

Because of a poorly constrained upper-age bound for the timing of the North Tian Shan suture zone, collision between the Yili and Junggar terranes along the suture zone has been variably inferred as occurring in (1) the late Carboniferous to early Permian (Allen et al., 1993; Carroll et al., 1995; Charvet et al., 2007; Li et al., 2008), (2) the late Carboniferous (Windley et al., 1990; B. Wang et al., 2006), the early Permian (C.M. Han et al., 2006; Q. Wang et al., 2007), and (3) the latest early Carboniferous (Gao et al., 1998). Accordingly, the late Carboniferous and older magmatic rocks and related porphyry ore deposits in the northern margin of the Yili terrane have been commonly accepted as the product of arc magmatism caused by southward subduction of the North Tian Shan Ocean (Zhu et al., 2005; Li et al., 2006; Z.L. Wang et al., 2006; B. Wang et al., 2006; Zhai et al., 2006; Q. Wang et al., 2007), whereas the Permian volcanic rocks and A-type granites were related to postcollisional processes (Liu et al., 2005; Chen et al., 2007; Tang et al., 2008; Zhao et al., 2008). This debate highlights the importance of a narrow constraint on the timing of collision between the Yili and Junggar terranes, and the plutons intruding the North Tian Shan suture zone may place a crucial upper-age bound for this timing.

THE SIKESHU STITCHING PLUTON

Among the plutons intruding the North Tian Shan suture zone, the Sikeshu pluton is the largest one (Fig. 3A). The pluton occurs between the Bayingou and Motuogou ophiolites (Fig. 3A), crops out in an area of ~200 km^2, has an east-west–elongated, irregular shape, and is crosscut by northwest-striking, right-slip faults (Fig. 3B). Zones of hornfels and skarns ranging from several to tens of centimeters wide occur locally around the pluton. Roof pendants of the accretionary complex are also present in the pluton. Along the Sikeshu River (Fig. 3B), the pluton intrudes siliceous-pelagic sedimentary rocks of the accretionary complex in the suture zone (Fig. 5A), and together they have been thrust over Triassic and Jurassic strata (Fig. 5B).

The Sikeshu pluton is undeformed and includes a variety of petrofacies, such as medium- and coarse-grained granodiorite, K-feldspar granite, and diorite. The K-feldspar granite (Figs. 5C–5E) intrudes the granodiorite, which is the predominant component of the pluton and contains microgranular dioritic enclaves (Fig. 5F). The granodiorite consists of plagioclase (50%–55%), K-feldspar (15%–20%), quartz (15%–20%), amphibole (10%–15%), biotite (2%–3%), and minor Fe-Ti-oxides and apatite. The K-feldspar granite is composed of K-feldspar (55%–60%), plagioclase (10%–20%), quartz (20%–25%), amphibole (<3%), and apatite. Sometimes graphic texture was observed in thin sections of the K-feldspar granite. The diorite is made up of plagioclase (~60%), amphibole (~45%), and minor biotite, apatite, and Fe-Ti-oxides (~5%).

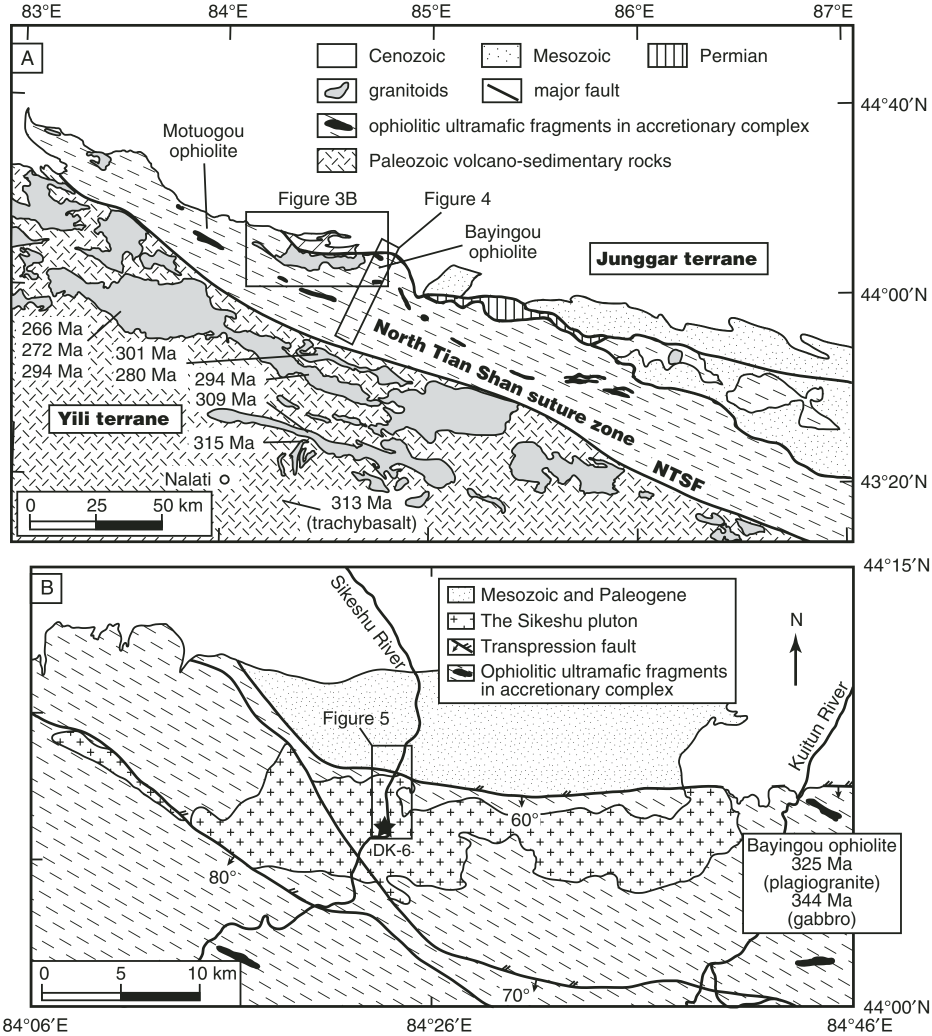

Figure 3. (A) Sketch map (simplified from H.L. Wang et al., 2007) showing the North Tian Shan suture zone, the late Carboniferous to Permian granitoids in northern margin of the Yili terrane, and their zircon U-Pb ages (B. Wang et al., 2006, 2007b; Zhu et al., 2005). NTSF—North Tian Shan fault. (B) Simplified geological map of the Sikeshu pluton showing the location of sample DK-6 for zircon U-Pb dating. Zircon U-Pb ages of plagiogranite and gabbro from the Bayingou ophiolite are from X.Y. Xu et al. (2005, 2006).

ANALYTICAL PROCEDURES

Sample DK-6 was collected from the granodiorite in the central part of the Sikeshu pluton (44°05′53″N, 84°23′37″E, see Fig. 3B for sampling location). Zircons were separated using heavy liquid and magnetic methods. Cathodoluminescence (CL) images were taken at Peking University using a Quanta 200FEG scanning electronic microscope equipped with MONOCL3 cathodoluminescence operating at 15 kV.

U-Th-Pb zircon data (see GSA Data Repository, Table DR1[1]) were obtained using SHRIMP II at Beijing SHRIMP center. The data consist of five scans through the mass range of Zr, Pb, U, and Th. An ~25-µm-diameter spot was applied to measure zircon domains. The U-Pb ages were normalized to 417 Ma from zircon standard TEMORA 1 (Black et al., 2003a, 2003b). Common Pb was corrected following the methods of Compston et al. (1984). Errors given on individual analyses are at the 1σ level, but the weighted mean age and its error are reported at 95% confidence level.

Major-element and trace-element concentrations (Table DR2 [see footnote 1]) were analyzed using X-ray fluorescence spectroscopy (XRF, Rigaku RIX-2100) on fused-glass disks and inductively coupled plasma–mass spectrometry (ICP-MS, Perkin Elmer ELAN 6100DRC) after acid digestion of samples in Teflon bombs, respectively, at Northwest University in Xi'an, China. Four U.S. Geological Survey standards (AGV-1, BCR-2, BHVO-2, and G-2) were analyzed during the course of these analyses. Detailed analytical procedures are to be found in Rudnick et al. (2004).

Samples for Sr and Nd isotopic analysis were dissolved in Teflon bombs in HF + HNO_3. Sr and Nd were separated using conventional ion exchange procedures, and the Sr and Nd isotopic compositions (Table DR2 [see footnote 1]) were obtained using a Finnigan MAT 262 multicollector mass spectrometer at the Institute of Geology and Geophysics, Chinese Academy of Sciences, China, following the procedures of Yang et al. (2004). The $^{87}Sr/^{86}Sr$ ratio for the NBS-987 Sr standard measured during this study was 0.710248 ± 0.000011 (2σ, n = 8), and the measured $^{87}Sr/^{86}Sr$ ratios were normalized to $^{86}Sr/^{88}Sr$ = 0.1194. The $^{143}Nd/^{144}Nd$ ratio for the JNdi standard measured during this study was 0.512111 ± 0.000006 (2σ, n = 10), and the measured $^{143}Nd/^{144}Nd$ ratios were normalized to $^{146}Nd/^{144}Nd$ = 0.7219. Procedural blanks were <100 pg for Nd and <500 pg for Sr, respectively.

[1]GSA Data Repository item 2009209, geochronological and geochemical data, is available at http://www.geosociety.org/pubs/ft2009.htm or by request to editing@geosociety.org.

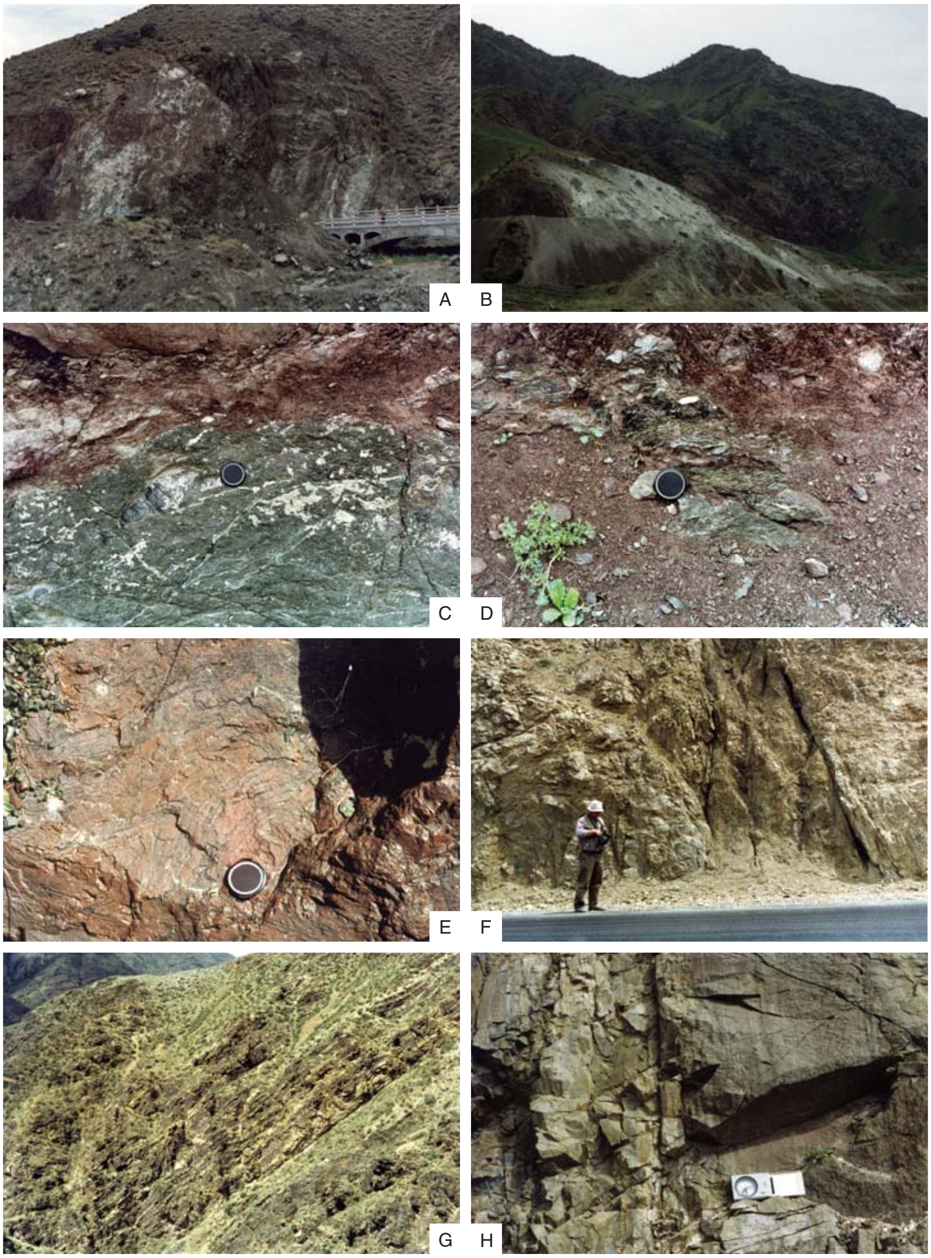

Figure 4. (A–B) Strongly serpentinized peridotite fragments, (C–D) sheared volcanic and pelagic sedimentary rocks, (E) a radiolarian chert fragment, (F) fractured volcano-sedimentary rocks, and (G–H) turbiditic flysch deposits in the North Tian Shan accretionary complex.

RESULTS

Zircon U-Pb Age

Zircon grains from sample DK-6 are typically euhedral or near-euhedral prismatic crystals, 70–250 μm in length and 45–80 μm in width. These zircons commonly show well-preserved concentric oscillatory zoning, but inherited cores and other mineral inclusions are present in some grains (Fig. DR1 [see footnote 1]).

In total, 13 spots on 13 zircon grains were analyzed. Their Th and U concentrations are positively correlated with each other, and the Th/U ratios are in a range of 0.48–0.96. The majority of the analyzed spots are on rims of individual zircon grains, having a narrow range of Th/U ratios (0.48–0.65), but spot 13.1 is on a dark core and hence has the highest U and Th concentrations, Th/U ratio, and radiogenic ^{206}Pb (Table DR1 [see footnote 1]). After common Pb correction using measured ^{204}Pb, the $^{206}Pb/^{238}U$ ages are in a range 329–311 Ma, and all the spots give a weighted mean $^{206}Pb/^{238}U$ age of 318.8 ± 2.9 Ma, with a mean square of weighted deviates (MSWD) of 1.4. Because some spots are off the concordia to some degree, they also give a lower-intercept age of 314.7 ± 4.0 Ma, MSWD = 0.82. With common Pb correction by assuming $^{206}Pb/^{238}U$-$^{208}Pb/^{232}Th$ age-concordance, the $^{206}Pb/^{238}U$ ages vary in a range 323–309 Ma, the weighted mean $^{206}Pb/^{238}U$ age is 315.9 ± 2.5 Ma, MSWD = 0.75, and all the spots cluster on and near the concordia more tightly (Fig. 6).

Whole-Rock Geochemistry

Four samples from the Sikeshu pluton show a wide variation in major-element contents (Table DR2 [see footnote 1]), and SiO_2 and other oxides show linear correlations. TiO_2, Al_2O_3, CaO, and P_2O_5 contents and Mg# significantly decrease with increasing SiO_2 contents, whereas total alkali contents increase with increasing SiO_2 contents (Fig. 7). They are metaluminous with A/CNK (molar Al_2O_3/[CaO + Na_2O + K_2O]) = 0.85 – 1.00 and A/NK (molar Al_2O_3/[Na_2O + K_2O]) = 1.12 – 1.84 (Table DR2 [see footnote 1]). In the Fe# (FeO^T/[FeO^T + MgO]) and (Na_2O + K_2O-CaO) versus SiO_2 discrimination diagrams (Fig. 8), sample 07WS04 falls in the magnesium and calcic-alkali fields, but the other three samples fall in the ferroan and alkali-calcic fields.

The four samples also show parallel primitive mantle–normalized rare earth element (REE) patterns (Fig. 9A). As SiO_2 increases, REE concentrations increase from 99 to 198 ppm. Light REE (LREE) concentrations are considerably more enriched than heavy REEs (HREEs); LREE/HREE ratios vary from 4.91 to 5.85, with $(La/Lu)_n$ = 4.35–4.87. LREE fractionation is more striking than HREE fractionation: $(La/Sm)_n$ = 2.25–2.85 and $(Gd/Lu)_n$ = 1.43–1.25, and HREEs have a concave shape. Negative Eu anomalies vary from 0.77 to 0.20 with increasing SiO_2 contents. Similarly, primitive mantle–normalized trace-element patterns (Fig. 9B) are nearly parallel to each other, with significantly negative Ba, Nb, Ta, Sr, P, Eu, and Ti anomalies.

After age correction, the samples show low initial $^{87}Sr/^{86}Sr$ ratios, ranging from 0.70304 to 0.70421, and their initial $^{143}Nd/^{144}Nd$ ratios are in a range of 0.51258–0.51261 (Table DR2 [see footnote 1]). Correspondingly, the $\varepsilon_{Nd}(t)$ values at t = 316 Ma are positive, varying between +6.8 and +7.3, and the depleted-mantle Nd model ages (T_{DM}) are very young, ranging from 462 to 516 Ma (Table DR2 [see footnote 1]).

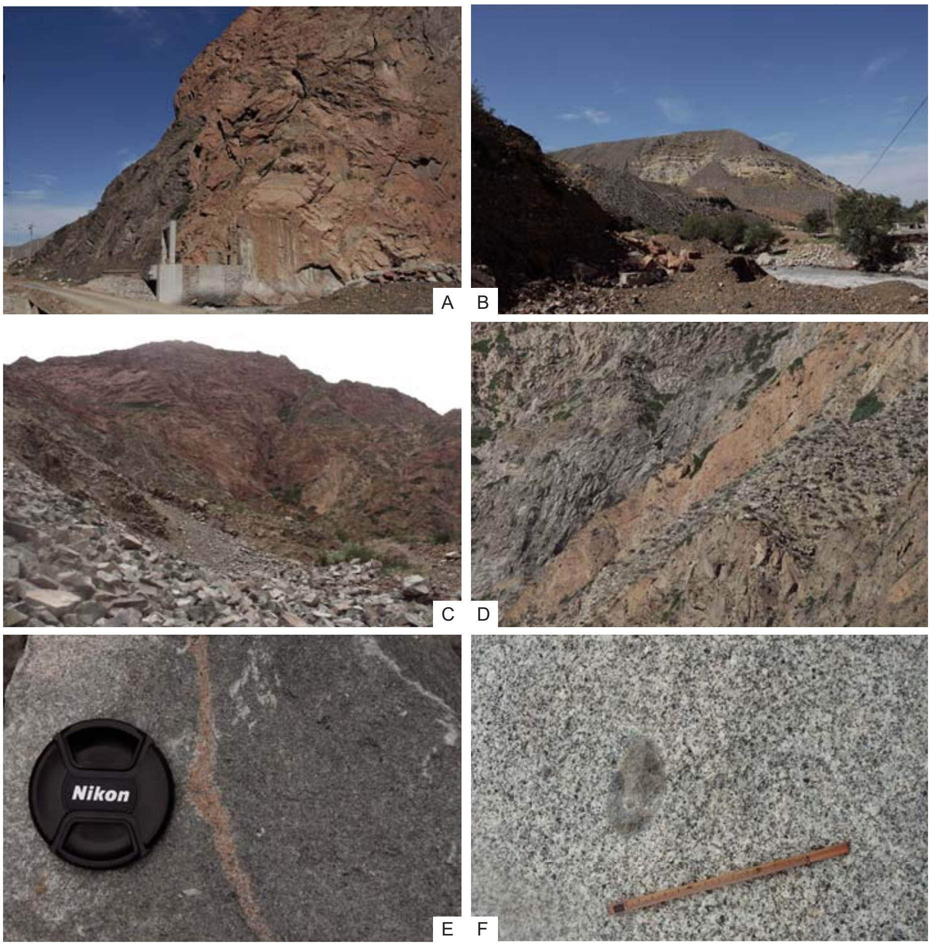

Figure 5. (A) K-feldspar granite of the Sikeshu pluton intruding the accretionary complex. (B) View of the Triassic-Jurassic coal-bearing sequences, over which the pluton and accretionary complex together were thrust. (C, D, E) K-feldspar granite crosscutting granodiorite of the pluton with (F) microgranular dioritic enclaves.

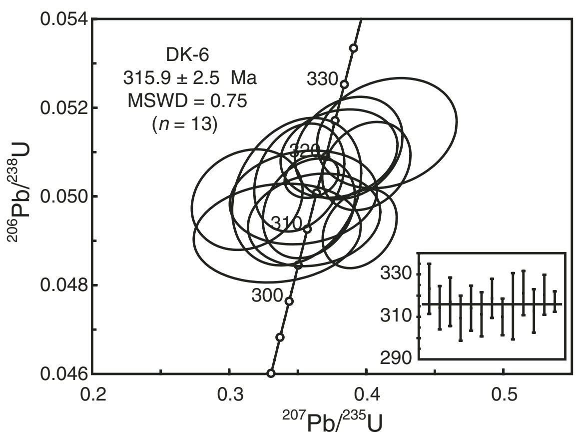

Figure 6. U-Pb concordia diagram after common Pb correction by assuming $^{206}Pb/^{238}U$-$^{208}Pb/^{232}Th$ age concordance (see text for details), constructed using ISOPLOT/Ex 3.00 (Ludwig, 2003). Error ellipses and bars are at 2σ level. MSWD—mean square of weighted deviates.

DISCUSSION

Timing of the North Tian Shan Suture Zone and Implications

Generally, the timing of a suture zone can be bracketed by the youngest ophiolitic rocks and the plutons or dikes intruding the suture zone. For example, zircon U-Pb ages from gabbro and plagiogranite of the Northland ophiolite, New Zealand, are 31.6 ± 0.2 and 28.3 ± 0.2 Ma, respectively, whereas the Miocene arc-related, calc-alkaline dikes intruding the ophiolitic rocks yielded zircon U-Pb ages of ca. 20 Ma (Whattam et al., 2006). These data constrain a period of ~10 Ma from generation of oceanic crust to emplacement of the Northland ophiolite. In Mongolia, the Bayankhongor ophiolite (Sm-Nd age = 569 ± 21 Ma; Kepezhinskas et al., 1991) is intruded by undeformed granite plutons with zircon evaporation $^{207}Pb/^{206}Pb$ ages of 545–539 Ma, suggesting an interval of ~25–30 Ma between formation of oceanic crust and emplacement of the Bayankhongor ophiolite (Buchan et al., 2002).

In the case of the North Tian Shan suture zone, the Sikeshu pluton just intrudes the suture zone, and the U-Pb zircon age of 316 ± 3 Ma of the pluton places an upper-age bound for the formation of the North Tian Shan suture zone. The Sikeshu pluton postdates the Bayingou ophiolite of the North Tian Shan suture zone, from which the plagiogranite and gabbro yielded SHRIMP zircon U-Pb ages of 325 ± 7 and 344 ± 3 Ma (X.Y. Xu et al., 2005, 2006) and the siliceous rocks yielded Upper Devonian conodonts and Lower Carboniferous radiolarians (Xiao et al., 1992). The zircon U-Pb ages of the ophiolitic plagiogranite and the Sikeshu pluton together suggest that the North Tian Shan suture zone was formed between 325 and 316 Ma, a maximum interval of ~10 Ma between generation of oceanic crust and emplacement of the Bayingou ophiolite.

Possibly, oceanward retreat of the subduction zone might have caused the North Tian Shan suture zone to be intruded by younger arc plutons, like the western Klamath Mountains of western America. In the western Klamath Mountains, the Jurassic arc plutons not only crosscut contacts between terranes, but they also stitched various terranes together (Dickinson, 2008), and the ophiolites become younger in age toward subduction zone: the Trinity ophiolite in the east has zircon U-Pb ages of 431–398 Ma (Wallin and Metcalf, 1998), whereas the Josephine ophiolite in the west has zircon U-Pb ages of 164–162 Ma (Wright and Wyld, 1986; Harper et al., 1994). If this occurred in the North Tian Shan, retreat of subduction zone could have

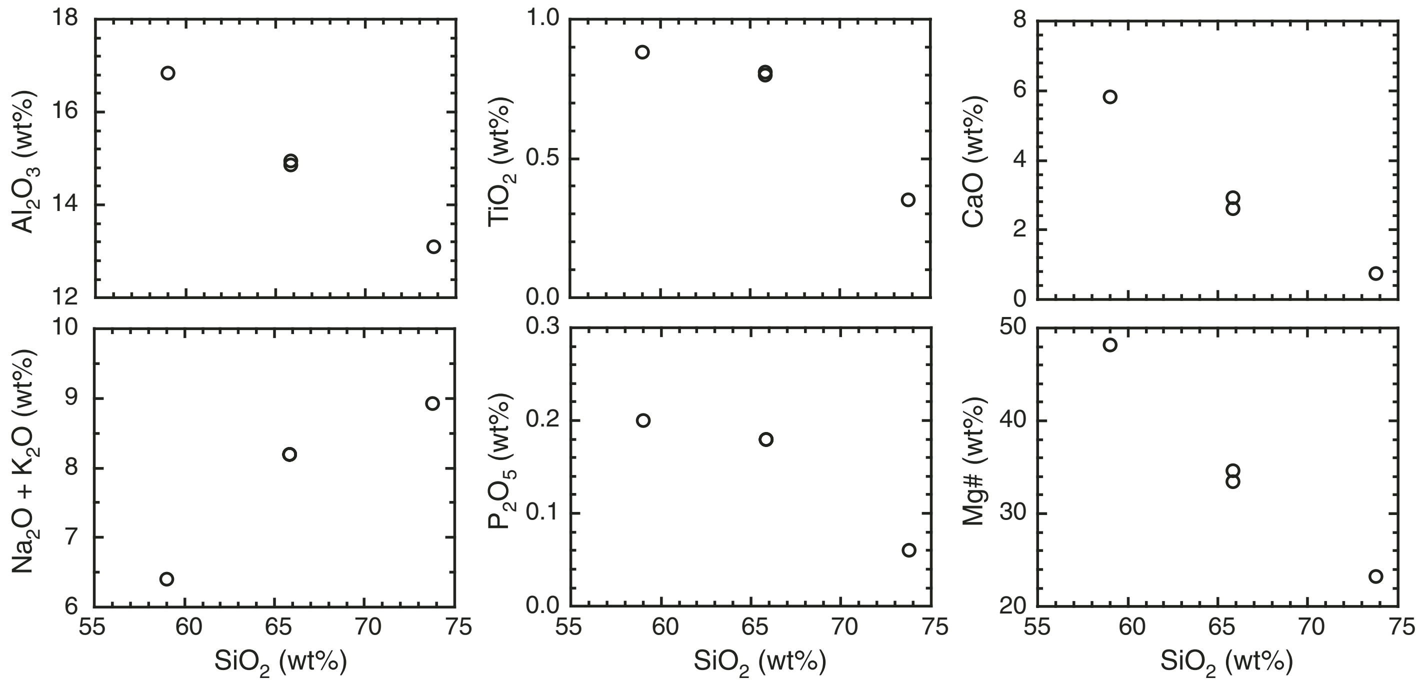

Figure 7. Harker diagrams for the Sikeshu pluton, showing the negative correlations of TiO_2, Al_2O_3 Mg#, CaO, and P_2O_5 and a positive correlation of $Na_2O + K_2O$ versus SiO_2.

been northward (present orientation), and such a process might have left younger ophiolites in the north of the North Tian Shan suture zone. However, all the ophiolites in West Junggar are much older than the Bayingou ophiolite in the North Tian Shan (Fig. 2B), which is inconsistent with the subduction-zone retreat model.

Importantly, while the late Carboniferous strata are characterized by shallow-marine to nonmarine sedimentary and volcanic rocks in the Junggar and Altai regions, there are no Permian marine sedimentary and volcanic rocks in the Junggar, Altai, and Tian Shan (BGMRXUAR, 1993, p. 136–194; X. Xu et al., 2006). Furthermore, the North Tian Shan suture zone is unconformably covered by the Permian nonmarine volcanic rocks (C.Q. Su et al., 2006; Yang et al., 2006b; H.L. Wang et al., 2007). Similar circumstances occur in Kazakhstan and Kyrgyzstan, where the late Carboniferous to Permian strata were produced by epicontinental marine to nonmarine sedimentation (see Figure 6 *in* Windley et al., 2007).

The Bayingou ophiolite in the North Tian Shan suture zone is the youngest one in the North Xinjiang region (Fig. 2B), and thus collision between the Yili and Junggar terranes along the North Tian Shan suture zone may represent the youngest collisional event in the region (e.g., Xiao et al., 1992; C.M. Han et al., 2006; Charvet et al., 2007). This study indicates that the Yili and Junggar terranes collided together at the beginning of the late Carboniferous, before emplacement of the Sikeshu pluton. This collisional event is younger than those along the suture zones in the East Junggar and similar to those along the suture zones in West Junggar and the Irtysh-Zaysan suture zone (see section on Major Suture Zones in the North Xinjiang Region). After the collision event, the Yili terrane might have been the constituent part of the late Carboniferous, Kazakhstan-Junggar composite terrane, and this composite terrane nearly simultaneously collided with the Altai terrane.

A Composite Magmatic Belt in the Northern Margin of the Yili Terrane

Previously, all of the Carboniferous and older magmatic rocks and related ore deposits in the northern margin of the Yili terrane have been interpreted as products of arc magmatism (Zhu et al., 2005; Z.L. Wang et al., 2006; B. Wang et al., 2006; Zhai et al., 2006), but the late Carboniferous magmatic rocks may be subduction-related (Zhu et al., 2005; Z.L. Wang et al., 2006; B. Wang et al., 2006; Q. Wang et al., 2007) or syncollisional (J.F. Chen et al., 2000). Generally, the Permian magmatic rocks are considered to have been generated in a postcollisional setting (Liu et al., 2005; B. Wang et al., 2006; Zhao et al., 2008; Tang et al., 2008). The debates on the tectonic setting of the late Carboniferous and Permian magmatic rocks and related ore deposits are closely related to the time of collision between the Yili and Junggar terranes.

If the timing of the North Tian Shan suture zone indicates a collision event between the Yili and Junggar terranes during the interval of 325–316 Ma, probably at the end of the early Carboniferous, the Paleozoic magmatism in the northern margin of the Yili terrane can be divided into a subduction and postcollisional setting (Fig. 10). The south-facing subduction of the North Tian Shan oceanic lithosphere beneath the Yili terrane might have started from the late Ordovician and continued through the Devonian and early Carboniferous, generating the gneissic and mylonitized granitoids (zircon U-Pb ages of 442 ± 4–408 ± 5 Ma; Zhu and Song, 2006; Yang et al., 2006a; Shi et al., 2007), undeformed granitoids (zircon U-Pb ages of 368 ± 9–361 ± 11 Ma; Li et al., 2006; Shi et al., 2007), and basalts (zircon U-Pb age of 354 ± 5 Ma; Zhu et al., 2005), andesites (zircon U-Pb age of 363 ± 6 Ma; Zhai et al., 2006), and rhyolites (Zircon U-Pb age of 386 ± 6 Ma; An and Zhu, 2008) (Fig. 10A). After the collision in the latest early Carboniferous (Fig. 10B), a new cycle of magmatism started with the emplacement of the Sikeshu pluton into the North Tian Shan suture zone at 316 ± 3 Ma ago and possibly lasted for ~50 Ma, producing diorite, granodiorite, biotite granite, alkali-feldspar granite, and A-type granite (zircon U-Pb ages of 315 ± 3–266 ± 6 Ma; B. Wang et al., 2006, 2007b; Liu et al., 2005;

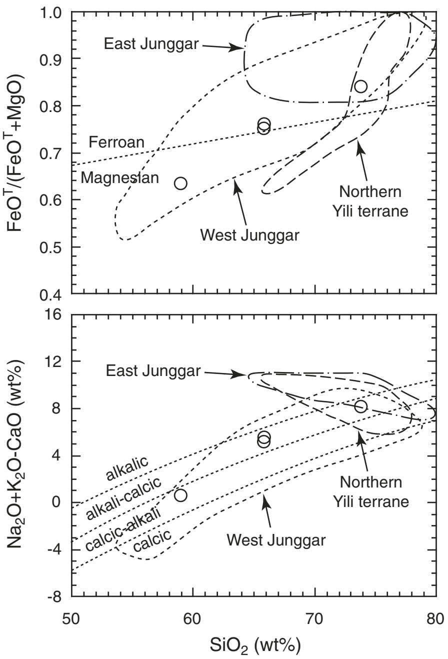

Figure 8. $FeO^T/(FeO^T + MgO)$ and (Na_2O + K_2O-CaO) versus SiO_2 discrimination diagrams of Frost et al. (2001), showing a trend from the magnesium and calcic-alkali to the ferroan and alkali-calcic with increasing SiO_2 contents. The late Carboniferous and Permian granitoids in West Junggar (Chen and Jahn, 2004; Chen and Arakawa, 2005; Y.P. Su et al., 2006b), East Junggar (Han et al., 1997; Chen and Jahn, 2004; Y.P. Su et al., 2006a, 2008; Tang et al., 2007a), and northern margin of the Yili terrane (J.F. Chen et al., 2000; Liu et al., 2005; Tang et al., 2008) are shown for comparison.

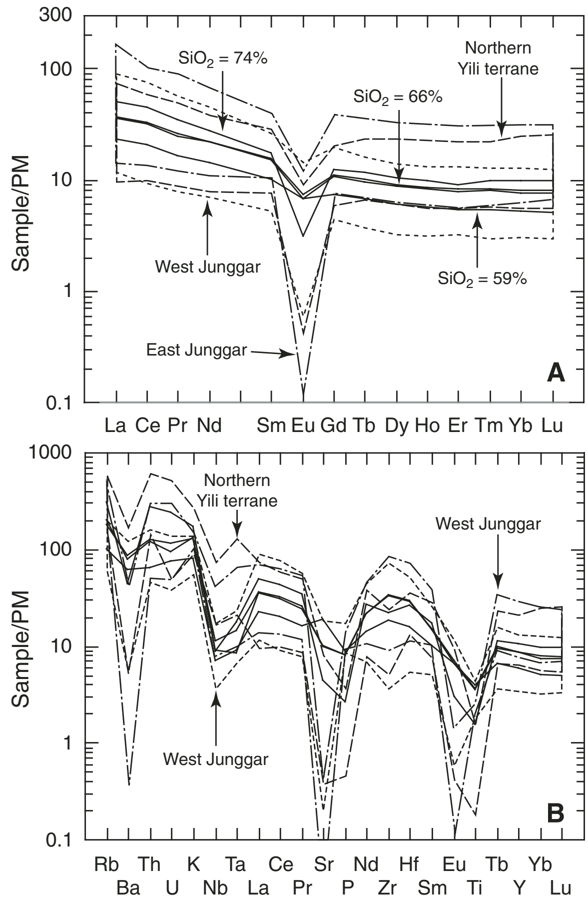

Figure 9. (A) Primitive mantle (PM)–normalized rare earth element (REE) and (B) trace-element patterns. The PM values are from Sun and McDonough (1989). Symbols and data sources are the same as in Figure 8.

Chen et al., 2007; Tang et al., 2008), trachybasalts (zircon U-Pb age of 313 ± 4 Ma; Zhu et al., 2005), and rhyolites (zircon U-Pb ages of 300–271 Ma; Liu et al., 2005; Chen et al., 2007) in the northern margin of the Yili terrane (Fig. 10C). Both postcollisional and subduction-related rocks together constitute the present magmatic belt in the northern margin of the Yili terrane, and they record a rapid change in tectonic setting from subduction to postcollision.

Q. Wang et al. (2007) reported early Carboniferous (ca. 320 Ma) adakites and Nb-enriched basalts and late Carboniferous (ca. 310–306 Ma) high-K calc-alkaline andesites, dacites, and rhyolites from the Alataw Shan, the western segment of the northern margin of the Yili terrane (Fig. 2), and they interpreted them as the products of arc volcanism related to the southwestward subduction of the North Tian Shan Ocean beneath the Yili terrane prior to the formation of the North Tian Shan suture zone in the earliest Permian. Because the collision between the Yili and Junggar terranes occurred at the end of the early Carboniferous, the late Carboniferous high-K calc-alkaline volcanic rocks in the western segment of northern margin of the Yili terrane were produced in a postcollisional setting.

Late Carboniferous and Early Permian Tectonic Setting of the North Xinjiang Region

The Sikeshu pluton is one of the earliest postcollisional granitoid plutons and displays variations from the magnesium and calcic-alkali to the ferroan and alkali-calcic with increasing SiO_2 contents (Fig. 8), negative correlations of TiO_2, Al_2O_3, Mg#, CaO, and P_2O_5 against SiO_2, a positive correlation of $Na_2O + K_2O$ (Fig. 7) against SiO_2, parallel rare earth element (REE) patterns (Fig. 9A), and increasingly negative Ba, Nb, Ta, Sr, P, Eu, and Ti anomalies (Fig. 9B). All these features are indicative of fractionation crystallization of a primitive parental magma, and they are similar to the late Carboniferous and early Permian granitoids in West Junggar. Besides, the pluton also shares the geochemical features of postcollisional (Fig. 11A) and juvenile granitoids (Fig. 11B), including low initial Sr isotopic ratios, positive $\varepsilon_{Nd}(t)$ values, and young depleted-mantle Nd model ages (T_{DM}).

It is important to note that the late Carboniferous and Permian granitoids are also widespread in East Junggar (zircon U-Pb ages of 319 ± 6–268 ± 4 Ma; B.F. Han et al., 2006) and West Junggar (zircon U-Pb ages between 318 ± 5 and 287 ± 6 Ma; B.F. Han et al., 2006). They are characterized by coeval I- and A-type granitoids, including the Ulungur-River A-type granites (Han et al., 1997) and the Kalamaili A-type granites (B.F. Han et al., 2006; Y.P. Su et al., 2006b, 2008; Tang et al., 2007a) in East Junggar, and the Saur A-type granites (Zhou et al., 2006) and Kelamayi A-type granites (B.F. Han et al., 2006; Y.P. Su et al., 2006a) in West Junggar. Such an association of A- and I-type granitoids is generally accepted as the product of postcollisional magmatism (B.F. Han et al., 1997, 2006; Chen and Jahn, 2004; Chen and Arakawa, 2005; Y.P. Su et al., 2006a, 2006b, 2008; Zhou et al., 2006). The Kelamayi A-type granites (B.F. Han et al., 2006; Y.P. Su et al., 2006a) just intrude the Western Junggar accretionary complex.

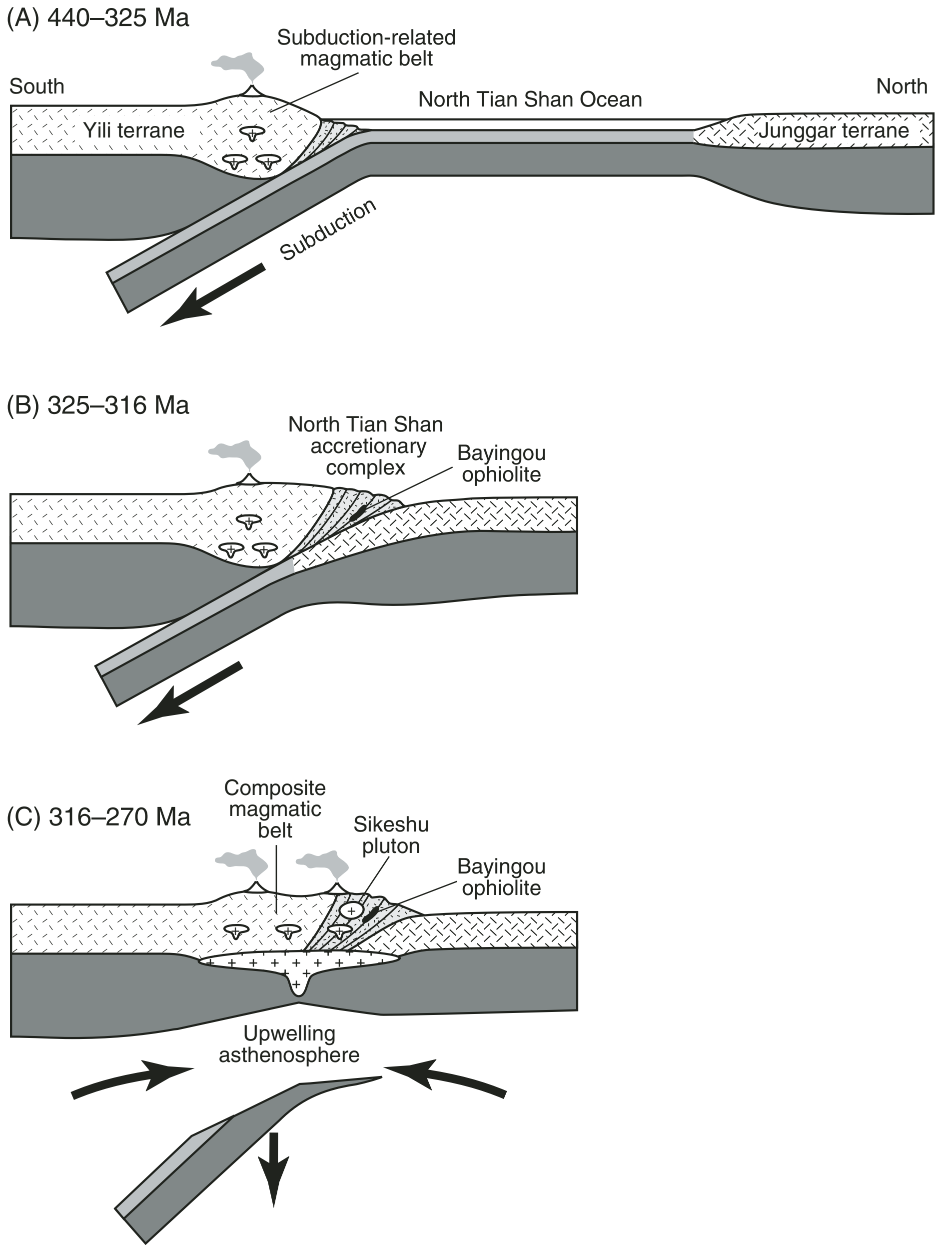

Figure 10. Three-stage tectonic model. (A) Southward subduction of the North Tian Shan Ocean beneath the Yili terrane, producing arc magmatism in northern margin of the Yili terrane. (B) Collision between the Yili and Junggar terranes and formation of the North Tian Shan accretionary complex. (C) Emplacement of the Sikeshu pluton into the accretionary complex and development of a composite magmatic belt in northern margin of the Yili terrane (see text for details).

In addition, the late Carboniferous and Permian magmatic ore deposits are suggested to have occurred in a postcollisional setting in the North Xinjiang region (C.M. Han et al., 2006, and references therein), including the Permian Cu-Ni-sulfide–bearing, mafic-ultramafic magmatic complexes such as the Kalatongke (zircon U-Pb age of 287 ± 5 Ma; Han et al., 2004) and the Huangshandong (zircon U-Pb age of 274 ± 4 Ma; Han et al., 2004). The Permian mafic-ultramafic complexes exhibit similarities and differences in comparison with Alaskan-type complexes (Gu et al., 1994), and the temporal-spatial relationship of the mafic-ultramafic complexes and A-type granites implies that they occurred in a postcollisional setting (B.F. Han et al., 1997, 2004, 2006; C.M. Han et al., 2006b; Mao et al., 2008; Pirajno et al., 2008). A similar conclusion is reached for the Triassic A-type granites and coeval Cu-Ni-sulfide–bearing, mafic-ultramafic magmatic complexes in northeast China (Wu et al., 2004).

More importantly, the late Carboniferous and Permian postcollisional granitoids are not confined to some specific belts, but they occurred almost simultaneously in all the terranes in the North Xinjiang region, and some crosscut major suture zones. Such a temporal-spatial relationship of magmatism and terranes also implies that these terranes were amalgamated together prior to the late Carboniferous. Furthermore, widespread distribution of the late Carboniferous and Permian granitoids, including A-type granites and coeval Cu-Ni-sulfide–bearing, mafic-ultramafic complexes, was not readily created by ridge subduction, although the mechanism may account for the increased heat necessary to cause partial melting of the crust (Windley et al., 2007), because these postcollisional magmatic rocks and related ore deposits are so dispersed that ridge subduction must have occurred nearly simultaneously in all the terranes. Instead, basaltic underplating caused by slab breakoff or delamination of mantle lithosphere may be an alternative mechanism for the generation of these granitoids and coeval mafic-ultramafic complexes with depleted-mantle–like Sr-Nd isotopic characteristics (Han et al., 1999; Chen and Jahn, 2004; Jahn et al., 2000; Zhao et al., 2008) and the Permian andalusite-type metamorphism in the southern Altai (Wei et al., 2007; W. Wang et al., 2009).

In addition, a recent paleomagnetic study reveals no or small relative motion between the Yili and Junggar terranes and no significant or small relative latitudinal movement between Tarim, Yili, Junggar, and Siberia since the late Carboniferous (B. Wang et al., 2007a). Geological and paleomagnetic results indicate that the complicated accretionary orogenesis in the North Xinjiang region may have lasted until the beginning of the late Carboniferous. Therefore, the North Xinjiang region was in a postcollisional setting during most of the late Carboniferous and the Permian.

CONCLUSIONS

Geologically, the North Tian Shan suture zone between the Yili and Junggar terranes was certainly formed before emplacement of the Sikeshu pluton, because this stitching pluton crosscuts the suture zone. A SHRIMP zircon U-Pb age of 316 ± 3 Ma from the pluton and the youngest zircon U-Pb age from plagiogranite of the Bayingou ophiolite within the North Tian Shan

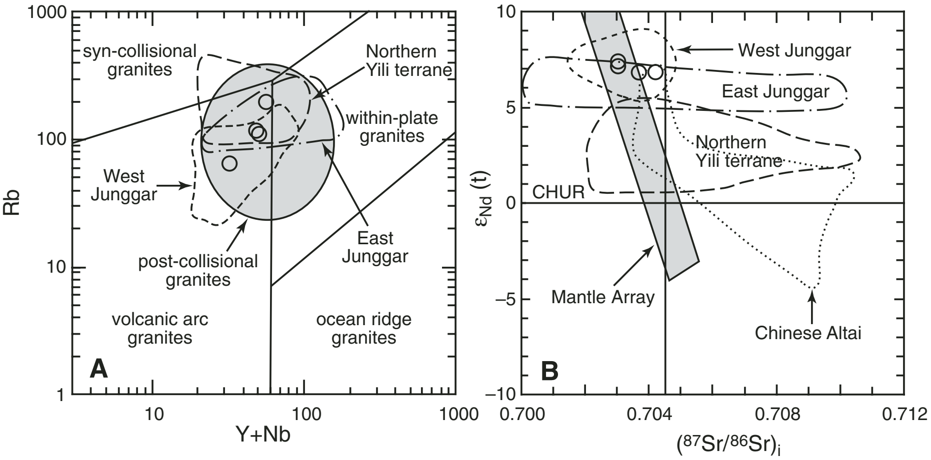

Figure 11. The Sikeshu pluton shares the geochemical features of postcollisional granites in the North Xinjiang region. (A) Plot of Rb versus Y + Nb granitoid tectonomagmatic diagram of Pearce (1996). (B) Plot of initial Sr isotopic compositions ($^{87}Sr/^{86}Sr)_i$ versus ε_{Nd}(t) values showing that the Sikeshu pluton and the late Carboniferous and Permian granitoids of West Junggar display similar isotopic features, but they generally have higher ε_{Nd}(t) and more restricted ($^{87}Sr/^{86}Sr)_i$ values than the late Carboniferous and Permian granites in northern margin of the Yili terrane, East Junggar, and the Chinese Altai. The Sr-Nd data of the Chinese Altai are from T. Wang et al. (2009), and the other symbols and data sources are the same as in Figure 8. CHUR—chondrite uniform reservoir.

suture zone (Xu et al., 2005) together confine the timing of the North Tian Shan suture zone to the interval 325–316 Ma. Therefore, the Paleozoic tectonic evolution of the North Tian Shan and the Yili terrane may be divided into subduction (442–325 Ma), syncollision (325–316 Ma), and postcollision (316–270 Ma) stages, and the Sikeshu pluton represents the earliest postcollisional magmatic rocks in the North Tian Shan and adjacent terranes. Accordingly, the Paleozoic magmatic belt in the northern margin of the Yili terrane is made up of subduction-related and postcollisional magmatic rocks. According to their zircon ages, the porphyry-type copper-molybdenum–bearing magmatic rocks in the belt were generated in two contrasting settings: subduction and postcollision.

In the North Xinjiang region, the major suture zones formed before and during the late Carboniferous. The Kazakhstan-Junggar composite terrane occurred in the beginning of the late Carboniferous due to the amalgamation of the Yili terrane with the Junggar and other terranes in East Junggar and West Junggar, and then this composite terrane collided with the Altai terrane during the late Carboniferous. The late Carboniferous and Permian postcollisional magmatism occurred across the Kazakhstan-Junggar composite terrane and the Chinese Altai, and some stitching plutons such as the Sikeshu and the Kelamayi A-type granites crosscut major suture zones. In particular, the late Carboniferous and Permian A-type granites extensively occur in the composite terrane, hinting that their generation was related to basaltic underplating caused by slab breakoff or delamination of mantle lithosphere, and that the Cu-Ni-sulfide–bearing, mafic-ultramafic magmatic complexes, which were emplaced coeval with A-type granites in the composite terrane, are the products of postcollisional magmatism, instead of subduction-related Alaskan-type complexes.

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REFERENCES CITED

Allen, M., Windley, B., and Zhang, C., 1993, Palaeozoic collisional tectonics and magmatism of the Chinese Tienshan, Central Asia: Tectonophysics, v. 220, p. 89–115, doi: 10.1016/0040-1951(93)90225-9.

An, F., and Zhu, Y.F., 2008, Study on trace element geochemistry and SHRIMP chronology of volcanic rocks in Tulasu Basin: Northwest Tianshan: Acta Petrologica Sinica, v. 24, p. 2741–2748.

Badarch, G., Cunningham, W.D., and Windley, B.F., 2002, A new terrane subdivision for Mongolia: Implications for the Phanerozoic crustal growth of Central Asia: Journal of Asian Earth Sciences, v. 21, p. 87–110, doi: 10.1016/S1367-9120(02)00017-2.

BGMRXUAR (Bureau of Geology and Mineral Resources of Xinjiang Uygur Autonomous Region), 1993, Regional Geology of Xinjiang Uygur Autonomous Region: Beijing, Geological Publishing House, 841 p. (in Chinese with English summary).

Black, L.P., Kamo, S.L., Allen, C.M., Aleinikoff, J.N., Davis, D.W., Korsch, R.J., and Foudoulis, C., 2003a, TEMORA 1: A new zircon standard for Phanerozoic U-Pb geochronology: Chemical Geology, v. 200, p. 155–170, doi: 10.1016/S0009-2541(03)00165-7.

Black, L.P., Kamo, S.L., Williams, I.S., Mundil, R., Davis, D.W., Korsch, R.J., and Foudoulis, C., 2003b, The application of SHRIMP to Phanerozoic geochronology; a critical appraisal of four zircon standards: Chemical Geology, v. 200, p. 171–188, doi: 10.1016/S0009-2541(03)00166-9.

Briggs, S.M., Yin, A., Manning, C.E., Chen, Z.L., Wang, X.F., and Grove, M., 2007, Late Paleozoic tectonic history of the Ertix fault in the Chinese Altai and its implications for the development of the Central Asian orogenic system: Geological Society of America Bulletin, v. 119, p. 944–960, doi: 10.1130/B26044.1.

Buchan, C., Pfänder, J., Kröner, A., Brewer, T.S., Tomurtogoo, O., Tomurhuu, D., Cunningham, D., and Windley, B.F., 2002, Timing of accretion and collisional deformation in the Central Asian orogen: Implications of granite geochronology in the Bayankhongor ophiolite zone: Chemical Geology, v. 192, p. 23–45, doi: 10.1016/S0009-2541(02)00138-9.

Buckman, S., and Aitchison, J.C., 2001, Middle Ordovician (Llandeilan) radiolarians from West Junggar, Xinjiang, China: Micropaleontology, v. 47, p. 359–367, doi: 10.2113/47.4.359.

Bullen, M.E., Burbank, D.W., and Garver, J.I., 2003, Building the Northern Tien Shan: Integrated thermal, structural and topographic constraints: The Journal of Geology, v. 111, p. 149–165, doi: 10.1086/345840.

Buslov, M.M., Saphonova, I.Yu., Watanabe, T., Obut, O.T., Fujiwara, Y., Iwata, K., Semakov, N.N., Sugai, Y., Smirnova, L.V., and Kazansky, A.Yu., 2001, Evolution of the paleo–Asian Ocean (Altai-Sayan region, Central Asia) and collision of possible Gondwana-derived terranes with the southern marginal part of the Siberian continent: Geosciences Journal, v. 5, p. 203–224, doi: 10.1007/BF02910304.

Buslov, M.M., Watanabe, T., Fujiwara, Y., Iwata, K., Smirnova, L.V., Saphonova, I.Yu., Semakov, N.N., and Kiryanova, A.P., 2004, Late Paleozoic faults of the Altai region, Central Asia: Tectonic pattern and model of formation: Journal of Asian Earth Sciences, v. 23, p. 655–671, doi: 10.1016/S1367-9120(03)00131-7.

Carroll, A.R., Graham, S.A., Hendrix, M.S., Ying, D., and Zhou, D., 1995, Late Paleozoic tectonic amalgamation of northwestern China: Sedimentary record of the northern Tarim, northwestern Turpan, and southern Junggar Basins: Geological Society of America Bulletin, v. 107, p. 571–594, doi: 10.1130/0016-7606(1995)107<0571:LPTAON>2.3.CO;2.

Charvet, J., Shu, L.S., and Laurent-Charvet, S., 2007, Paleozoic structural and geodynamic evolution of eastern Tianshan (NW China): Welding of the Tarim and Junggar plates: Episodes, v. 30, p. 162–186.

Chen, B., and Arakawa, Y., 2005, Elemental and Nd-Sr isotopic geochemistry of granitoids from the West Junggar foldbelt (NW China), with implications for Phanerozoic continental growth: Geochimica et Cosmochimica Acta, v. 69, p. 1307–1320, doi: 10.1016/j.gca.2004.09.019.

Chen, B., and Jahn, B.M., 2004, Genesis of post-collisional granitoids and basement nature of the Junggar terrane, NW China: Nd-Sr isotope and trace element evidence: Journal of Asian Earth Sciences, v. 23, p. 691–703, doi: 10.1016/S1367-9120(03)00118-4.

Chen, B.H., Luo, Z.H., Jia, B.H., Liu, W., Wei, Y., and Han, Y.G., 2007, SHRIMP U-Pb zircon geochronology of igneous rocks from southern margin of the Alataw

Mountains, Xinjiang, China: Acta Petrologica Sinica, v. 23, p. 1756–1764.

Chen, J.F., Zhou, T.X., Xie, Z., Zhang, X., and Guo, X.S., 2000, Formation of positive εNd (T) granitoids from the Alataw Mountains, Xinjiang, China, by mixing and fractional crystallization: Implication for Phanerozoic crustal growth: Tectonophysics, v. 328, p. 53–67, doi: 10.1016/S0040-1951(00)00177-3.

Chen, Y.B., Hu, A.Q., Zhang, G.X., and Zhang, Q.F., 1999, Zircon U-Pb age and Nd-Sr isotopic composition of granitic gneiss and its geological implications from Precambrian window of western Tianshan, NW China: Geochimica, v. 28, p. 515–520.

Chen, Y.B., Hu, A.Q., Zhang, G.X., and Zhang, Q.F., 2000, Zircon U-Pb age of granitic gneiss on Duku highway in western Tianshan of China and its geological implications: Chinese Science Bulletin, v. 45, p. 649–653, doi: 10.1007/BF02886044.

Coleman, R.G., 1989, Continental growth of northwest China: Tectonics, v. 8, p. 621–635, doi: 10.1029/TC008i003p00621.

Compston, W., Williams, I.S., and Meyer, C., 1984, U-Pb geochronology of zircons from Lunar breccia 73217 using a sensitive high mass-resolution ion microprobe: Journal of Geophysical Research, v. 89, p. 525–534, doi: 10.1029/JB089iS02p0B525.

De Grave, J., Buslov, M. M., and Van den haute, P., 2007, Distant effects of India-Eurasia convergence and Mesozoic intracontinental deformation in Central Asia: Constraints from apatite fission-track thermochronology: Journal of Asian Earth Sciences, v. 29, p. 188–204, doi: 10.1016/j.jseaes.2006.03.001.

Dickinson, W.R., 2008, Accretionary Mesozoic-Cenozoic expansion of the Cordilleran continental margin in California and adjacent Oregon: Geosphere, v. 4, p. 329–353, doi: 10.1130/GES00105.1.

Dobretsov, N.L., Buslov, M.M., Delvaux, D., Berzin, N.A., and Ermikov, V.D., 1996, Meso- and Cenozoic tectonics of the central Asian mountain belt: Effects of lithospheric plate interaction and mantle plumes: International Geology Review, v. 38, p. 430–466.

Fedorovskii, V.S., Khain, E.E., Vladimirov, A.G., Kargopolov, S.A., Gibsher, A.S., and Izokh, A.E., 1995, Tectonics, metamorphism, and magmatism of collisional zones of the Central Asian Caledonides: Geotectonics, v. 29, p. 193–212.

Filippova, I.B., Bush, V.A., and Didenko, A.N., 2001, Middle Paleozoic subduction belts: The leading factor in the formation of the Central Asian fold-and-thrust belt: Russian Journal of Earth Sciences, v. 3, p. 405–426, doi: 10.2205/2001ES000073.

Frost, B.R., Barnes, C.G., Collins, W.J., Arculus, R.J., Ellis, D.J., and Frost, C.D., 2001, A geochemical classification for granitic rocks: Journal of Petrology, v. 42, p. 2033–2048, doi: 10.1093/petrology/42.11.2033.

Gao, J., Li, M.S., Xiao, X.C., Tang, Y.Q., and He, G.Q., 1998, Paleozoic tectonic evolution of the Tianshan orogen, northwestern China: Tectonophysics, v. 287, p. 213–231, doi: 10.1016/S0040-1951(97)00211-4.

Gu, L.X., Zhu, J.L., Guo, J.C., Liao, J.J., Yan, Z.F., Yang, H., and Wang, J.Z., 1994, The East Xinjiang–type mafic-ultramafic complexes in orogenic environments: Acta Petrologica Sinica, v. 10, p. 339–356.

Gu, L.X., Yu, C.S., Hu, S.X., and Li, H.Y., 2000, Carboniferous volcanites in the Bogda orogenic belt of eastern Tienshan: Their tectonic implications: Acta Petrologica Sinica, v. 16, p. 305–316.

Han, B.F., Wang, S.G., Jahn, B.M., Hong, D.W., Kagami, H., and Sun, Y.L., 1997, Depleted-mantle source for the Ulungur River A-type granites from North Xinjiang, China: Geochemistry and Nd-Sr isotopic evidence, and implications for Phanerozoic crustal growth: Chemical Geology, v. 138, p. 135–159, doi: 10.1016/S0009-2541(97)00003-X.

Han, B.F., He, G.Q., and Wang, S.G., 1999, Postcollisional mantle-derived magmatism, underplating and implications for basement of the Junggar Basin: Science in China–Earth Science, v. 42, p. 113–119.

Han, B.F., Ji, J.Q., Song, B., Chen, L.H., and Li, Z.H., 2004, SHRIMP zircon U-Pb ages of Kalatongke No. 1 and Huangshandong Cu-Ni–bearing mafic-ultramafic complexes, north Xinjiang, and geological implications: Chinese Science Bulletin, v. 49, p. 2424–2429, doi: 10.1360/04wd0163.

Han, B.F., Ji, J.Q., Song, B., Chen, L.H., and Zhang, L., 2006, Late Paleozoic vertical growth of continental crust around the Junggar Basin, Xinjiang, China (Part I): Timing of post-collisional plutonism: Acta Petrologica Sinica, v. 22, p. 1077–1086.

Han, C.M., Xiao, W.J., Zhao, G.C., Mao, J.W., Li, S.Z., Yan, Z., and Mao, Q.G., 2006, Major types, characteristics and geodynamic mechanism of Upper Paleozoic copper deposits in northern Xinjiang, northwestern China: Ore Geology Reviews, v. 28, p. 308–328, doi: 10.1016/j.oregeorev.2005.04.002.

Harper, G.D., Saleeby, J.B., and Heizler, M., 1994, Formation and emplacement of the Josephine ophiolite and the Nevadan orogeny in the Klamath Mountains, California-Oregon: U/Pb zircon and $^{40}Ar/^{39}Ar$ geochronology: Journal of Geophysical Research, v. 99, p. 4293–4321, doi: 10.1029/93JB02061.

He, G.Q., Liu, J.B., Zhang, Y.Q., and Xu, X., 2007, Keramay ophiolitic mélange formed during early Paleozoic in western Junggar Basin: Acta Petrologica Sinica, v. 23, p. 1573–1576.

Hendrix, M.S., Dumitru, T.A., and Graham, S.A., 1994, Late Oligocene–early Miocene unroofing in the Chinese Tien Shan: An early effect of the India-Asia collision: Geology, v. 22, p. 487–490, doi: 10.1130/0091-7613(1994)022<0487:LOEMUI>2.3.CO;2.

Hu, A.Q., Wei, G.J., Zhang, J.B., Deng, W.F., and Chen, L.L., 2008, SHRIMP U-Pb ages for zircons of the amphibolites and tectonic evolution significance from the Wenquan domain in the West Tianshan Mountains, Xinjiang, China: Acta Petrologica Sinica, v. 24, p. 2731–2740.

Iwata, K., Watanabe, T., Akiyama, M., Dobretsov, N.L., and Belyaev, S.Yu., 1994, Paleozoic microfossils from the Chara belt (eastern Kazakhstan): Russian Geology and Geophysics, v. 35, p. 145–151.

Iwata, K., Obut, O.T., and Buslov, M.M., 1997, Devonian and Lower Carboniferous radiolarians from the Chara ophiolite belt: East Kazakhstan: News Osaka Micropaleontologists, v. 10, Special Issue, p. 27–32.

Jahn, B.-M., Wu, F.Y., and Chen, B., 2000, Massive granitoid generation in Central Asia: Nd isotope evidence and implication for continental growth in the Phanerozoic: Episodes, v. 23, p. 82–92.

Jian, P., Liu, D.Y., Shi, Y.R., and Zhang, F.Q., 2005, SHRIMP dating of SSZ ophiolites from northern Xinjiang Province, China: Implications for generation of oceanic crust in the Central Asian orogenic belt, *in* Sklyarov, E.V., ed., Structural and Tectonic Correlation across the Central Asia Orogenic Collage: North-Eastern Segment; Guidebook and Abstract Volume of the Siberian Workshop IGCP-480: Irkutsk, Institute of the Earth Crust, Siberian Branch of Russian Academy of Sciences, p. 246.

Kelty, T.K., Yin, A., Dash, B., Gehrels, G.E., and Ribeiro, A.E., 2008, Detrital-zircon geochronology of Paleozoic sedimentary rocks in the Hangay-Hentey basin, north-central Mongolia: Implications for the tectonic evolution of the Mongol-Okhotsk Ocean in Central Asia: Tectonophysics, v. 451, p. 290–311, doi: 10.1016/j.tecto.2007.11.052.

Kepezhinskas, P.K., Kepizhinskas, K.B., and Pukhtel, I.S., 1991, Lower Paleozoic oceanic crust in Mongolian Caledonides: Sm-Nd isotope and trace element data: Geophysical Research Letters, v. 18, p. 1301–1304, doi: 10.1029/91GL01643.

Khain, E.V., Bibokova, E.V., Kröner, A., Zhuravlev, D.Z., Sklyarov, E.V., Fedotova, A.A., and Kravchenko-Berezhnoy, I.R., 2002, The most ancient ophiolites of the Central Asian fold belt: U-Pb and Pb-Pb zircon ages for the Dunzhugur complex, eastern Sayan, Siberia, and geodynamic implications: Earth and Planetary Science Letters, v. 199, p. 311–325, doi: 10.1016/S0012-821X(02)00587-3.

Khain, E.V., Bibikova, E.V., Salnikova, E.E., Kröner, A., Gibsher, A.S., Didenko, A.N., Degtyarov, K.E., and Fedotova, A.A., 2003, The palaeo–Asian Ocean in the Proterozoic and early Palaeozoic: New geochronologic data and palaeotectonic reconstructions: Precambrian Research, v. 122, p. 329–358, doi: 10.1016/S0301-9268(02)00218-8.

Kheraskova, T.N., Didenko, A.N., Bush, V.A., and Volozh, Y.A., 2003, The Vendian–early Paleozoic history of the continental margin of eastern Paleogondwana, Paleoasian ocean, and Central Asian foldbelt: Russian Journal of Earth Sciences, v. 5, p. 165–184, doi: 10.2205/2003ES000123.

Kovalenko, V.I., Yarmolyuk, V.V., Kovach, V.P., Kotov, A.B., Kozakov, I.K., Salnikova, E.B., and Larin, A.M., 2004, Isotopic provinces, mechanism of generation and sources of the continental curst in the Central Asian mobile belt: Geological and isotopic evidence: Journal of Asian Earth Sciences, v. 23, p. 605–627, doi: 10.1016/S1367-9120(03)00130-5.

Laurent-Charvet, S., Charvet, J., Monié, P., Chen, Y., and Shu, L.S., 2003, Late Paleozoic strike-slip shear zones in eastern Central Asia (NW China): New structural and geochronological data: Tectonics, v. 22, doi: 10.1029/2001TC901047.

Li, H.Q., Wang, D.H., Wan, Y., Qu, W.J., Zhang, B., Lu, Y.F., Mei, Y.P., and Zou, S.L., 2006, Isotopic geochronology study and its significance of the Lailisigao'er Mo deposit, Xinjiang: Acta Petrologica Sinica, v. 22, p. 2437–2443.

Li, J.Y., Zhu, B.Q., and Feng, Y.M., 1989, Unconformity of the Carboniferous Nanmingshui Formation with underlying ophiolites and its implications: Regional Geology of China, v. 8, p. 250–255.

Li, J.Y., Xiao, X.C., Tang, Y.Q., Zhao, M., Zhu, B.Q., and Feng, Y.M., 1990, Main characteristics of late Paleozoic plate tectonics in the southern part of East Junggar, Xinjiang: Geologica1 Review, v. 35, p. 305–316 (in Chinese with English abstract).

Li, J.Y., Xiao, X.C., and Chen, W., 2000, Late Ordovician continental basement of the eastern Junggar Basin in Xinjiang, NW China: Evidence from the Laojunmiao metamorphic complex on the northeast basin margin: Regional Geology of China, v. 19, p. 297–302.

Li, Q.G., Liu, S.W., Wang, Z.Q., Han, B.F., Shu, G.M., and Wang, T., 2008, Electron microprobe monazite geochronological constraints on the late Palaeozoic tectonothermal evolution in the Chinese Tianshan: Journal of the Geological Society of London, v. 165, p. 511–522, doi: 10.1144/0016-76492007-077.

Liu, Z.Q., Han, B.F., Ji, J.Q., and Li, Z.H., 2005, Ages and geochemistry of the post-collisional granitic rocks from eastern Alataw Mountains, Xinjiang, and implications for vertical crustal growth: Acta Petrologica Sinica, v. 21, p. 623–639.

Ludwig, K.R., 2003, User's Manual for Isoplot 3.00: A Geochronological Toolkit for Microsoft Excel: Berkeley Geochronological Center Special Publication 4, 71 p.

Mao, J.W., Pirajno, P., Zhang, Z.H., Chai, F.M., Wu, H., Chen, S.P., Cheng, L.S., Yang, J.M., and Zhang, C.Q., 2008, A review of the Cu-Ni sulphide deposits in the Chinese Tianshan and Altay orogens (Xinjiang Autonomous Region, NW China): Principal characteristics and ore-forming processes: Journal of Asian Earth Sciences, v. 32, p. 184–203, doi: 10.1016/j.jseaes.2007.10.006.

Mossakovsky, A.A., Ruzhentsev, S.V., Samygin, S.G., and Kheraskova, T.N., 1993, Central Asian fold belt: Geodynamic evolution and history of formation: Geotectonics, v. 6, p. 3–33.

Pearce, J.A., 1996, Sources and settings of granitic rocks: Episodes, v. 19, p. 120–125.

Pirajno, F., Mao, J.W., Zhang, Z.C., Zhang, Z.H., and Chai, F.M., 2008, The association of mafic-ultramafic intrusions and A-type magmatism in the Tianshan and Altay orogens, NW China: Implications for geodynamic evolution and potential for the discovery of new ore deposits: Journal of Asian Earth Sciences, v. 32, p. 165–183, doi: 10.1016/j.jseaes.2007.10.012.

Rudnick, R.L., Gao, S., Ling, W.L., Liu, Y.S., and McDonough, W.F., 2004, Petrology and geochemistry of spinel peridotite xenoliths from Hannuoba and Qixia, North China craton: Lithos, v. 77, p. 609–637, doi: 10.1016/j.lithos.2004.03.033.

Sengör, A.C., and Natal'in, B.A., 1996, Turkic-type orogeny and its role in the making of continental crust: Annual Review of Earth and Planetary Sciences, v. 24, p. 263–337, doi: 10.1146/annurev.earth.24.1.263.

Sengör, A.C., Natal'in, B.A., and Burtman, V.S., 1993, Evolution of the Altaid tectonic collage and Palaeozoic crustal growth in Eurasia: Nature, v. 364, p. 299–306, doi: 10.1038/364299a0.

Shi, Y.R., Liu, D.Y., Zhang, Q., Jian, P., Zhang, F.Q., and Miao, L.C., 2007, SHRIMP zircon U-Pb dating of the Gangou granitoids, Central Tianshan Mountains, northwest China, and tectonic significances: Chinese Science Bulletin, v. 52, p. 1507–1516, doi: 10.1007/s11434-007-0204-2.

Shu, L.S., and Wang, Y.J., 2003, Late Devonian–early Carboniferous radiolarian fossils from siliceous rocks of the Kelameili ophiolite, Xinjiang: Geological Review, v. 49, p. 408–412.

Shu, L.S., Zhu, W.B., Wang, B., Faure, M., Charvet, J., and Cluzel, D., 2005, The post-collision intracontinental rifting and olistostrome on the southern slope of Bogda Mountains, Xinjiang: Acta Petrologica Sinica, v. 21, p. 25–36.

Su, C.Q., Yang, X.K., Cui, J.J., and Liu, J.Q., 2006, Redefinition of the Devonian-Permian in the Tengger Mountain–Ewirgol area, eastern segment of the West Tianshan Mountains, and its geological significance: Geology of China, v. 33, p. 516–528.

Su, Y.P., Tang, H.F., Hou, G.S., and Liu, C.Q., 2006a, Geochemistry of aluminous A-type granites along Darabut tectonic belt in West Junggar, Xinjiang: Geochimica, v. 35, p. 55–67.

Su, Y.P., Tang, H.F., Liu, C.Q., Hou, G.S., and Liang, L.L., 2006b, The determination and a preliminary study of Sujiquan aluminous A-type granites in East Junggar: Xinjiang: Acta Petrologica et Mineralogica, v. 25, p. 175–184.

Su, Y.P., Tang, H.F., and Cong, F., 2008, Zircon U-Pb age and petrogenesis of the Huangyangshan alkaline granite body in East Junggar, Xinjiang: Acta Mineralogica Sinica, v. 28, p. 117–126.

Sun, M., Yuan, C., Xiao, W.J., Long, X.P., Xia, X.P., Zhao, G.C., Lin, S.F., Wu, F.Y., and Kröner, A., 2008, Zircon U-Pb and Hf isotopic study of gneissic rocks from the Chinese Altai: Progressive accretionary history in the early to middle Palaeozoic: Chemical Geology, v. 247, p. 352–383, doi: 10.1016/j.chemgeo.2007.10.026.

Sun, S.S., and McDonough, W.F., 1989, Chemical and isotopic systematics of oceanic basalts: Implications for mantle composition and processes, *in* Saunders, A.D., and Norry, M.J., eds., Magmatism in the Ocean Basins: Geological Society of London Special Publication 42, p. 313–345.

Tang, G.J., Chen, H.H., Wang, Q., Zhao, Z.H., Wyma, D.A., Jiang, Z.Q., and Jia, X.H., 2008, Geochronological age and tectonic background of the Dabate A-type granite pluton in the west Tianshan: Acta Petrologica Sinica, v. 24, p. 947–958.

Tang, H.F., Qu, W.J., Su, Y.P., Hou, G.S., Du, A.D., and Cong, F., 2007a, Genetic connection of Sareshike tin deposit within the alkaline A-type granites of Sabei body in Xinjiang, constraint from isotopic ages: Acta Petrologica Sinica, v. 23, p. 1989–1997.

Tang, H.F., Su, Y.P., Liu, C.Q., Hou, G.S., and Wang, Y.B., 2007b, Zircon U-Pb age of the plagiogranite in Kalamaili belt, northern Xinjiang, and its tectonic implications: Geotectonica et Metallogenia, v. 31, p. 110–117.

Tong, Y., Hong, D.W., Wang, T., Wang, S.G., and Han, B.F., 2006, TIMS U-Pb zircon ages of Fuyun post-orogenic linear granite plutons on the southern margin of Altay orogenic belt and their implications: Acta Petrologica et Mineralogica, v. 25, p. 85–89.

Vladimirov, A.G., Kozlov, M.S., Shokalsky, S.P., Khalilov, V.A., Rudnev, S.N., Kruk, N.N., Vystavnoi, S.A., Borisov, S.M., Berezikov, Yu.K., Metsner, A.N., Babin, G.A., Mamlin, A.N., Murzin, O.M., Nazarov, G.V., and Makarov, V.A., 2001, Major epochs of intrusive magmatism of Kuznetsk Alatau, Altai, and Kalba (from U-Pb isotope dates): Russian Geology and Geophysics, v. 42, p. 1089–1109.

Vladimirov, A.G., Kruk, N.N., Rudnev, S.N., and Khromykh, S.V., 2003, Geodynamics and granitoid magmatism of collision orogens: Russian Geology and Geophysics, v. 44, p. 1275–1292.

Vladimirov, A.G., Kruk, N.N., Khromykh, S.V., Polyansky, O.P., Chervov, V.V., Vladimirov, V.G., Travin, A.V., Babin, G.A., Kuibida, M.L., and Khomyakov, V.D., 2008, Permian magmatism and lithospheric deformation in the Altai caused by crustal and mantle thermal processes: Russian Geology and Geophysics, v. 49, p. 468–479, doi: 10.1016/j.rgg.2008.06.006.

Volkova, N.I., and Sklyarov, E.V., 2007, High-pressure complexes of Central Asian fold belt: Geologic setting, geochemistry, and geodynamic implications: Russian Geology and Geophysics, v. 48, p. 83–90, doi: 10.1016/j.rgg.2006.12.008.

Wallin, E.T., and Metcalf, R.V., 1998, Supra-subduction zone ophiolite formed in an extensional forearc: Trinity terrane, Klamath Mountains, California: The Journal of Geology, v. 106, p. 591–608.

Wang, B., Faure, M., Cluzel, D., Shu, L., Charvet, J., Meffre, S., and Ma, Q., 2006, Late Paleozoic tectonic evolution of the northern West Chinese Tianshan belt: Geodinamica Acta, v. 19, p. 237–247, doi: 10.3166/ga.19.237-247.

Wang, B., Chen, Y., Zhan, S., Shu, L., Faure, M., Cluze, D., Charvet, J., and Laurent-Charvet, S., 2007a, Primary Carboniferous and Permian paleomagnetic results from the Yili block (NW China) and their implications on the geodynamic evolution of Chinese Tianshan belt: Earth and Planetary Science Letters, v. 263, p. 288–308, doi: 10.1016/j.epsl.2007.08.037.

Wang, B., Shu, L.S., Cluzel, D., Faure, M., and Charvet, J., 2007b, Geochronological and geochemical studies on the Boruhoro plutons, north of Yili, NW Tianshan and their tectonic implication: Acta Petrologica Sinica, v. 23, p. 1885–1900.

Wang, H.L., Xu, X.Y., He, S.P., and Chen, J.L., eds., 2007, Geological Map of Tianshan and Adjacent Regions of China: Beijing, Geological Publishing House, scale 1:1,000,000, 2 sheets (in Chinese).

Wang, Q., Wyman, D.A., Zhao, Z.H., Xu, J.F., Bai, Z.H., Xiong, X.L., Dai, T.M., Li, C.F., and Chu, Z.Y., 2007, Petrogenesis of Carboniferous adakites and Nb-enriched arc basalts in the Alataw area, northern Tianshan Range (western China): Implications for Phanerozoic crustal growth in the Central Asia orogenic belt: Chemical Geology, v. 236, p. 42–64, doi: 10.1016/j.chemgeo.2006.08.013.

Wang, T., Hong, D.W., Jahn, B.M., Tong, Y., Wang, Y.B., Han, B.F., and Wang, X.X., 2006, Timing, petrogenesis, and setting of Paleozoic synorogenic intrusions from the Altai Mountains, northwest China: Implications for the tectonic evolution of an accretionary orogen: The Journal of Geology, v. 114, p. 735–751, doi: 10.1086/507617.

Wang, T., Jahn, B.M., Kovach, V.P., Tong, Y., Hong, D.W., and Han, B.F., 2009, Nd-Sr isotopic mapping of the Chinese Altai and implications for continental growth in the Central Asian orogenic belt: Lithos, v. 110, p. 359-372, doi: 10.1016/j.lithos.2009.02.001.

Wang, W., Wei, C.J., Wang, T., Lou, Y.X., and Chu, H., 2009, Confirmation of pelitic granulite in the Altai orogen and its geological significance: Chinese Science Bulletin, v. 54, p. 2543–2548, doi: 10.1007/s11434-009-0041-6.

Wang, Y.X., Gu, L.X., Zhang, Z.Z., Wu, C.Z., Zhang, K.J., Li, H.M., and Yang, J.D., 2006, Geochronology and Nd-Sr-Pb isotopes of the bimodal volcanic rocks of the Bogda rift: Acta Petrologica Sinica, v. 22, p. 1215–1224.

Wang, Z.L., Mao, J.W., Zhang, Z.H., Zuo, G.C., and Wang, L.S., 2006, Geology, time-space distribution and metallogenic geodynamic evolution of porphyry copper (molybdenum) deposits in the Tianshan Mountains: Acta Geologica Sinica, v. 80, p. 943–955.

Wei, C.J., Clarke, G., Tian, W., and Qiu, L., 2007, Transition of metamorphic series from the kyanite- to andalusite-types in the Altai orogen, Xinjiang, China: Evidence from petrography and calculated KMnFMASH and KFMASH phase relations: Lithos, v. 96, p. 353–374, doi: 10.1016/j.lithos.2006.11.004.

Whattam, S.A., Malpas, J., Smith, I.E.M., and Ali, J.R., 2006, Link between SSZ ophiolite formation, emplacement and arc inception, Northland, New Zealand: U-Pb SHRIMP constraints; Cenozoic SW Pacific tectonic implications: Earth and Planetary Science Letters, v. 250, p. 606–632, doi: 10.1016/j.epsl.2006.07.047.

Windley, B.F., Kröner, A., Guo, J.H., Qu, G.S., Li, Y.A., and Zhang, C., 2002, Neoproterozoic to Paleozoic geology of the Altai orogen, NW China: New zircon age data and tectonic evolution: The Journal of Geology, v. 110, p. 719–739, doi: 10.1086/342866.

Windley, B.F., Allen, M.B., Zhang, C., Zhao, Z.Y., and Wang, G.R., 1990, Paleozoic accretion and Cenozoic redeformation of the Chinese Tien Shan Range, Central Asia: Geology, v. 18, p. 128–131, doi: 10.1130/0091-7613(1990)018<0128:PAACRO>2.3.CO;2.

Windley, B.F., Alexeiev, D., Xiao, W.J., Kröner, A., and Badarch, G., 2007, Tectonic models for accretion of the Central Asian orogenic belt: Journal of the Geological Society of London, v. 164, p. 31–47, doi: 10.1144/0016-76492006-022.

Wright, J.E., and Wyld, S.J., 1986, Significance of xenocrystic Precambrian zircon contained within the southern continuation of the Josephine ophiolite: Devils Elbow ophiolite remnant, Klamath Mountains, northern California: Geology, v. 14, p. 671–674, doi: 10.1130/0091-7613(1986)14<671:SOXPZC>2.0.CO;2.

Wu, F.Y., Wilde, S.A., Zhang, G.L., and Sun, D.Y., 2004, Geochronology and petrogenesis of the post-orogenic Cu–Ni sulfide-bearing mafic-ultramafic complexes in Jilin Province, NE China: Journal of Asian Earth Sciences, v. 23, p. 781–797, doi: 10.1016S1367-9120(03)00114-7.

Xiao, W.J., Windley, B.F., Hao, J., and Zhai, M.G., 2003, Accretion leading to collision and the Permian Solonker suture, Inner Mongolia, China: Termination of the Central Asian orogenic belt: Tectonics, v. 22, p. 1069, doi: 10.1029/2002TC001484.

Xiao, W.J., Windley, B.F., Badarch, G., Sun, S., Li, J.L., Qin, K.Z., and Wang, Z., 2004a, Palaeozoic accretionary and convergent tectonics of the southern Altaids: Implications for the growth of Central Asia: Journal of the Geological Society of London, v. 161, p. 339–342.

Xiao, W.J., Zhang, L.C., Qin, K.Z., Sun, S., and Li, J.L., 2004b, Paleozoic accretionary and collisional tectonics of the eastern Tienshan (China): Implications for the continental growth of Central Asia: American Journal of Science, v. 304, p. 370–395, doi: 10.2475/ajs.304.4.370.

Xiao, W.J., Windley, B.F., Yan, Q.R., Qin, K.Z., Chen, H.L., Yuan, C., Sun, M., Li, J.L., and Sun, S., 2006, SHRIMP zircon age of the Aermantai ophiolite in the north Xinjiang, China, and its tectonic implications: Acta Geologica Sinica, v. 80, p. 32–36.

Xiao, W.J., Han, C.M., Yuan, C., Sun, M., Lin, S.F., Chen, H.L., Li, Z.L., Li, J.L., and Sun, S., 2008, Middle Cambrian to Permian subduction-related accretionary orogenesis of northern Xinjiang, NW China: Implications for the tectonic evolution of Central Asia: Journal of Asian Earth Sciences, v. 32, p. 102–117, doi: 10.1016/j.jseaes.2007.10.008.

Xiao, X.C., Tang, Y.Q., Feng, Y.M., Zhu, B.Q., Li, J.Y., and Zhao, M., 1992, Tectonic Evolution of Northern Xinjiang and its Adjacent Regions: Beijing, Geological Publishing House, 169 p. (in Chinese with English abstract).

Xu, X.Y., Ma, Z.P., Xia, L.Q., Wang, Y.B., Li, X.M., Xia, Z.C., and Wang, L.S., 2005, SHRIMP dating of plagiogranites from Bayingou ophiolite in the northern Tianshan Mountains: Geological Review, v. 22, p. 523–527.

Xu, X.Y., Li, X.M., Ma, Z.P., Xia, L.Q., Xia, Z.C., and Pen, G.X., 2006a, LA-ICPMS zircon U-Pb dating of gabbro from the Bayingou ophiolite in the northern Tianshan Mountains: Acta Geologica Sinica, v. 80, p. 1168–1176.

Xu, X., He, G.Q., Li, H.Q., Ding, T.F., Liu, X.Y., and Mei, S.W., 2006b, Basic characteristics of the Karamay ophiolitic mélange, Xinjiang, and its zircon SHRIMP dating: Geology in China, v. 33, p. 470–475.

Yakubchuk, A., 2004, Architecture and mineral deposit settings of the Altaid orogenic collage: A revised model: Journal of Asian Earth Sciences, v. 23, p. 761–779, doi: 10.1016/j.jseaes.2004.01.006.

Yang, J.H., Wu, F.Y., Chung, S.L., Chu, M.F., and Wilde, S.A., 2004, Multiple sources for the origin of granites: Geochemical and Nd/Sr isotopic evidence from the Gudaoling granite and its mafic enclaves, northeast China: Geochimica et Cosmochimica Acta, v. 68, p. 4469–4483, doi: 10.1016/j.gca.2004.04.015.

Yang, T.N., Li, J.Y., Sun, G.H., and Wang, Y.B., 2006a, Earlier Devonian active continental arc in Central Tianshan: Evidence of geochemical analyses and zircon SHRIMP dating on mylonitized granitic rock: Acta Petrolgica Sinica, v. 22, p. 41–48.

Yang, X.K., Su, C.Q., Chen, H., Zhang, H.J., Yan, H.Q., Li, X.F., and Kiu, J.Q., 2006b, Discovery of the Permian volcanic rocks in the Bingdaban-Houxia, Tianshan Mountains, and its geological significance: Geological Bulletin of China, v. 25, p. 969–976.

Yin, A., Nie, S., Craig, P., Harrison, T.M., Ryerson, F.J., Qian, X.L., and Yang, G., 1998, Late Cenozoic tectonic evolution of the southern Chinese Tian Shan: Tectonics, v. 17, p. 1–27, doi: 10.1029/97TC03140.

Yuan, C., Sun, M., Xiao, W.J., Li, X.H., Chen, H.L., Lin, S.F., Xia, X.P., and Long, X.P., 2007, Accretionary orogenesis of the Chinese Altai: Insights from Paleozoic granitoids: Chemical Geology, v. 242, p. 22–39, doi: 10.1016/j.chemgeo.2007.02.013.

Zhai, W., Sun, X.M., Gao, J., He, X.P., Liang, J.L., Miao, L.C., and Wu, Y.L., 2006, SHRIMP dating of zircons from volcanic host rocks of Dahalajunshan Formation in Axi gold deposit, Xinjiang, China, and its geological implications: Acta Petrologica Sinica, v. 22, p. 1399–1404.

Zhang, C., Zhai, M.G., Allen, M.B., Sounders, A.D., Wang, G.R., and Huang, X., 1993, Implications of Palaeozoic ophiolites from Western Junggar, NW China, for the tectonics of Central Asia: Journal of the Geological Society of London, v. 150, p. 551–561.

Zhang, H.X., Niu, H.C., Terada, K., Yu, X.Y., Sato, H., and Ito, J., 2003, Zircon SHRIMP U-Pb dating on plagiogranite from the Kuerti ophiolite in Altay, north Xinjiang: Chinese Science Bulletin, v. 48, p. 2231–2235, doi: 10.1360/02wd0593.

Zhang, H.X., Shen, X.M., Ma, L., Niu, H.C., and Yu, X.Y., 2008, Geochronology of the Fuyun adakites, north Xinjiang, and its constraint to the initiation of the paleo–Asian Ocean subduction: Acta Petrologica Sinica, v. 24, p. 1054–1058.

Zhang, L.F., 1997, $^{40}Ar/^{39}Ar$ age of blueschists in Tangbale, western Junggar, Xinjiang, and its significance: Chinese Science Bulletin, v. 42, p. 2178–2181.

Zhao, Z.H., Xiong, X.L., Wang, Q., Wyman, D.A., Bao, Z.W., Bai, Z.H., and Qiao, Y.L., 2008, Underplating-related adakites in Xinjiang Tianshan, China: Lithos, v. 102, p. 374–391, doi: 10.1016/j.lithos.2007.06.008.

Zheng, J.P., Sun, M., Zhao, G.C., Robinson, P.T., and Wang, F.Z., 2007, Elemental and Sr-Nd-Pb isotopic geochemistry of late Paleozoic volcanic rocks beneath the Junggar basin, NW China: Implications for the formation and evolution of the basin basement: Journal of Asian Earth Sciences, v. 29, p. 778–794, doi: 10.1016/j.jseaes.2006.05.004.

Zhou, T.F., Yuan, F., Tan, L.G., Fan, Y., and Yue, S.C., 2006, Geodynamic significance of the A-type granites in the Sawuer region in West Junggar, Xinjiang: Rock geochemistry and SHRIMP zircon age evidence: Science in China–Earth Sciences, ser. D, v. 49, p. 113–123, doi: 10.1007/s11430-005-0121-7.

Zhu, Y.F., and Song, B., 2006, Petrology and SHRIMP chronology of mylonitized Tianger granite, Xinjiang: Also about the dating on hydrothermal zircon rim in granite: Acta Petrologia Sinica, v. 22, p. 135–144.

Zhu, Y.F., and Xu, X., 2006, The discovery of early Ordovician ophiolite mélange in Taerbahatai Mts., Xinjiang, NW China: Acta Petrologica Sinica, v. 22, p. 2833–2842.

Zhu, Y.F., Zhang, L.F., Gu, L.B., Guo, X., and Zhou, J., 2005, The zircon SHRIMP chronology and trace element geochemistry of the Carboniferous volcanic rocks in western Tianshan Mountains: Chinese Science Bulletin, v. 50, p. 2201–2212, doi: 10.1360/03wd0154.

Zhu, Y.F., Xu, X., Chen, B., and Xue, Y.X., 2008, Dolomite marble and garnet amphibolite in the ophiolitic mélange in western Junggar: Relics of the early Paleozoic oceanic crust and its deep subduction: Acta Petrologica Sinica, v. 24, p. 2767–2777.

Zonenshain, L.P., Kuzmin, M.I., and Natapov, L.M., 1990, Geology of the USSR: A Plate-Tectonic Synthesis: Washington, D.C., American Geophysical Union, 242 p.

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