Postcollisional Eastward Extrusion and Tectonic Exhumation along the Eastern Tianshan Orogen, Central Asia: Constraints from Dextral Strike-Slip Motion and \(^{40}\text{Ar}/^{39}\text{Ar}\) Geochronological Evidence

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ABSTRACT

Postcollisional extrusion and tectonic evolution in the eastern Tianshan orogenic belt (ETOB) remains poorly known, especially the mechanism of dextral strike-slip motion and associated tectonic exhumation. To better constrain this development, a structural and \(^{40}\text{Ar}/^{39}\text{Ar}\) geochronological study was carried out on a syndextral strike-slip intrusion—the Jueluotag batholith—as well as on other granitic plutons in the ETOB. \(^{40}\text{Ar}/^{39}\text{Ar}\) analyses of hornblende, biotite, K-feldspar, and plagioclase from quartz-mica diorite, granodiorite, and dioritic porphyry dykes were used to construct cooling histories of the ETOB. Hornblendes have cooling ages of 277–272 Ma, similar to the syntectonic granitic intrusions, but biotite ages are 261–254 Ma along the syndextral strike-slip pluton from east to west. The dextral strike-slip motion cuts through ∼268-Ma dioritic porphyry dikes as well. From these data we conclude that dextral strike-slip motion occurred from ∼270 to 245 Ma. Based on the syntectonic granitic intrusions, structural features, and cooling ages along or outside of the dextral strike-slip belt, we demonstrate that a positive flower structure is the main structural framework for the Paleozoic northern segment of the ETOB. Rapid cooling and tectonic exhumation occurred during ∼240–220 Ma along the ETOB but did not occur in the western Tianshan orogen. The central Tianshan crystalline belt along the Gangou-Aqikekuduk fault zone was cut and offset southeastward by the dextral strike-slip motion. This suggests that dextral strike-slip motion occurred later than sinistral strike-slip along the southern margin of the ETOB. Geological features and age constraints suggest that the postcollisional eastward extrusion occurred at ∼270–245 Ma with dextral strike-slip motion, syntectonic granitic intrusions, and synextrusion tectonic exhumation.

Online enhancements: appendix, table, extended figure.

Introduction

The eastern Tianshan orogenic belt (ETOB) is located in the southern part of the central Asian Orogenic Belt (fig. 1). A common interpretation of the early Paleozoic evolution and collisional processes in the ETOB is that during pre-Carboniferous time, the Tianshan orogenic belt was characterized by island-arc and oceanic basins (Coleman 1989; Windley et al. 1990; Xiao et al. 1992, 2004, 2008; Allen et al. 1993a, 1993b; Ma et al. 1993; Yin and Nie 1996; Gao et al. 1998; Dumitru et al. 2001; Zhou et al. 2001; Li et al. 2002; Li 2004). During the Late Carboniferous–Early Permian, the area was thought to have experienced collision or accretion caused by the convergence among the Kazakhstan, Kalakum-Tarim, and Siberian plates (Şengör et al. 1993; Şengör and Natal’in 1996; Li et al. 2003).

Questions remain about the tectonic origin of different exhumation histories in the eastern and western Tianshan orogenic belt, principally on the formation of the great dextral strike-slip faults. Li et al. (2002) described the structural framework of the northeastern Tianshan as an asymmetric fan of thrust faults, wider on the south than on the north. They proposed a three-stage model for the formation and evolution of the fault system: southvergent thrusting, vertical extrusion by compression, and dextral strike-slip motion. Xu (1996) and Xu et al. (2003) suggested that deformation in the eastern Tianshan was the result of coaxial N-S compression, not dextral motion. Laurent-Charvet...
Figure 1. Regional tectonics and main faults in the eastern Tianshan and adjacent regions (simplified from Li et al. 2003). The western and eastern regions of Tianshan are separated by the 80°E longitude line. Figure 2 is also shown. CAOB = Central Asian Orogenic Belt.
et al. (2003) suggested that northward motion of the Tarim Block resulted in dextral strike-slip deformation of the Tianshan. However, the mechanism of that dextral strike-slip motion is still unclear. Their hypothesis did not explain the structural framework, such as dextral strike-slip motion, distributions of postcollisional granitic plutons, or differential tectonic exhumation along the west and ETOB. Documenting these issues will allow us to better reconstruct the tectonic framework in west China and improve the mineral resource exploration along the Tianshan orogenic belt.

Based on field investigations of deformation associated with compression and dextral shear, as well the $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology of granitic batholiths along the shear zone, we document the duration of dextral shear, emplacement ages of granitic intrusions, and the tectonic exhumation of the Tianshan orogenic belt, all of which lead to a better understanding of the tectonic evolution of the eastern Tianshan orogen.

Geological Characteristics

**Tectonic Setting.** The Tianshan orogenic belt is bounded by the Tarim Block to the south and the Siberian plate to the north. The eastern and western Tianshan are separated by the 88°E longitude line (Li et al. 2006). The ETOB is composed of three segments: north, central, and south (fig. 2). The central and northern ETOB are separated by the Kawabulak Gangou-Aqikekuduk fault, while the central and southern segments of the ETOB are separated by the Dacaotan fault zone (figs. 2, 3). Several E-W-striking fault zones comprise the northern segment of the ETOB—from north to south, the Dacaotan, Kangguertag, and Jiabaishan faults.

Because of different closure times for the southern and northern segments of the ETOB (Chen et al. 1999; Li et al. 2002, 2003; Li 2004), various oceanic and crystalline rocks and stratigraphic sequences were exposed. In the northern segment, Carboniferous island-arc and oceanic sedimentary rocks are exposed. Ma et al. (1993) suggested that this is an arc-island collisional zone from the interarc basins on the northern Tarim Block.

The ETOB is also characterized by emplacement of several mafic-ultramafic complexes and A-type granitic intrusions at $\sim$280–270 Ma (Xinjiang Bureau of Geology and Mineral Resources 1987; Han et al. 1997, 1998; Zhou et al. 2004). Most of the granite bodies occur in the northern segment, although a few are found in the northern part of the central segment. None have been observed in the southern ETOB or in the western Tianshan (fig. 2).

**Structural Features of the Kangguertag-Huangshan Tectonic Belt.** The Kangguertag-Huangshan tectonic belt is a $\sim$600-km-long and 5–30-km-wide structural zone (figs. 2–5). On the northern side of the Kangguertag fault are Devonian-Carboniferous volcano-sedimentary sequences, with basaltic rocks, andesitic tuffs, and limestones containing Carboniferous fossils (Li et al. 2002; Li 2004). Between the Kangguertag and Jiabaishan faults, are basaltic rocks, flysch, and Devonian(?)-Carboniferous passive continental marginal sedimentary rocks. All of them are covered by an Early Carboniferous relict oceanic basin volcano-sedimentary system (Li et al. 2002).

Also on the northern side of the Kangguertag fault is the S-dipping, N-vergent Dacaotan thrust fault (figs. 2–4). In general, the associated cleavage dips to south and near vertical adjacent to the fault zone (figs. 3 and 4). On the cleavage surface is a subhorizontal sliding lineation, suggesting a component of dextral slip. Within the volcano-sedimentary sequences, steep to vertical-dipping cleavages (fig. 6) and dextral strike-slip deformation coexist. South-vergent inclined folding dips 40°–45° north and N-dipping mylonitic foliation within the Carboniferous limestone and marble also occur (fig. 7A, 7B). These features indicate S-vergent crustal contraction (such as fig. 7A–7C). Superposed structural fabrics indicate that this deformation is earlier than the E-W-trending dextral strike-slip deformation. On the southern side of the fault zone, foliation is from vertical to shallow-dipping to north.

Between the Jiabaishan and Aqikekuduk faults, deformational structures are weaker than those developed along the Kangguertag fault zone. Within the fault zone, a 5-m-wide N-S-trending dextral porphyry dike was dextrally offset by 10–30 m.

In summary, the Kangguertag-Huangshan tectonic belt consists of an older deformational phase characterized by S-vergent faults and folds. After the dextral strike-slip motion, structural framework was built up of as a positive flower feature (such as fig. 3).

**Tongue-Shaped Batholith in the Kangguertag Area.** Granitic plutons, intruded into Carboniferous and Early Permian volcano-sedimentary sequences, are distributed along the Kangguertag dextral shear zone (figs. 2, 5). A tongue-shaped pluton (the Jueluotag pluton) $\sim$20.5 km long and 6.5 km wide intruded into the upper Carboniferous Gandun Formation. It is bounded by the Dacaotan and Kangguertag faults (figs. 2, 3). On both the northern and southern sides of this batholith, Carboniferous volcanic rocks and strata ($\sim$350–300 Ma) are in-
Figure 2. Simplified tectonic diagram based on the TM images and the sampled site in the eastern Tianshan orogenic belt. Positions of the structural cross sections in figure 3 are shown, as well as those in figures 4, 5, and 7. Several main faults are shown: the Gangou-Aqikekuduk, Dacaotan, Jiabaishan, Gongbaizi, and Kawabulak faults and the Kangguertag-Huangshan tectonic belt. K = K-feldspar, B = biotite, H = hornblende, Pl = plagioclase.
Figure 3. Structural cross sections in the north and central Tianshan orogenic belt. Along the northern segment of the eastern Tianshan orogenic belt, a positive flower structure is composed of several main faults (Dacaotan, Kangguertag, Yamansu, Aqikekuduk). Locations are shown in figure 2. B1-B1' geologic corridor is parallel to structural cross section of B-B'.
involved in the compression and dextral shear deformation [figs. 3, 4, 7C–7H]. This has resulted in bedding that dips from 350° to 30° north and 180° to 200° south (fig. 6). Syndextral shear rotated granitic bodies and related dextral strike-slip shear-related fabrics are observed in the field [figs. 4, 5, 7F–7H]. Dextral strike-slip movement offsets granitic and quartz veins that cut axial-plane cleavages.

The tongue-shaped pluton is composed of plagiogranite, adamellite, granitite, and quartz-diorite. A U-Pb zircon age of 286 ± 13 Ma was obtained for the quartz-diorite (Xinjiang Bureau of Geology and Mineral Resources 1987). The deformed and metamorphosed country rock on the eastern side of the pluton exhibits transpressional features, such as inclined folds and steeply dipping cleavages (fig. 7D), and low-grade contact-thermal metamorphism, such as albite-epidote-hornfels facies. On the northwestern side of the pluton, there is high-grade thermal-contact metamorphism, such as beerbachite. Southwest of the

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**Figure 4.** Local structural corridor and cross section in eastern Tianshan [location is shown in fig. 2]. Abbreviations are the same as in figure 3.
Figure 5. Local structures and correlated granitic pluton (tongue-shaped batholith) in the Jueluotag area (modified from Xinjiang Bureau of Geology and Mineral Resources 1987). Stereograms of Devonian-Carboniferous bedding and cleavages are shown in figure 6. $^{40}$Ar/$^{39}$Ar age data and sampled sites are also shown. K = K-feldspar, B = biotite, H = hornblende.
The country rocks occur with deformed granitic dykes and quartz veins (fig. 7F), both of which indicate the dextral strike-slip shearing deformation.

Along the same dextral strike-slip zone and on the eastern side of the tongue-shaped pluton is a biotite-adamellite pluton (fig. 2), deformed by the dextral shearing (see fig. 4). Likewise dioritic porphyry dykes in the area are displaced by E-W-trending dextral shear. Only the margins of the pluton and surrounding country rocks have been deformed.

**Sampling Methods**

We sampled the eastern and northwestern parts of the tongue-shaped granitic batholith and surrounding country rocks as well as other plutons from the central Tianshan orogenic belt. Sample locations are shown in figures 2 and 5. Four hornblende, five biotite, seven potassium feldspar, and one plagioclase samples separate from granitic and dioritic porphyry rocks were analyzed for \( {^{40}}\text{Ar}/^{39}\text{Ar} \) geochronology. The \( {^{40}}\text{Ar}/^{39}\text{Ar} \) analyses were completed on a MM-5400 micromass spectrometer in the China University of Geosciences (Beijing). For experimental procedures, see the appendix, available in the online edition or from the *Journal of Geology* office.

The \( {^{40}}\text{Ar}/^{39}\text{Ar} \) data are listed in table A1, available in the online edition or from the *Journal of Geology* office and table 1. Selected release spectra are shown in figure 8, and other spectra are available in figure A1 in the online edition or from the *Journal of Geology* office.

**Analytical Results**

**The Tongue-Shaped Granitic Pluton.** Within the tongue-shaped granitic pluton, three hornblende samples [D256H, D255H, and D254H] from different positions yield \( {^{40}}\text{Ar}/^{39}\text{Ar} \) plateau ages of 277 ± 2, 272 ± 2, and 278 ± 2 Ma, respectively (table 1). Isochron ages for these three samples are the same as the plateau ages, within error. Three biotite samples—D256B, D255B, and D254B—from the same rocks as the hornblende yield \( {^{40}}\text{Ar}/^{39}\text{Ar} \) plateau ages of 261 ± 1, 257 ± 1, and 254 ± 2 Ma, respectively. The isochron ages are similar to their plateau ages. K-feldspars (D256K, D255K, and D254K) yield \( {^{40}}\text{Ar}/^{39}\text{Ar} \) plateau ages of 240 ± 4, 226 ± 1, and 241 ± 5 Ma, respectively.

Three samples yield an age span (226–241 Ma) for their preferred ages (PA) and weighted mean plateau ages (WMPA). The isochron age of D256K is 242 ± 6 Ma. And samples D254K and D255K yield isochron ages of 236 ± 6 and 225 ± 1 Ma. The plateau and isochron ages are similar to each other.

**Samples from Around the Tongue-Shaped Pluton.** On the southern side of the tongue-shaped pluton, samples D251K and D253K (K-feldspar) yield preferred ages of 231 ± 3 and 230 ± 2 Ma. Sample D259, hornblende and biotite, from the northeastern side of the pluton, yields an apparent age of 386 ± 6 Ma and a preferred age of 376 ± 4 Ma. Sample D265K from ~50 km east of the pluton (in the dextral strike-slip motion), yields a weighted mean plateau age of 239 ± 1 Ma.

Along the ETOB, dioritic porphyry dykes cut and offset by the dextral strike-slip fault zone yield a plagioclase apparent age of 268 ± 3 Ma. Another sample, D57 from the southern side of the Aqike-kuduk fault zone, yields a biotite \( {^{40}}\text{Ar}/^{39}\text{Ar} \) preferred age of 252 ± 2 Ma. K-feldspar from the same rock exhibits K-feldspar diffusion features, from

![Figure 6. Stereograms of cleavages, beddings surrounding tongue-shaped granitic pluton and along the E-W-trending dextral shear zone: A, bedding along the dextral shear zone but piled up by cleavages; B, cleavages; C, bedding on the south, north, and southwestern sides of the tongue-shaped pluton; D, bedding on the northeastern side of the tongue-shaped pluton. All stereograms are equal area projection, lower hemisphere.](image-url)
Figure 7. Photos of structures and micro-structures along the north and central Tianshan orogenic belt. 

A, Carboniferous System was involved with S-vergent fold along the Kangguertag-Huangshan tectonic belt, showing N-S compression. 

B, Cleavages and inclined fold flanks showing S-vergent folding and piled-up deformation along the Kangguertag fault zone. 

C, Steep-vertical cleavages changed the former bedding of the Carboniferous System along the positive flower structures. 

D, Vertical-dipping fold plane and shear-sense fold showing eastward shearing (position at east of tongue-shaped pluton). 

E, Steep-dipping cleavages within the fold flanks along the E-W-trending dextral strike-slip zone (position at central part of D). 

F, Deformed quartz veins on the southern side of the granitic emplacement along the syndextral strike-slip motion (at site of sample D251). 

G, Carboniferous metavolcanic mylonite with a sigmoid criteria rotated porphyroclast of feldspar. A layer rich in sericite on the front of the porphyroclast shows an oblique mica fabric. Section is parallel to the aggregate lineation and normal to the foliation. Dextral shear sense. 

H, Low-grade Carboniferous metaconglomerate with highly elongated, mainly monocrystalline feldspar and quartz pebbles. Some pebbles are more deformed than others, probably due to the favorable lattice-preferred orientation for easy flattening. Dextral shear sense.
lower to higher temperatures, the apparent ages of which are from ~200 to ~250 Ma.

**Cooling Ages.** The U/Pb zircon age for the quartz-diorite of tongue-shaped pluton is 286 ± 13 Ma (Xinjiang Bureau of Geology and Mineral Resources 1987). In our study, three hornblende samples yield similar plateau ages of 277–272 Ma within error, which indicate cooling of the granite following emplacement in the interval of 277–272 Ma. After the cooling of hornblende, biotite yields cooling ages of 261 ± 1 to 254 ± 2 Ma for samples from the eastern and central parts of the pluton (fig. 9). Based on the spatial distribution of these samples, we deduce that the tongue-shaped granitic pluton experienced differential cooling following emplacement from east to west.

All of the samples from outside the tongue-shaped pluton give different cooling ages, but these ages mainly correspond to their structural positions. For example, an earlier granitic intrusion on the northern side of the pluton (sample D259) gave a cooling age of 380–376 Ma. The cooling from hornblende to biotite minerals of sample D256 experienced a relatively rapid cooling process, with cooling rates as ~10°–15°C/yr from 277 to 254 Ma. From biotite to K-feldspar closure temperature at 240–220 Ma, cooling decreases to ~5°C/yr.

**Discussion**

**Deformational History.** In the ETOB, several deformational stages have been recorded: subduction between the Siberian and Tarim plates (>320–340 Ma) followed by regional N- and S-vergent thrusting and folding (~320–290 Ma) that corresponds to continent-arc-arc-continent collision (e.g., Windley et al. 1990; Ma et al. 1993; Gao et al. 1998; Li et al. 2002; Xiao et al. 2004; table 2). During

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Lithopetrology</th>
<th>Sampled site</th>
<th>Determined minerals</th>
<th>J value</th>
<th>Isochron age [Ma] and 40Ar/36Ar initial ratio</th>
<th>WMPA or PA [Ma]</th>
</tr>
</thead>
<tbody>
<tr>
<td>D57</td>
<td>Granite</td>
<td>Southern side of the Aqikekuduk fault zone</td>
<td>Biotite, K-feldspar</td>
<td>0.001580, 0.001572</td>
<td>264 ± 19, 256 ± 41, 206 ± 10, 274 ± 42</td>
<td>252.2 ± 2.1 [PA] no plateau age</td>
</tr>
<tr>
<td>D251</td>
<td>Granitic dike</td>
<td>42°07′17″N, 91°1′49″E</td>
<td>K-feldspar</td>
<td>0.001524</td>
<td>233.3 ± 5.2, 268 ± 61</td>
<td>231.4 ± 3.0 [PA]</td>
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<td>D253</td>
<td>Mylonitic granite</td>
<td>42°07′36″N, 91°32′02″E</td>
<td>K-feldspar</td>
<td>0.001472</td>
<td>237.3 ± 5.4, 213 ± 160</td>
<td>230.2 ± 1.6 [PA]</td>
</tr>
<tr>
<td>D254</td>
<td>Granite</td>
<td>42°08′33″N, 91°33′12″E</td>
<td>Hornblende, Biotite, K-feldspar</td>
<td>0.001867, 0.001838, 0.001823</td>
<td>282.1 ± 1.8, 34 ± 160, 264.7 ± 7.9, 269 ± 200, 236.4 ± 5.6, 309 ± 83</td>
<td>278.4 ± 1.5 [WMPA]</td>
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<tr>
<td>D255</td>
<td>Granite</td>
<td>42°09′04″N, 91°33′49″E</td>
<td>Hornblende, Biotite, K-feldspar</td>
<td>0.001532, 0.001564, 0.001476</td>
<td>268.5 ± 5.3, 311 ± 58, 259 ± 1.6, 297 ± 29, 224.7 ± 1.2, 236 ± 240</td>
<td>272.2 ± 1.5 [PA]</td>
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<tr>
<td>D256</td>
<td>Granite</td>
<td>42°06′40″N, 91°38′56″E</td>
<td>Hornblende, Biotite, K-feldspar</td>
<td>0.001859, 0.001852, 0.001809</td>
<td>278.9 ± 5.9, 156 ± 320, 262.1 ± 1.4, 44 ± 210, 241.8 ± 6.3, 130 ± 230</td>
<td>276.5 ± 1.6 [WMPA]</td>
</tr>
<tr>
<td>D259</td>
<td>Granite</td>
<td>42°18′36″N, 91°37′54″E</td>
<td>Hornblende, Biotite</td>
<td>0.001556, 0.001548</td>
<td>374 ± 47, 562 ± 400, 382.3 ± 4.5, 220 ± 42</td>
<td>385.6 ± 6.1 [single age]</td>
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<td>D264</td>
<td>Dike of dioritic porphyrite</td>
<td>41°56′59″N, 92°08′48″E</td>
<td>Plagioclase</td>
<td>0.001532</td>
<td>267 ± 27, 304 ± 120</td>
<td>268.1 ± 2.7 [PA]</td>
</tr>
<tr>
<td>D265</td>
<td>Granite</td>
<td>42°04′08″N, 92°32′31″E</td>
<td>K-feldspar</td>
<td>0.001468</td>
<td>238 ± 12, 309 ± 260</td>
<td>238.6 ± 1.2 [PA]</td>
</tr>
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</table>

Note. WMPA = weighted mean plateau age; PA = preferred age.
Early Permian time, molasse-like sediments unconformably covered the collisional belt and the central Tianshan gneissic belt (Xu 1996; Shu et al. 1998, 1999; Li et al. 2002). At $\sim$284–268 Ma, N-S-trending mafic-ultramafic magmatic dykes intruded (Han et al. 1997, 1998; Li et al. 2002; Zhou et al. 2004; table 2).

After these tectonic events, shearing and magmatic intrusions occurred in the ETOB and perhaps more widely in central Asia. Published cooling ages in the western Tianshan orogenic belt are $\sim$400–350 Ma, with a few at $\sim$320 Ma (Che et al. 1995; Gao et al. 1998; Zhou et al. 2001; Laurent-Charvet et al. 2003). Only along the ETOB are cooling ages $\sim$270–245 Ma (Che et al. 1995; Laurent-Charvet et al. 2002, 2003; Wang et al. 2002; Chen et al. 2005; Charvet et al. 2008). This suggests that in the eastern and western Tianshan, different cooling histories correspond to various deformation features and that the later dextral strike-slip motion might be the main cause of later denudation of the ETOB.

**Timing of Dextral Strike-Slip Motion along the Northern Segment of the ETOB.** The origin of N-S-trending, $\sim$285–270 Ma mafic-ultramafic dykes have been suggested to be postcollisional mantle-

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**Figure 8.** $^{40}$Ar/$^{39}$Ar release spectra and isochron plots for hornblende, biotite, and K-feldspar. Other spectra are available in the online edition or from the *Journal of Geology* office. H = hornblende, B = biotite, K = K-feldspar, WMPA = weighted mean plateau age, PA = preferred age.
derived magmatism and vertical growth of the continental crust in central Asia (Han et al. 1997, 1998; Li et al. 2002) or the result of plume-related activity within a continental setting (Zhou et al. 2004). Granitoid magmatism is probably related to postcollisional lithospheric thinning, magmatic underplating, and crustal relaxation (Kuster and Harms 1998). The large horizontal movements along shear zones during the postcollisional period can trigger magmatism, in particular from young mantle that is still hot or a crustal source (Liegeois 1998).

For the tongue-shaped pluton, satellite images and field characteristics show dextral strike-slip shear deformation (figs. 2, 3, 5). The deformed Carboniferous metavolcanic rocks and sedimentary formations east and south of the tongue-shaped batholith were involved in dextral strike-slip deformation (fig. 7) and show $^{40}$Ar/$^{39}$Ar ages of $\sim$265–245 Ma [whole rock; Chen et al. 2005], similar to synemplacement cooling ages for the tongue-shaped pluton in this study. During this dextral shear, recrystallized sericite minerals were aligned parallel to the stretching lineation. Deformation temperatures of the dextral shearing in the area are estimated to be 270°–330°C based on newly formed sericite and quartz recrystallization and their microstructural criteria (Edwards and Ratschbacher 2005; Passchier and Trouw 2005). $^{40}$Ar/$^{39}$Ar cooling ages of the syntectonic sericite formed during dextral shearing under $\sim$330°C will be very close to the deformation age, since their closure temperatures are on the order of the highest bracket. The cooling of biotite collected from the tongue-shaped batholith indicates its cooling occurred at a temperature of $\sim$335° ± 50°C (Harrison et al. 1985) and differently from $\sim$261 to 254 Ma from east to west. These features imply that the tongue-shaped pluton emplaced during dextral shearing at $\sim$270–245 Ma.

Predextral shear granites were intruded before $\sim$280 Ma [U-Pb and Rb-Sr dating; data collected by Xu 1996]. No solid-state deformation has been observed within the plutons along the northern segment of the ETOB. The tongue-shaped pluton ($\sim$280–270 Ma) intrudes middle-late Carboniferous volcanic rocks and metavolcanic rocks, and cleavage trajectories in the country rocks are parallel to the pluton trace, with E-W- and WNW-ESE-striking (fig. 5). This pluton trace, as well the surrounding cleavages, is coeval with a dextral regional shear zone in the northern segment of the ETOB. The closure temperature of the biotite ($\sim$300°–350°C; Harrison et al. 1985) is similar to the temperature of brittle-ductile transition at time of emplacement during $\sim$264–256 Ma. That is, a dextral strike-slip shear may have acted parallel to the pluton trace and controlled the emplacement of the tongue-shaped pluton (fig. 10).

Case studies and experiments of the emplacement of granitic plutons along strike-slip zones indicate that the intrusion shape of such a pluton
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<td>Granitic events together with NE-trending sinistral strike-slip motion</td>
<td>Late Triassic-Jurassic coal-bearing sedimentation</td>
<td>Turpan-Hami Basin, Junngar Basin, eastern Tianshan</td>
<td>Younger than 240-220 Ma</td>
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<td>EW-trending dextral strike-slip motion</td>
<td>Syndextral granitic emplacement</td>
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<td>270-250 Ma</td>
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<tr>
<td>Arc-arc subduction-collision</td>
<td>N-S-compression, sinistral strike-slip motion in some tectonic boundaries</td>
<td></td>
<td>North, central of Eastern Tianshan, sinistral strike-slip motions along the southern boundary of the central Tianshan, Altay</td>
<td>310-290 Ma</td>
<td></td>
<td>Laurent-Charvet et al. 2003; Yang et al. 2004, 2007</td>
</tr>
<tr>
<td>Western Tianshan oceanic closing</td>
<td>NS-compression, ultrahigh pressure metamorphism</td>
<td>Granitic intrusions, island-volcanic eruptions</td>
<td>Arc-basins sedimentation</td>
<td>Western Tianshan orogenic belt</td>
<td>&gt;380 Ma</td>
<td>Windley et al. 1990, Allen et al. 1995; Gao et al. 1998; Li 2004; Yang et al. 2006</td>
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</table>
exhibits normal asymmetry with its long axis tracking the local principal stretching direction of the dextral strike-slip shear (Román-Berdiel et al. 1997; Vigneresse and Bouchez 1997; Acocella and Mulugeta 2002; Corti et al. 2005). The shape of the magmatic body was controlled by the synintrusion lateral displacement, resulting in a symmetric, drop-shaped pluton with a sheared tail elongating in the sense of the strike-slip displacement (normal asymmetry; Corti et al. 2005). The normal asymmetric shape such as like tongue-shaped pluton thus results from synintrusion lateral and horizontal displacement (e.g., Román-Berdiel et al. 1997) along the Kangguertag-Huangshan tectonic belt in the ETOB, and consequently this pluton was a postcollisional syndextral shear intrusion (fig. 10).

This conclusion implies that emplacement of the tongue-shaped granitic pluton marks the end of N-S compression in the ETOB. The similar 40Ar/39Ar hornblende ages indicate that dextral shear did not influence the emplacement of the granite between ~277 and 272 Ma. In the eastern part of the tongue-shaped granitic batholith, biotite closed to diffusion at 261 ± 1 Ma, corresponding to regional shearing. During the intrusion of the granite, the dextral shear stress controlled the emplacement of the intrusion, and then the magma flowing from west to east formed the present granitic batholith (fig. 10). This also implies that between ~270 and 254 Ma, extensive dextral shear occurred in the ETOB. Potassium feldspar indicates that the granite uniformly cooled between 240 and 230 Ma. However, the cooling rate, from biotite to K-feldspar, was relatively slower in the eastern part compared with the western part of the granitic pluton (fig. 9). This implies that after biotite cooling in the western part of the pluton, there was no strong shear stress influencing the cooling or exhumation of granitic magma. It also suggests that after 254 Ma, perhaps, dextral shear had ended in this region.

Dextral strike-slip motion developed after formation of the N-S-trending magmatic dykes, when the E-W-trending steep-dipping cleavages cut through the N-S-trending magmatic dykes. Based on the above evidence, the E-W-trending dextral strike-slip motion occurred at ~270–250 Ma. This time interval is the same as for the dextral strike-slip deformation in Altay Mountains and part of the Aqikekuduk fault zone that was suggested by Shu et al. (1998, 1999) and Laurent-Charvet et al. (2003).

On the eastern Tianshan, especially on the eastern side of the Gangou fault, the Kangguertag-Huangshan tectonic belt is composed of the northern segment of the ETOB. The fault system defines positive flower structures (fig. 11). Also along this belt, granitic intrusions were emplaced and a N-S-trending mafic-ultramafic magmatic event occurred between ~280 and 270 Ma (Han et al. 1997, 1998; Zhou et al. 2004). The region then experienced dextral strike-slip motion during the emplacement of the granitic pluton. On the southern side of the Gangou fault, ~290–270 Ma exhumation and sinistral strike-slip motion occurred (Yang et al. 2004), but we did not observe ~270–245 Ma dextral strike-slip motion. That is, the dextral strike-slip motion and granitic intrusions took place in the northern and part of the central segments of the ETOB but not in the western Tianshan or the southern segment of the ETOB. The different deformation and exhumation since ~270 Ma in the north, central, and south segments of the ETOB may point to a controlling factor by an eastward postcollisional extrusion.

Figure 10. Cartoon shows relationships among syndeformation granitic emplacement, correlated dextral shear deformation, and contact metamorphism. Inset is from figure 2. Age data are from this study.
Mechanism of Formation of the Dextral Strike-Slip Motion and Syndextral Granitic Emplacement. The origin of dextral strike-slip motion along the ETOB is a significant problem because its structural framework was developed after an arc-arc collision. Two hypotheses have been proposed, suggesting that (1) dextral motion is the result of formation of the Kunlun orogenic belt and continuous motion of the Tarim Block northward (e.g., Laurent-Charvet et al. 2002, 2003), or (2) dextral motion is the result of postcollisional eastward extrusion of central Asia.

The first hypothesis suggests that the force driving dextral strike-slip was the closure of the Kunlun oceanic basin from the southern side of the Tarim Block or the collision between the Tarim and Yili-central Tianshan plates (Laurent-Charvet et al. 2002, 2003; Charvet et al. 2008). However, closure of the Kunlun oceanic basin occurred during the Early Triassic (~245–230 Ma; Wang et al. 2005; Xiao et al. 2005), later than dextral strike-slip motion in the ETOB; likewise, the collision between the Tarim and Yili-central Tianshan plates occurred at ~230–220 Ma (Zhang et al. 2007). Moreover, the age, deformation, and spatial distribution of the granitic intrusions do not support this hypothesis. These granitic intrusions are widely distributed in the ETOB and occurred at a similar time (~280–270 Ma) and with similar geochemical and petrological features (Han et al. 1997, 1998; Li et al. 2002; Zhou et al. 2004). Between the Tarim Block and the central Tianshan, there is no similar dextral strike-slip deformation at ~270–245 Ma nor a correlated mafic-ultramafic complex or A-type granitic intrusions (Li et al. 2002; Yang et al. 2007). The Gangou-Aqikekuduk fault zone (an older thrust fault zone ~290–300 Ma; Yang et al. 2007) is the southern boundary for dextral strike-slip motion, but this dextral strike-slip motion occurred at ~267 Ma (Wang et al. 1994; Shu et al. 1998, 1999). No dextral deformation has been found in the southern Tianshan, with the exception of the earlier ~310–290-Ma N-S compression. In the southern and central Tianshan, N-S compression and its correlated N- and S-vergent thrusting system occupy the main deformation features (fig. 12). Along the western Tianshan orogenic belt on the western side of the Gangou-Aqikekuduk fault zone, no dextral strike-slip motion occurred at ~270–250 Ma and thus no similar eastward extrusion; there also were no similar granitic intrusions in the western belt. Another consideration is that along the ETOB, the magmatic intrusions are widely distributed, but similar granitic intrusion did not occur in the western Tianshan orogenic belt.

The second hypothesis implies that the driving mechanism for dextral shear was the postcollisional extrusion of northern Tianshan or more widely, central Asia, and associated eastward escape of the central Asian orogenic belt. In this case, the Gangou-Aqikekuduk fault zone defines the southern boundary of the eastward extrusion in the North Tianshan. Obviously, this ESE extrusion must occur postcollision between Siberian and Tarim plates during ~270–245 Ma (table 2; fig. 12). Several major exposed faults in the south and southwest of the Siberian plate, such as the central Kazakhstan fault, Talas Fergana fault, and the north Tianshan fault system, underwent right-lateral strike-slip at ~270–245 Ma (Wang et al. 2002; Laurent-Charvet et al. 2003; Chen et al. 2005; Allen...
Figure 12. Kinematics of postcollisional eastward extrusion and tectonic framework of the eastern Tianshan orogenic belt. Age data are from Shu et al. (1998, 1999), Wang et al. (2002), Laurent-Charvet et al. (2003), Chen et al. (2005), Allen et al. (2006), and this study. The sinistral strike-slip motion of the southern boundary of the central Tianshan orogenic belt is based on Yang et al. (2004, 2007). The diagram between the East European and the Siberian cratons is simplified and modified from Şengör and Natal’ in (1996), Buslov et al. (2004), and Allen et al. (2006).
et al. 2006). At a similar time, some faults underwent left-lateral strike-slip, such as the Bolnai Fault on the north of Altay (Şengör et al. 1996; Buslov et al. 2004). Areas along the Irtysh Shear Zone and its subparallel and synchronous shear zones underwent right- and left-lateral strike-slip (Laurent-Charvet et al. 2003) within the Altay. Such right-lateral motion is consistent with the right-lateral shear invoked elsewhere in Eurasia during the late Paleozoic to Early Triassic evolution of the Paleo-Tethyan closure (Natal’ in and Şengör 2005). Also, this time interval is the same as that of the NW-SE extension and eruption of flood basalts between the Urals (east European) and the Siberian craton (fig. 12; Allen et al. 2006). Both NW-SE extension and southeastward dextral strike-slip motion occurred at the same time and were related to motion between the East European and Siberian cratons. In this case, the dextral and left-lateral strike-slip motion of the strike-slip faults can be interpreted as expression of postcollisional east-southeastward extrusion (fig. 12).

From the foregoing, it is apparent that current geologic evidence indicates that postcollisional lateral extrusion is a likely explanation for the dextral strike-slip motion along the northern side of the Gangou-Aqikekuduk fault zone, which was accompanied by the synkinematic A-type granitic intrusion. A similar tectonic stage during the syn- or postcollisional stage has been studied widely (e.g., Tapponnier et al. 1982; Ratschbacher et al. 1991a, 1991b; Jones et al. 1997; Keep 2000).

**Conclusions**

Different cooling and tectonic exhumation histories have been identified in the ETOB. Along the northern segment of the eastern Tianshan, syntectonic intrusions were emplaced at ~270–254 Ma. The different cooling histories in the eastern and western parts of the tongue-shaped pluton indicate that, because of dextral strike-slip motion at ~270–245 Ma, the dextral shear stress controlled the emplacement of the granitic magma along the northern segment of the ETOB. Corresponding to the dextral strike-slip motion, the tectonic exhumation is different in the different segments of the Tianshan. Hornblende and biotite cooling ages of ~270–250 Ma in the granite indicate the formation age of dextral shear in the ETOB. The positive flower structures are the main tectonic framework in the northern segment of the ETOB, and postcollisional extrusion occurred just on the northern side of the Gangou-Aqikekuduk superimposed fault zone. Dextral strike-slip motion, syndextral granitic emplacement, and differential tectonic exhumation along the Tianshan orogenic belt were controlled by the WNW-ESE eastward extrusion of the central Asian orogenic belt between the Tarim Block and the Siberian plate. This postcollisional eastward extrusion was controlled not by northward motion of the Tarim Block but more regionally, and it is related to the escape from shortening between the East European and Siberian cratons in the Late Permian–Early Triassic interval.

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