Detrital zircon provenance constraints on the initial uplift and denudation of the Chinese western Tianshan after the assembly of the southwestern Central Asian Orogenic Belt

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1. Introduction
The Tianshan mountain belt extends east–west along the southwestern part of the Central Asian Orogenic Belt (CAOB) and represents a composite orogenic collage assembled by the amalgamation of the Tarim–Karakum cratons with several tectonic domains to the north, including the Central Tianshan (CTS), Kazakhstan–Yili, and Junggar blocks (Fig. 1) (Xiao et al., 2004, 2013; Charvet et al., 2011; Gao et al., 2011; Han et al., 2011, 2015; Wang et al., 2011; Wilhem et al., 2012; Xiao and Santosh, 2014; Zhang et al., 2015a, 2015b, 2016). The South Tianshan (STS) Orogenic Belt (Fig. 1a, c), and the Solonker suture zone to further east (Fig. 1a), record Proterozoic to Paleozoic accretionary history of the Paleo-Asian Ocean and mark the site of final collision of the Tarim and North China cratons with the CAOB during late Paleozoic and early Mesozoic time (Şengör et al., 1993; Jahn et al., 2000, 2004; Khain et al., 2003; Xiao et al., 2003, 2009, 2015; Jahn, 2004; Windley et al., 2007; Wilhem et al., 2012; Eizenhöfer et al., 2014, 2015a, 2015b; Kröner et al., 2014; Safonova and Santosh, 2014; Li et al., 2015; Liu et al., 2015; J. Zhang et al., 2015; Han et al., 2016a).

Despite numerous studies in the western Tianshan region, there is still much debate about the timing of final collision between the Tarim Craton and the CTS–Yili Block, with competing tectonic models suggesting collision time in the late Permian to Triassic (e.g., Li et al., 2005a; Y.J. Li et al., 2010; Zhang et al., 2007a; Xiao et al., 2013), or in the late Carboniferous or earlier (e.g., Charvet et al., 2011; Gao et al., 2011; Han et al., 2011, 2016b; Wang et al., 2011; Klend et al., 2015). Another relevant and important controversy is the timing of initial uplift and denudation of the western Tianshan range after the assembly of the southwestern Central Asian Orogenic Belt. This uplifting event represents an intracontinental orogeny most likely in response to the collision between the Qiangtang Block and southern Eurasia, following the closure of the western part of the Paleo-Tethys Ocean.

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reconcile current data and observations is crucial to clarify the above controversies.

Sedimentary provenance analysis based on detrital zircon age and Hf data has been shown to be powerful in tracing source regions of detritus and reconstructing tectonic evolution and mountain-building processes (e.g., Cawood et al., 2012, 2013; DeCelles et al., 2014; Gehrels, 2014). In this study, we present new and compiled detrital zircon U–Pb age and Hf isotopic data of the Permian and Mesozoic clastic successions in the southern piedmont of the Chinese western Tianshan to reveal the change of sedimentary provenances through time. These data, in combination with stratigraphic record and tectono-thermal evidence, provide important constraints on the amalgamation time of this region and the early stage uplift and denudation history of the western Tianshan.

2. Geological background

2.1. Regional geology

The Tianshan orogenic belt occurs as a series of mountainous ranges extending latitudinally for over 2500 km in central Asia, across the borders of China, Kazakhstan, Kyrgyzstan, Tajikistan, and Uzbekistan (Fig. 1b). This study places emphasis mainly on the region of Chinese西部天山 and partially Kyrgyz Tianshan, with a longitude range of ca. 75°E to 90°E. Based on geological records, especially the occurrence of ophiolitic mélanges and (ultra)high-pressure ((U)HP) metamorphic suites, this region is subdivided into the South Tianshan (STS) Orogenic Belt, the CTS–Yili Block, and the North Tianshan Belt, by major faults and Paleozoic-age suture zones (Fig. 1c) (Windley et al., 1990; Gao et al., 2011; Han et al., 2011; Xiao et al., 2013).

The Tarim Craton to the south of the Tianshan is roughly equivalent to the Tarim Basin (Fig. 1b) and has an Archean to early Neoproterozoic metamorphic basement, which was stabilized by the Tarim Orogeny occurring in the early Neoproterozoic (e.g., Lu et al., 2008; Zhao and Cawood, 2012). The middle Neoproterozoic to Phanerozoic cover overlying the basement is dominated by carbonate–siliciclastic sedimentary successions. Ca. 470–390 Ma granitic intrusions have been discovered in the Kuluketage and Alty areas (e.g., Wu et al., 2007; Lin et al., 2013; Ge et al., 2014). Early Permian magmatism was widespread in the craton and characterized by bimodal magmatic suites, which are attributed to mantle plume activities beneath the Tarim cratonic lithosphere (e.g., Zhou et al., 2009; Xu et al., 2014).

The STS Orogenic Belt is separated from the Tarim Craton by the North Tarim Fault (Fig. 1c), a thrust front along the southern margin of the mountainous region. The STS Belt consists mainly of Paleozoic low-grade and unmetamorphosed carbonates and siliciclastic rocks, with Mesozoic–Cenozoic clastic successions occurring along its southern margin. Recent detrital zircon U–Pb–Hf data of the Paleozoic strata in the STS region suggest that this region was connected to the northern margin of the Tarim Craton during Paleozoic time (Han et al., 2016b). A linear belt containing ophiolitic mélanges and (U)HP metamorphic suites occurs along the northern margin of the STS Belt (Fig. 1c) and represents the relics associated with the mid- to late Paleozoic evolution of
the STS Ocean (Gao et al., 2011; Han et al., 2011, 2015; Zhang et al., 2013; Jiang et al., 2014). The strata in the STS Belt were intensely folded and thrust-faulted. However, the ages of these structures, especially those possibly related to Paleozoic–Mesozoic evolution, have not been well constrained, partially due to the intensive tectonic reactivation during Cenozoic time (Yin et al., 1998; Dumitru et al., 2001; Li et al., 2004; Yang et al., 2014).

The CTS–Yili Block (Fig. 1c) contains Precambrian metamorphic rocks overlain by Phanerozoic sedimentary and volcanic successions. A prominent feature of this region is widespread and intense felsic-intermediate volcanic and plutonic magmatism during Paleozoic time. Recent radiometric dating indicates that the magmatic rocks have crystallization ages ranging continuously from ~500 to ~260 Ma (e.g., B. Wang et al., 2007, 2009; Wang et al., 2012; Ma et al., 2014, 2015).

2.2. Permian–Mesozoic strata in Suxiang–Heiyingshan–Kuche River area and sampling

Strata in the Suxiang–Heiyingshan area in the Kuche Basin along the southern flank of the Chinese western Tianshan preserve a complete exposure of Mesozoic deposition (Figs. 2a, 3a–c), which was either eroded in more northern part of the Tianshan region or largely buried under desert sand in the Tarim Basin. Permian rocks that underlain the Mesozoic strata are composed of lower felsic volcanic and tuffaceous rocks of the Xiaotikanlike Formation and middle–upper sedimentary sequence of Kuergan and Biyulebaoguzi formations (Fig. 3). The Mesozoic siliciclastic strata overlie the Permian successions with an angular unconformity (Figs. 3, 4a). The Early–Middle Triassic Ehuobulake Formation consists of basal conglomerates and upsuction alternate greenish green fine sandstones and purple coarse sandstones. The Middle Triassic Kelamayi Formation is composed of medium-thick bedded sandstones and intercalated mudstones, siltstones, and conglomerates. The Late Triassic Huangshanjie and Taliqike formations form several cycles of conglomerates, coarse–fine sandstones, siltstones, and mudstones, with coal seams at the upper part. The Triassic sediments were deposited in alluvial and braided-fluvial systems (Hendrix et al., 1992). The Jurassic sequence includes the Early–Middle Jurassic Kelasu Group and the Middle Jurassic Qiakemake Formation, which conformably overlie the Triassic strata. The Jurassic clastic strata consist primarily of conglomerates and coarse sandstones in the lower part and more siltstones, mudstones/shales, and abundant coal in the middle–upper part. This sequence probably reflects a transition from braided fluvial to meandering fluvial and lacustrine depositional environments (Hendrix et al., 1992). The Cretaceous clastic rocks unconformably overlie the Jurassic strata and consist of basal conglomerates and upsuction sandstones, siltstones, and mudstones, which were formed primarily in alluvial and braided fluvial environments (Hendrix et al., 1992). Cross-beds are fairly common in the Mesozoic strata (Fig. 4b, c) and have been investigated by Hendrix et al. (1992) and Li et al. (2004), with the data summarized in Fig. 3d.

We collected two clastic samples from the Early–Middle Triassic Ehuobulake Formation in the Quexiang area for detrital zircon analysis (Figs. 2b–d, 4), since Late Triassic to Cretaceous strata have been intensively studied by other workers (Fig. 3) (Peng et al., 2009; Carroll et al., 2013; Liu et al., 2013; Wang et al., 2014). Sample LT36A is a gray coarse-grained quartz arenite from the Wenquan area. The rock is dominated by 0.2–1 mm subrounded–subangular quartz and quartzose rock fragments, with minor muscovites (Fig. 4d). Sample LT34A is a purple conglomerate from the north of the Dawanqi mining area. The conglomerates contain poorly sorted 0.2–4 cm gravels, which are mainly quartzites, cherts, gneisses, schists, and volcanic rock fragments (Fig. 4e).

Fig. 2. (a) Geological map of the Suxiang–Heiyingshan–Kuche River area along the southern piedmont of the Chinese western Tianshan showing sample names and localities for new and compiled detrital zircon data. Superscripts indicate references: 1 = Peng et al., 2009, 2 = Carroll et al., 2013, 3 = Liu et al., 2013, 4 = Wang et al., 2014. (b) Geological map of the Suxiang area and sample sites in this study. (c and d) Cross sections along the Wenquan (A–A’) and Dawanqi (B–B’) areas.
3. Analytical methods

3.1. Zircon separation and CL imaging

Heavy minerals were separated from crushed rock samples using magnetic and heavy-liquid concentration techniques. Zircon grains were handpicked from the heavy minerals, mounted in epoxy resin, and then polished down to expose the interior of crystals. Cathodoluminescence (CL) images were taken on a FEI Quanta 400 FEG environmental scanning electron microscope equipped with an Oxford energy dispersive spectroscopy and a Gatan CL3+ detector at the State Key Laboratory of Continental Dynamics at the Northwest University in Xi’an, China.

3.2. Zircon U–Pb dating

U–Pb isotopic ratios of zircons were analyzed in situ using a laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) at the State Key Laboratory of Continental Dynamics at the Northwest University in Xi’an, China. The instrument consists of an ArF-exciemer 193 nm laser ablation system (GeoLas 200M) and a quadrupole ICP-MS (Agilent 7500a). The laser frequency and beam size were 6 Hz and 45 μm, respectively. The ablation time was 29 s during each analysis. For the detailed instrumental settings and higher aspect ratios relative to Precambrian zircons.

Fig. 3. (a–c) Stratigraphic columns of Permian to Cretaceous strata in the Quexiang, Heylingshan, and Kuche River areas, also showing approximate positions of sedimentary samples used in this study. The references of these samples are noted in Fig. 2. (d) Data of cross beds for paleocurrent directions, compiled from Hendrix et al. (1992) and Li et al. (2004). Abbreviations of names for stratigraphic formation (Fm.) and group (Gr.): Qk = Qiakemake, Kl = Kelasu, Tl = Taliqike, Hs = Huangshanjie, Eh = Ehuobulake, Xt = Xiaotikanlike, Kg = Kuergan, By = Biyoulebaoguzi, Kp = Kapushaliang.

3.3. Zircon Lu–Hf isotopic analysis

Zircon Lu–Hf isotopes were determined in situ by LA-ICP-MS at the Guangzhou Institute of Geochemistry of Chinese Academy of Sciences. The instrument is composed of a 193 nm Ar–F excimer laser ablation system (RESOlution M-50-LR) and a multi-collector ICP-MS (Neptune Plus). The laser frequency and beam size were 6 Hz and 45 μm, respectively. The ablation time was 29 s during each analysis. For the detailed analytical procedures and isobaric interference corrections, refer to the descriptions in Wu et al. (2006). Penglai zircons were analyzed as the unknown and yielded an average $^{176}\text{Hf}/^{177}\text{Hf}$ ratio of 0.282893 ± 0.000039 (2σ, n = 57), which is, within error, consistent with the reference value of 0.282906 ± 0.000010 (X.H. Li et al., 2010).

4. Analytical results and data compilation

Detrital zircons from the two samples (LT34A and LT36A) have colors varying from colorless to pink, lengths between ~70 and ~300 μm, and aspect ratios of 1–3. Almost all analyzed zircons have Th/U ratios larger than 2.0 and most of them show oscillatory zoning on CL images (Figs. 5, 6), characterizing a magmatic origin. Zircons with Paleozoic ages commonly show more euhedral/subhedral shapes and higher aspect ratios relative to Precambrian zircons.

A total of 175 detrital zircon grains from the two samples were analyzed for U–Pb dating (Supplementary Table S1). Ninety of them were chosen for Lu–Hf isotopic analyses (Supplementary Table S2). Eleven U–Pb analyses were discarded from the discussion because of their high discordance. Detrital zircons from the two samples yielded similar U–Pb age patterns: two prominent age populations at 310–270 Ma and 500–390 Ma, and a small amount of Precambrian ages clustering at ~2.5 Ga, 2.0–1.8 Ga, 1.200–930 Ma, and 900–600 Ma (Fig. 7). Only a few zircon grains have ages between 390 and 310 Ma. All Lu–Hf isotopic
analysis of detrital zircons yielded $\varepsilon_{\text{Hf}}(t)$ values ranging from $-25$ to $+15$ (Fig. 8). Ca. 500–310 Ma zircons are characterized by a large variation of $\varepsilon_{\text{Hf}}(t)$ values ($-15$ to $+15$), whereas 310–270 Ma grains show mostly negative $\varepsilon_{\text{Hf}}(t)$ values ($-15$ to $0$).

Apart from the analytical results in this study, we compiled 1181 published detrital zircon U–Pb ages of 13 clastic samples from Triassic, Jurassic, and Cretaceous strata in the northern Tarim region (Supplementary Table S3). For the comparison with magmatic episodes and sediment provenance analysis, we used the published crystallization ages of felsic-intermediate magmatic rocks from the Tarim and Tianshan regions (data compiled in Han et al., 2016b), and those of the Triassic counterparts from the Western Kunlun Orogen (Supplementary Table S4). In addition, we collected 52 published apatite fission-track age data (Supplementary Table S5) from the Kyrgyz and Chinese western Tianshan for further discussion.

5. Discussion

5.1. A marked change of detrital zircon provenance in the mid-Triassic

5.1.1. Permian and Early–Middle Triassic siliciclastic rocks

Our new detrital zircon age results, together with compiled data, indicate that a predominant number of Paleozoic detrital zircons exist in the Permian and Early–Middle Triassic clastic rocks (Fig. 9e, f). These zircons mostly show euhedral shapes and are primarily magmatic in origin, as indicated by their high Th/U ratios (Fig. 6) and oscillatory
zoning on the CL images (Fig. 5). The ages of these zircons cluster at two main populations at 500–390 Ma and 310–260 Ma, with only a small number of 390–310 Ma grains (Fig. 9e, f). Precambrian detrital zircons are subordinate in these clastic rocks and have several age populations clustering mainly at ~2.5 Ga, 2.0–1.7 Ga, 1.2–0.9 Ga, and 900–600 Ga. Both the age patterns and the $\varepsilon_{Hf}(t)$ values of these zircons are consistent with those of the Precambrian–Paleozoic magmatic rocks in the northern Tarim and STS regions (Figs. 8, 9a) (e.g., Lu et al., 2008; Zhou et al., 2009; Shu et al., 2011; Long et al., 2012, 2014; Zhang et al., 2012; Lin et al., 2013; Ge et al., 2014; Xu et al., 2014), and also comparable to those of detrital zircons from the Silurian to Carboniferous sedimentary rocks in these regions (Carroll et al., 2013; Zou et al., 2013; Han et al., 2015, 2016b). A paucity of 390–310 Ma detrital zircons in the Permian and Early–Middle Triassic clastic rocks contrasts with contemporaneous felsic-intermediate magmatism being intense and widespread in this region but insignificant in northern Tarim and western Tianshan regions (Fig. 9a, b). The 260–220 Ma detrital zircons, however, do not have contemporaneous magmatic equivalent in the northern Tarim and western Tianshan regions, but exhibit age patterns similar to intense 260–220 Ma magmatism in the Western Kunlun Orogen (Fig. 9a), which is represented by widespread granitic

5.1.2. Late Triassic to Cretaceous siliciclastic rocks

Late Triassic to Cretaceous siliciclastic rocks inherit all main detrital zircon populations of the Permian to Middle Triassic clastic rocks, but in particular contain large amounts of distinct zircon components with ages clustering at two intervals: 390–310 Ma and 260–220 Ma (Fig. 9c, d). The 390–310 Ma detrital zircons were probably shed from the CTS–Yili Block, since contemporaneous felsic-intermediate magmatism was intense and widespread in this region but insignificant in northern Tarim and STS regions (Fig. 9a, b). The 260–220 Ma detrital zircons, however, do not have contemporaneous magmatic equivalent in the northern Tarim and western Tianshan regions, but exhibit age patterns similar to intense 260–220 Ma magmatism in the Western Kunlun Orogen (Fig. 9a), which is represented by widespread granitic
intrusions (e.g., Xiao et al., 2005; Liao et al., 2012; Robinson et al., 2012; Jiang et al., 2013; Wang et al., 2015; Y. Zhang et al., 2015). Therefore, the Late Triassic to Cretaceous sediments deposited in the northern Tarim and STS area were probably sourced from multiple regions, i.e. local areas in the northern Tarim and STS, the CTS–Yili Block, and the Western Kunlun Orogen.

In summary, the above analyses based on detrital zircon U–Pb–Hf data reveal that a marked change of sedimentary provenances occurred in the mid-Triassic: a local source region for the Permian to Middle Triassic clastic rocks and multiple source regions for the Late Triassic to Cretaceous successions.

5.2. Stratigraphic and sedimentary record: Mid-Triassic transition

The mid-Triassic change of sedimentary provenances can be correlated with the variation of depositional environments recorded in late Paleozoic to Mesozoic sedimentary strata along the northern Tarim and STS regions, as indicated by a significant regional unconformity that lies between the Permian and the Triassic sedimentary successions (Figs. 2–4). The Permian below the unconformity is mainly composed of carbonate–siliciclastic rocks and Early Permian felsic-intermediate volcanic suites. The sedimentary rocks consist of lowermost carbonates and upward gray-greenish sandstones, siltstones, and mudstone, with local conglomerates in the uppermost part, reflecting a transition from shallow-marine/lacustrine to fluvial environments (Jia et al., 2004).

Throughout Permian time the region of the northern Tarim and the STS Belt did not receive significant detritus from the CTS–Yili Block, as indicated by the detrital zircon data and provenance analyses in this study (Fig. 9f) and in Han et al. (2016b). A massive supply of clastic sediments occurred in the Early Mesozoic, when large amounts of Triassic alluvial conglomerates and braided-fluvial sandstones and siltstones, up to ~2 km thick, accumulated unconformably atop the Permian sedimentary–volcanic successions (Fig. 3) (Hendrix et al., 1992). The Triassic rocks, together with Jurassic and Cretaceous continental clastic rocks and coal and oil shale-bearing deposits, are asymmetrically distributed along the north-south profile and form an EW-trending depocenter to the north along the northern margin of the Tarim Craton (Hendrix et al., 1992). Such a pattern of the sedimentation reflects tectonic subsidence of a foreland basin associated with basin-bounding reverse faults and the uplift of the Tianshan range (Hendrix et al., 1992).

Despite the continuous accumulation of clastic sediments throughout the Triassic along the northern Tarim and STS regions, the summed paleocurrent data collected from the Mesozoic strata (Hendrix et al., 1992; Li et al., 2004) indicate a significant change of sediment dispersal...
directions occurring at the mid-Triassic (Fig. 3d). The Early–Middle Triassic paleocurrent indicators record varying flow directions trending clockwise from east-northeast to southwest. This wide range of directions may suggest that the Tianshan to the north of the depocenter was not uplifted significantly in the Early–Middle Triassic, although it had been a positive topographic feature in that time. In contrast, the Late Triassic paleocurrent data document a bimodal pattern dominated by southward and northward sediment dispersal (Fig. 3d). The predominance and consistency of the south-directed paleocurrent directions can be interpreted by the significant uplift of the Tianshan in the Late Triassic, rendering this range a primary sedimentary source region. Such a scenario is consistent with the aforementioned detrital zircon provenance analyses, which indicate a significant contribution of detritus from the CTS–Yili region to the northern Tarim region in the Late Triassic (Fig. 9d). The bimodal paleocurrent directions for the Late Triassic strata is also in accord with the multiple source regions inferred from the detrital zircon data, i.e. the Tianshan region to the north and the western Kunlun region to the south. Therefore, the stratigraphic and detrital zircon data consistently indicate a tectonic reactivation of the Tianshan starting from the mid-Triassic.

5.3. Triassic tectono-thermal events in the Tianshan region

Maggmatic activities ceased at the end of the Permian in the region of the northern Tarim, Chinese western Tianshan, and Kyrgyz Tianshan. Despite scarce Mesozoic–Cenozoic magmatism in the region, recent low-temperature thermochronological data have revealed multiple episodes of exhumation and cooling events during this period. A compilation of published apatite fission-track ages in an interval between 300 and 150 Ma for magmatic, metamorphic, and magmatic rocks are shown in Fig. 10. In the Chinese western Tianshan and the Kepingtage uplift in the northwestern Tarim, both single-grain apatite ages and the modeling of fission-track data suggest that the major episode of rock exhumation and cooling commenced since the Middle Triassic (Hendrix et al., 1994; Dumitru et al., 2001; Guo et al., 2006), although minor Permian to Early Triassic ages were also detected. Rocks in the Kyrgyz Tianshan preserved similar age pattern of cooling events (Fig. 10), which appear to be initiated slightly later in the Late Triassic (De Grave et al., 2011, 2012, 2013; Glorie et al., 2011; Glorie and De Grave, 2015).

Middle–Late Triassic tectono-thermal events in the Tianshan region are also recorded in monomolecular U–Pb and 40Ar/39Ar radiometric systems. Zhang et al. (2007a) dated four eclogite samples from the Akeyazi (U)HP terrane in the STS orogen using SHRIMP zircon U–Pb method and obtained a number of zircon-rim ages clustering at 240–220 Ma. Although the authors regarded the ages as corresponding to peak (U)HP metamorphism, the results most likely reflect late-stage thermal events possibly due to fluid metasomatism, since the age of (U)HP metamorphism in the STS has recently been verified between 325 and 310 Ma by multiple radiometric dating methods (Klemd et al., 2015 and references therein). This interpretation is more consistent with recent 40Ar/39Ar dating of mica schists in the (U)HP terrane (Scheltens et al., 2015), yielding a well-defined plateau age of 236.3 ± 1.5 Ma. Seltmann et al. (2011) also detected ~219 and ~237 Ma zircon-rim ages from granitic intrusions in the STS in Uzbekistan. Contemporaneous 40Ar/39Ar cooling ages of 240.5 ± 4.8, 202.9 ± 1.4, and 195 ± 3 Ma were reported from a Caledonian granite (Glorie et al., 2010) and a pegmatite dyke (Rolland et al., 2013) in the Kyrgyz Tianshan, and an Early Permian granite in the Chinese western Tianshan (Zhou et al., 2001), respectively. Middle–Late Triassic ductile shearing and hydrothermal activities have been reported in the Bingsaban area in the Chinese western Tianshan, where 40Ar/39Ar dating of mica from gold-bearing granitic rocks and Rb–Sr dating of gold ores yielded ages ranging from ~245 to ~220 Ma (Zhu et al., 2007; Zhu, 2011). On the basis of field observations and structural studies, Chen et al. (2015) conclude that the Bogeda Shan (Fig. 1c), a northern branch of the Chinese Tianshan range, was also uplifted in the Middle Triassic. These data, in combination with the above detrital zircon and stratigraphic evidence, indicate that the mid-Triassic (~240 Ma) likely represents a time of significant uplift of the Tianshan mountain belt.

5.4. Tectonic implications

Two contrasting tectonic models have been proposed to interpret the Triassic depositional and tectono-thermal events in the western Tianshan region. One group of thoughts considers these events as a response to late Permian to Triassic continent–continent collision between the Tarim Craton and the CTS–Yili Block, following the closure of the intervening South Tianshan Ocean (e.g., Li et al., 2005a; Y.J. Li et al., 2010; Zhang et al., 2007a; Xiao et al., 2013). The other studies interpret these as intracontinental events related to the reactivation of the Tianshan range, long period after the Tarim and CTS–Yili amalgamation (Hendrix et al., 1992, 1994; Dumitru et al., 2001; Jolivet et al., 2010; Glorie and De Grave, 2015).

The model advocating late Permian to Triassic continental collision is primarily based on three key lines of evidence: (1) Triassic molasse-like coarse clastic rocks in the southern flank of the Chinese western Tianshan (Y.J. Li et al., 2010), (2) late Permian radiolarian cherts in the Baleigong ophiolite mélanges in the STS belt (Li et al., 2005a, 2005b), and (3) 230–220 Ma (U)HP metamorphism in the Akeyazi area (Zhang et al., 2007a, 2007b). It seems reasonable to interpret the Triassic coarse sediments in the Kuche–Heiyingshans area as foreland basin deposition possibly due to continental collision. However, the other two lines of evidence are questionable. The poor preservation of so-called “late Permian” radiolarian fossils in the Baleigong area makes this age inconclusive (Shu et al., 2007; Wu and Li, 2013). Recent reexamination of radiolarian fossils in the STS belt has indicated that their ages range from the Devonian to Carboniferous, without unequivocal Permian-age fossils (Alekseev et al., 2007; Shu et al., 2007; Han et al., 2011; Wu and Li, 2013). The 230–220 Ma zircon ages of the Akeyazi eclogites (Zhang et al., 2007a), previously interpreted as a (U)HP metamorphic age, have not been reproduced by recent radiometric dating results, which otherwise demonstrate the peak (U)HP metamorphic ages primarily between 325 and 310 Ma (Klemd et al., 2011, 2015; Li et al., 2011; Yang et al., 2013). It is noteworthy that magmatism in the northern Tarim and western Tianshan regions nearly completely ceased after late Permian (~260 Ma), and Triassic and younger magmatic rocks are scarce (Fig. 9a). Such a magmatic record does not support a continental collision during late Permian–Triassic time, because the collision would have produced intensive magmatism during post-collisional stage (i.e. the Late Triassic to Jurassic). Therefore, the continent–continent...
collision model is not favored in this study to interpret the Triassic depositional and tectonothermal events occurring in the western Tianshan.

Alternatively, the intracratonic orogeny model is more appropriate to interpret Triassic events in the western Tianshan, since many recent studies suggest that the collision between the Tarim Craton and the CTS–Yili Block occurred in the late Carboniferous, based on magmatic, metamorphic, and zircon U–Pb–Hf isotopic evidence (e.g., Gao et al., 2011; Han et al., 2011, 2016b; Klemd et al., 2015). Nevertheless, the intracratonic evolution of the Tianshan region after the assembly of the southern CAOB remains controversial, especially concerning the time of initial uplift and denudation of the western Tianshan range. Yin et al. (1998) carried out structural and stratigraphic analyses of fold and thrust system along the northern margin of the Tarim basin and suggested that the significant uplift of the STS range began in the Oligocene (~24 Ma). On the basis of mineral compositions of clastic rocks and apatite fission track data of granites from the Chinese western Tianshan, Q.C. Wang et al. (2009) proposed that the first phase of uplift of this region occurred in the Early Cretaceous. Hendrix et al. (1992) and Hendrix (2000) put emphasis on Mesozoic uplift of the Tianshan on the basis of sedimentological and stratigraphic analyses, which was supported by fission-track data in the region of Chinese (Hendrix et al., 1994; Dumitru et al., 2001) and Kyrgyz (Glorie and De Grave, 2015 and references therein) Tianshan. A.R. Carroll and coworkers conducted comprehensive sedimentological studies on Paleozoic strata in the Kepingtage area (Carroll et al., 1995, 2001) and detrital zircon dating of clastic rocks from Aksu and Kuche areas (Carroll et al., 2013). They suggested that the Tianshan region has been a topographic high since the late Carboniferous and shed sediments onto the northern Tarim Basin.

The aforementioned detrital zircon age and sedimentological data from the northern Tarim and STS regions presented in this study and in Han et al. (2016b) suggest that the entire Tianshan region was unlikely uplifted significantly from the late Carboniferous to Early Triassic, although local uplifting may occur in the Early Triassic. The occurrence of abundant 390–310 Ma detrital zircons in the Late Triassic to Cretaceous strata (Fig. 9c, d) and the paleocurrent data (Fig. 3d) indicates that the Tianshan was significantly uplifted in the Late Triassic and provided detritus for deposits in the northern Tarim foreland basin, which is consistent with thermochronological data (Fig. 10). Therefore, the Late Triassic was probably the first phase of uplift and denudation of the Tianshan range since the late Carboniferous when the southwestern part of the CAOB was finally amalgamated.

We suggest that the Middle–Late Triassic uplift of the Tianshan range was an intracratonic orogeny possibly driven by far-field effects of the collision between the southern margin of the Tarim Craton and the Qiangtang Block to the south (Hendrix et al., 1992; Xiao et al., 2002; Jolivet et al., 2010; Glorie and De Grave, 2015). During Middle Triassic to Early Jurassic time, the Cimmerian blocks, including the Qiangtang Block, progressively accreted onto southern Eurasia and subsequently closed the Paleo-Tethys Ocean (Li et al., 2009; Roger et al., 2010; Ding et al., 2013; Metcalfe, 2013; Xu et al., 2015). Recent paleomagnetic data indicate that the collision of the Qiangtang Block with the southern margin of the Tarim Craton was most likely took place in the Middle to Late Triassic (Song et al., 2015), because these two blocks have indistinguishable paleolatitudes (~33°N) since ~210 Ma. Relevant collisional events could be represented by ~225 Ma synorogenic magmatism in the West Kunlun Orogen (Y. Zhang et al., 2015) and ~245–220 Ma (U)HP metamorphism in the Qiangtang area (Li et al., 2009; Pullen and Kapp, 2014; Xu et al., 2015). The presence of 260–220 Ma detrital zircons in the Late Triassic to Cretaceous clastic rocks in the northern Tarim region (Fig. 9c, d) indicates a source region from the Western Kunlun Orogen, suggesting nearly synchronous uplift and denudation of the Tianshan and western Kunlun ranges. The far-field effect of the collisional events likely reactivated preexisting structures in the Tianshan belt and resulted in a widespread surface uplift (Fig. 11).

6. Conclusions

New and published U–Pb and Lu–Hf isotopic data of detrital zircons from Permain and Mesozoic sedimentary strata in the southern piedmont of the Chinese western Tianshan reveal a marked change of sedimentary provenances in the mid-Triassic. Permian to Middle Triassic strata show detrital zircon age and εHf(t) patterns comparable to the data of magmatic rocks in the Tarim and STS regions, but distinct from those in the CTS–Yili Block. In contrast, Late Triassic to Cretaceous strata contain large amounts of detrital zircons characterizing the CTS–Yili Block and Western Kunlun Orogen, implying diverse source regions. This change of sedimentary provenances can be correlated with regional sedimentary records, paleocurrent data, and tectonothermal events during Mesozoic time. These data overall suggest that the first phase of significant surface uplift and denudation of the Tianshan range began in the mid-Triassic after the amalgamation of the southwestern CAOB in the late Carboniferous. The uplifting event could be caused by the far-field compressional forces associated with the collision of the Qiangtang Block with the southern margin of the Tarim Craton.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.sedgeo.2016.03.028.

Acknowledgments

This work was funded by a NSFC Project (41190075) entitled “Final Closure of the Paleo-Asian Ocean and Reconstruction of East Asia Blocks in Pangea”, which is the fifth project of NSFC Major Program (41190070) “Reconstruction of East Asian Blocks in Pangea”, a Hong Kong RGC GRF (HKU7063/13P and 17301915), and NSFC General Projects (41230207 and 41390441). This paper is a contribution to IGCP no. 648. We thank Xiaoming Liu, Zhongyuan Ren, and Le Zhang for their kind help during experimental analysis. We appreciate valuable comments from Wenjiao Xiao and editor Brian Jones.

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