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ORIGINAL PAPER

Provenance evolution of the Jurassic northern Qaidam Basin (West China) and its geological implications: evidence from detrital zircon geochronology

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Abstract The Jurassic system is the major hydrocarbon source rock and of crucial importance for understanding the Mesozoic intra-continental tectonics in West China. This paper presents systematic detrital zircon geochronology of the Jurassic outcropping at the Dameigou locality in the northern Qaidam Basin, and reports ~1000 single-grain U-Pb zircon ages that have implications for the provenance, the corresponding basin property as well as the tectonic setting of West China during Jurassic. Zircon ages exhibit two major clusters at ~250 and ~2400 Ma whereas two minor clusters at ~450 and ~850 Ma, suggesting primary sources from the East Kunlun Shan and Oulongbuluke Block, secondary sources from the North Qaidam UHP belt and South Qilian Shan. Combined with observation of lithology and sedimentary facies, two rifting periods were inferred in the earliest Jurassic and the early stage of the Middle Jurassic, respectively, accompanied by further extension throughout the Jurassic. Our results do not support a foreland basin related to the Jurassic southward thrusting of the South Qilian Shan, but favor that the Mesozoic intra-continental tectonics in West China were characterised by pulsed responses to specific collisions rather than a persisting contractional setting during Jurassic period.

Keywords Jurassic · U-Pb dating · Detrital zircon · Provenance · Qaidam Basin

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Introduction

The Jurassic system contains the major coal-bearing sequences and hydrocarbon source rocks in West China (Hendrix et al. 1992; Ritts et al. 1999; Ding et al. 2003; Yang et al. 2004; He et al. 2004; Qiu et al. 2008). It was deposited between two significant tectonic events in the Mesozoic: the accretion of the Qiangtang Block and the Lhasa Block onto the Eurasia Plate in the late Triassic and late Jurassic, respectively (Dewey et al. 1988; Yin and Harrison 2000; Wu et al. 2011a; Yang et al. 2015a). Whilst the Jurassic stratigraphy and depositional environments have been described in detail and are regionally well correlated (Hendrix et al. 1992; Ritts et al. 1999; Duan et al. 2006; Cheng et al. 2008), their origin and tectonic background are not well understood.

Whilst it is widely accepted that Mesozoic accretion produced a regional contractional regime (Hendrix 2000; Ritts and Biffi 2001; Darby and Ritts 2002; Jia et al. 2005; Wu et al. 2011a); however, it remains controversial whether the associated deformation was continuous or punctuated by a number of discrete events (Ritts and Biffi 2001; Wu et al.

2011a). The controversy was further aggravated by the contrasting views on the basin property during the Jurassic, which was regarded as either foreland basins or extensional basins based on different interpretation of geological observations (Hendrix et al. 1992; Ritts and Biffi 2001; Zheng et al. 2003; He et al. 2004; Chen et al. 2005; Wang et al. 2006; Wu et al. 2011a). A possible reason for this uncertainty is that the Jurassic sequences have been largely altered by subsequent thrusting in the Cretaceous and the Cenozoic (Hendrix et al. 1992; Jia et al. 2003; Zhang et al. 2005; Shen et al. 2009; Yin 2010; Wu et al. 2011a; Wang et al. 2012a), leading to the basin structure incomplete and hardly recognizable.

Detrital zircon U-Pb geochronology is an ideal and widely used tool for understanding sediment sources and basin setting (e.g., Cawood et al. 2012; Gehrels 2014; Bush et al. 2016; Wang et al. 2016). In this paper, we first report the systematic detrital zircon geochronology of the Jurassic sediments in the northern Qaidam Basin in West China, and provide ~1000 single-grain U-Pb zircon ages that can shed light on the Jurassic provenance evolution, the corresponding basin property, and the tectonic setting in West China in the Jurassic.

Geological setting

The Qaidam Basin has an area of 120,000 km^2 and an average elevation of ~2800 m and is one of the major sedimentary and petroliferous basins in West China (Jia 2005). It is bounded by the Qilian Shan, the East Kunlun Shan and the Altyn Shan to the northeast, the south and the northwest, respectively (Fig. 1), and contains over 10,000 m-thick accumulation of Meso-Cenozoic clastic rocks (GMBQP 1991). The Jurassic sediments are entirely non-marine and non-volcanogenic (GMBQP 1991; Ritts et al. 1999) and are mostly exposed along the margins of the basin (Fig. 1), due to intensive late Cenozoic upper crustal shortening (Yang et al. 2001; Chen et al. 2005; Yin et al. 2008). Unconformities separate the Jurassic strata from the underlying Proterozoic-Paleozoic basement and overlying Cretaceous and Cenozoic sequences (GMBQP 1991; Ritts and Biffi 2001; Wu et al. 2011a). The Jurassic strata have been divided into five formations, from oldest to youngest (Table 1): the Lower Jurassic Xiaomeigou Formation (J_1 *x*), the Middle Jurassic Dameigou Formation (J_2 *d*) and Shimengou Formation (J_2 *s*), and the Upper Jurassic Caishiling Formation (J_3 *c*) and Hongshuigou Formation (J_3 *h*). The Lower-Middle Jurassic series generally consists of grey to green conglomerates and sandstones intercalated with dark mudstones, shale and coalbeds, while the Upper Jurassic series is composed mainly of reddish and green sandstones interbedded with mudstones and conglomerates (GMBQP 1991; Ritts and Biffi 2001; Wu et al. 2011a). A number of studies has been conducted to uncover the geodynamics of the Jurassic basin based on observations of lithology, sedimentary facies, palaeocurrents and sandstone compositions of limited outcrops, but came to mutually discrepant viewpoints: (1) an Early Jurassic rift basin, overlaid by a Middle-Late Jurassic extensional depression (Chen et al. 2005; Lou et al. 2009; Wu et al. 2011a); (2) an Early-Middle Jurassic rift basin that was inverted to be a contractional basin in the Late Jurassic (Jin et al. 1999; Zeng et al. 2002); and (3) a foreland basin controlled by southward thrusting of the south Qilian Shan throughout the Jurassic (Xia et al. 1998; Ritts and Biffi 2001).

Analytical methods

Samples

The Dameigou section in the northern Qaidam Basin was selected for study as it preserves the most complete and continuous Jurassic sequence in and around the Qaidam Basin. The lithology and sedimentary facies were studied in detail and sandstone samples collected throughout the stratigraphic range for detrital zircon dating (Fig. 2).

In the studied section, the J_1x unconformably overlies the Proterozoic Dakendaban Group which contains intermediate- and high-grade metamorphic rocks and constitutes the oldest basement of the Qaidam Basin. J_1x consists mainly of fluvial-lacustrine grey or green sandstones, mudstone and conglomerates intercalated with coal beds. Palaeocurrents are mostly southward in the lower part but become northward in the middle and upper parts (Fig. 2). The J_2d, with generally southwestward palaeocurrents, contains typical fining-upward sequences consisting mainly of conglomerates in the lower part, sandstones in the middle part and mudstones, shales as well as some coal beds in the upper part, which were deposited in fluvial-lacustrine environments (Fig. 2). The J_2s conformably overlies the Dameigou Formation (J_2d) and is composed mainly of fluvial-lacustrine grey sandstones and mudstones also in an overall fining-upward trend (Fig. 2). The J_3c consists of yellowish green and red sandstones and mudstones deposited in a braided-river delta environment. The J_3h consists mainly of reddish mudstones intercalated with grey sandstone and gypsum layers, indicative of a lacustrine and arid environment at the time.

Nine sandstone samples (3–4 kg each) were collected for detrital zircon U-Pb analyses. The detailed locations and descriptions of these samples are shown in Fig. 2 and Table 2.

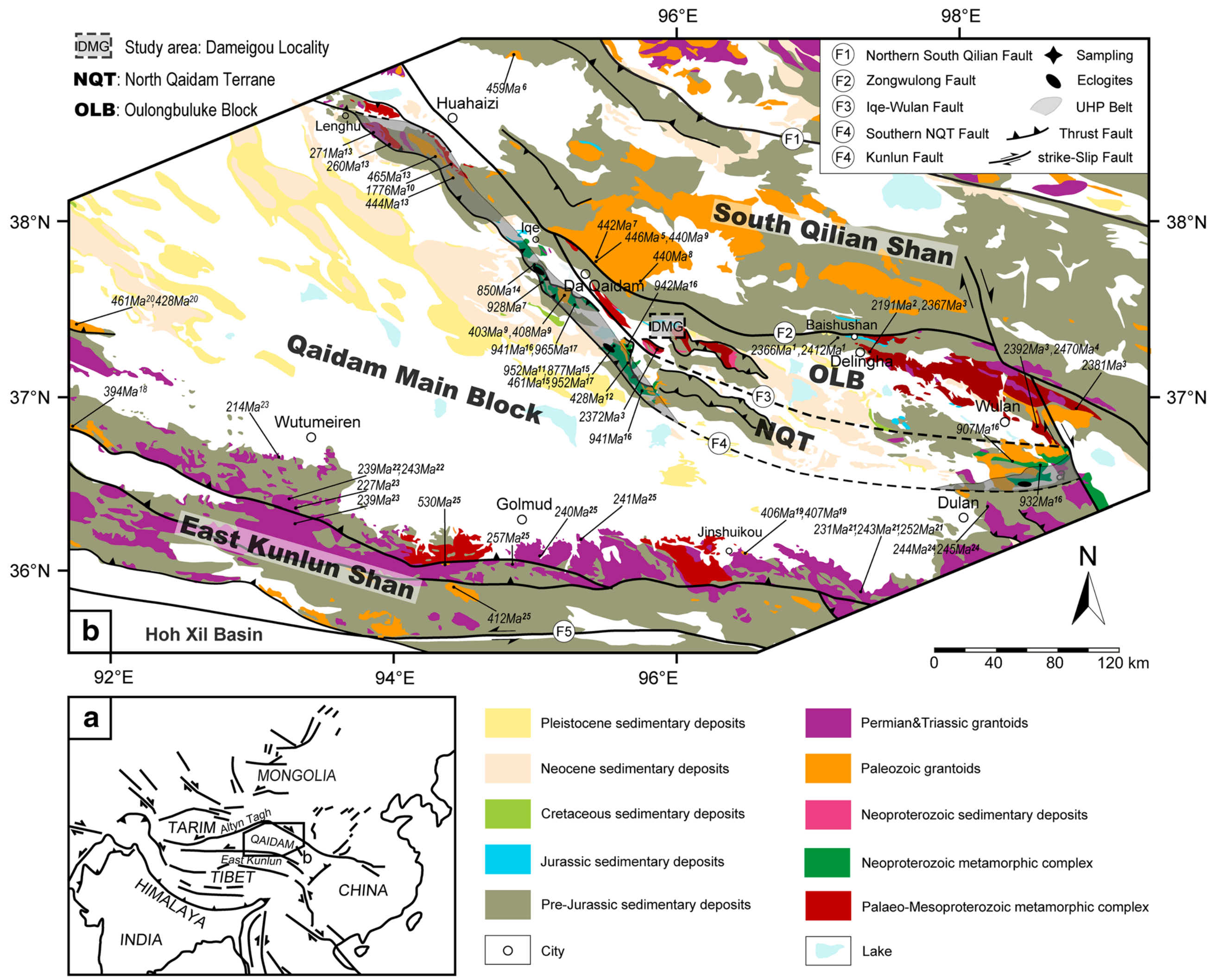


Fig. 1 **a** Geological sketch map showing the location of the Qaidam Basin; **b** Outline of the geology of the Qaidam basin and surrounding areas (modified from Bush et al. 2016) showing the location of the study area (*dashed box*) and principal rock units and their corresponding zircon U-Pb ages. *Superscripts* give the references for the age data: (1) Lu et al. (2002); (2) Huang et al. (2011); (3) Gong et al. (2012); (4) Chen et al. (2012a); (5) Wu et al. (2001); (6) Cowgill et al. (2003); (7) Gehrels et al. (2003); (8) Lu et al. (2007); (9) Wu et al. (2007); (10) Xiao et al. (2003); (11) Zhang et al. (2003); (12) Meng et al. (2005); (13) Wu et al. (2009); (14) Song et al. (2010); (15) Zhang et al. (2011); (16) Song et al. (2012); (17) Yu et al. (2015); (18) Chen et al. (2006); (19) Liu et al. (2012); (20) Li et al. (2013); (21) Zhang et al. (2012a); (22) Chen et al. (2014); (23) Wang et al. (2014); (24) Li et al. (2015); (25) Harris et al. (1988)

Table 1 The Jurassic strata in the Qaidam Basin

Formation	Symbol	Series	Stage	Source
Hongshuigou	J_3h	Late Jurassic	Oxfordian-Kimmeridgian	GMBQP (1991)
Caishiling	J_3c			
Shimengou	J_2s	Middle Jurassic	Bathonian	Zhou and Li (1980)
Dameigou	J_2d		Aalenian-Bajocian	Ye and Li (1982)
Xiaomeigou	J_1x	Early Jurassic	Sinemurian-Toarcian	Wang et al. (2005) Wu et al. (2011a)

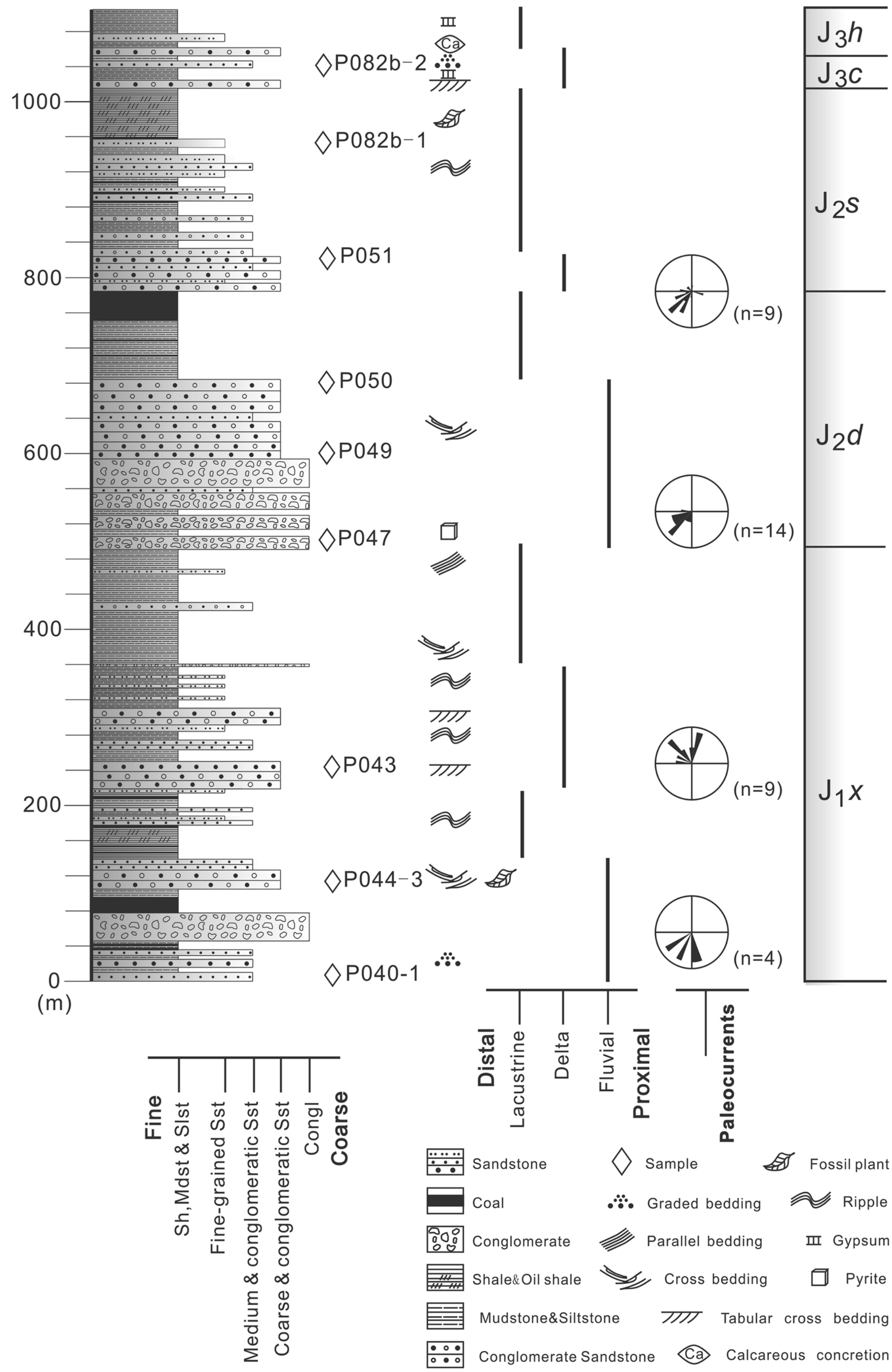


Fig. 2 Synoptic straitigraphic column for exposed sections in the Dameigou area, northern Qaidam Basin. Palaeocurrents are mainly from Ritts and Biffi (2001)

LA-ICP-MS analysis

Following heavy mineral separated by conventional heavy liquids and magnetic techniques, zircon grain mounts were polished and analysed using a New Wave NWR 193 nm laser ablation system coupled to an Agilent 7700 quadrupole-based ICP-MS at the London Geochronology Centre (UCL). LA-ICPMS procedures followed Jackson et al. (2004).

Approximately 150 grains were analysed per sample. Plešovice zircon (Sláma et al. 2008) was chosen as the natural standard, and the standard silicate glass NIST 610

Table 2 Summary of major characteristics and corresponding statistical data from the U-Pb geochronology of zircons of the nine samples

Formation	Sample location	Sample number (total effective grain numbers)	Percentage in total effective grains (effective grain numbers in each age group)				
			200–300 Ma	300–550 Ma	750–1100 Ma	2000–2600 Ma	Other ages
Lower Jurassic samples							
J_1x	37°30′22″N 96°01′29″E	P040-1 (43)	–	–	–	100% (43)	–
J_1x	37°30′46″N 96°01′41″E	P044-3 (91)	–	–	–	100% (91)	–
J_1x	37°33′38″N 96°01′27″E	P043 (125)	54% (67)	10% (13)	14% (18)	10% (12)	12% (15)
Middle Jurassic samples							
J_2d	37°30′54″N 96°01′24″E	P047 (127)	–	–	–	98% (125)	2% (2)
J_2d	37°37′54″N 95°44′17″E	P049 (120)	32% (38)	32% (38)	8% (9)	16% (19)	13% (16)
J_2s	37°37′59″N 95°44′24″E	P050 (135)	35% (47)	34% (46)	15% (20)	10% (13)	7% (9)
J_2s	37°37′30″N 95°43′54″E	P051 (82)	29% (24)	30% (25)	17% (14)	5% (4)	18% (15)
J_2s	37°32′05″N 96°00′34″E	P082b-1 (110)	16% (18)	28% (31)	25% (28)	15% (17)	15% (16)
Upper Jurassic samples							
J_3c	37°32′15″N 96°00′43″E	P082b-2 (130)	26% (34)	18% (24)	28% (37)	11% (14)	16% (21)

and NIST 612 (Jochum et al. 2011) were used to optimise the instrument and to correct for instrumental mass bias and depth-dependent inter-element fractionation of Pb, Th and U. Temora (Black et al. 2003) and 91500 (Wiedenbeck et al. 2004) zircon were used as secondary age standards. A typical laser operating condition used 30 microns spot and an energy density of ca 2.5 J/cm^2 with a repetition rate of 10 Hz. Glitter 4.4 (Griffin et al. 2008) was used for data reduction and ages were calculated following Ludwig (2008) using the calculated $^{206}Pb/^{238}U$ age for grains younger than 1100 Ma, and the $^{207}Pb/^{206}Pb$ age for older grains (Gehrels 2014). Grains with mixed ratios or discordance values outside of +5/−15% were rejected (Gehrels et al. 2003). A total of 963 single-grain effective U-Pb zircon ages was finally obtained; the detailed data can be found in the Supplementary Material.

Results

The Concordia plots for the nine samples are shown in Fig. 3. The histograms and kernel density estimates for detrital zircon ages of each sample are shown in Fig. 4a, and the related cumulative probability curves are plotted in Fig. 5. The zircon age distributions show four major age peaks at ~250, ~450, ~850 and ~2400 Ma (Fig. 4a). The analysed samples can be subdivided into four groups according to their different age patterns. *Group I* contains two samples (P040-1, P044-3) from the basal part of the J_1x and one sample (P047) from the bottom of the J_2d. All detrital zircons in this group fall into Palaeoproterozoic and Neoarchean ages (~2000 to 2600 Ma), and >85% of the total dated grains fall within a single peak at ~2400 Ma (Table 2; Figs. 4a, 5).

Group II consists of only one sample (P043) from the middle part of the J_1x, and has a predominant age peak at ~250 Ma accounting for 54% of the total dated grains and three minor peaks at ~450, ~850 and ~2400 Ma (Table 2; Figs. 4a, 5).

Group III includes three samples (P049, P050, P051) from the J_2d and J_2s, and is characterised by two dominant age populations of 200–300 and 300–550 Ma that account for ~65% of the total grains. Two other small clusters at ~850 and ~2400 Ma account for most of the other analysed grains (Table 2; Figs. 4a, 5).

Group IV is composed of two samples (P082b-1, P082b-2) from the upper part of the J_2s and the J_3c. Most dated grains form populations at ~250, ~450, ~850 and ~2400 Ma, respectively (Table 2; Figs. 4a, 5).

Discussion

Provenances

Figure 4b summarises the diagnostic zircon age signatures of potential source areas for the Jurassic sediments deposited in northern Qaidam Basin based on published zircon ages. The results show that: (1) the East Kunlun Shan, the southern boundary of the Qaidam Basin, has a zircon age signature characterised by two obvious peaks at ~250 and ~450 Ma (Figs. 1, 4b); (2) the North Qaidam Ultra High-Pressure (UHP) belt (Fig. 1) has two zircon age clusters at 350–550 and 750–950 Ma (Figs. 1, 4b); (3) the Oulongbuluke Block, where the studied Dameigou section is located, is dominated by zircon ages between 2000 and 2600 Ma peaking at ~2400 Ma (Figs. 1, 4b); (4) the South Qilian Shan to the north of the studied section has a zircon age

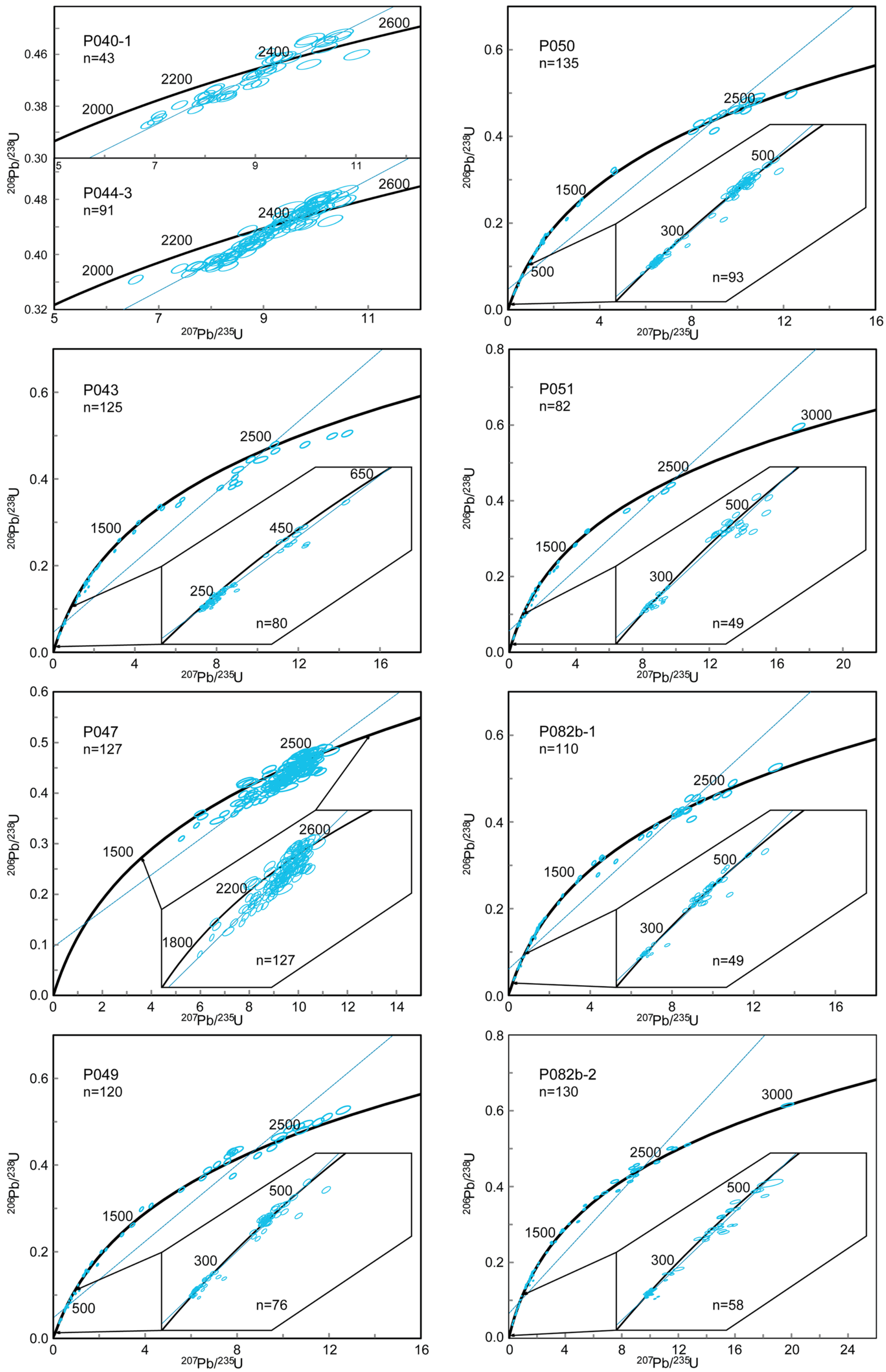


Fig. 3 U-Pb concordia plots for detrital zircons of the nine samples in the Dameigou locality, northern Qaidam Basin

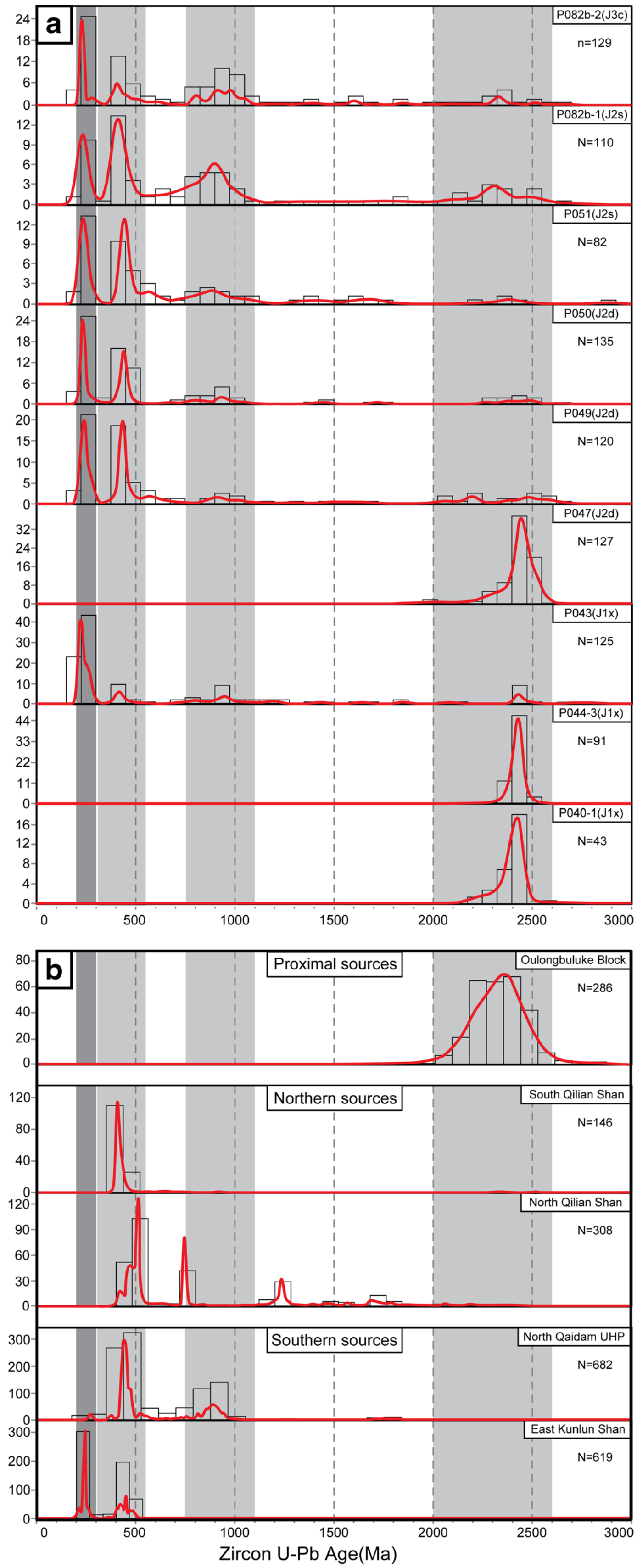


Fig. 4 Histograms and corresponding Kernel density estimates (KDE) for U-Pb ages of **a** dated detrital zircons from the Jurassic samples in the Dameigou locality, northern Qaidam Basin, and **b** published plutonic and detrital zircons of the five potential source areas: Oulongbuluke Block (Lu et al. 2002; Huang et al. 2011; Gong et al. 2012; Chen et al. 2012a); South Qilian Shan (Wu et al. 2001, 2007; Cowgill et al. 2003; Gehrels et al. 2003; Lu et al. 2007; Zhang et al. 2012b; Zhou et al. 2013; Shi et al. 2015; Liu et al. 2016); North Qilian Shan (Wu et al. 2010, 2011b; Chen et al. 2014; Cheng et al. 2016; Yang et al. 2016; Zhang et al. 2016a); North Qaidam UHP (Xiao et al. 2003; Zhang et al. 2003, 2011, 2016b; Meng et al. 2005; Wu et al. 2009; Song et al. 2010, 2012; Zhu et al. 2012; Zhou et al. 2013; Fu et al. 2014; Yang et al. 2015b; Yu et al. 2015) and East Kunlun Shan (Bian et al. 2004; Liu et al. 2004, 2012; Wu et al. 2005; Chen et al. 2006, 2014; Cui et al. 2011; Li et al. 2012, 2013, 2015; Wang et al. 2012b, 2014; Zhang et al. 2012a; Xiong et al. 2016). All data are graphed using the programs of ISOPLOT 4.15 (Ludwig 2008) and DensityPlotter 7.0 (Vermeesch 2012). The histograms display the numbers of concordant zircons in 80 Ma intervals. *N* is the number of total effective zircons of each sample

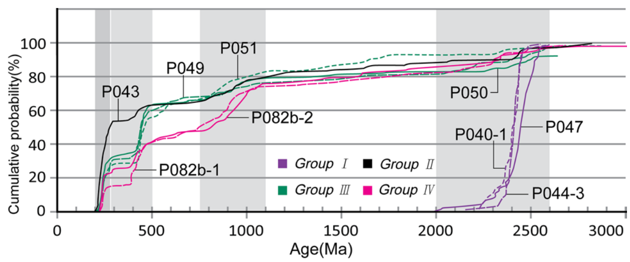


Fig. 5 Cumulative probability distributions of the effective U-Pb Zircon ages of the nine samples

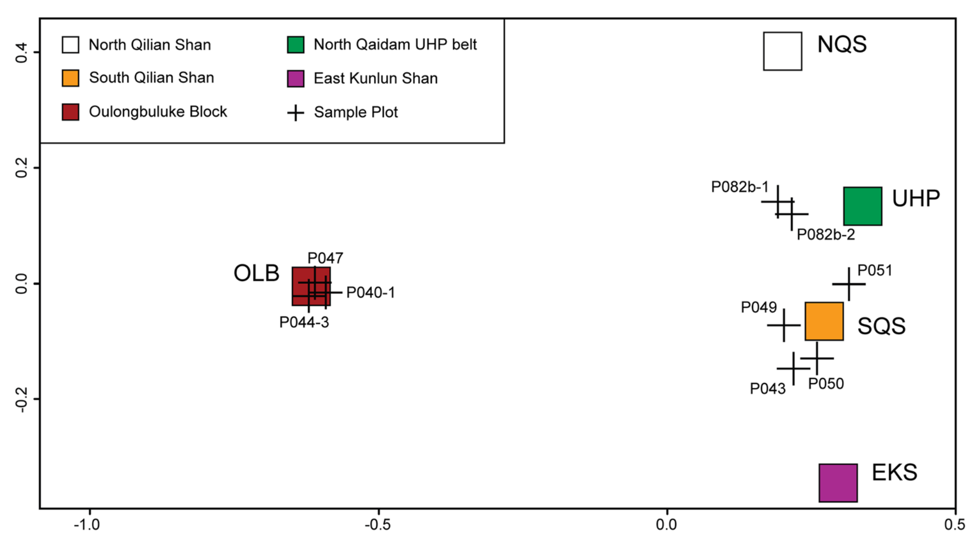
signature with a single peak at ~450 Ma; and (5) the North Qilian Shan is defined by three major zircon age modes at 400–550, 650–800 and 1200–1300 Ma and one minor cluster at 1700–1800 Ma (Fig. 4b). This summary implies that (1) except for the Oulongbuluke Block, the other four potential source areas share ~450 Ma zircons, (2) age modes of ~250, ~850 and ~2400 Ma have unique sources from the East Kunlun Shan, the North Qaidam UHP belt and the Oulongbuluke Block, respectively (Fig. 4). It is noticeable that Neo-Proterozoic zircon ages were also recently reported in the easternmost South Qilian Terrane, near the Xining City (Yan et al. 2015). However, we do not regard it as a potential provenance because it is too far away from our study locality (~800 km).

By comparing the detrital zircon age distributions from Jurassic samples with age spectra from potential source areas the sediment sources and routing system can be reconstructed. To help with this interpretation the age distributions were converted into a Multidimensional Scaling Map (Vermeesch 2013). The resultant map shows a close affinity between samples in *Group I* and the Oulongbuluke Block. The other samples plot close to each other consistent with a common origin shared among the South Qilian Shan, the North Qaidam UHP belt and the East Kunlun Shan (Fig. 6).

Samples from *Group I* (P040-1, P044-3 and P047) were interpreted to have a local source from the Oulongbuluke Block because their detrital zircon ages have a single probability peak at ~2400 Ma (Figs. 2, 4, 6). This is consistent with the coarse lithology of these samples indicative of a nearby source. Sample P043 (*Group II*) is inferred to be sourced mainly from the East Kunlun Shan to the south according to the primary zircon age peak at ~250 Ma (Fig. 4). This is consistent with palaeocurrent measurements suggesting a northward transport direction at the time (Fig. 2). The minor zircon age peaks at ~850 and ~2400 Ma suggested that the North Qaidam UHP belt and the Oulongbuluke Block may also have had a contribution (Figs. 1, 4). Samples from *Group III* (P049, P050 and P051) have provenances from southern sources, similar to Sample P043 (Fig. 4b). Because their detrital zircon distributions (Fig. 4a) mainly comprise not only ~250 Ma ages (from the East Kunlun shan) but also ~850 Ma ages (from North Qaidam UHP belt) (Appendix A). Besides, the South Qilian Shan also shed clastics into the northern Qaidam Basin at the same period, according to the relatively larger proportion of the zircon ages peaking at ~450 Ma and the measured southward palaeocurrents (Figs. 2, 4). Samples from *Group IV* (P082b-1 and P082b-2) have nearly same provenances as those from *Group III* except larger contributions from the North Qaidam UHP belt and the Oulongbuluke Block implied by the higher proportions of zircon ages peaking at ~850 and ~2400 Ma (Figs. 3, 6).

To summarise, the results indicate that the Jurassic sediments in the northern Qaidam Basin came primarily from the East Kunlun Shan and the Oulongbuluke Block, and secondarily from the North Qaidam UHP belt and the South Qilian Shan. This finding differs from previous

Fig. 6 Multidimensional Scaling (MDS) Map based on calculated K–S distances between U-Pb age spectra, comparing Jurassic samples of this study (~1000 zircon ages) with potential possible source areas based on published data (see Figs. 1, 4)



studies on the same section which proposed, based on palaeocurrent measurements and sandstone petrology alone, that there was a constant source of sediment from the South Qilian Shan throughout the Jurassic (Ritts and Biffi 2001). Though some uncertainty exists (e.g., the zircon age signatures of the potential sources for correlation were not the actual ones in the Jurassic because zircons eroded since the Jurassic were not included), the results report for the first time a quantitative and continuous study of the Jurassic provenance evolution of the northern Qaidam Basin, which provides important insight into Mesozoic tectonism of the Qaidam Basin as well as West China. As a consequence, the Jurassic paleogeography needs to be revisited.

Implications for the Jurassic basin property

Whether the Jurassic Qaidam Basin was a foreland basin or an extensional basin remains debatable (Ritts and Biffi 2001; Chen et al. 2005; Wu et al. 2011a) and is a subject that is of crucial importance not only for further petroleum exploration, but also to help understand the nature of the Jurassic deformation regime of West China. Previous work proposed tectonism to be the result of either far-field effects of block collisions in the late Triassic, late Jurassic and late Cretaceous, respectively (Hendrix et al. 1992; Wu et al. 2011a), or by a sustained contractional setting persisting throughout the Mesozoic (Sobel 1999; Ritts and Biffi 2001).

Ritts and Biffi (2001) proposed that the northern Qaidam Basin was a foreland basin related to southward thrusting of the South Qilian Shan, and that the Dameigou locality was in a proximal foredeep position in the Early Jurassic but shifted to a wedge-top (piggyback) position in the Middle Jurassic. Under such a setting, the majority of Jurassic sediments in the study area would be expected to derive from the South Qilian Shan. This does not fit well with the results of this study, which indicates that the South Qilian Shan was only a minor source region (Fig. 4). The dated zircon age distributions vary among samples of different groups, especially those in the Early and Middle Jurassic (*Group I, II* and *III*, Figs. 2, 4a), implying a changing provenance through time. The variations may result from either shifts in climatic or changes in tectonic (flexural) loading. The former can be discounted as previous studies show that a warm and humid climate prevailed during the Early-Middle Jurassic (Wang et al. 2005; Jian et al. 2013), although the climate may have shifted abruptly to a cool and arid climate in the Late Jurassic (Wang et al. 2005; Jian et al. 2013). However, there is no corresponding change of provenance (Samples P082b-1 and P082b-2 in *Group IV*, Fig. 4a) suggesting that tectonically driven changes were more likely the cause.

Based on the analysis above, we try to unravel the nature of the northern Qaidam Basin in the Jurassic:

In the early stage of the Early Jurassic (Samples P040-1 and P044-3), clastic sources were confined to the Oulongbuluke Block (KDE age spectra and MDS map in Figs. 4, 5, 6, as well as characters of lithology and sedimentary facies in Fig. 2). We inferred that the northern Qaidam Basin was a rift basin then (Chen et al. 2005; Lou et al. 2009; Wu et al. 2011a). The current Dameigou locality might have been situated at the depositional center and very close to the boundary normal faults at the time, accumulating clastics derived mainly from the nearby footwall of the Oulongbuluke Block (Fig. 7a). This inference is consistent with the regional tectonics. The Palaeo-Tethys Ocean started to subduct northward beneath the Eurasia continent since the late Permian and finally closed in the late Triassic, forming a wide Andes-type arc in the East Kunlun Shan and eastern Qaidam Basin areas (Yang et al. 1996; Chen et al. 2012b, 2015; Li et al. 2013; Wang et al. 2014). Granite petrology indicates that these areas underwent post-collisional extension in the late Triassic (Luo et al. 2014; Wang et al. 2014; Xiong et al. 2014), which may have continued to the Jurassic and therefore induced the formation of Early Jurassic extensional basins in the Qaidam Basin. Likewise, the Jiuquan, Minle, Chaoshui and Longzhong basins along the northern margin of the Qilian Shan are also regarded as rift basins in the Early Jurassic according to several lines of evidence from seismic reflection data and observations of lithology and sedimentary facies (Vincent and Allen 1999; He et al. 2004; Wang et al. 2013).

In the middle stage of the Early Jurassic (Sample P043), the dominant source of clastics from the East Kunlun Shan to the south mixed with minor sources from the local Oulongbuluke Block and the adjacent North Qaidam UHP belt, indicating a provenance change from a unique proximal source to multiple distal sources (Figs. 4a, 6). This possibly suggests a wider sedimentary regime, and could be interpreted to be as the result of the onset of an extensional depression (Fig. 7b). This interpretation would fit the typical late stage of a rift basin due to thermal subsidence (Mckenzie 1991).

The dominance of the local source from the Oulongbuluke Block appears again in the early stage of the Middle Jurassic (Sample P047) (Figs. 4a, 6), which we interpreted to be suggestive of a new rifting stage at the time (Fig. 7c). This coincides with the abrupt change from lacustrine mudstones in the upper part of the Lower Jurassic series to fluvial conglomerates and sandstones in the lower part of the Middle Jurassic series (Fig. 2). This rifting stage lasted for a very short time and the northern Qaidam Basin quickly turned to be an extensional depression, as suggested by the multiple sources from the East Kunlun Shan, the North Qaidam UHP belt, the Oulongbuluke Block and the South

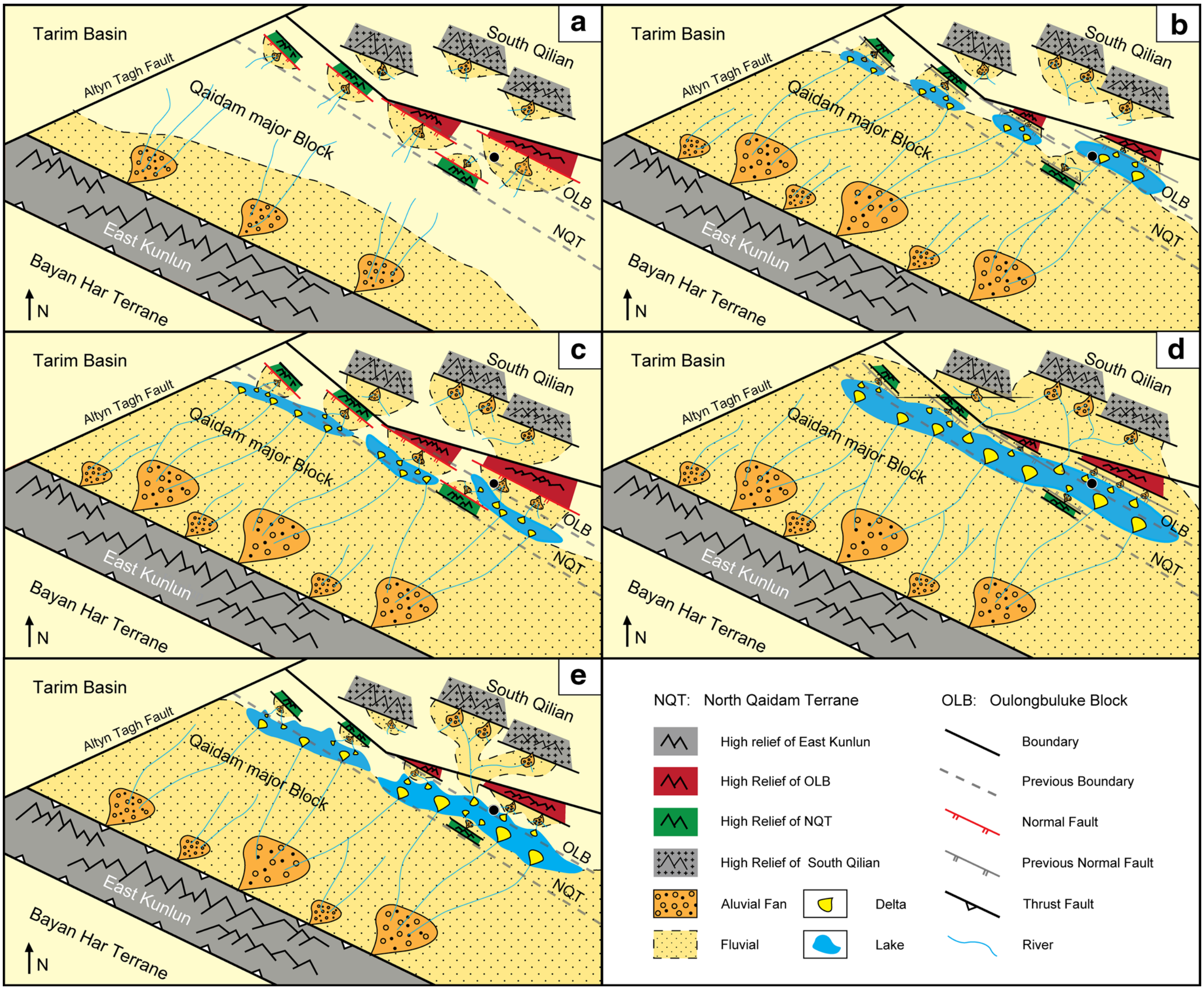


Fig. 7 Cartoons to show the changes in depositional environments and paleogeography of the northern Qaidam Basin during: **a** the Early Jurassic; **b** late stage of Early Jurassic; **c** early stage of Middle Jurassic; **d** middle-late stages of Middle Jurassic; **e** the Late Jurassic

Qilian Shan in most of the Middle-Late Jurassic (Samples P049, P050, P051, P082b-1, P082b-2), indicative of a wider depositional area (Fig. 7d, e). This correlates with the generally lacustrine-delta environments at the time and the syn-depositional normal faults ever-found in the Upper Jurassic series in the western Qaidam Basin (Wu et al. 2011a). At the end of the Jurassic, the South Qilian Shan started to uplift and thrust over the northern Qaidam Basin in response to the collision between the Lhasa Block and the Eurasia Plate, folding the Jurassic sequences and therefore forming a regional unconformity between the Jurassic and the Cretaceous system (Wu et al. 2011a).

In short summary, the provenance analysis does not infer a foreland basin related to the southward thrusting of the South Qilian Shan in the Jurassic, but implies two rifting periods in the early Early Jurassic and early Middle Jurassic, respectively, accompanied by extensional depression in the rest Jurassic time. Our results do not support a persisting contractional setting throughout the Jurassic, rather, favor that the Mesozoic intra-continental tectonics in West China are featured by pulsed responses to specific collisions to the south.

Jurassic evolution of the northern Qaidam Basin

Based on the above analysis of the Jurassic provenance and the inferred basin geodynamics, we reconstructed the Jurassic evolution of the northern Qaidam Basin involving multiple source regions, as shown schematically in Fig. 7. In the early stage of the Early Jurassic, a series of rift basins were developed in the northern part of the today's Qaidam Basin and accumulated coarse clastics sourced mainly from nearby basements in the footwalls of the boundary faults of these rift basins (Fig. 7a). In the late stage of the Early Jurassic, the basins evolved into extensional depressions with long-distance sedimentary influence, accumulating fine sediments sourced mainly from the East Kunlun Shan to the south (Fig. 7b). Another rifting phase occurred in the earliest Middle Jurassic, and the local Oulongbuluke Block became the primary source of the coarse sediments in the Dameigou locality again (Fig. 7c). The northern Qaidam Basin turned to be extensional basins again since the middle stage of the Middle Jurassic and was sustained until the end of the Jurassic (Fig. 7d, e). Sediments in the Dameigou locality have multiple sources from surrounding mountains and were generally fine-grained sandstones, mudstone and shales that are well correlated with their counterparts in other localities in the northern Qaidam Basin (Wu et al. 2011a), indicating a united sedimentary regime with long-distance transport of clastics or low relief of the source areas at that time.

Conclusions

We conducted a systematic study of the detrital zircon geochronology of the Jurassic sediments at the Dameigou locality, northern Qaidam Basin, with results obtained to help understand the Jurassic provenance evolution, the corresponding basin property and tectonic setting in West China. The conclusions are as follows:

1. Dated zircon ages exhibit two major clusters peaking at ~250 and ~2400 Ma, which account for ~60% of the total grains and are interpreted to have unique sources from the East Kunlun Shan and the Oulongbuluke Block, respectively. Two further age populations, peaking at ~850 and ~450 Ma, accounting for ~30% of the total grains. The ~850 Ma cluster is regarded to be sourced from the North Qaidam UHP belt whereas the ~450 Ma one could originate from any of the studied source areas, including the North Qaidam UHP belt. This disagrees with the previous view that the South Qilian Shan served as the main source of the northern Qaidam Basin sediments throughout the Jurassic.
2. Zircon age distributions vary among different samples, providing a proxy to study the Jurassic basin property of the northern Qaidam Basin. The results imply two periods of rifting, in the earliest Jurassic and the early stage of the Middle Jurassic, accompanied by extensional depression in the rest Jurassic time, and thus do not support a foreland basin related to the southward thrusting of the South Qilian Shan during Jurassic.

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