Geological evolution of Central Asian Basins and the western Tien Shan Range

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Abstract: The geological evolution of Central Asia commenced with the evolution of a complex Precambrian–Palaeozoic orogen. Cimmerian blocks were then accreted to the southern margin during the Mesozoic, leading to tectonic reactivation of older structures and discrete episodes of basin formation. The Indian and Arabian blocks collided with Asia during the Cenozoic, leading to renewed structural reactivation, intracontinental deformation and basin development. This complex evolution resulted in the present-day setting of an elongated Tien Shan range flanked by large Mesozoic–Cenozoic sedimentary basins with smaller intramontane basins distributed within the range. The aim of this volume is to present multidisciplinary results and reviews from research groups in Europe and Central Asia that focus on the western part of the Tien Shan and some of the large sedimentary basins in that area. These works elucidate the Late Palaeozoic–Cenozoic tectono-sedimentary evolution of the area. Emphasis is placed on the collision of terranes and/or continents and the ensuing fault reactivation; the impact of changes in climate on the sedimentation is also examined.

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with the building of new highways and planned railways and pipelines. Trade is once again crossing the numerous borders, partially driven by the presence of the large, still poorly studied petroliferous basins in the area.

The Phanerozoic tectonic history of the region commenced with the accretion of the main units of northern Asia. These accretionary events were associated with the subduction/collision of various microcontinents, terranes and island arc complexes during Palaeozoic and Mesozoic times. Many of these events remain poorly defined, leading to obvious confusion in the literature with various reconstructions and collision timings being proposed (e.g. Zonenshain et al. 1990; Berzin et al. 1994; Şengör & Natal’in 1996; Buslov et al. 2004; Natal’in & Şengör 2005; De Grave et al. 2012; Zanchetta et al. 2013; Şengör et al. 2014; Yang et al. 2017). The southern margin of Eurasia contained a range of pre-Cenozoic structures, including suture zones and/or large-scale fault zones between blocks, some of which were Gondwana-derived (e.g. Audet & Bürgmann 2011). These structures were particularly susceptible to subsequent Cenozoic-age intraplate deformation related to the India–Eurasia (Early–Middle Eocene) and Arabia–Eurasia (Late Eocene–Early Oligocene) collisions (e.g. Molnar & Tapponnier 1975; Tapponnier & Molnar 1979; Şengör & Natal’in 1996; Windley et al. 2007; Allen 2010; Dupont-Nivet et al. 2010; van Hinsbergen et al. 2012; Kröner et al. 2014). These latter events were marked by the docking of strong and resistant Archaean–Proterozoic continental lithosphere with the weaker southern margin of Eurasia. The consequence of these collisions was the formation of two major topographical features – the Zagros and Himalaya orogenic belts – both of which are outside of our immediate area of investigation. The various tectonic events, including terrane collisions, major continent–continent collisions (including the Pamir Spur) and the related oceanic closures (e.g. Tien Shan Ocean, Mongol–Okhotsk Ocean, Palaeotethys, branches of Neotethys) all combined to broadly reshape a continental mass whose tectonic history was already complex.

The Tien Shan is one of the world’s largest mountain belts comprising the well-exposed southern portion of a much larger Phanerozoic-age orogenic belt, the so-called Central Asian Orogenic Belt (CAOB) (e.g. Jahn et al. 2000, 2004; Windley et al. 2007; Kröner et al. 2014). The Tien Shan stretches over 2800 km along an E–W axis from Xinjiang in NW China through to the Aral Sea in Uzbekistan via Kazakhstan, Tajikistan and

Fig. 1. Location map for the papers presented in this volume, superimposed on a shaded relief background. Stars indicate the approximate regions presented in the papers included in this volume. We provide only the name of the first author. Two papers (Jolivet 2015; Robert et al. 2015) dealing with a wide area are positioned in the middle of the map without stars. The location of Figure 2 is shown. Green line: political borders and Caspian Sea shoreline; ATB: Afghan Tajik Basin; B: Basin; FB: Fergana Basin; Kyr: Kyrgyzstan, Taj: Tajikistan; TFF: Talas–Fergana Fault.
Kyrgyzstan, with the highest peaks exceeding 7000 m asl and the lowest point at 154 m bsl in the eastern Tien Shan. The chain has had an extremely complex evolution, commencing with the formation of the various small, scattered Precambrian blocks, followed by a Palaeozoic history involving the development of accretionary belts, marine sedimentary basins and relatively minor collisions. To the west the Central Tien Shan Ocean closed completely in the latest Carboniferous, and closure was followed by a phase of Early Permian post-collisional exensional magmatism (e.g. Dolgopolova et al. 2017; Konopelko et al. 2017). The subsequent Mesozoic history of the Tien Shan is characterized by episodes of intracontinental tectonism, with the final phase in Cenozoic times related to far-field effects of the India–Asia collision (e.g. Burtman 1980, 1997; Bazhenov et al. 1999; Buslov et al. 2008; Jolivet et al. 2010; Macaulay et al. 2014). During this last phase older structures were often preferentially reactivated, creating the misleading impression that the Palaeozoic and Cenozoic belts are identical.

The Tien Shan is often subdivided into three sectors, namely: the Western, Central and Eastern Tien Shan. The Talas–Fergana Fault, a notable strike-slip feature, marks the boundary between the Western and Central Tien Shan sectors. However, depending on where a study is located, different concepts have been used for both the geographic and geological subdivisions (i.e. as a result of the different authors), leading to potential confusion. In particular, the Chinese and the ex-Soviet terminologies are not compatible. Here we follow the subdivisions depicted in Figure 2. These three geographic regions can be further subdivided into the North, Middle and South Tien Shan. This latter subdivision is broadly based on the regional Palaeozoic evolution; the ensuing amalgamation of various terranes resulted in the formation of distinctive tectonic zones (e.g. Şengör et al. 1993; Wang et al. 2006; Windley et al. 2007; Xiao et al. 2008; Burtman 2010).

The North Tien Shan, situated east of the Talas–Fergana Fault, comprises several Precambrian-age blocks as well as Cambrian–Lower Ordovician ophiolites and marine sediments (Biske & Seltmann 2010), overlain by Ordovician-age sediments and volcanic rocks, and cut by I-type granites. The region includes the southern margin of the Kazakh–Kyrgyz continent, which was deformed as a result of subduction and accretion during the Late Carboniferous and Early Permian (i.e. accretion of Turan, Alai, Tarim area to Kazakh–Kyrgyz continent, e.g. Thomas et al. 1999a; McCann et al. 2013; Burtman 2015). To the north, the Late Palaeozoic-age Yili volcanic belt or Yili Block represents a continental arc, which overlaps Early Palaeozoic
accretionary collages and sutures in the region of SE Kazakhstan (e.g. Alekseev et al. 2016).

The Middle Tien Shan (=Syrdarya, Naryn or Ishim–Middle Tien Shan microcontinent) comprises a range of Neoproterozoic units which include tillites and acid volcanic rocks (Biske & Seltmann 2010). It is separated from the North Tien Shan by the Turkestan Suture (suture of the Terskey Early Palaeozoic ocean; e.g. Burtman 2010; Glorie et al. 2011). The Middle Tien Shan wedges out eastwards near the border of Kyrgyzstan with China; further east, it has no recognized equivalent (Xiao et al. 2013). To the NW, the Karatau–Talas terrane (e.g. Alekseev et al. 2016) is considered to form a marginal part of the Middle Tien Shan microcontinent, based on similarities in terms of the Early Palaeozoic depositional facies from both areas. From Middle Devonian to Late Carboniferous times, the Middle Tien Shan probably formed part of the passive margin of the Kazakh–Kyrgyz continent and was characterized by shallow-marine carbonate and silicilastic sediments (e.g. Alekseev et al. 2009; Biske & Seltmann 2010).

The South Tien Shan, separated from the Middle Tien Shan by the South Tien Shan Suture (=Turkestan Suture, characterized by Early Ordovician–Early Carboniferous ophiolites; Kurekova & Aristov 1995; Gao et al. 1998; Chen et al. 1999), is a Late Palaeozoic-age, fold-and-thrust belt formed during the closure of the Turkestan Ocean (=Central Tien Shan Ocean; Zonenshain et al. 1990; Kheraskova et al. 2010; Seltmann et al. 2011; McCann et al. 2013). The direction of subduction vergence of the Central Tien Shan Ocean is uncertain, and both northerly directed (e.g. Windley et al. 1990; Allen et al. 1992; Xiao et al. 2004; Hegner et al. 2010) and southerly directed (e.g. Charvet et al. 2007, 2011; Lin et al. 2009; Ma et al. 2014) models have been proposed. The South Tien Shan is situated along the SW margin of the Central Asian Orogenic Belt (CAOB, =Altaids; Şengör et al. 1993, 2014), a key region for our understanding of both the amalgamation of Eurasia (see above) and the Phanerozoic growth of the CAOB (Windley et al. 1990, 2007; Bazhenov et al. 1999; Gao et al. 2009; Kröner et al. 2014). Only the South Tien Shan is continuous along the whole length of the belt (e.g. Xiao et al. 2013); the Middle and North Tien Shan are not always present. In its western part, the South Tien Shan can be subdivided into several units from west to east (Konopelko et al. 2007, 2017): the Kyzylkum, Gissar, and Alai (=Alay) segments west of the Talas–Fergana Fault; and the Kokshai segment to the east. Lithologically they are all similar, comprising Ordovician–mid-Carboniferous pelagic sediments, partly associated with intraplate volcanics, and thick carbonate platforms (mainly Late Devonian–Early Carboniferous in age) which are best developed in the latter two segments (Biske & Seltmann 2010; Seltmann et al. 2011). Post-collisional intrusions east and west of the Talas–Fergana Fault are dated as Early Permian (e.g. Konopelko et al. 2007, 2017; Dolgopolova et al. 2017). Seltmann et al. (2011) have noted that the South Tien Shan region contains deformed forearc accretionary complexes as well as passive margin sediments.

Lateral variations within the South Tien Shan serve to illustrate the complexity of the regional geology. The Chinese part of the South Tien Shan, for example, was separated from the Tarim block by a South Tien Shan Ocean, which opened in a back-arc setting and probably closed in the Late Carboniferous–Early Permian (e.g. Xiao et al. 2013). In the Kyrgyz part of the South Tien Shan, the presence of minor Devonian-age ophiolites (on the China map of Tien Shan; Wang et al. 2007) may represent the westward continuation of the suture between the Tarim block and the Chinese South Tien Shan as suggested by Küßner et al. (2017). To the west of the Talas–Fergana Fault, the small Gissar Ocean (e.g. Brookfield 2000) formed as a result of Carboniferous-age rifting, possibly in a back-arc setting. This ocean was located to the south of the South Tien Shan and to the north of the Karakum Block. It subsequently closed in the latest Carboniferous, forming the Gissar Suture (e.g. Burtman 2010; Dolgopolova et al. 2017; Konopelko et al. 2017).

This volume assembles the results from projects supported fully, or in part, by the DARIUS Programme as well as invited external studies. The DARIUS Programme (2009–14) was a multidisciplinary geological programme that comprised original scientific projects, executed by academic scientific teams involving more than 350 scientists representing 150 research institutions from 25 countries in Europe, the Middle East and western Central Asia. The DARIUS consortium was sponsored by major oil companies (BHP Billiton, BP, ENI, Maersk Oil, Petronas Carigali, Shell, Statoil, Total) and French research organizations (Centre National de la Recherche Scientifique-INSU, University Pierre & Marie Curie). The main objective of DARIUS was to characterize the tectono-stratigraphic evolution of a vast domain around the central Tethys extending from the eastern Black Sea in the west to western Central Asia in the east, and to reconstruct the post-Late Palaeozoic geodynamic evolution of the domain. The priority was to investigate the 6000 km long continuous orogenic belt extending from Crimea/Anatolia in the west to the western Tien Shan in the east, including the surrounding basins, through the collection of original data and the development of regional syntheses.
The present volume is one of the end-products of the DARIUS Programme, which also gave rise to three other special volumes – one on Cimmerian Terranes (Zanchi et al. 2015); one on Anatolia (Robertson et al. 2016); and one on the Eastern Black Sea–Caucasus domain (Sosson et al. 2017) – as well as an atlas of 20 palaeotectonic maps ranging in age from the Late Permian through to the Pliocene (Barrier & Vrielynck 2017).

The papers in the present volume represent up-to-date work and reviews on some of the geological elements (see Fig. 1 for locations) of the western part of the Tien Shan as well as some of the large basins of Central Asia, with the overarching goal of attaining a better understanding of the regional geological evolution. The volume is subdivided into four sections and these and their constituent papers are discussed in order in the following sections.

**Regional evolution and extensional sedimentary basins**

The volume commences with a synthesis of the main geodynamic episodes which occurred during the Late Palaeozoic–Mesozoic in Central Asia, providing a general framework for the other, more localized, studies in the book. This is followed by a detailed review of the post-Variscan evolution of the Afghan orogenic segments. Such a review is long overdue in the international literature, given the difficulties of working in present-day Afghanistan. The subsequent three papers analyse the evolution of two major extensional sedimentary basins in the western part of the studied area: the Amu Darya Basin and the South Caspian Basin.

Jolivet (2015) reviews the various geodynamic episodes which occurred across the region of Central Asia and Tibet during the Late Palaeozoic–Mesozoic and which induced either large-scale compression or widespread extension. The various events, including the Late Palaeozoic final amalgamation of the Central Asian Orogenic Belt, the accretion of the Cimmerian blocks, the closure of the Mongol–Okhotsk Ocean and the accretion of the Neoimager blocks, determined the structural pattern of the region. These Mesozoic events were significant in the localization and evolution of Tertiary deformation (e.g. Tapponnier et al. 2001; Searle et al. 2011; van Hinsbergen et al. 2011). In many areas, the degree of post-Mesozoic exhumation has been sufficiently small that it is still possible to discern relict low-relief landforms that formed over c. 100 Ma ago. This, in turn, evidences the long-lasting aridity and low levels of erosion outside of the extremely localized deformation zones.

The Afghan orogenic segment is located within the collision zone of Eurasia and the Gondwana-derived continental blocks. Siehl (2015) points out that this zone has remained active up to the present day as a result of the northward drift of India to the east and Arabia to the west (Stöcklin 1977; Şengör 1984; Boulin 1991). He reviews the geology of the Afghan portion of the Afghan–Tajik Basin, and examines the period following the Variscan orogenic events at the end of the Palaeozoic Era. These events heralded the onset of successive suturing events (Eo-Cimmerian, Late Cimmerian) and involved the accretion of Gondwana-derived fragments to the southern margin of Eurasia and the closure of the Palaeo Tethys Ocean, as well as branches of the Neotethys Ocean. Additionally, these tectonic events were related to the development of the Cimmerian and Himalayan ‘Tethyside Orogenic Zone’ of Şengör et al. (1988). The successive collisions and sutures resulted in the formation of the c. 1300 km long Afghan orogenic segment, which extends in a west–east direction from the eastern Iranian Kopet Dagh to the Pamir–Punjab region in southern Kyrgyzstan–northern Pakistan. It has a width of c. 1100 km in a north–south direction from the North Afghan–Tajik Basin in the north to the Markhel Basin of Balochistan in the south.

Brunet et al. (2017) use a set of depth-structure maps and isopach maps as well as regional cross-sections to examine the tectono-sedimentary evolution of the Amu Darya Basin during the Late Palaeozoic and the Mesozoic. The evolution is considered from the point of view of basin subsidence, and can be explained by two main extensional events. The first, and most important, event probably occurred during the Late Palaeozoic–Triassic after closure of the Turkestan Ocean, and resulted in the deposition of several kilometres of sediments. This event followed the final amalgamation of the Turan Platform, composed of several individual crustal blocks of varying sizes, thus creating an inhomogeneous basement. Inherited structures were reactivated during subsequent periods of extension as well as during collisions. The second extensional event took place in Early–Middle Jurassic times, following the Eo-Cimmerian orogeny. This event was concentrated in the eastern half of the Amu Darya Basin, and resulted in the deposition of thick Jurassic-age successions which subsequently formed the main petroleum system of the basin.

Detailed analysis of a series of cross-sections from the Bukhara-Khiva area allows Mordvintsev et al. (2017) to examine, in detail, the evolution of the northeastern margin of the Amu Darya Basin during the Mesozoic (focusing mainly on the Jurassic). Sections are based on subsurface data: seismic lines, boreholes and depth-structure maps. The structures of the Bukhara step and the
Modelling the collisional and sedimentary evolution of the western part of the Tien Shan

Models of the tectono-sedimentary evolution of the Tien Shan region are complex and incomplete (see also Xiao et al. 2010). This is due to a combination of factors including the complex geology (see Nurtaev et al. 2013), problems of access (to some areas) and the lack of published and accessible information (particularly in English and/or in western scientific journals). Additionally, there are significant problems correlating the different geological subdivisions between the various countries through which the Tien Shan runs (see Xiao et al. 2010 for a Chinese version of the main terminologies). From east to west, two papers in the volume examine the suture zones and the vergence of subduction in the Tien Shan. Another paper takes a broad regional approach, examining the entire area while also extending further to the south to include the colliding Arabian and Indian plates.

Loury et al. (2015) present two crustal-scale cross-sections of the Kyrgyz portion of the Central Tien Shan and correlate the major faults and units eastwards from Kyrgyzstan to China. Based on field and seismic data, they suggest that the broad structure conforms to that of a doubly vergent mountain belt where the Chinese and Kyrgyz areas show identical structural and metamorphic histories. This double-vergence appears to be inherited from two major steps: (1) subduction towards the south of the Central Tien Shan Ocean; and (2) strike-slip kinematics, mainly during the Early Permian. Based on the structure and kinematics of the South Tien Shan belt, they suggest that the Central Tien Shan Ocean was subducted during the Late Carboniferous, resulting in continental collision at c. 320–310 Ma when the Tarim block collided with the Kazakh–Kyrgyz continent. Top-to-north thrusting and top-to-south detachment within the accretionary prism resulted in the exhumation of a large continental unit which had been metamorphosed under eclogite facies conditions. This tectonic evolution is broadly consistent with a published numerical model by Vogt & Gerya (2014). The time span for this collision–accretion orogeny is at least 27 Ma between the onset of subduction and final exhumation.

Alexeiev et al. (2015) examine passive-margin Devonian–Permian-age carbonate successions in the Middle Tien Shan region of Kyrgyzstan. These sediments record c. 150 Ma of tectonic history in the region and provide important insights into the reconstructions of the sedimentary basins and the regional geodynamic framework in one of the least-understood regions of the Central Asian Orogenic Belt. Major reorganizations in the architecture of the carbonate platform were caused by eustatic drowning events in the early Tourmaisian, early Visean and near the Visean–Serpukhovian boundary. Similar carbonate deposits are also observed in South Kazakhstan and the North Caspian Basin, suggesting a common origin and hence a similar petroleum reservoir potential. A convergent margin formed in the middle Bashkirian; subsequently, flexurally driven subsidence documents the encroachment of an orogenic thrust wedge. Deposition is superseded by deformation and plutonism after the Asselian, documenting the onset of the final hard collision.

Robert et al. (2015) analyse crustal and lithospheric thickness maps for Central Eurasia combining elevation and geoid anomaly data and thermal analysis. Their results are constrained by older data derived from seismological and seismic
The link between fault reactivation and far-field effects is explored by Bande et al. (2015b) in their analysis of Cenozoic deformation within the Fergana Basin. Deformation is concentrated along thrusts on the northern and southern basin margins, while the eastern margin is transpressive. All of the observed deformation can be associated with movement along the Talas–Fergana Fault. The close association of the Fergana Basin with the Talas–Fergana Fault resulted in the development of a basin morphology that differs from that of other Cenozoic-age intramontane basins within the Tien Shan typically bounded by north- or south-verging faults (e.g. Cobbold et al. 1996; Burbank et al. 1999; Macauley et al. 2014). The Fergana Basin is located due north of the Pamir, suggesting a possible tectonic link between indentation of the latter and basin evolution. While folding and thrusting in the Tajik Basin is clearly related to the indentation of the Pamir Mountains, no convincing mechanism has, thus far, been proposed for tectonic linkage between compression and the morphology of the Fergana Basin. It would however now appear that shortening (beginning in the Oligocene) was transferred along the Talas–Fergana Fault, reaching the western Kyrgyz and Uzbek Tien Shan and resulting in exhumation in the Chatkal and Fergana ranges by c. 25 Ma.

Fault reactivation and far-field effects

As noted in the introduction, the Tien Shan region is characterized by a complex orogenic history. The various collisional episodes, coupled with strike-slip activity, resulted in the development of a significant fault zone, the Talas–Fergana Fault, examined in detail below. Additionally, the role of far-field effects – particularly related to the Cenozoic collisions occurring along the southern margin of the Eurasian continent, especially that of the Pamir indentation – and their role in the development of the broader orogeny are also examined.

Bande et al. (2015a) examine the role of major structural features, in particular the role of regional strike-slip faults in continental interiors in the region. The Talas–Fergana Fault is of great significance in terms of understanding the hinterland kinematics of the India–Asia collision. New apatite fission track data from mountain ranges bounding the northern end of the Talas–Fergana Fault suggest that there was a rapid exhumation event there at c. 25 Ma. This can be correlated with a synchronous pulse of cooling and thrust belt propagation in the South Tien Shan, implying that both ranges underwent coeval and rapid exhumation. Strike-slip motion along the Talas–Fergana Fault commenced at c. 25 Ma, facilitating anticlockwise rotation of the Fergana Basin as well as exhumation of the linked horsetail splays. Pamir indentation was underway by c. 20 Ma. The Talas–Fergana Fault was therefore largely responsible for transferring Pamir-induced shortening to the NW Tien Shan.

Sedimentary, environment and climate

Sedimentary basins, and the depositional successions within them, provide the most tangible and accessible records of the lithospheric, geographical, oceanographic and ecological developments which occur in a specific area over a specific period of time (McCann & Saintot 2003). Investigation of the sedimentary successions contained within the basins which formed within the broader Tien Shan orogen thus provide overviews of the Mesozoic (five papers) and Cenozoic (two papers) history across the region, focusing as they do on the interlinkage of sedimentation, tectonics and climate.

Schnyder et al. (2016) examine palynological and high-resolution carbon isotope data measured on bulk organic matter from the Lower Jurassic continental succession in the Leontiev Graben of Kazakhstan. The two datasets are in agreement, allowing the recognition of the transition zone between the Pliensbachian and the Toarcian. The major palaeoclimatic changes associated with large carbon-cycle perturbations at the Pliensbachian–Toarcian transition have, to date, been primarily studied in marine settings. This study presents one of the best continental sequences in the world for documenting this transition. Identification of the transition also facilitates correlation with the
worldwide Toarcian Oceanic Anoxic Event and negative (organic) carbon isotope excursion, as well as identifying a warming trend.

Fürsich et al. (2015) reconstruct the Early Jurassic–Early Cretaceous period, which was characterized by complex, low-intensity tectonic deformation and major climate changes from humid (Middle Jurassic) to arid conditions (Late Jurassic) to semi-arid conditions (Cretaceous). Using the sediment record in the Junggar, Tarim and Fergana basins to describe the tectonic evolution of the Tien Shan area, therefore requires differentiation between tectonic and climatic influences on sedimentation. Tectonic deformation in the region commenced during the Middle Jurassic, leading to basin inversion and the recycling of older sedimentary successions. The change to a humid climate in Middle Jurassic times favoured the development of extensive vegetation cover and the establishment of permanently flowing rivers. However, by Late Jurassic times there was a shift towards a monsoon-type, semi-arid climate with the development of desert environments, with an aridity peak at the Late Jurassic–Early Cretaceous boundary. Aridity coincided with an increase in alluvial fan deposition, the timing of which cannot be related to the most-often-proposed geodynamic event (i.e. the Early Cretaceous accretion of the Lhasa Block) since fan growth would appear to predate this event.

Klocke et al. (2015) study a c. 10 km section of sediments deposited in the NE part of the Tajik Basin. This comprises an Upper Cretaceous–Oligocene pre-tectonic shallow-marine to continental succession and a younger syntectonic succession of clastic deposits derived from the uplifting mountain ranges of the Tien Shan in the north and the Pamir in the south and east. The evolution of the Tajik Basin is documented by facies, palaeo-transport directions and provenance analysis. The Cenozoic-age sediments within the basin reflect large fluvial plains running from the margins of the northern Pamir and the southern Tien Shan mountains. Subsequently, in Neogene times the basin fill was progressively deformed by folding and thrusting.

Bosboom et al. (2015) investigate the Cretaceous and Palaeogene sedimentary successions in three areas (Tarim Basin, China; Fergana Valley and the Alai Valley, Kyrgyzstan; Afghan–Tajik Basin, Tajikistan) in order to reconstruct the epicontinental sea that was present across the region at that time. The results indicate that the various locations, while geographically distant, shared a similar palaeogeographical evolution, one characterized by a long-term stepwise retreat punctuated by short-term shallow-marine incursions. The final Late Eocene disappearance of this sea probably occurred (with a degree of diachronicity) prior to the isolation of the Paratethys Sea. This shifting of the coast
towards the west would have had profound effects on the climate of Central Asia, resulting in reduced moisture supply to the interior.

Geological evolution of Central Asian Basins and the western Tien Shan Range: integration of new results

The Palaeozoic Tien Shan forms part of the extensive Central Asian Orogenic Belt (CAOB) (Jahn et al. 2000, 2004). The CAOB formed as a result of continuous subduction-accretion from the Neo-proterozoic through to the Late Palaeozoic, culminating with the final amalgamation of the East European Craton in the west, the Siberian Craton in the east and the Karakum and Tarim continents to the south (Konopelko et al. 2007). Subsequent accretion and associated oceanic closures were often related to the movement of Cimmerian terranes, which became detached from Gondwana during the Permain due to the opening of the Neotethys Ocean and subsequently collided with the southern margin of Eurasia. The earliest collisional episode, involving various Iranian blocks, occurred in the Late Triassic. This was followed by the collision of the Central Afghanistan and Central Pamir blocks at the end of the Triassic. Two of these events resulted in the formation of the Eo-Cimmerian unconformity and the Eo-Cimmerian Belt (e.g. Zanchi et al. 2009; Zanchetta et al. 2013). Coevally, the end of the Indosinian Orogeny in SE Asia as well as the accretion of the Qiangtang Block in Tibet during the Triassic–Early Jurassic (e.g. Jolivet 2015) marked the end of this initial Mesozoic-age deformational phase in Central Asia. Subsequent tectonic activity was more diffuse, and would appear to have been partly driven by far-field processes associated with a series of events, including: the poorly understood closure of the Mongol–Okhotsk Ocean in Siberia (Late Jurassic–Early Cretaceous, van der Voo et al. 2015; Early Cretaceous, Jolivet 2015); the accretion of the Lhasa Block along the southern Tibet margin (Early Cretaceous); and slab pull along the palaeo-Pacific and ‘Meso-Tethys’ subduction zones (e.g. Hendrix et al. 1992; Sobel 1999; Jolivet 2015; van der Voo et al. 2015). The Cenozoic-age collision of India and Eurasia resulted in significant deformation across the region (e.g. Liu et al. 2013; Yang et al. 2013, 2014), with far-field effects being traced as far north as the Sea of Okhotsk (e.g. Worrall et al. 1996). The regional evolution of the Tien Shan region is therefore characterized by two major orogenic phases: the Early Mesozoic Eo-Cimmerian Orogeny and the Cenozoic collision of India and Eurasia (e.g. Dumitru et al. 2001; Jolivet et al. 2010; Jolivet 2015; Siehl 2015). These two major events are separated by a transitional period characterized by a series of less-well-understood events (in terms of their far-field effects) extending from the Jurassic through the Cretaceous. The impact of these events, related to the accretion of smaller blocks (e.g. Lhasa Block) to Eurasia, is unclear; published reconstructions and timings for the various events often vary. In summary, the various accretionary events from Late Palaeozoic times onwards varied both in terms of their timing as well as their location, resulting in variations both in deformation as well as the related post-collisional magmatism towards the east (Klett et al. 2006; Zanchi et al. 2009, 2012; Siehl 2015).

Deformation in Central Asia related to the various accretionary events outlined above has been significant, ranging from crustal thickening through to more localized effects related to fault reactivation. In addition to lithospheric changes, far-field effects related to the various continental collisions are also of significant importance since pre-existing discontinuities may transfer stress from distant geodynamic processes, both compressional (e.g. accretion of the Cimmerian, Qiangtang, Lhasa and Indian blocks) and extensional (e.g. back-arc extension, slab roll-back). The far-field effects of continental collision (e.g. Molnar & Tapponnier 1975; Allen et al. 1991; Hendrix et al. 1994) and the role of older structures (e.g. Jolivet et al. 2010; Selander et al. 2012; Macauley et al. 2013) have been extensively studied in the Tien Shan region, particularly on the Eastern (Chinese) Tien Shan (e.g. Allen & Vincent 1997; Yin et al. 1998; Chen et al. 2007; Sun et al. 2009) and the Central (Kyrgyz) Tien Shan (e.g. Abdrahmatov et al. 1996; Cobbold et al. 1996; Sobel et al. 2006a, b; De Grave et al. 2011; Macauley et al. 2014). In contrast, far less has been published on the western Tien Shan. Robert et al. (2015) provide evidence of crustal thickening in both major frontal ranges (Himalayas, Zagros, Pamir, Caucasus) as well as more distal ranges, such as the Alborz, Kopet Dagh and the Tien Shan, while also noting that crustal thinning is restricted to the Arabian and Indian oceanic domains, the South Caspian Sea, the Red Sea and the Black Sea. The width of the zone of deformation (>1200 km) highlights the extent of the area affected by crustal thickening, which is also a testament to the efficient transfer of tectonic forces for hundreds to thousands of kilometres from the respective collisional zones. Robert et al. (2015) also note that within these broad zones of deformation some tectonic blocks (e.g. Central Iran, Tarim) exhibit only slightly thickened crust and relatively uniform topography, suggesting only moderate deformation. This would suggest that these blocks have a degree of rheological resistance to the ongoing deformation.
During the Mesozoic and Early Cenozoic, parts of the Tien Shan were periodically reactivated in response to distal collisions (e.g. Hendrix et al. 1992; Sobel & Dumitru 1997; Allen et al. 2001; Dumitru et al. 2001; Glorie et al. 2011). Indeed, the role of Palaeozoic structures and sutures is particularly important during later Cenozoic deformation. In central parts of Asia, major structures such as the Talas–Fergana or the Altyrn Tagh faults were reactivated with strike-slip motion. The Talas–Fergana Fault, which is c. 2000 km long, is one of the best examples of a reactivated intra-continental strike-slip fault, and a prominent morphological feature within the western Tien Shan. Deformation along the fault trace during the Late Oligocene–Early Miocene (e.g. Hendrix et al. 1999) and again in the Late Miocene (e.g. Bullen et al. 2003; Macaulay et al. 2014) can be linked to the evolution of the Pamir (Bande et al. 2015b).

In southern Tajikistan the sinistral strike-slip Darvaz Fault marks the boundary between the North Pamir and the Tajik Basin, along which 200–300 km of left-lateral offset has been estimated (Burtman & Molnar 1993). Stratigraphic work by Klocke et al. (2015) suggests that there was Late Oligocene uplift of the northern Pamir. Generally, strike-slip faults within continental interiors often move in response to distal plate collisions (e.g. Burtman et al. 1996; Yin et al. 2002). Constraining the spatio-temporal distribution of activity along such faults is therefore of great significance in terms of our understanding of how oblique deformation is accommodated in transpressional settings. Strike-slip movements and fault reactivation also affected large sedimentary basins in the region, such as the Amu Darya Basin, from Late Palaeozoic through to Cenozoic times (Thomas et al. 1999a, b; Natal’in & Şengör 2005; Brunet et al. 2017; Mordvintsev et al. 2017), although the precise effects on basin evolution are difficult to document.

The reactivation of older structures under changing geodynamic conditions is examined by Loury et al. (2015) for the Kyrgyz portion of the South Tien Shan. They note that reactivation of Palaeozoic-age structures in Permian–Mesozoic times occurred mainly in a strike-slip regime, featuring left-lateral motion localized in the centre of the South Tien Shan. Subsequently, in Cenozoic times a flower structure developed as a result of the reactivation of former top-to-the-north Carboniferous thrusts to the north of the South Tien Shan. This was coeval with the development of top-to-the-south thrusts in a fold-and-thrust belt propagating over the Tarim block, south of the South Tien Shan.

Subsequent to the collisions of the Cimmerian terranes with Eurasia in the Late Triassic (e.g. Stampfli & Borel 2002; Barrier & Vrielynck 2008, 2017; Wilmsen et al. 2009; Zanchi et al. 2009, 2012), a number of new or rejuvenated sedimentary basins formed north of the main collision zone in Central Asia, including the Amu Darya Basin (extending mainly across Turkménistan and Uzbekistan) and the Afghan-Tajik Basin (extending across Uzbekistan, Tajikistan and Afghanistan) (e.g. Thomas et al. 1999a; Melikhov 2000, 2013, 2017; Brookfield & Hashmat 2001; Ulmishek 2004; Klett et al. 2006; Fürsich et al. 2015; Brunet et al. 2017). The evolution of these two basins was closely linked from the Late Palaeozoic onwards; indeed, during Jurassic times the two basins were connected. A similar connection existed to the WSW between the South Caspian and the Kopet Dagh basins, which formed in the Jurassic (Brunet et al. 2003; Taheri et al. 2009; Robert et al. 2014; Abdullayev et al. 2015). The Jurassic–Cretaceous was characterized by a general planation of the previously formed relief (e.g. Makarov 1977; Che-diya 1986; Burbank et al. 1999; Allen et al. 2001; Cunningham et al. 2003; Jolivet et al. 2010, 2013, 2015), providing sediments to these newly forming extensional basins (Brookfield & Hashmat 2001; Klett et al. 2006; Fürsich et al. 2015; Brunet et al. 2017).

The deposits within sedimentary basins related to orogenic systems provide a record of the evolution of uplift and subsequent erosion of the adjacent mountain ranges, as well as the history of changing depositional systems, subsidence, tectonic deformation, sea-level variations (e.g. Alexeev et al. 2015) and climate within the basins themselves (e.g. DeCelles & Giles 1996; Schlunegger et al. 1997; Piffner et al. 2002; Sinclair & Naylor 2012). In Central Asia, the Mesozoic period was marked by pronounced tectonic activity but also by climatic changes, specifically, the transition from a humid climate during the Middle Triassic–Middle Jurassic to a semi-arid-arid climate through to the Late Jurassic–Early Cretaceous (e.g. Hendrix et al. 1992; Shao et al. 2003; Cecca et al. 2005; Fürsich et al. 2015; Jolivet et al. 2015; McCann 2016a, b; Schnyder et al. 2016; Brunet et al. 2017). Subsequently, during the early Cenozoic regionally well-correlated marine transgressions occurred (Bosboom 2013; Bosboom et al. 2015). These transgressive events have been linked to Paratethys Sea which was open to the west (Black Sea, Caucasus, Caspian Sea) and extended eastwards through the Amu Darya, Tajik, Fergana and Tarim basins of Central Asia (Popov et al. 2004).
Concluding remarks

This Special Publication was prepared as a contribution to our understanding of the geological evolution of selected Central Asian basins and the western Tien Shan Range. There are very few international publications which focus on the evolution of Central Asia, especially its Mesozoic evolution, and this volume aims to fill some of the gaps in our existing knowledge on this dynamic and key region. It combines the results obtained by interdisciplinary groups from numerous institutions in Europe and Central Asia. Structural, geophysical, sedimentological, stratigraphical, palaeontological, thermochronological, geochemical and subsidence analyses are all used to decipher the complex tectono-sedimentary evolution of the area and to unravel the complete history of the collisions and subsequent intra-continental deformation that commenced in Late Palaeozoic times across Central Asia.

This history began with the assemblage of the Late Palaeozoic Central Asian Orogenic Belt, which in itself involved a complex series of collisional events. In the Mesozoic, the first significant orogenic event can be linked to the docking of the Cimmerian blocks to Asia during Triassic–Early Jurassic times. The main central Asia sedimentary basins therefore developed prior to the onset of the India–Eurasia collision during the Cenozoic.

New evolutionary models are presented, examining the timing of the various tectonostratigraphic events and emphasizing the reactivation of inherited structures. They illustrate the diversity of processes involved in the ongoing construction of the mountains and the adjacent basins and the mutual relationship between internal and external mechanisms, as well as far-field deformation, mountain building, topographic evolution, basin development and climatic conditions.

The editors would like to acknowledge the entire team of the Geological Society of London Publishing House, and especially Angharad Hills, Rachael Kriefman, Tamzin Anderson and Sarah Gibbs, for their support, patience and work to produce this Special Publication. The manuscript greatly benefited from a review by Randall Stephenson who is also the GSL book editor for this volume.

References

Abdrakhmatov, K.Y., Aldazhanov, S.A. et al. 1996. Relatively recent construction of the Tien Shan inferred from GPS measurements of present-day crustal deformation rates. Nature, 384, 450–453, https://doi.org/10.1038/384450a0

Abdullayev, N.A., Kadirov, F. & Guliyev, I.S. 2015. Subsidence history and basin-fill evolution in the South Caspian Basin from geophysical mapping, flexural backstripping, forward lithospheric modelling and gravity modelling. In: Brunet, M.-F., McCann, T. & Sobel, E.R. (eds) Geological Evolution of Central Asian Basins and the Western Tien Shan Range. Geological Society, London, Special Publications, 427. First published online August 27, 2015, https://doi.org/10.1144/SP427.5

Alekseev, D.V., Degtyarev, K.E. et al. 2009. Late Palaeozoic subductional and collisional igneous complexes in the Naryn segment of the Middle Tien Shan (Kyrgyzstan). Doklady Earth Sciences, 427, 760–763, https://doi.org/10.1134/S1028334X09050122

Alekseev, D.V., Cook, H.E., Djenchuraeva, A.V. & Mikolaichuk, A.V. 2015. The stratigraphic, sedimentological and structural evolution of the southern margin of the Kazakhstan continent in the Tien Shan Range during the Devonian to Permian. In: Brunet, M.-F., McCann, T. & Sobel, E.R. (eds) Geological Evolution of Central Asian Basins and the Western Tien Shan Range. Geological Society, London, Special Publications, 427. First published online July 15, 2015, https://doi.org/10.1144/SP427.3

Alekseev, D.V., Kröner, A. et al. 2016. Middle to Late Ordovician arc system in the Kyrgyz Middle Tianshan: from arc-continent collision to subsequent evolution of a Palaeozoic continental margin. Gondwana Research, 39, 261–291.

Allen, M.B. 2010. Roles of strike-slip faults during continental deformation: examples from the active Arabia–Eurasia collision. In: Kusky, T.M., Zhai, M.-G. & Xiao, W. (eds) The Evolving Continents: Understanding Processes of Continental Growth. Geological Society, London, Special Publications, 338, 329–344, https://doi.org/10.1144/SP338.15

Allen, M.B. & Vincent, S.J. 1997. Fault reactivation in the Junggar region, northwest China: the role of basement structures during Mesozoic-Cenozoic compression. Journal of the Geological Society, 154, 151–155, https://doi.org/10.1144/jgs.154.1.0151

Allen, M.B., Windley, B.F., Zhang, C., Zhao, Z.Y. & Wang, G.R. 1991. Basin evolution within and adjacent to the Tianshan range, NW China. Journal of the Geological Society, London, 148, 369–378, https://doi.org/10.1144/jgs.148.2.0369

Allen, M.B., Windley, B.F. & Zhang, C. 1992. Palaeozoic collisional tectonics and magmatism of the Chinese Tien Shan, central Asia. Tectonophysics, 220, 89–115, https://doi.org/10.1016/0040-1951(93)90225-9

Allen, M.B., Alsdorf, G. & Zhemchuzhnikov, V.G. 2001. Dome and basin refolding and transpressive inversion along the Karatau fault system, southern Kazakhstan. Journal of the Geological Society, London, 158, 83–95, https://doi.org/10.1144/jgs.158.1.83

Aldazhanov, S.A. 2010. Exhumational history of the north central Pamir. Tectonics, 29, https://doi.org/10.1029/2009TC002589

Audet, P. & Bürgmann, R. 2011. Dominant role of tectonic inheritance in supercontinent cycles. Nature Geoscience, 4, 184–187.

Bande, A., Sobel, E.R., Mikolaichuk, A. & Torres Acosta, V. 2015a. Talas–Fergana Fault Cenozoic timing of deformation and its relation to Pamir indentation. In: Brunet, M.-F., McCann, T. & Sobel, E.R.
(eds) Geothermal Evolution of Central Asian Basins and the Western Tien Shan Range. Geological Society, London, Special Publications, 427. First published online July 17, 2015, https://doi.org/10.1144/SP427.1

BANDE, A., RADIABOV, S., SOBEL, E.R. & SIM, T. 2015b. Cenozoic palaeoenvironmental and tectonic controls on the evolution of the northern Fergana Basin. In: BRUNET, M.-F., McCANN, T. & SOBEL, E.R. (eds) Geothermal Evolution of Central Asian Basins and the Western Tien Shan Range. Geological Society, London, Special Publications, 427. First published online December 18, 2015, https://doi.org/10.1144/SP427.12

BARRIER, E. & VRIELYNCK, B. 2008. Palaeotectonic maps of the Middle East. Tectono-Sedimentary-Palinspastic maps from Late Norian to Pliocene. Publisher CGMW, Paris, http://www.ccgm.org. Atlas of 14 maps, scale 1/18 500 000.

BARRIER, E. & VRIELYNCK, B. 2017. Palaeotectonic maps of Middle East and Western Central Asia from the Middle Permian to the Pliocene. Scale 1:17 000 000, 20 sheets. CGMW, Paris, ISBN: 9782917310304.

BAZHENOV, M.L., BURTMAN, V.S. & DVORAVA, A.V. 1999. Permian palaeogeomagnetism of the Tien Shan fold belt, Central Asia: post-collisional rotations and deformation. Tectonophysics, 312, 303–329.

BERZIN, N.A., COLEMAN, R.G., DOBRETSOV, N.L., ZONENSHAIN, L.P., XUCHANG, X. & CHANG, E.Z. 1994. Geodynamic map of Paleo-Asian Ocean: eastern segment. Russian Geology and Geophysics, 35, 5–23.

BISKE, YU.S. & SELTMANN, R. 2010. Paleozoic Tian Shan as a transitional region between the Rhei and Ural-Turkestan oceans. Gondwana Research, 17, 602–613, https://doi.org/10.1016/j.gr.2009.11.014

BOXBOOM, R.E. 2013. Paleogeography of the Central Asian proto-Paratethys Sea in the Eocene: controlling mechanisms and palaeoenvironmental impacts, PhD thesis, Utrecht University (Utrecht Studies in Earth Sciences, 38, 223).

BOXBOOM, R., MANDIC, O., DUPONT-NIVET, G., PROUST, J.-N., ORMUOK, C. & AMINOV, J. 2015. Late Cenozoic palaeogeography of the proto-Paratethys Sea in Central Asia (NW China, Southern Kyrgyzstan and SW Tibet). In: BRUNET, M.-F., McCANN, T. & SOBEL, E.R. (eds) Geothermal Evolution of Central Asian Basins and the Western Tien Shan Range. Geological Society, London, Special Publications, 427. First published online September 7, 2015, https://doi.org/10.1144/SP427.11

BOULIN, J. 1991. Structures in Southwest Asia and evolution of the eastern Tethys. Tectonophysics, 196, 211–268.

BROOKFIELD, M.E. 2000. Geological development and Phanerozoic crustal accretion in the western segment of the southern Tien Shan (Kyrgyzstan, Uzbekistan and Tajikistan). Tectonophysics, 328, 1–14.

BROOKFIELD, M.E. & HASHMAT, A. 2001. The geology and petroleum potential of the North Afghan platform and adjacent areas (northern Afghanistan, with parts of southern Turkmenistan, Uzbekistan and Tajikistan). Earth-Science Reviews, 55, 41–71.

BRUNET, M.-F., KOROTAIEV, M.V., ERSHOV, A.V. & NIKISHIN, A.M. 2003. The South Caspian Basin: a review of its evolution from subsidence modelling. In: BRUNET, M.-F. & CLOETINGH, S. (eds) Integrated Peri-Tethyan Basins Studies (Peri-Tethys Programme). Elsevier, The Netherland, Sedimentary Geology, 156, 119–148.

BRUNET, M.-F., ERSHOV, A.V., KOROTAIEV, M.V., MELIKHOV, V.N., BURGER, E., MORDVINTSEV, D.O. & SIDOROVA, I.P. 2017. Late Palaeozoic and Mesozoic evolution of the Amu Darya Basin (Turkmenistan, Uzbekistan). In: BRUNET, M.-F., McCANN, T. & SOBEL, E.R. (eds) Geological Evolution of Central Asian Basins and the Western Tien Shan Range. Geological Society, London, Special Publications, 427. First published online July 14, 2017, https://doi.org/10.1144/SP427.18

BULLEN, M.E., BURBANK, D.W. & GARVER, J.I. 2003. Building the Northern Tien Shan: integrated thermal, structural, and topographic constraints. Journal of Geology, 111, 149–165, https://doi.org/10.1086/345840

BURBANK, D.W., McLEAN, J.K., BULLEN, M., ABDRAKHMATOV, K.Y. & MILLER, M.M. 1999. Partitioning of intermontane basins by thrust-related folding, Tien Shan, Kyrgyzstan. Basin Research, 11, 75–92.

BURTMAN, V.S. 1980. Faults of Middle Asia. American Journal of Sciences, 280, 725–744.

BURTMAN, V.S. 1997. Kyrgyz Republic. In: MOORES, E.M. & FAIRBRIDGE, R.W. (eds) Encyclopedia of European and Asian Regional Geology. Chapman & Hall, London, 483–492.

BURTMAN, V.S. 2010. Tien Shan, Pamir, and Tibet: history and geodynamics of Phanerozoic oceanic basins. Geotectonics, 44, 388–404, https://doi.org/10.1134/S001685211005002X

BURTMAN, V.S. 2015. Tectonics and geodynamics of the Tian Shan in the Middle and Late Paleozoic. Geotectonics, 49, 302–319.

BURTMAN, V.S. & MOLNAR, P. 1993. Geological and Geophysical Evidence for Deep Subduction of Continental Crust Beneath the Pamir. Geological Society of America, Boulder, Special Papers, 281.

BURTMAN, V.S., SKOBELEV, S.F. & MOLNAR, P. 1996. Late Cenozoic slip on the Talas-Ferghana fault, the Tien Shan, central Asia. Geological Society of America Bulletin, 108, 1004–1021.

BUSLOV, M.M., FUJIIWARA, Y., IWATA, K. & SEMAKOV, N.N. 2004. Late Paleozoic–Early Mesozoic geodynamics of Central Asia. Gondwana Research, 7, 791–808.

BUSLOV, M.M., KOHK, D.A. & DE GRAVE, J. 2008. Mesozoic–Cenozoic tectonics and geodynamics of Altai, Tien Shan, and Northern Kazakhstan, from apatite fission-track data. Russian Geology and Geophysics, 49, 648–654.

CECCA, F., MARTIN GARIN, B., MARCHAND, D., LATHUILIERE, B. & BARTOLONI, A. 2005. Palaeoclimatic control of biogeographic and sedimentary events in Tethyan and peri-Tethyan areas during the Oxfordian (Late Jurassic). Palaeogeography, Palaeoclimatology, Palaeoecology, 222, 10–32.

CHARVET, J., SHU, L.S. & LAURENT-CHARVET, S. 2007. Paleozoic structural and geodynamic evolution of eastern Tian Shan (NW China): welding of the Tarim and Junggar plates. Episodes, 30, 162–186.
Cunningham, D., Dolgopolova, J., Charvet, P., De Grave, S., DeCelles, J., Clarke, S., Chen, E., Chediya, S., Davidzon, V., Evenson, J., and Gao, J.: Evolution of Sedimentary Basins in the South Tianshan orogen and adjacent regions, NW China: geochemical and age constraints of granitoid rocks. International Journal of Earth Sciences (Geologisches Rundschau), 98, 1221–1238, 2010. DOI:10.1007/s00531-008-0370-8

Glorie, S., De Grave, J. et al.: 2011. Tectonic history of the Kyrgyz South Tien Shan (Atbashi-Inylchek) suture zone: the role of inherited structures during deformation-propagation. Tectonics, 30, TC6016, https://doi.org/10.1029/2010TC002949

Heermann, R.V., Chen, J., Burbank, D.W. & Miao, J. 2008. Temporal constraints and pulsed Late Cenozoic deformation during the structural disruption of the active Kashi foreland, northwest China. Tectonics, 27, TC6012, https://doi.org/10.1029/2007TC002226

Hegner, E., Klemm, R. et al.: 2010. Mineral ages and P–T conditions of late Paleozoic high-pressure eclogite and provenance of mélangé sediments from Atbashi in the South Tianshan orogen of Kyrgyzstan. American Journal of Science, 310, 916–950, https://doi.org/10.2475/09.2010.07

Hendrix, M.S., Graham, S.A., Carroll, A., Sobel, E., McKnight, C., Schulein, B., & Wang, Z. 1992. Sedimentary record and climatic implications of recurrent deformation in the Tian Shan: evidence from Mesozoic strata of the north Tarim, south Dzungar, and Turpan basin, northwest China. Geological Society of America Bulletin, 104, 53–79.

Hendrix, M.S., Dumitrutu, T.A., & Graham, S.A. 1994. Late Oligocene–early Miocene unroofing in the Chinese Tian Shan: an early effect of the India-Asia collision. Geology, 22, 487–490, https://doi.org/10.1130/0091-7613(1994)022%3C487:LOEMUI%3E2.0.CO;2

Jahn, B.M., Griffin, W.L. & Windley, B.F. (eds) 2000. Continental growth in the Phanerozoic: evidence from Central Asia. Tectonics, 32B, 227.

Jahn, B.M., Windley, B., Natal’In, B. & Dobretsov, N. 2004. Phanerozoic continental growth in Central Asia. Journal of Asian Earth Sciences, 23, 599–603.

Jolivet, M. 2015. Mesozoic tectonic and topographic evolution of Central Asia and Tibet: a preliminary synthesis. In: Brunet, M.-F., McCann, T. & Sobel, E.R.
Kloosterman, W. & U.S. Geological Survey–Afghanistan 2006. Undiscovered Technically Recoverable Conventional Petroleum Resources of Northern Afghanistan. United States Geological Survey, Open-File Report 2006-1253, 237 and 182 figures and plates, http:// pubs.usgs.gov/of/2006/1253/

Klocker, M., Voigt, T., Kley, J., Pfeiffer, S., Rocktäschel, T., Keil, S. & Gaupp, R. 2015. Cenozoic evolution of the Pamir and Tien Shan Mountains reflected in syntectonic deposits of the Tajik Basin. In: Brunet, M.-F., McCann, T. & Sobel, E.R. (eds) Geological Evolution of Central Asian Basins and the Western Tien Shan Range. Geological Society, London, Special Publications, 427. First published online September 11, 2015, https://doi.org/10.1144/SP427.7

Konopelko, D., Biske, G., Seltmann, R., Eklund, O. & Belyatsky, B. 2007. Hercynian post-collisional A-type granites of the Kokshaal Range, Southern Tien Shan, Kyrgyzstan. Litos, 97, 140–160.

Konopelko, D., Seltmann, R. & et al. 2017. A geotraverse across two paleo-subduction zones in Tien Shan, Tajikistan. Gondwana Research, 47, 110–130, https://doi.org/10.1016/j.gr.2016.09.010

Kröner, A., Kovach, V. et al. 2014. Reassessment of continental growth during the accretionary history of the Central Asian Orogenic Belt. Gondwana Research, 25, 103–125.

Kurenkov, S.A. & Aristov, V.A. 1995. About formation time of crust of Turkestan paleoocean. Geotectonics, 6, 469–477.

Lin, W., Faure, M., Shi, Y., Wang, Q. & Li, Z. 2009. Palaeozoic tectonics of the south-western Chinese Tianshan: new insights from a structural study of the high-pressure/low-temperature metamorphic belt. International Journal of Earth Sciences, 98, 1259–1274.

Liu, D., Jolivet, M., Yang, W., Zhang, Z., Cheng, F., Zhu, B. & Guo, Z. 2013. Latest Palaeozoic – Early Mesozoic basin-range interactions in South Tien Shan (Northwest China) and their tectonic significance: constraints from detrital zircon U-Pb ages. Tectonophysics, 599, 197–213.

Loury, C., Rolland, Y., Guillot, S., Mikolaichuk, A.V., Lanari, P., Bruguier, O. & Bosch, D. 2015. Crustal-scale structure of South Tien Shan: implications for subduction polarity and Cenozoic reactivation. In: Brunet, M.-F., McCann, T. & Sobel, E.R. (eds) Geological Evolution of Central Asian Basins and the Western Tien Shan Range. Geological Society, London, Special Publications, 427. First published online 22 July, 2015, https://doi.org/10.1144/SP427.4

Ma, X., Shu, L., Meert, J.G. & Li, J. 2014. The Palaeozoic evolution of Central Tian Shan: geochemical and geochronological evidence. Gondwana Research, 25, 797–819.

Macaulay, E.A., Sobel, E.R., Mikolaichuk, A., Landgraf, A., Kohn, B. & Stuart, F. 2013. Thermochemical insight into late Cenozoic deformation in the basement-cored Terskey Range, Kyrgyz Tien Shan. Tectonics, 32, 487–500, https://doi.org/10.1002/ tect.20040

Macaulay, E.A., Sobel, E.R., Mikolaichuk, A., Kohn, B. & Stuart, F.M. 2014. Cenozoic deformation and exhumation history of the Central Kyrgyz Tien Shan. Tectonics, 33, 135–165, https://doi.org/10.1002/2013TC003376

Makarov, V.I. 1977. New Tectonic Structure of the Central Tien Shan. Nauka, Moscow.

Markowski, A. (ed). 1959. Tajik SSR. USSR Geological Description. State of Scientific and Technical Publishing, Moscow.

McCann, T. 2016a. The Jurassic of the Western Tien Shan: the Central Kyzyl Kum region, Uzbekistan. In: Brunet, M.-F., McCann, T. & Sobel, E.R. (eds) Geological Evolution of Central Asian Basins and the Western Tien Shan Range. Geological Society, London, Special Publications, 427. First published online March 31, 2016. https://doi.org/10.1144/SP427.13

McCann, T. 2016b. The Cretaceous of the South Kyzyll Kum and Nuratau region, Western Tien Shan, Central Uzbekistan. In: Brunet, M.-F., McCann, T. & Sobel, E.R. (eds) Geological Evolution of Central Asian Basins and the Western Tien Shan Range. Geological Society, London, Special Publications, 427. First published online April 29, 2016. https://doi.org/10.1144/SP427.14
McCann, T. & Saintot, A. 2003. Tracing tectonic deformation using the sedimentary record: an overview. In: McCann, T. & Saintot, A. (eds) Tracing Tectonic Deformation Using the Sedimentary Record. Geological Society, London, Special Publications, 208, 1–28.

McCann, T., Nurtaje, B., Kharin, V. & Valdivia-Manchego, M. 2013. Ordovician-Carboniferous tectono-sedimentary evolution of the North Nuratau region, Uzbekistan (westernmost Tien Shan). Tectonophysics, 590, 196–312.

Melikov, V.N. 2000. Geological framework and ways of implementing the oil and gas potential of the South Turan Plate. Ph.D. Dissertation, Moscow [in Russian], http://earthpapers.net/geologicheskaya-osnova-i-ptri-realizatsii-potentiala-gazonefrosnostsi-yuga-turanskoj-plity-1

Melikov, V.N. 2013. Resource potential and exploration prospects of cross-border oil and gas basins of southeastern Turkmenistan, southern Uzbekistan and Tajikistan, northern Afghanistan and northeastern Iran. Neftegazovaya Geologiya. Teoriya i Praktika, 8/1 [in Russian], http://www.ngtp.ru/rub/6/6_2013.pdf

Melikov, V.N. 2017. Geology and oil and gas potential of the Karakum province. Evaluation of oil and gas perspective zones, direction of exploration in the platform part of Turkmenistan. Publishing house of Polytechnic University, St Petersburg [in Russian].

Molnar, P. & Tapponnier, P. 1975. Cenozoic tectonics of Asia: effects of a continental collision. Science, 189, 419–426.

Mordvinsev, D., Barrer, E., Brunet, M.-F., Blanpied, C. & Sidorova, I. 2013. Structure and evolution of the Bukhara-Khiva region during the Mesozoic: the pre-history of the Palaeo-Tethyan closure. Tectonics, 404, 175–202.

Nasrabadi, A., Tatar, M., Priestley, K. & Sepahvand, M.R. 2008. Continental lithosphere structure beneath the Iranian Plateau, from analysis of receiver functions and surface waves dispersion. In 14th World Conference on Earthquake Engineering, 12–17 October 2008, Beijing, China.

Natal’in, B.A. & Şengör, A.M.C. 2005. Late Palaeozoic to Triassic evolution of the Turan and Scythian platforms: the pre-history of the Palaeo-Tethyan closure. Tectonophysics, 404, 175–202.

Nurtaje, B., Kharin, V., McCann, T. & Valdivia-Manchego, M. 2013. The North Nuratau Fault Zone, Uzbekistan – Structure and evolution of Palaeozoic Suture Zone. Journal of Geodynamics, 64, 1–14.

Paul, A., Kaviani, A., Hatzfeld, D., Vergne, J. & Mokhtari, M. 2006. Seismological evidence for crustal-scale thrusting in the Zagros mountain belt (Iran). Geophysical Journal International, 166, 227–237.

Paul, A., Hatzfeld, D., Kaviani, A., Tatar, M. & Pequegnat, C. 2010. Seismic imaging of the lithospheric structure of the Zagros mountain belt (Iran). In: Leturmy, P. & Robin, C. (eds) Tectonic and Stratigraphic Evolution of Zagros and Makran during the Mesozoic–Cenozoic. Geological Society, London, Special Publications, 330, 5–18, https://doi.org/10.1144/SP330.2

Pfeiffer, O.A., Schlunegger, F. & Butler, S.J.H. 2002. The Swiss Alps and their peripheral foreland basin: stratigraphic response to deep crustal processes. Tectonics, 21, 3–1–3–15, https://doi.org/10.1029/2000TC000039

Popov, S., Rögl, F., Rozanov, A.Y., Steininger, F.F., Scherra, I.G. & Kovac, M. 2004. Lithological-paleogeographic maps of Paratethys. 10 maps late Eocene to Pliocene. Courier Forschungsinstitut Senckenberg, 250, 1–46.

Robert, A.M.M., Letouzey, J., Kavoosi, M.A., Sherkati, S., Müller, C., Vergés, J. & Aghababaei, A. 2014. Structural evolution of the Kopeh Dag fold-and-thrust-belt (NE Iran) and interactions with the South Caspian Sea Basin and Amu Darya Basin. Marine and Petroleum Geology, 57, 68–87.

Robert, A.M.M., Fernández, M., Jiménez-Munt, I. & Vergés, J. 2015. Lithospheric structure in Central Eurasia derived from elevation, geoid anomaly and thermal analysis. In: Brunet, M.-F., McCann, T. & Sobel, E.R. (eds) Geological Evolution of Central Asian Basins and the Western Tien Shan Range. Geological Society, London, Special Publications, 427. First published online September 7, 2015, https://doi.org/10.1144/SP427.10

Robertson, A.H.F., Parlat, O. & Ustaömer, T. (eds) 2016. Permain–Recent palaeogeographical and tectonic development of Anatolia: some recent contributions. International Journal of Earth Sciences (Geologische Rundschau), 105, 1–485.

Schlunegger, F., Jordan, T.E. & Klaper, E.M. 1997. Controls of erosional denudation in the orogen on foreland basin evolution: the Oligocene central Swiss Molasse Basin as an example. Tectonics, 16, 823–840.

Schnyder, J., Pons, D., Yans, J., Tramoy, R. & Abdulanova, S. 2016. Integrated stratigraphy of a continental Pliensbachian–Toarcian Boundary (Lower Jurassic) section at Taskomiray, Leontiev Graben, southwest Kazakhstan. In: Brunet, M.-F., McCann, T. & Sobel, E.R. (eds) Geological Evolution of Central Asian Basins and the Western Tien Shan Range. Geological Society, London, Special Publications, 427. First published online November 14, 2016, https://doi.org/10.1144/SP427.15

Searle, M.P., Elliott, J.R., Phillips, R.J. & Chung, S.-L. 2011. Crustal–lithospheric structure and continental extrusion of Tibet. Journal of the Geological Society, London, 168, 633–672.

Selander, J., Öskin, M., Ormukov, C. & Abdurakhmatov, K. 2012. Inherited strike-slip faults as an origin for basement-cored uplifts: example of the Kungey and Zailiskey ranges, northern Tian Shan. Tectonics, 31, TC4026, https://doi.org/10.1029/2011TC003002

Seltmann, R., Konopelko, D., Yans, J., Tramoy, R. & Abdulova, S. 2011. Hercynian post-collisional magmatism in the context of Paleozoic magmatic evolution of the Tien Shan orogenic belt. Journal of Asian Earth Sciences, 42, 821–838, https://doi.org/10.1016/j.jseaes.2010.08.016

Şengör, A.M.C. 1984. The Cimmeride Orogenic System and the Tectonics of Eurasia. Geological Society of America, Boulder, Special Papers, 195 pp.
Šengör, A.M.C. & Natal’in, B.A. 1996. Palaeotectonics of Asia: fragments of a synthesis. In: Yin, A. & Harrison, M. (eds) Tectonic Evolution of Asia, Rubey Colloquium. Cambridge University Press, Cambridge, 486–640.

Šengör, A.M.C., Altiner, D., Cın, A., Ustaömer, T. & Hsu, K.J. 1988. Origin and assembly of the Tethyside orogenic collage at the expense of Gondwanaland (in Gondwana and Tethys). In: Audley-Charles, M.G. & Hallam, A. (eds) Gondwana and Tethys. Geological Society, London, Special Publications, 37, 119–181.

Šengör, A.M.C., Natal’in, B.A. & Burtman, V.S. 1993. Evolution of the Altaid tectonic collage and Palaeozoic crustal growth in Eurasia. Nature, 364, 299–307, https://doi.org/10.1038/364299a0

Šengör, A.M.C., Natal’in, B.A., van der Voo, R. & Sunal, G. 2014. A new look at the Altoids: a superogenseric complex in northern and central Asia as a factory of continental crust. Part II: palaeomagnetic data, reconstructions, crustal growth and global sea-level. Austrian Journal of Earth Sciences, 107, 131–181.

Shao, L., Zhang, P., Hilton, J., Gayer, R., Wang, Y., Zhao, C. & Luo, Zh. 2003. Palaeoenvironments and Palaeoecography of the Lower and lower Middle Jurassic coal measures in the Turpan-Hami oil-prone coal basin, northwestern China. American Association of Petroleum Geology Bulletin, 87, 335–355.

Sieg, H. 2015. Structural setting and evolution of the Afghan orogenic segment – a review. In: Brunet, M.-F., McCann, T. & Sobel, E.R. (eds) Geologic Evolution of Central Asian Basins and the Western Tien Shan Range. Geological Society, London, Special Publications, 427. First published online 3 August, 2015, https://doi.org/10.1144/SP427.8

Sinclair, H.D. & Naylor, M. 2012. Foreland basin subsidence driven by topographic growth v. plate subduction. Geological Society of America Bulletin, 124, 368–379, https://doi.org/10.1130/B30383.1

Sobol, E.R. 1999. Basin Analysis of the Jurassic - Lower Cretaceous southwest Tarim basin, northwest China. Geological Society of America Bulletin, 111, 709–724.

Sobol, E.R. & Dumitru, T.A. 1997. Thrusting and exhumation around the margins of the western Tarim Basin during the India-Asia collision. Journal of Geophysical Research, 102, 5043–5063, https://doi.org/10.1029/96JB03267

Sobol, E.R., Chen, J. & Heermance, R.V. 2006a. Late Oligocene — Early Miocene initiation of shortening in the Southwestern Chinese Tian Shan: implications for Neogene shortening rate variations. Earth and Planetary Science Letters, 247, 70–81, https://doi.org/10.1016/j.epsl.2006.03.048

Sobol, E.R., Oskin, M., Burbank, D. & Mikolachuk, A. 2006b. Exhumation of basement-cored uplifts: example of the Kyrgyz Range quantified with apatite fission track thermochronology. Tectonics, 25, TC2008, https://doi.org/10.1029/2005TC001809

Sosson, M., Stephenson, R.A. & Adamia, S.A. (eds) 2017. Tectonic Evolution of the Eastern Black Sea and Caucasus. Geological Society, London, Special Publications, 428.

Stampfl, G.M. & Borel, G.D. 2002. A plate tectonic model for the Palaeozoic and Mesozoic constrained by dynamic plate boundaries and restored synthetic oceanic isochrons. Earth and Planetary Science Letters, 196, 17–33.

Stöcklin, J. 1977. Structural correlation of the Alpine ranges between Iran and Central Asia. In: L’histoire provengale et catalane (1845—1875): Contribution a l’étude de l’histoire geologique de l’ancien Mediterranéen. Memorie de Albert F. de Lapparent (1905–1975). Sociétè Geologique de France. Mémoire Hors série, 8, 333–353.

Sun, J., Li, Y., Zhang, Z. & Fu, B. 2009. Magnetostriatigraphic data on Neogene growth folding in the foreland basin of the southern Tianshan Mountains. Geology, 37, 1051–1054, https://doi.org/10.1130/G30278.1

Taheri, J., Fursich, F.T. & Wilmsen, M. 2009. Stratigraphy, depositional environments and geodynamic significance of the Upper Bajocian-Bathonian Kashafrud Formation, NE Iran. In: Brunet, M.-F., Wilmsen, M. & Granath, J.W. (eds) South Caspian to Central Iran Basins. Geological Society, London, Special Publications, 312, 205–218, https://doi.org/10.1144/ SP312.10

Tapponnier, P. & Molnar, P. 1979. Active faulting and Cenozoic tectonics of the Tien Shan, Mongolia and Baykal regions. Journal of Geophysical Research, 84, 3425–3459.

Tapponnier, P., Xu, Z.Q., Roger, F., Meyer, B., Arnaud, N., Wittlinger, G. & Yang, J.S. 2001. Oblique stepwise rise and growth of the Tibet Plateau. Science, 294, 1671–1677.

Thomas, J.-C., Cobbold, P.R., Shein, V.S. & Le Douaran, S. 1999a. Sedimentary record of late Palaeozoic to Recent tectonism in central Asia – analysis of subsurface data from the Turan and south Kazak domains. Tectonophysics, 313, 243–263.

Thomas, J.-C., Grasso, J.R., Bossu, R., Martinod, J. & Nurlaev, B. 1999b. Recent deformation in the Turan and South Kazakh platforms, western central Asia, and its relation to Arabia-Asia and India-Asia collisions. Tectonics, 18, 201–214.

Ulmišek, G.F. 2004. Petroleum geology and resources of the Amu-Darya Basin, Turkmenistan, Uzbekistan, Afghanistan, and Iran. United States Geological Survey Bulletin, 2201–H, http://pubs.usgs.gov/bul/ 2201/H/

Ulmišek, G.F. & Masters, C.D. 1993. Estimated petroleum resources in the former Soviet Union. United States Geological Survey Bulletin, 93–316, https://pubs.usgs.gov/of/1993/0316/report.pdf

van der Voo, R., van Hinsbergen, D.J.J., Domeier, M., Spakman, W. & Torsvik, T.H. 2015. Latest Jurassic—earliest Cretaceous closure of the Mongol-Okhotsk Ocean: A paleomagnetic and seismological-tomographic analysis. In: Anderson, T.H., Didenko, A.N., Johnson, C.L., Khanchuk, A.I. & MacDonald, J.H. Jr (eds) Late Jurassic Margin of Laurasia – A Record ofFaulting Accommodating Plate Rotation. Geological Society of America, Boulder, Special Paper, 513, 589–606, https://doi.org/10.1130/2015.2513(19)

van Hinsbergen, D.J.J., Kapp, P., Dupont-Nivet, G., Lippert, P.C., DeCelles, P.G. & Torsvik, T.H. 2011. Restoration of Cenozoic deformation in Asia and the size of greater India. Tectonics, 30, TC5003, https://doi.org/10.1029/2011TC002908
van Hinsbergen, D.J.J., Lippert, P.C., Dupont-Nivet, G., McQuarrie, N., Doubrovine, P.V., Spakman, W. & Torsvik, T.H. 2012. Greater India Basin hypothesis and a two-stage Cenozoic Collision between India and Asia. *Proceedings of the National Academy of Sciences*, 109, 7659–7664, https://doi.org/10.1073/pnas.1117262109

Vialov, O.S. 1948. *Paleogenovie Ustrichi Tadzhikskoi Depressii* (Paleogene Osteoids from Tajik Depression). Trudy VNIGRI, Leningrad.

Vogt, K. & Gerya, T.V. 2014. From oceanic plateaus to allochthonous terranes: numerical modelling. *Gondwana Research*, 25, 494–505.

Wang, B., Faure, M., Cluzel, D., Shi, L., Charvet, J., Meffre, S. & Ma, Q. 2006. Late Paleozoic tectonic evolution of the northern west Chinese Tian Shan belt. *Geodinamika Acta*, 19, 237–247, https://doi.org/10.3166/ga.19.237-247

Wang, H.L., Xu, X.Y., He, S.P. & Chen, J.L. 2007. *Geological map of the Chinese Tian Shan and its adjacent areas*. Geological Publishing House, Beijing, China, scale 1:1,000,000 [in Chinese].

Wei, H.-H., Meng, Q.-R., Deng, L. & Li, Z.-Y. 2013. Tectonic evolution of the western Tarim basin, north-west China: a tectono-sedimentary response to northward indentation of the Pamir salient. *Tectonics*, 32, 558–575, https://doi.org/10.1002/tect.20046

Wilmsen, M., Fursich, F.T., Seyed-Emami, K. & Mahdizadeh, M.R. 2009. The Cimmerian Orogeny in Iran – a foreland perspective. *Terra Nova*, 21, 211–218.

Windley, B.F., Allen, M.B., Zhang, C., Zhao, Z.-Y. & Wang, G.-R. 1990. Paleozoic accretion and Cenozoic redeformation of the Chinese Tian Shan Range, central Asia. *Geology*, 18, 128–131.

Windley, B.F., Alexeev, D.V., Xiao, W., Kröner, A. & Badarch, G. 2007. Tectonic models for accretion of the Central Asian Orogenic Belt. *Journal of the Geological Society, London*, 164, 31–47, https://doi.org/10.1144/0161-76492006-022

Worrall, D.M., Kruglyak, V., Kunst, F. & Kuznetsov, V. 1996. Tertiary tectonics of the Sea of Okhotsk, Russia: far-field effects of the India-Eurasia collision. *Tectonics*, 15, 813–826.

Xiao, W., Han, C. et al. 2008. Middle Cambrian to Permian subduction-related accretionary orogenesis of Northern Xinjiang, NW China: implications for the tectonic evolution of central Asia. *Journal of Asian Earth Sciences*, 32, 102–117.

Xiao, W.J., Huang, B.C., Han, C.M., Sun, S. & Li, J.L. 2010. A review of the western part of the Altaias: a key to understanding the architecture of accretionary orogens. *Gondwana Research*, 18, 253–273.

Xiao, W.J., Windley, B.F., Badarch, G., Sun, S., Li, J.L., Qin, K.Z. & Wang, Z.H. 2004. Palaeozoic accretionary and convergent tectonics of the southern Altaias: implications for the lateral growth of Central Asia. *Journal of the Geological Society, London*, 161, 339–342.

Xiao, W.J., Windley, B.F., Allen, M.B. & Han, C.M. 2013. Paleozoic multiple accretionary and collisional tectonics of the Chinese Tianshan orogenic collage. *Gondwana Research*, 23, 1316–1341, https://doi.org/10.1016/j.gr.2012.01.012

Yang, W., Jolivet, M., Dupont-Nivet, G., Guo, Z., Zhang, Z. & Zhang, Z. 2013. Source to sink relations between the Tian Shan and Junggar Basin (northwest China) from Late Palaeozoic to Quaternary: evidence from detrital U-Pb zircon geochronology. *Basin Research*, 25, 219–240.

Yang, W., Jolivet, M., Dupont-Nivet, G. & Guo, Z. 2014. Mesozoic–Cenozoic tectonic evolution of southwestern Tian Shan: evidence from detrital zircon U/Pb and apatite fission track ages of the Ulganqat area, Northwest China. *Gondwana Research*, 26, 986–1008, https://doi.org/10.1016/j.gr.2013.07.020

Yang, Y.-T., Guo, Z.-X. & Luo, Y.-J. 2017. Middle–Late Jurassic tectonostratigraphic evolution of Central Asia, implications for the collision of the Karakoram-Lhasa Block with Asia. *Earth-Science Reviews*, 166, 83–110, https://doi.org/10.1016/j.earscirev.2017.01.005

Yin, A., Nie, S., Craig, P., Harrison, T.M., Ryerson, F.J., Xianglin, Q. & Geng, Y. 1998. Late Cenozoic tectonic evolution of the southern Chinese Tian Shan. *Tectonics*, 17, 1–27, https://doi.org/10.1029/97TC03140

Yin, A., Rumelhart, P.E. et al. 2002. Tectonic history of the Altyn Tagh fault system in northern Tibet inferred from Cenozoic sedimentation. *Geological Society of America Bulletin*, 114, 1257–1295, https://doi.org/10.1130/0016-7606(2002)1142.0.CO;2

Zanchetta, S., Berra, F., Zanchi, A., Bergomi, M., Cardiott, M., Nicora, A. & Heidarzadeh, G. 2013. The record of the Late Palaeozoic active margin of the Palaeotethys in NE Iran: constraints on the Cimmerian orogeny. *Gondwana Research*, 24, 1237–1266, https://doi.org/10.1016/j.gr.2013.02.013

Zanchi, A., Zanchetta, S. et al. 2009. The Eo-Cimmerian (Late Triassic) orogeny in north Iran. In: Brunet, M.-F., Wilmsen, M. & Granath, J.W. (eds) *South Caspian to Central Iran Basins*. Geological Society, London, Special Publications, 312, 31–55, https://doi.org/10.1144/SP312.3

Zanchi, A., Zanchetta, S., Angioli, L. & Vezzoli, G. 2012. Is SE-Pamir a Cimmerian Block? *Riunione Annuale IGGS 2012 Gruppo Italiano Geologia Strutturale Modena*, 25–26 Ottobre 2012. Rendiconti online della Società Geologica Italiana, 22, 239–242, http://rendiconti.socgeol.it/244/fulltext.html?id=528

Zanchi, A., Fürsich, F.T. & Santosh, M. (eds) 2015. Special issue on Cimmerian Terranes. *Journal of Asian Earth Sciences*, 102, 1–204.

Zonenshain, L.P., Kuzmin, M.I. & Natapov, L.M. 1990. *Geology of the USSR. A Plate Tectonic Synthesis*. American Geophysical Union, Washington, DC, Geodynamics Series, 21, 242.

Zor, E., Sandvol, E., Gürbüz, C., Türkelli, N., Seber, D. & Barazangi, M. 2003. The crustal structure of East Anatolian Plateau (Turkey) from receiver functions. *Geophysical Research Letters*, 30, 8044.