Tectonophysics 590 (2013) 196–213

Contents lists available at SciVerse ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Ordovician–Carboniferous tectono-sedimentary evolution of the North Nuratau region, Uzbekistan (Westernmost Tien Shan)

T. McCann [a,*], B. Nurtaev [b], V. Kharin [c], M. Valdivia-Manchego [a]

[a] Steinmann Institute-Geology, Bonn University, Germany
[b] Institute of Geology and Geophysics, Uzbekistan
[c] Institute of Mineral Resources, Tashkent, Uzbekistan

ARTICLE INFO

Article history:
Received 15 September 2011
Received in revised form 27 January 2013
Accepted 29 January 2013
Available online 8 February 2013

Keywords:
Uzbekistan
Palaeozoic
Turkestan Ocean
Tien Shan

ABSTRACT

The Tien Shan is a c. 2500 km long orogenic belt of which the Nuratau region of eastern Uzbekistan forms the western part. Petrographical and field analysis of the Ordovician–Carboniferous succession in the North Nuratau region provided the basis for a reconstruction of the depositional settings along part of the northern margin of the Alai continent and their evolution during the period of closure of the Turkestan Ocean, which separated the Alai and the Kazakh–Kyrgyz continents. Initial sedimentation (Ordovician) was broadly carbonate dominated, although by Mid-Late Ordovician times siliciclastic input predominated in some areas. These variations, between clastic- and carbonate-dominated regions may have been related to tectonic activity within the Alai continent. Carbonate sedimentation was reestablished in the ?Wenlock, with broad shelf systems forming along the continental margin. Volcanic activity in the Early Devonian records a period of tectonic instability, and this was followed by the reestablishment of the carbonate mosaic, albeit with a greater degree of instability (as indicated by stratigraphic gaps) than in the Silurian. This pattern extended up into the Carboniferous culminating in backarc-related magmatic activity. Final closure of the Turkestan Ocean involved significant folding and thrusting, as well as a major change from compressional to strike-slip movement.

1. Introduction

The Southern Tien Shan extends for c. 2500 km along an E–W axis from Xinjiang in NW China as far as central Uzbekistan (Fig. 1). The tectonic history of this mountain range is of great importance in terms of understanding the amalgamation history of Eurasia as well as the Phanerozoic evolution of the Central Asian Orogenic Belt (CAOB = Altaids; Bazhenov et al., 1999; Gao et al., 2009; Windley et al., 1990); this latter represents the final amalgamation of the East European Craton in the west, the Siberian Craton to the east and the smaller Karakum and Tarim continents to the south (Konopelko et al., 2007).

The western part of the Tien Shan (Kyrgyzstan and Uzbekistan) comprises three major structural units/terranes, namely: 1) the Northern Tien Shan which comprises Precambrian-age blocks, as well as Cambrian–Early Ordovician ophiolites and marine sediments (Biske and Seltmann, 2010), overlain by Ordovician-age sedimentary and volcanic rocks and cut by I-type granites. The region represents the deformed margin of the Kazakh–Kyrgyz (= Palaeo-Kazakhstan) continent. 2) The Middle Tien Shan (= Syrdarya, Naryn or Ishim-Middle Tien Shan microcontinent) which consists of Neoproterozoic units (including tillites and acid volcanic rocks, Alekseev et al., 2009) as well as late Palaeozoic volcano-plutonic arc rocks (representing the latest epidodes of the evolution of this unit), and, 3) the Southern Tien Shan (STS), a fold-and-thrust belt which formed as a result of the closure of the Turkestan Ocean (Seltmann et al., 2011; Zonenshain et al., 1990). Seltmann et al. (2011) noted that the STS contains deformed forearc accretionary complexes as well as passive margin sediments. The Southern Tien Shan Suture, which includes Early Ordovician–Early Carboniferous ophiolites, separates the Middle and Southern Tien Shan units (Chen et al., 1999; Gao et al., 1998; Kurenkov and Aristov, 1995). In Uzbekistan and Kyrgyzstan, the STS is subdivided into three units, from west to east, the Kyzylkum, Alai and Kokshaal segments. The Taras–Ferghana Fault, a dextral, strike–slip dislocation, separates the western terranes of the Tien Shan, as well as the Kyzylkum and Alai segments of the STS, from the eastern terranes (Konopelko et al., 2007).

The aim of the current study is to describe the sedimentary successions of the North Nuratau region, with the work mainly concentrated in an area (100 km × 25 km) located to the west of the town of Jizzakh, as well as the Kitab region to the east of Samarkand (and adjacent to the Uzbekistan–Tajikistan border) (Fig. 1). The North Nuratau region is part of a complex fold-and-thrust belt (part of the south-vergent Bukantau–Kokshaal foldbelt) which forms the western prolongation of the Alai range of the western Tien Shan (Bakirov and Burtman, 1984) (Fig. 2). Deformation mainly occurred during the Carboniferous, and was associated with the collision of the Alai and Kazakh–Kyrgyz continents, subsequent to the closure of the Turkestan

* Corresponding author at: Steinmann Institute-Geology, Nussallee 8, 53115 Bonn, Germany. Tel.: +49 288 73 5569.
E-mail address: tmccann@uni-bonn.de (T. McCann).

0040-1951/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.tecto.2013.01.031

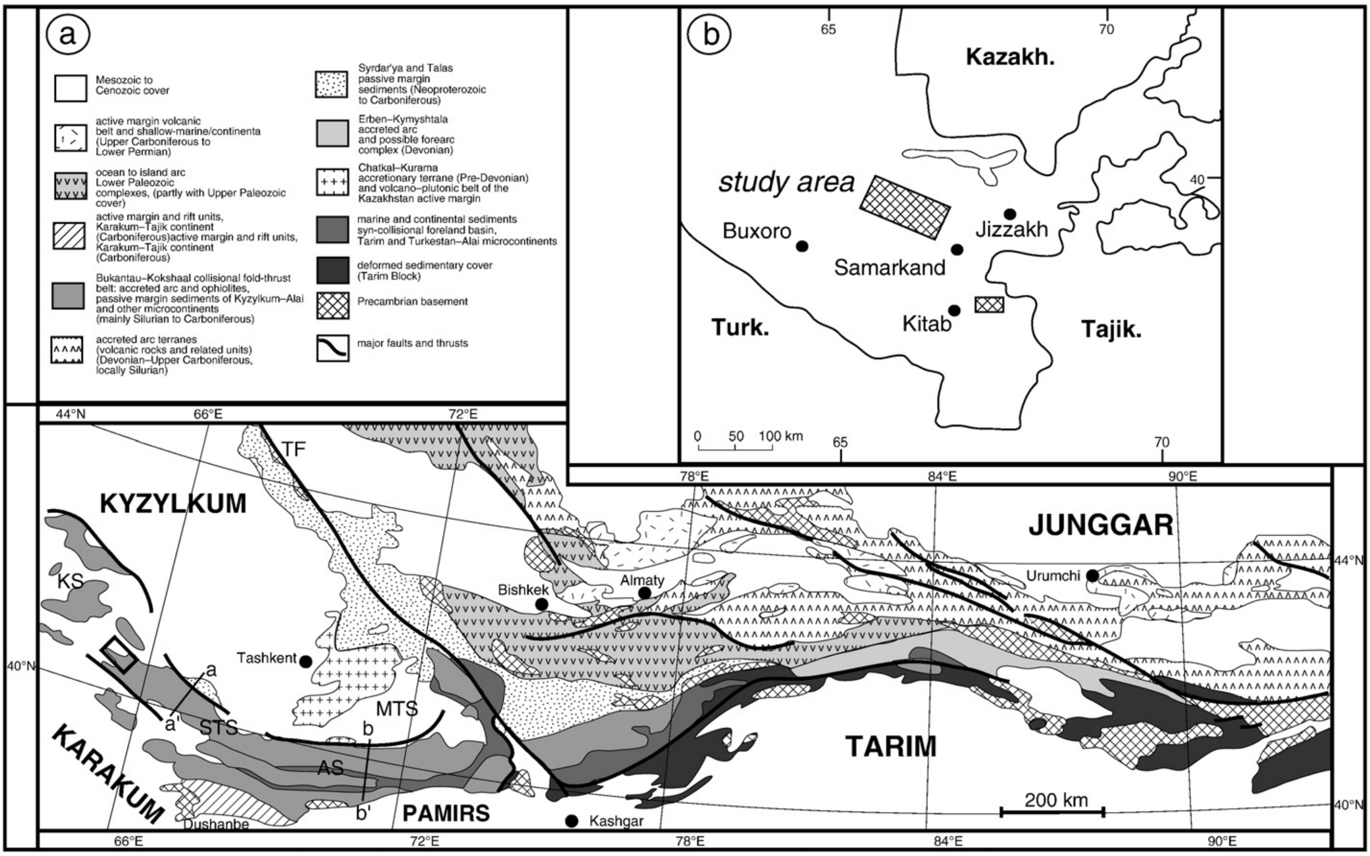

Fig. 1. a. Simplified geology of the Palaeozoic Tien Shan (after Biske and Seltmann, 2010). b. Location map of the study area, Uzbekistan. Fieldwork was mainly concentrated in the marked area to the west of the town of Jizzak, and N of Samarkand.

Ocean (Allen et al., 1991; Bakirov and Burtman, 1984; Burtman, 1975). Work focussed on the gathering of primary field data, in both the Nuratau and Kitab regions in order to provide a framework for the reconstruction of the depositional history along the northern margin of the Alai microcontinent from the Ordovician through to the Middle/Late Carboniferous. Field analysis was supplemented by detailed

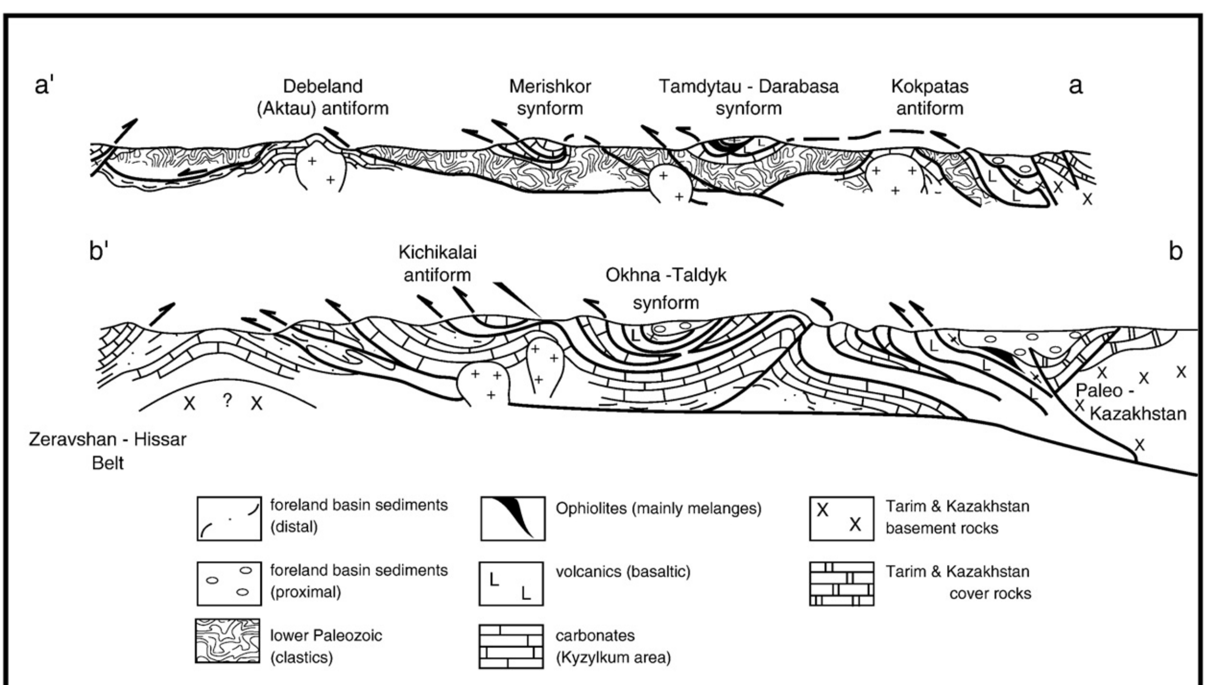

Fig. 2. Two structural profiles across the Buktanau–Kokshaal branch of the Southern Tien Shan collisional fold-thrust belt (after Biske and Seltmann, 2010). Locations indicated on Fig. 1.

petrography of the samples (n = 48). The overlying continental Permian succession (parts of which, due to the difficulties of dating continental successions, may possibly be Late Carboniferous in age, cf. McCann et al., 2008a) which unconformably overlies the Ordovician–Carboniferous sediments, was deposited subsequent to the closure of the Turkestan Ocean and the subsequent continent–continent collision.

2. Geological setting

Models of the tectono-sedimentary evolution of the Southern Tien Shan region are complex, and incomplete (see also Xiao et al., 2010). Additionally, there are significant problems correlating the established 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). Part of the reason for this confusion is that the region of Central Asia comprises a complex mosaic of basement fragments derived from the subduction and collision of various microcontinents and terranes (e.g. Berzin et al., 1994; Buslov et al., 2001; Zonenshain et al., 1990), many of which are poorly defined. Previous work in the Soviet Union (e.g. Bukharin et al., 1989; Burtman, 1975; Khain, 1985) described several magmatic arcs, as well as ophiolitic and intramontane belts in the region, whilst more recent work (e.g. Biske, 1995, 1996; Burtman et al., 1998; Bykadorov et al., 2003; Filippova et al., 2001; Klishevich and Khramov, 1993) have examined the palaeogeographical and tectonic evolution of the area.

The regional history commenced with the break-up of Rodinia (including Kazakhstan, Xu et al., 2005) during the Late Proterozoic (see Kheraskova et al., 2010; Golonka, 2007, 2009, for details). The Kazakh–Kyrgyz continent formed mainly in Ordovician–Silurian times (Buslov et al., 2004; Windley et al., 2007; Xiao et al., 2010; Zonenshain et al., 1990) as a result of a series of collisions extending into the Silurian–Devonian (e.g. Biske and Seltmann, 2010; Blakey, 2008; Kheraskova et al., 2010; Levashova et al., 2009). The precise sequence of accretional events, however, remains unclear with different models proposed (e.g. Samygin and Burtman, 2009). The initial growth of the continent was associated with folding and thrusting (including the obduction of ophiolites), as well as granite intrusion (Ghes, 2008; Jenchuraeva, 2001; Windley et al., 2007). Once established, however, the southern margin (in present-day coordinates) of the Kazakh–Kyrgyz continent was passive from Middle Devonian–Early Carboniferous times, and characterised by the deposition of thick units of siliclastic and carbonate shelf sediments (Biske and Seltmann, 2010).

The break-up of Rodinia also resulted in the formation of the Palaeo-Asian Ocean (e.g. Berzin et al., 1994; Didenko et al., 1994; Dobretsov et al., 1995; Zonenshain et al., 1990), although the details of its evolution remain unclear (Buslov et al., 2004). Evidence of bimodal volcanisism in the Neoproterozoic (c. 755–690 +/− 15 Ma) signalled the formation of the ocean (Kheraskova et al., 2010). Kheraskova et al. (2003) have suggested that the formation of the N–S-oriented Turkestan Ocean occurred later (at the boundary of the Middle and Late Ordovician) and that the ocean was well established by Early Devonian times (Buslov et al., 2001; Ruzhentsev and Mossakovskiy, 1996). Indeed, by Late Devonian times the Turkestan Ocean had achieved a width of c. 1500 km (Bai et al., 1987; Biske et al., 1993; Klishevich and Khramov, 1993; Klishevich et al., 1992).

Initial closure of the Turkestan Ocean and the (oblique) collision of the Alai and Kazakh–Kyrgyz continents occurred in the Late Carboniferous (Moscovian; Samygin and Burtman, 2009), although estimates range from Carboniferous through to Early Permian (e.g. Allen et al., 1992; Bazhenov et al., 2003; Gao and Klemd, 2003; Solomovich, 2007), whilst in the Chinese part of the Tien Shan, there is evidence of Devonian-age collision (Biske and Seltmann, 2010; Gao et al., 2009; Windley et al., 1990; Zhou et al., 2001). Collision resulted in overthrusting, followed by the deformation of the early nappes and extensive suture-parallel folding (Late Carboniferous–Early Permian) and a subsequent transition from compressional to strike–slip conditions (Early Permian; Bazhenov et al., 1999; Biske, 1995; Burtman, 1975, 1980, 1984). It has also been suggested that some small remnant marine basins may have existed along the suture into Permian times (Biske, 1995; Samygin and Burtman, 2009). The transition to continental crust subduction, with underthrusting of the Alai margin beneath the accretionary wedge and Kazakh–Kyrgyz continent extended through to the Late Permian (see also Nurtaev et al., 2013). The fold-and-thrust belt which formed, also contains material derived from the accretionary wedge (Samygin and Burtman, 2009) (Fig. 2). Precise details of the Alai–Kazakh–Kyrgyz collision, in particular, the mode and magnitude of horizontal movements, are still poorly understood (e.g. Bazhenov et al., 1999). Subsequent reactivation and deformation of the fold belt in the late Cenozoic, as a result of the India–Eurasia collision, have resulted in additional regional complexity (Molnar and Tapponnier, 1975).

According to Brookfield (2000), the western segment of the Southern Tien Shan can be subdivided into several distinct units (Fig. 3). From S to N, these are: 1) the Baysunta Unit, comprising a Proterozoic-age metamorphic core overlain by Early Carboniferous volcanics and Permo-Carboniferous clastics, 2) the South Gissar Unit, which represents an ophiolitic suture, comprising mainly Carboniferous and younger oceanic material, 3) the Gissar Unit, comprising Ordovician to Permian clastics and volcanics intruded by major late Palaeozoic batholiths, 4) the Zeravshan Unit, which comprises Cambrian to ?Permian clastics and carbonates with a zone of mafic greenschists developed along its northern margin, 5) the Zirabulak Unit, which is a mid-Carboniferous thrust zone (reactivated in the Cenozoic) including highly-deformed ophiolitic material and evidence of significant shearing, 6) the Turkestan-Alai Unit comprising Ordovician–Permian clastics and carbonates, and, 7) the South Ferghana Unit which is thrust over the Turkestan-Alai Unit, and comprises poorly exposed Palaeozoic-age arc and oceanic rocks, arranged in three main allochthons thrust southwards during the collision with the underlying unit. This latter unit has been interpreted as the suture zone between the southern and northern Tien Shan, marking the location of the Turkestan Ocean.

3. Depositional settings of the Ordovician–Carboniferous succession of the North Nuratau area

3.1. Distribution

The North Nuratau Ridge (corresponding with the North Nuratau Fault Zone) extends from the area of the Tamerlan Gates (near the town of Jizzakh) westwards to the Tamdytau and Bukantau mountains (Figs. 1, 4). The Nuratau region is part of the Southern Tien Shan which, as noted above, is a fold-and-thrust belt which formed subsequent to the closure of the Turkestan Ocean. Palaeozoic sedimentary, igneous (see Dalimov, 2011; Dalimov and Divaev, 2010 for details) and metamorphic tectonostratigraphic units have been incorporated into this fold-and-thrust belt, and crop out within isolated lensoid-shaped bodies which are oriented parallel to the main fault trend. Individual lenses range from 10s to 100s m in diameter and can extend over 100s of metres. Within each lens, there is a degree of stratigraphic and lithological coherence, although the rocks may also show evidence of deformation (particularly at the lens margins) as a result of strike–slip and thrust activity within the fault zone. Between the various lenses (even adjacent ones) there is no real stratigraphical or lithological coherence with a great deal of variation exhibited (e.g. Ordovician clastics and Devonian limestones may be adjacent) and clearly there has been considerable regional disruption. The Ordovician–Carboniferous-age units (which include some stratigraphic gaps, e.g. Eifelian, Late Devonian, Early Tournaisian, Serpukhovian, cf. Burtman, 2008) are unconformably overlain by ?Early Permian-age strata. These latter are more broadly distributed, with type sections close to the town of Farish (in the central part of the North Nuratau region).

The Ordovician succession is present mainly in four formations (Taskasgan, Bagambir, Jalatar and Illonchi; see Abduazimova, 2001;

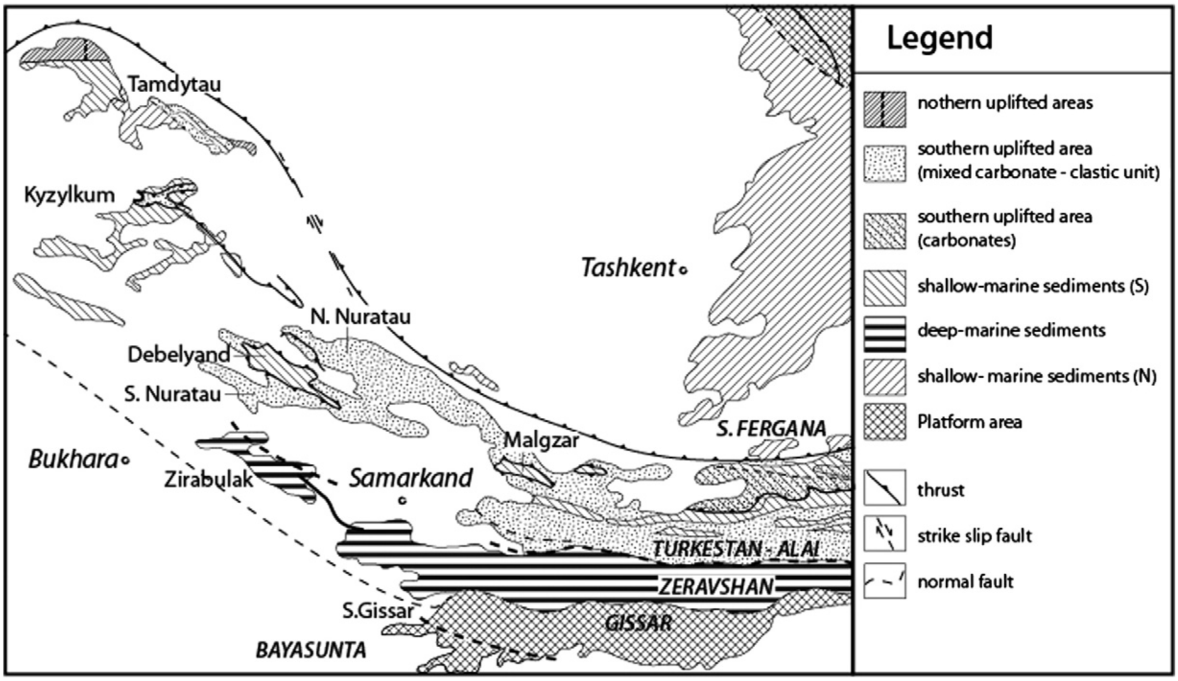

Fig. 3. Structural units of the western segment of the Southern Tien Shan (after Brookfield, 2000).

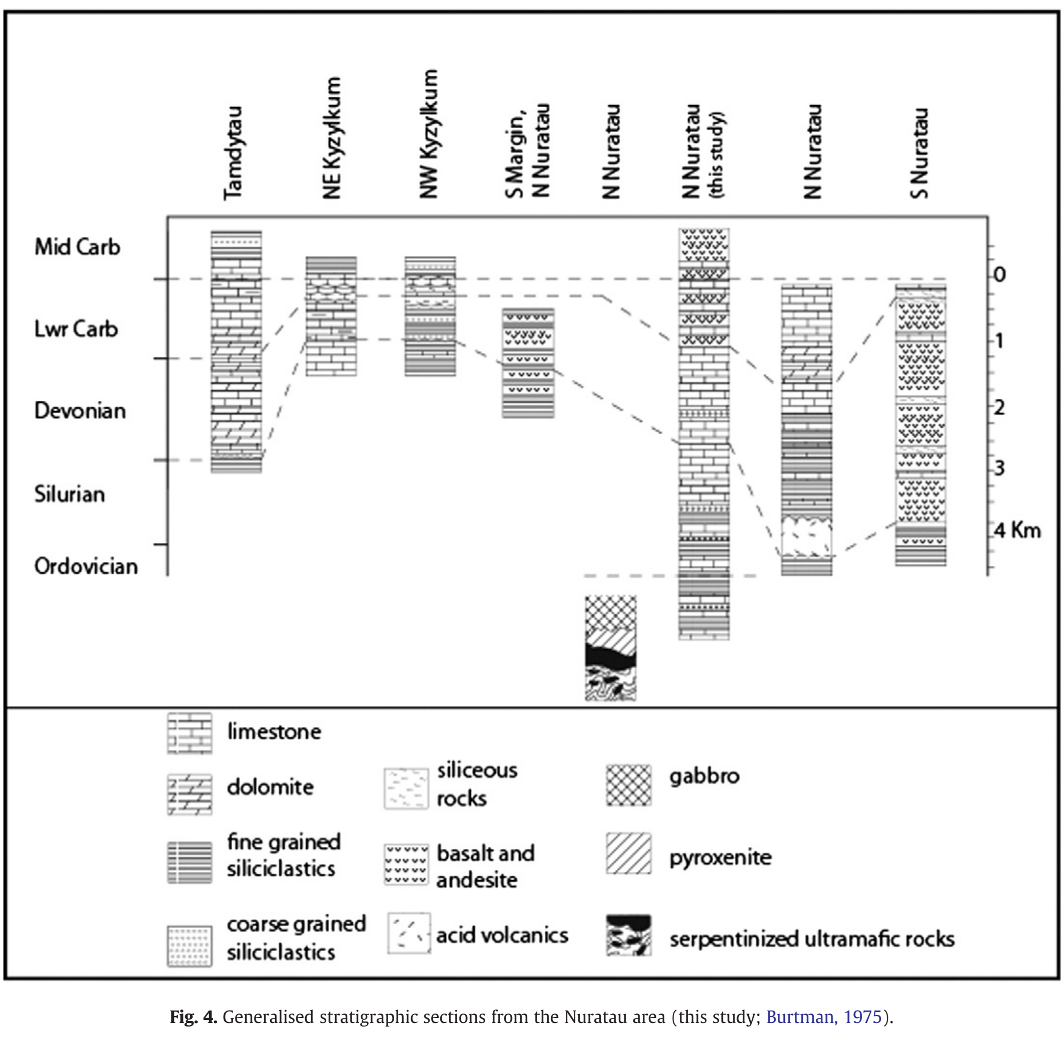

Fig. 4. Generalised stratigraphic sections from the Nuratau area (this study; Burtman, 1975).

Abduazimova et al., 2007, for stratigraphic details). These, however, are spread out over a number of different lenses, and sometimes (e.g. Jalatar & Illonchi fms) very poorly exposed. The overlying Silurian is present in only one formation (Jatak Fm), although additional outcrops were examined in the Kitab area (Fig. 1). Outcrops are good, albeit limited (cf. Abduazimova, 2001; Abduazimova et al., 2007; Kim et al., 2007). The Devonian succession is more widespread, and occurs as thick units within isolated lenses in the Nuratau region whilst the Khodza-Kurgan Fm was examined in the Kitab area (cf. Abduazimova, 2001; Abduazimova et al., 2007; Kim et al., 1982, 1984). The overlying Carboniferous units are mainly magmatic (e.g. Shavaz Fm) in the Nuratau region, although sediment-rich lenses are also present (e.g. Kelvasay & Novchomok fms; Abduazimova, 2001; Abduazimova et al., 2007).

As noted above, the sedimentary succession of the Nuratau region ranges in age from the Ordovician through to the Early Permian. In order to provide an overview of the geology of the region, both in terms of the depositional setting as well as the provenance of the sediments, a series of detailed lithological profiles were measured. Together, with the samples taken for petrographic analysis (n = 48), this dataset facilitated the detailed reconstruction of the depositional settings over time.

3.2. Ordovician

3.2.1. Description

The Ordovician-age succession was examined at six different locations (Figs. 5, 6). In some cases, the precise age of these units is not clear due to the lack of fossils within them. ?Precambrian ages have been suggested by some workers for these rocks (based on the lack of fossils, see Abduazimova, 2001; Abduazimova et al., 2007, for details), but the lack of Cambrian outcrops within the Nuratau region, together with the lithological similarity between the supposedly ?Precambrian and Ordovician units, would suggest that the rocks are most probably Ordovician.

The lowermost sediments belong to the Taskasgan Fm which, because of its location along the margin of a lens, is very deformed with evidence of metamorphism/metasomatism. The rocks are mainly carbonates with some chert bands and contain many quartz-filled veins. The contact with the overlying Bagambir Fm is sheared (with slickensides). Outcrops from this formation comprise mainly carbonates (both limestones and dolomites), and individual beds range in thickness from 1 to 64 cm (rarely up to 240 cm). Internally, the beds not only are structureless, but may also show evidence of parallel or cross lamination. In thin section, the carbonates show clear evidence of recrystallisation; in some samples dolomite rhombs are disseminated throughout the thin section. Microfossils (possible algae and calcispheres), as well as echinoid, fenestrate bryozoa and ?mollusc fragments are also noted, as are rare zircon grains. The fossil fragments are disarticulated and broken up. Some beds show possible evidence of bioturbation. These sediments also contain some intraclasts and ooids (oo-bio-intra-sparite), which in some areas may be dominant (intrasparite). Micritic envelopes are also common in some samples.

The interbedded cherts are mainly continuous and parallel, though they may also be folded (?slumped), nodular or lensoid. Bed thicknesses range from 8 to 40 cm, with thinner beds (c. 3 cm) noted in some areas. Internally, the cherts show rare evidence of parallel lamination. In some areas, the chert beds are absent, or markedly reduced. The chert:limestone ratio increases upwards in the stratigraphy. Petrographically, the sediments are chert-rich (micro- and cryptocrystalline) with rare algae present.

The Middle and Late Ordovician units are mainly clastic (Jalatar and Ilonchi fms) with poor, highly deformed outcrops. The mid-Ordovician-age Jalatar Fm comprises very thin- to thinly-bedded siltstones with rare sandstones. These latter are up to 6 cm thick, and internally show some parallel lamination with rarer cross lamination.

The Late Ordovician Ilonchi Fm sediments are mainly sandstones, with interbedded siltstones and mudstones. They are bedded (very thin to thin), with individual beds being up to 45 cm thick. Internally, the beds show evidence of parallel and cross lamination, including sequences where an individual bed may have a graded lower part and a parallel-laminated top (the bases of these beds may also be loaded). The coarser-grained sandstone beds also show evidence of small-scale channelling (1–1.2 m thick).

Petrographically, the Late Ordovician silliciclastics are often poorly sorted and comprise mainly monocrystalline quartz (Qm) crystals in a matrix of clays with patchy carbonate or quartz cements (Fig. 7). Individual Qm grains are subrounded to subangular (commonly the latter) and some show evidence of strain shadows (though these lack any common orientation). Accessory minerals include biotite, muscovite, polycrystalline quartz, plagioclase, K-feldspar, zircon and rock fragments (mainly siltstones, mudstones, and chert).

Middle–Late Ordovician-age units were also examined in the Kitab area. These not only are predominantly carbonate rich, but also contain mixed carbonate-siliciclastic units.

3.2.2. Interpretation

The lowermost Ordovician units are characterized by interbedded limestones and cherts. The former were deposited in a marine setting, as illustrated by the rare fossils. Individual beds are often thick, with no concentrations of fossils observed, suggesting deposition from medium density flows, probably in a shelf setting, located below storm-wave base and far from any terrigeneous sources. The presence of rare ooids would suggest that areas of higher energy – such as oolitic shoals – were possibly adjacent, but it is most likely that the depositional setting was a lower energy one, with the ooids being washed in by storm activity. In some beds, fossils are more concentrated, and these probably represent skeletal sand shoals within the broad low-energy setting. It is also possible that the Nuratau sediments were transported by offshore or alongshore currents, since there is clear evidence of transport within the carbonate sediments (i.e. fragmented fossils, isolated ooids, with no direct evidence of ooid ridges or banks noted),

The interbedded carbonate-poor, silica-rich units were also deposited in a marine setting, and probably represent repetitive changes in sediment input. Indeed, Elrick and Hinnov (2007) have noted that rhythmically-interbedded limestones and cherts are typical for deep-water carbonate-rich marine deposits, and are often related to changes in sediment input, particularly changes related to wet/dry climate cycles influencing the amount of continent-derived aeolian and/or fluvial sediment transported into the system. Such changes could also be associated with variations in the offshore transport of nearshore-derived terrigenous and/or carbonate sediments (cf. Elrick and Hinnov, 2007). These, together with changes in wind-driven upwelling and the availability of recycled biogenic silica, would have resulted in the deposition of such rhythmic successions in this middle-outer shelf area (cf. Alsharhan and Nairn, 1997; Elrick and Hinnov, 2007; Hampton et al., 2007). Energy levels within the depositional setting continued to be low, as indicated by the fine parallel lamination. Some disturbed beds (folded, slumped) suggest periodic storm activity, resulting in the deformation of these finely-laminated sediments. The increase in the amount of chert relative to limestone up section, may be an indication of an increased siliciclastic flux, and the gradual transition to a system dominated by clastic sediments. Indeed, by Mid- to Late Ordovician times this was indeed the case, with the exception of the more distal Kitab region. The Nuratau sediments from this time do not contain any fossils, and are poorly sorted, with little evidence of rounding. It is probable that these were deposited in a marginal marine, or even continental depositional setting.

The eustatic fall in sea-level throughout the Ordovician (cf. Loydell, 1998) may have resulted in the progradation of terrigeneous settings across parts of the exposed shelf, whilst in deeper areas, carbonate

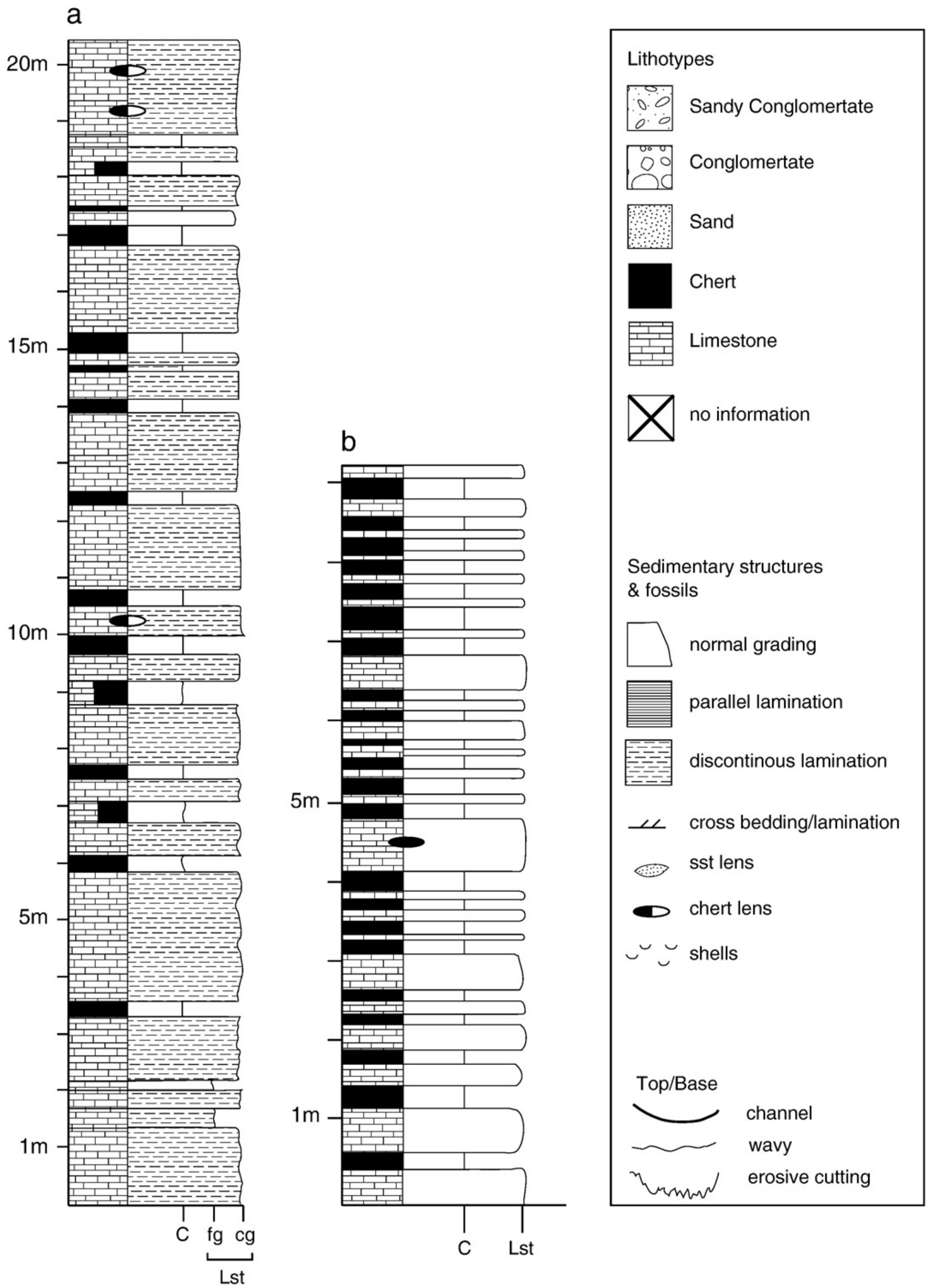

Fig. 5. Measured stratigraphic sections of lower Ordovician marine sedimentary strata of the Bagambir Formation documenting the occurrence of interbedded cherts and limestones. Note the variations in the abundance of chert: a. Egizburlak Village; b. Egiburlak Village, higher upsection (key: C — chert; fg — fine grained; cg — coarse grained; Lst — limestone).

deposition continued, The mosaic-like pattern of deposition observed in Mid- to Late Ordovician times may reflect a compartmentalization of the depositional setting, possibly due to fault activity (and the production of topographic highs and lows). However, there is little evidence for this in the sediments (e.g. relative absence of intraclasts/terrigeneous sediments). It is also possible, that the dominance of siliciclastics in the Nuratau region at this time may have been related to tectonic activity within the Alai continent. Uplift of the continental interior could have engendered farfield effects in the sedimentary record.

3.3. Silurian

3.3.1. Description

The main outcrop of Silurian-age rocks in the region belonged to the carbonate-dominated Jatak Fm (?Wenlock) (Figs. 7–9). This is underlain by a mixed limestone/siltstone/sandstone unit, where the siliciclastic sediments are similar to those of the latest Ordovician. Within the Jatak Fm, individual beds range in thickness from 8 to 260 cm. Of particular interest is the fact that the lowermost part of the section shows evidence of channel formation, where the

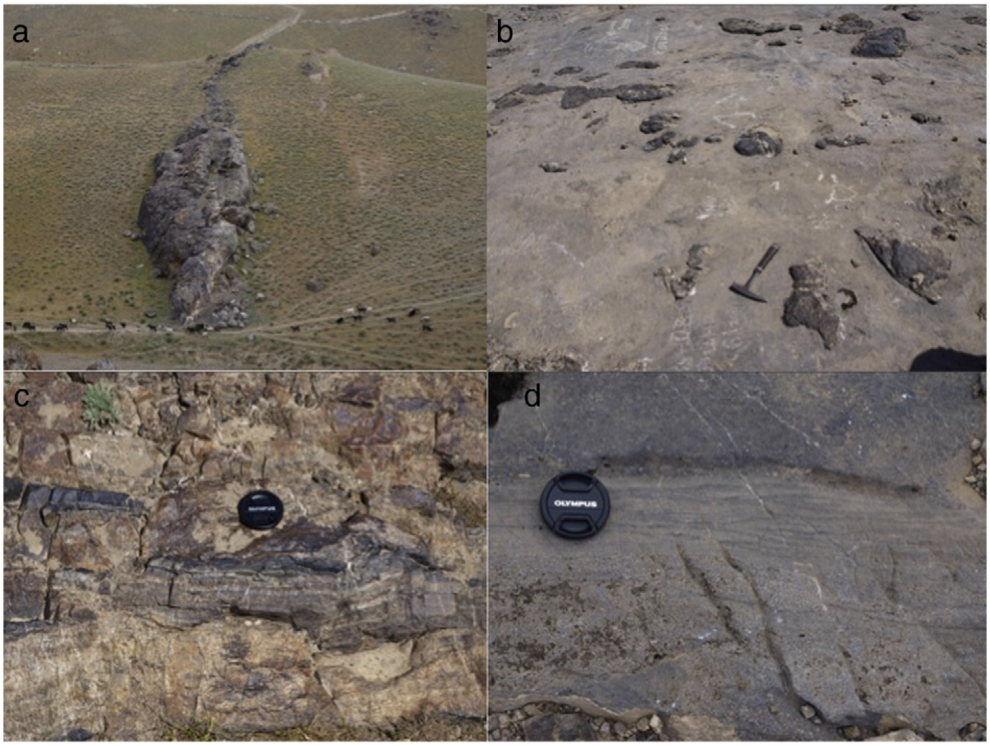

Fig. 6. Ordovician-age outcrops from the North Nuratau area. a. Ordovician outcrop, showing the typical lens-like outcrop form in the Nuratau region. b. close-up of Ordovician outcrop showing the chaotic distribution of chert lenses within a limestone “matrix”, possibly due to density-driven mass flow deposition, Egizburlak Village. c. close-up of chert-rich lens showing the fine lamination present within some of the lenses, Egizburlak Village. d. close-up of chert-rich lens showing cross-lamination, Egizburlak Village.

individual channels are stacked, with indications of channel migration. Individual channel bodies are up to 5 m wide. Petrographically, some of the carbonates are dolomitised, whilst upsection they are increasingly calcitic. Near the base of the section, i.e. below the channelised unit, some of the carbonates appear to be pelsparites. Thin sections from within the channel limestones indicate the presence of intraclasts as well as ?peloids (sparse intrasparite), whilst others are more micritic, with fossil fragments (brachiopods, calcispheres, i.e. sparse biomicrites). Near the section top the carbonates are packed pel-bio-sparites which include shelly fragments (including gastropod) as well as intraclasts (?grapestones) (Fig. 7).

In the Kitab area, Silurian-age strata are mainly limestones and dolomites, containing a range of predominantly benthic fossils including, stromatoporoids, corals (tabulate and rugosa), brachiopods and conodonts (Kim et al., 2007). Other carbonate fragments, such as peloids, were also noted. Petrographically, the top of the succession comprises packed pel-biosparites. The transition from the Silurian to the Devonian is marked by a change from echinoid (crinoid)-rich limestones with some siliciclastic (mudstone) beds to a fossil-free sparitic limestone.

3.3.2. Interpretation

The early Silurian succession is similar in terms of lithology and depositional setting to the Late Ordovician, comprising mainly interbedded carbonates and silicicilastics. However, this mixed carbonate-siliciclastic succession was rapidly replaced by thick carbonates deposited in a marine setting, located distal to any terrigeneous input (as indicated by the lack of a terrigeneous fraction). The sediments were mainly deposited as sand (often skeletal) shoals with a variety of peloids (both soft pellet muds and hard pellet sands) and probably in a low-energy, possibly restricted, setting. The channels, which as noted above, show evidence of lateral migration, may represent tidal channels on the shelf (cf. Grélaud et al., 2010). The channel orientation (i.e. NW–SE), however, was broadly perpendicular to the presumed palaeo-coastline which at this time was roughly NNE–SSW. Such an orientation would favour a tidal channel interpretation, with the channels being eroded by the passage of tidal currents on the shelf. Current directions would also have been strongly influenced by the barriers (i.e. shoals/ridges/bioherms) to the open marine areas to the east/southeast (see below).

The initial period of Silurian sedimentation, as noted above, comprised a mixed carbonate-siliciclastic succession. Such mixed units occur widely on both modern and ancient shelf successions and have a variety of causes, including punctuated mixing (due to sporadic input from storms or similar events), facies mixing (due to interdigitation of two particular facies) and source mixing (with sediment being derived from two distinctive source areas) (Mount, 1984). The period of deposition coincided with a gradual eustatic rise in sea level which commenced in the early Llandovery (cf. Loydell, 1998; Zhang and Barnes, 2002), and this may have played an important role in the ultimate cessation of siliciclastic input (due to flooding of the shelf during transgression). Thus, whilst the precise cause of the observed mixing in the Early Silurian sediments of the Nuratau area cannot be determined due to the lack of correlatable outcrop, it is highly likely that the cessation of terrigenous input was related to sea level rise.

Biske and Usmanov (1981) have reported the occurrence of Llandovery and Wenlock clastic successions from the region, and Burtman (2008) has noted that some of these contain graptolite-rich sediments. The interpretation of these units, however, as slope turbidites (e.g. Biske and Usmanov, 1981) is questionable – particularly in terms of the broader depositional setting, and a deeper shelf setting would be more appropriate. Further to the SE (in the Zeravshan area), Silurian-age shallow-marine benthic assemblages, comprising mainly corals and rhynchonelliformean brachiopods, as well as trilobites, have been noted, suggesting a similar depositional setting. Burtman (2008) has noted the rare presence of basalts within the Silurian succession of the region.

The sediments of the Kitab region represent a laterally more distal location on the shelf. These sediments are markedly different to those observed in the Nuratau region, in that they are dominated by fossils (including bioherms) with peloids also noted. As such, the depositional

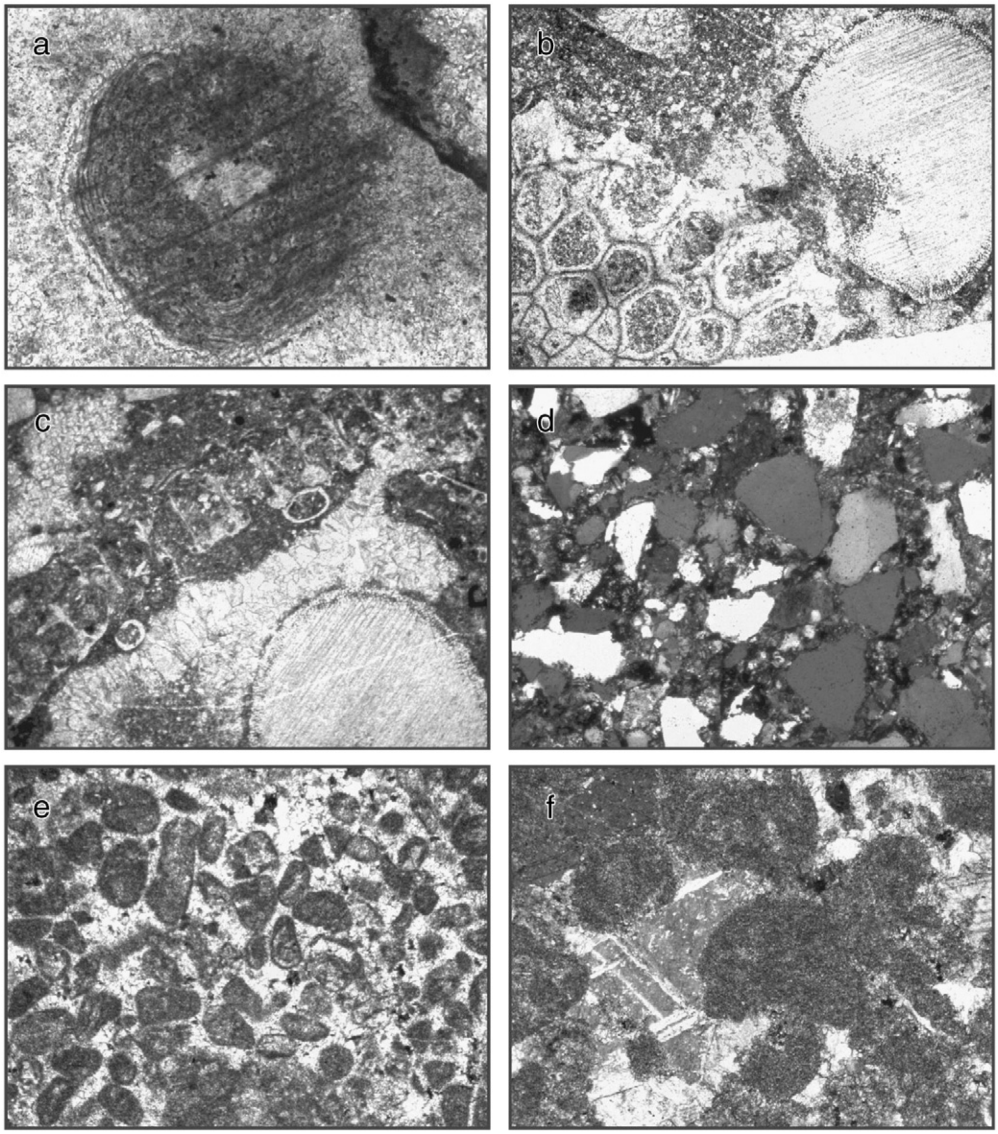

Fig. 7. Photomicrographs of selected samples from the Ordovician and Silurian of the North Nuratau area. a. recrystallised ooid (ppl), Ordovician, ×10, b. echinoid and bryozoan fragment (ppl), Ordovician, ×10, c. echinoid fragment and fenestrate bryozoa fragment (ppl), Ordovician, ×10, d. thin section view of siliciclastic Ordovician sediments showing quartz grains (mainly monocrystalline, with some polycrystalline) in matrix (xpl), ×10, e. pelsparite (ppl), Silurian, ×10, f. peloids and micritic intraclasts in a sparry cement (ppl), Silurian, ×10.

setting was probably one of skeletal sand shoals with reef-like structures which would have formed active barriers to open marine circulation on the rest of the shelf. Behind these sand bodies and reefs, both of which formed submarine highs, lower-energy peloidal-sands and muds were deposited. The longevity of this rimmed-shelf system throughout the Silurian suggests a long period of relative quiescent conditions in the region.

3.4. Devonian

3.4.1. Description

The Devonian-age succession was examined at four locations in the Nuratau area as well as briefly in the Kitab region, where more fossil-rich successions are evident (Figs. 9–11). It is dominated by carbonates, although clastics were also noted. The base of the Devonian is represented by a basal conglomerate (considered by many workers to represent an unconformity), although in the field the contact appears to be tectonic (at least at the examined location, see also Burtman, 2008). Along the contact, conglomerate beds range in thickness from 3 to 80 cm (average c. 30 cm) and contain a range of clasts (granules, pebbles) where the smaller clasts tend to be subrounded, whilst the larger clasts are subangular. The beds are matrix supported (though close to the base they may be clast supported) and are poorly graded. Bed amalgamation is common. Petrographically, the matrix is mainly monocrystalline quartz (both strained and unstrained forms) with clasts of carbonate (both microspar and micrite) also present (Fig. 12). These latter are rounded to angular (mostly subrounded to angular) and are contained within a matrix of quartz, patchy carbonate cement and rare clay minerals (matrix). Individual clasts may contain dolomite rhombs, monocrystalline quartz grains, as well as being internally laminated and/or micrite rich, as well as containing contain fossils (calcispheres, serpulid worm tubes, tabulate corals). Some of the lithic clasts are also conglomerates (which, in turn, may include conglomerate clasts), indicative of multiple phases of sediment recycling in the region. Accessory minerals, which are rare, include polycrystalline quartz and muscovite.

Associated with the conglomerates are rare carbonates comprising alternating laminae of microspar and micrite with sharp boundaries between them. Both laminae contain grains of subrounded to subangular monocrystalline quartz, although the amounts vary

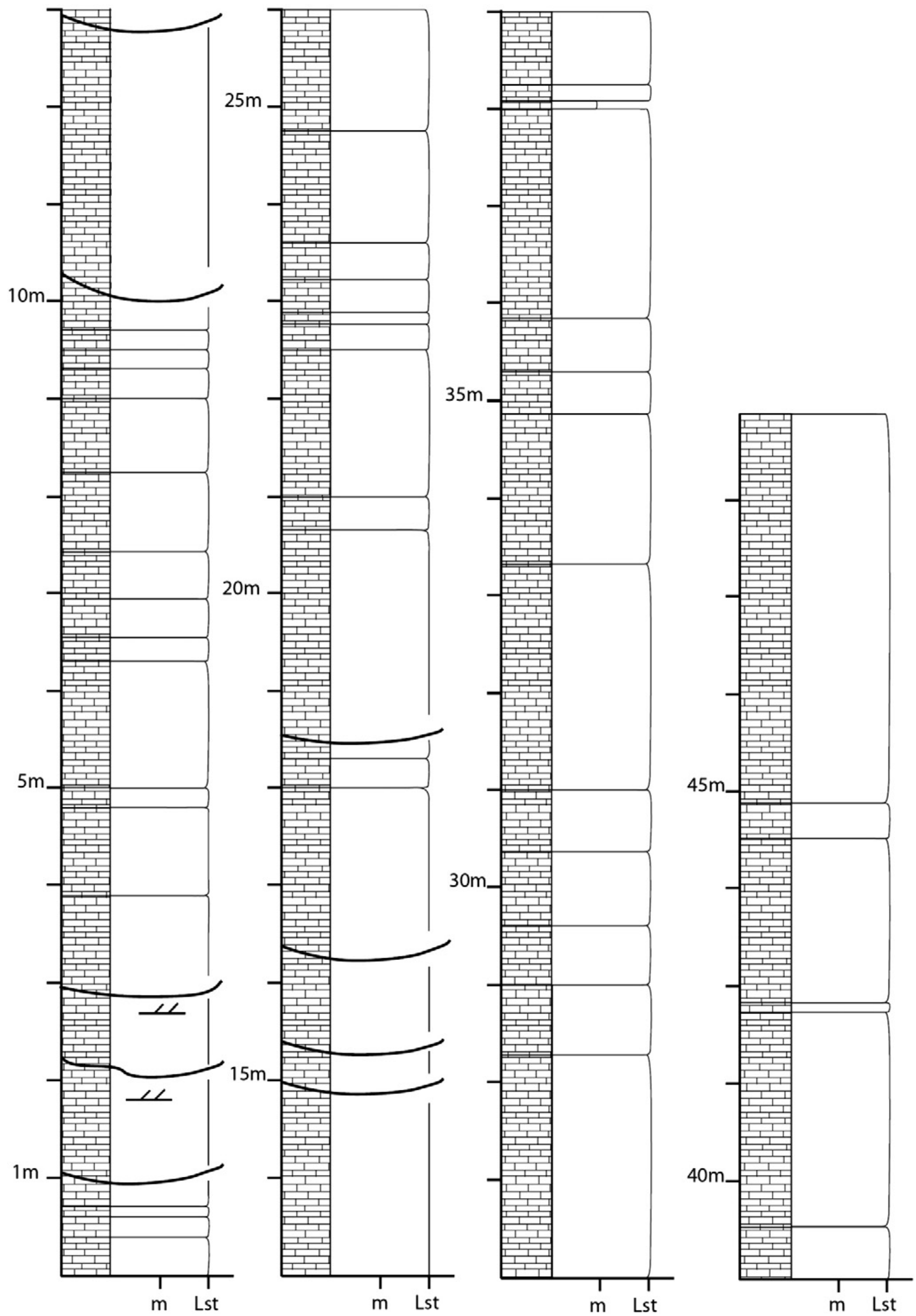

Fig. 8. Measured stratigraphic section from the Silurian-age Jatak Formation. Note the channelised nature of the limestones (stacked pattern). In addition, note the lack of chert interbeds, clearly distinguishing these units from the underlying Ordovician carbonate-rich succession. Silurian profile from the northern part of the Nuratau area. See Fig. 5 for legend; key: m — micrite; Lst — limestone.

(micrite: 5–10%, microspar: 3–4%), and may even vary within a single lamina. Polycrystalline quartz grains were also noted within the microspar laminae. Within the micrite layers, carbonate grains are also present (including one with a broken/eroded ooid, indicative of partial transport), as well as possible fossils (calcisphere). Zircon and muscovite may also be present.

Carbonates dominate the Devonian-age succession with individual beds ranging in thickness from 20 to 150 cm (up to c. 680 cm in some areas). Internally, the beds are structureless, or they may show evidence of parallel lamination. Rare fossils were noted, including shell and crinoid fragments, whilst in thin section calcispheres and microfossils were also noted. The larger fossils are disarticulated, and distributed throughout individual beds, with no evidence of concentration into layers or lags. In situ algae, in the form of algal mats, were also observed, suggestive of low-energy conditions. Petrographically, the thicker limestones may contain peloids and rare ooids (sometimes broken) as well as fossil material (i.e. packed bio-pelsparite, sparse pelsparite, sparse biomicrite). In some areas, the limestones are interbedded with units of laminated marls or micrites, which range in thickness from 1 to 300 cm. Carbonate breccias (minimum thickness – 4.0 m) were also noted, with individual clasts being subrounded to subangular, up to 35 cm in diameter, and matrix supported.

Fig. 9. Ordovician–Devonian outcrops in the North Nuratau area. a. thinly-bedded medium- to fine-grained sandstones of Ordovician age. b. outcrop view of thick-bedded Silurian-age limestones, Jatak Formation. c. close-up of thickly-bedded Silurian limestones, Jatak Formation. d. close-up of Devonian-age limestone bed.

In the Kitab region, a thick Devonian carbonate succession (with rare siltstones and mudstones) was examined. These rocks are Early–Middle Devonian in age and characterized by their abundant pelagic and benthic faunas and are characterized by the presence of stromatoporoids, corals (tabulate and rugose), brachiopods, trilobites, graptolites, goniatites, tentaculids, ostracods and conodonts (e.g. Kim et al., 1982, 1984,

Fig. 10. Devonian and Carboniferous outcrops in the North Nuratau area. a. Matrix-supported limestone bed of Devonian age, Kutarma Quarry. The bed represents a debrite, deposited as a result of mass flow activity. b. Pillow lava from the Carboniferous succession.

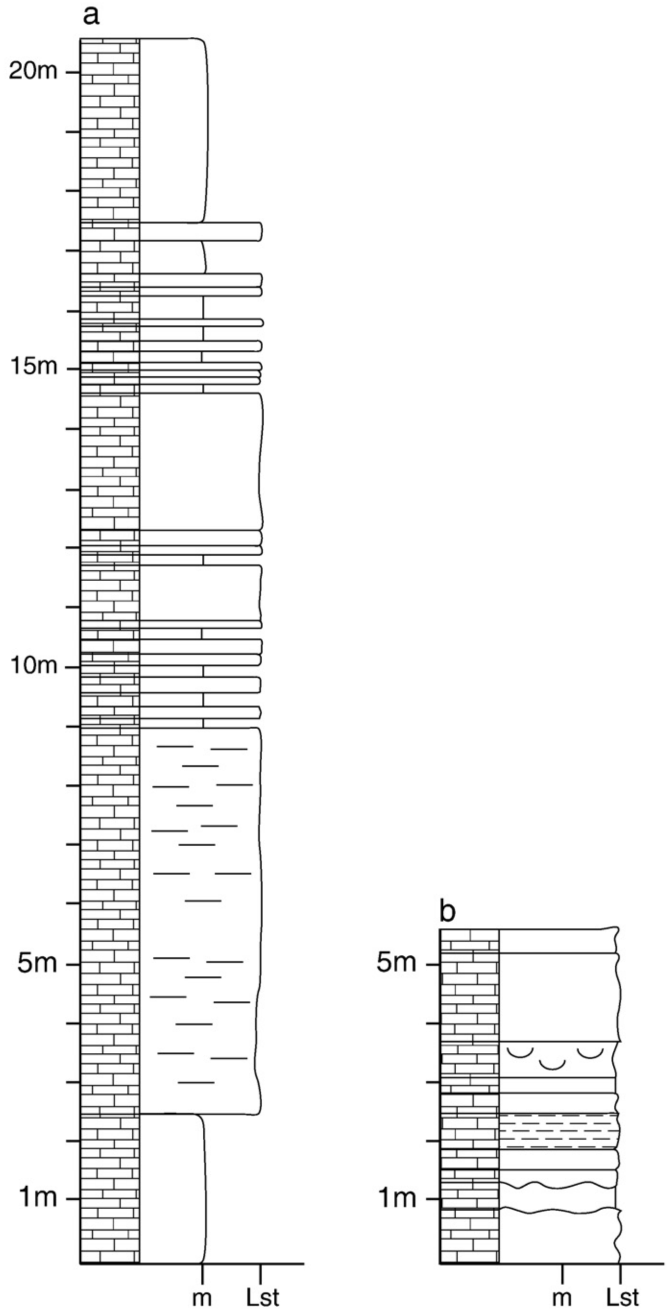

Fig. 11. Measured stratigraphic section from the Devonian-age units: a. interbedded limestones (some muddy) and micrites from the central Nuratau region; b. thick-bedded limestones from the Kutarma Quarry. See Fig. 5 for legend; key: m — micrite; Lst — limestone.

2007; Yolkin et al., 2000) as well as other carbonate fragments (e.g. pel-biosparite). The Early Devonian limestones are generally thick and structureless, with a thinning of the beds upsection. By the upper part of the Early Devonian, the limestones are again thicker, and packed with fossils and other fragments (e.g. packed biosparites, biopelsparites, pel-intrasparites and packed pel-bio-intrasparites). Fossils present include, goniatites, brachiopods, trilobites, corals (tabulate and rugose), stromatoporoids, echinoderms (crinoids) tentaculids, conodonts, chitinozoans, calcispheres and ?ostracods (e.g. Kim et al., 1982, 1984, 2007) which may form well-developed reefal bioherms. The limestones are interbedded with mudstones. In the Khodzha-Kurgan Fm (Kitab region), thick limestone beds with fossil accumulations (e.g. brachiopods, corals, crinoids) are interbedded with thinner marls which contain conodonts, tentaculids and graptolites (Kim et al., 1982, 1984).

The Middle Devonian in the Kitab region is carbonate rich (both sparite and micrite), with some carbonate breccias also present. Beds tend to be thinner than in the uppermost Lower Devonian succession and rare chert beds were noted. Fossils include, corals (tabulate and rugose), brachiopods, stromatoporoids and conodonts. The Late Devonian lithologies are very similar to those of the underlying Middle Devonian, with more fossil-rich micritic units in the Famennian-age units (e.g. packed biomicrites). Chert-rich limestones also occur as well as siliciclastic interbeds. Fossils present include stromatoporoids, corals (tabulate), echinoids (crinoids), brachiopods and conodonts (Kim et al., 1982, 1984).

3.4.2. Interpretation

As in Ordovician and Silurian times, the succession in the Nuratau region represents a more proximal location in the overal depositional system. The lowermost part of the Devonian succession in the Nuratau region contains a so-called basal conglomerate (indeed, some authors, e.g. Burtman (2008) suggest that there is an angular unconformity between the Silurian and the Devonian successions). The conglomerate may represent a rubble conglomerate or a transgressive lag. The fact that the conglomerate beds are predominantly matrix supported would suggest deposition from highly-concentrated flows, probably fluid-rich debris flows. The fact that some grading can be observed indicates that parts of the flows were in transition from a dense laminar flow to a more dilute turbulent one. The conglomerates were probably derived from local sources (?islands), as suggested by the predominance of carbonate clasts, although the rounded nature of some of the clasts would indicate that at least some material (i.e. rounded smaller clasts) had a more distal provenance.

The formation of the conglomerate unit may be related to the fall in sea level which occurred from Late Silurian through to Early Devonian times (cf. Haq and Schutter, 2008), although the lack of precise dates (see Abduazimova, 2001; Abduazimova et al., 2007) makes it difficult to say with any certainty. Additionally, the history of sea-level change in the Devonian was complex, with 18 sea level changes recorded in the Late Devonian alone (Sandberg et al., 2002). However, the only possible evidence of these changes in the Nuratau succession, is the presence of discontinuities within the sedimentary record (see Burtman, 2008 for details).

The overlying succession comprises carbonates which were deposited in thick, flat-lying beds in a low-energy (e.g. presence of algal mats), marine, shelf/platform setting. As such, it is very similar to that of the Silurian in the region, suggesting that the area was tectonically quiescent (for the most part) along the NW margin of the Alai microcontinent. Deposition generally occurred below storm-wave base. Carbonate sedimentation rates are generally high, and subsidence in shelf areas is rarely rapid enough to provide sufficient accommodation space for the amounts of sediment produced. It is, therefore, likely that the Ordovician–Devonian succession was deposited on a prograding shelf system. Progradation is often related to a relative rise and highstand of sea level (Mutti et al., 1996). Such prograding systems can result in great thicknesses of carbonate being formed (e.g. Triassic (Dolomites) of Italy, Cretaceous of Central Mexico, both with c. 2000–3000 m of carbonate shelf sediments being deposited along large offshore banks). It is probable that the carbonate-dominated succession along the NW margin of the Alai continent was similar.

Carbonate breccias were locally common. The lack of any internal structure within these beds would suggest that they are debrites, deposited from high density/viscosity flows. Such flows can be triggered by a variety of mechanisms (e.g. increased rates of sedimentation, storms generated on the shelf, seismic activity, slope failure) acting alone or in conjunction, and may even be generated at a distance of 100s of kilometres from the original landslide (e.g. Talling et al., 2007). It is also possible that early cementation of shelf sediments, followed by rapid progradation, resulted in increased loading which may have generated brittle fracturing in the early-lithified strata. Such fracturing

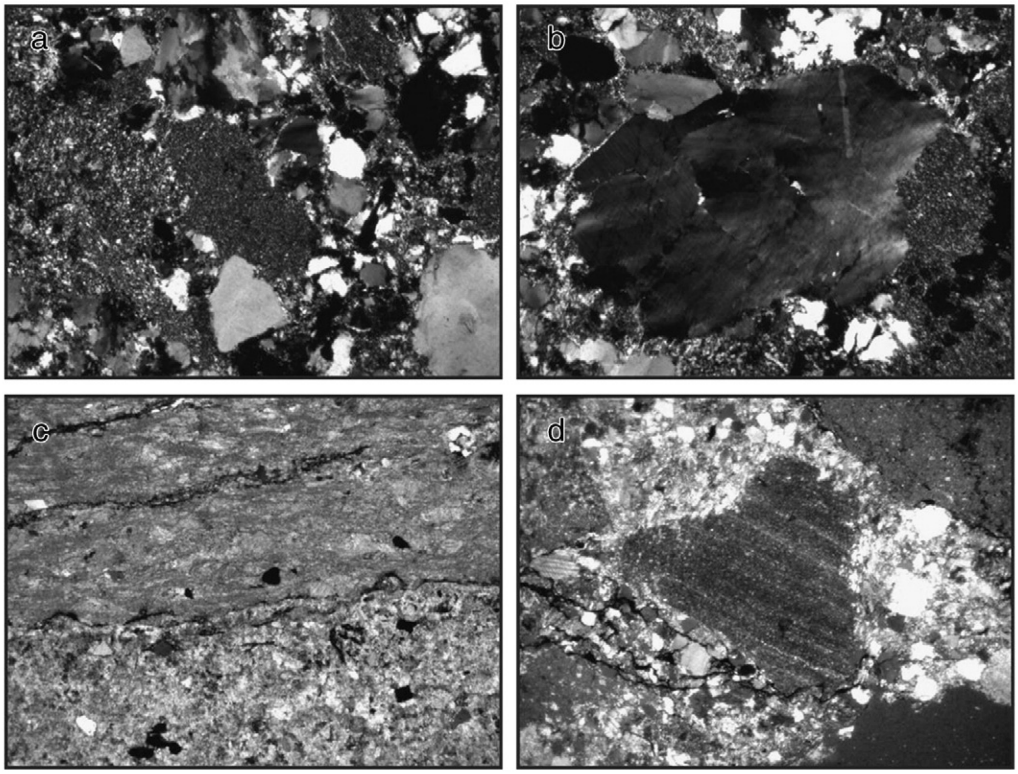

Fig. 12. Photomicrographs of selected samples from the Devonian of the North Nuratau area. a. thin section view of siliciclastic Devonian conglomerate showing mainly quartz (monocrystalline) and rare chert fragments (xpl), ×10, b. polycomposite monocrystalline quartz grain (xpl), ×10, c. banded micrite/microcrystalline limestone showing rare quartz (monocrystalline, subangular to angular) grains (ppl), ×10, d. banded chert fragment in limestone conglomerate (xpl), ×10.

may have resulted in the collapse of part of the platform and the possible generation of a debris flow on the adjacent slope or outer shelf. In the Kitab region (Khodzha-Kurgan Fm), thick limestone graded beds packed with disaggregated fossil material have been interpreted as tempestites, which would fit the broad interpretation of the depositional setting. Additionally, the rare, fine-grained siliciclastics from the Kitab region reflect the reduced input from terrigeneous sources. Deeper-marine facies (e.g. turbidites) have also been reported by some authors (e.g. Burtman, 1975), whilst Burtman (2008) also noted the presence of localised volcanics within the succession.

The bioherms of the Kitab region probably represent patch and pinnacle reef bodies with the more restricted environments located landwards of these bodies. Such restricted shelf regions can extend for 1000s of kilometres along shorelines (e.g. Brooks et al., 2003). To the SE of the North Nuratau (Zeravshan area), Devonian-age faunas suggest a shallow-marine setting (Cronier and Tsmeyrek, 2011; Owens et al., 2011; Webster and Rakhmonov, 2009). However, there is evidence of both neritic and pelagic associations (e.g. Kodza Kurgan area) in the Kitab region (Yolkin et al., 2008), suggesting regional variations including both shallower and deeper conditions in the Kitab area.

3.5. Carboniferous

3.5.1. Description

The Carboniferous succession in the Nuratau area was examined in two locations (Fig. 10), both of which were dominated by basalts, with some dolerites, and associated coarse- and fine-grained tuffs (sometimes metavolcanics and metatuffs), thin limestones beds and thin silica-rich beds. These are mainly confined to the mid-Carboniferous-age Shavaz Fm (total thickness c. 150 m). The associated Kelvasay Fm (not examined) comprises oolitic limestones (c. 100 m). The basalts are both amygdaloidal and vesicular, with extensive calcite-filled veins. Radial structures, as well as chilled margins were noted. Some parts of the succession appear to be blocky lavas.

Rare lowermost Carboniferous-age units in the Kitab area were briefly examined. These are mainly carbonate rich (e.g. Novchomok Fm), and extend up into the Tournaisian.

3.5.2. Interpretation

The Early Carboniferous succession is mainly absent in the region (Burtman, 2008). The Mid-Carboniferous succession of the Nuratau region comprises volcanic and shallow-marine successions. The presence of oolitic limestones would suggest a higher energy shelf area, with oolite shoals dominant. Burtman (1975) has noted that the sediments of the Early and Middle Carboniferous are up to 500 m thick and are mainly carbonates and mixed carbonate-siliciclastic units. Thus, it would appear that the relatively stable shelf conditions established in the Devonian continued on into the Carboniferous. The onset of significant siliciclastic sedimentation may have been related to changes in the broad tectonic setting in the region, where increased rates of subduction and ocean consumption resulted in increasing instability on the shelf. Burtman (2008) notes that the carbonate succession is always conformably overlain by deeper-marine siliciclastic sediments. These units are up to 500 m thick, and may be overlain by possible olistostromes (Burtman, 2008) which testify to an increase in regional instability. Foraminifera recovered from the deep-marine beds suggest a Moscovian age (Burtman, 2008).

Carboniferous magmatism has been interpreted as being related to the development of a back-arc basin in the region associated with the final stages of collision along the suture zone (Jenchuraeva, 1997), although Biske (1996) has suggested that the geochemical signal implies an intraplate (Oceanic Island Basalt) signature. However, some authors have noted that it is possible for the upwelling mantle in backarc regions to have an ocean island basalt (OIB) component (Hickey-Vargas, 1992; Stern et al., 1990). Thus, it is possible for magmatism to be chemically heterogeneous, with both island-arc and oceanic-island basalts coexisting; such a signature may be related to the propagation of asthenopheric mantle beneath the region (e.g. Trua et al., 2007, 2011), or the presence of a hotspot (e.g. Lupton et al., 2012a,b). Volcanic activity occurred in a subaqueous setting, and its onset was presumably related to the closure of the Turkestan Ocean. The precise dimensions of the oceanic basin, however, have not been defined, although the volume of the volcanic material would suggest that it may have been similar to the Lower Palaeozoic Welsh Basin (cf. Krawczyk et al., 2008).

Regionally, Jenchuraeva (1997) has noted that there was a magmatic pulse in the middle Devonian–?Early Carboniferous; the products were mainly basaltic lavas — including pillow structures, with tuffs comprising up to 40% of the succession in some areas. Subsequently, in the middle Carboniferous a series of magmatic bodies (gabbros, amphibolites, diorites) was intruded in the Nuratau area (Dalimov and Divaev, 2010). Related activity in the Middle Tien Shan to the W of the Talas–Ferghana Fault includes calc-alkaline intrusions and the associated volcanics of the Beltau-Kurama arc (Seltmann et al., 2011), probably related to active subduction, albeit predating the closure of the Turkestan Ocean (Seltmann et al., 2011). A final phase of intrusive activity (Late Carboniferous-mid Permian) comprised mainly acid bodies, and includes quartz monzonites and granites (Dalimov and Divaev, 2010). This final phase of plutonic activity coincided with the oblique closure of the Turkestan Ocean. Deformation at this time was extensive and related to the development of sinistral transpressional faults, typically NW–SE trending, as well as shear zones (Nurtaev et al., 2013).

4. Discussion and conclusions

The Central Asian region is a geologically complex region comprising a variety of microcontinental/terrane fragments which were accreted to the southern margin of Laurasia.

The formation of the Palaeo-Asian Ocean and subsequently the Turkestan Ocean were primary events (e.g. Buslov et al., 2004; Kheraskova et al., 2010; Ruzhentsev and Mossakovskiy, 1996; Zonenshain et al., 1990), with the closure of the latter in late Carboniferous/Early Permian times of significant importance for the growth of the Central Asian continent. The precise identification of the landmasses, with the exception of a Kazakh–Kyrgyz (=Kazakhstania) continent (e.g. Didenko et al., 1994; Dobretsov et al., 1995; Filippova et al., 2001; Mossakovsky et al., 1993), surrounding the Turkestan Ocean is problematic. The Nuratau region comprises part of the Alai "block", and this is considered by some authors to form part of the Tarim continent (e.g. Alai-Tarim, Bazhenov et al., 1999), or to be a separate entity (e.,g Biske, 2000), sometimes in combination with the Kyzylkum region to form part of a Kyzylkum-Alai "block" (e.g. Biske and Seltmann, 2010; see also Nurtaev et al., 2013). However, other authors (e.g. Mukhin, 1997) have suggested that the Uzbekistan region forms the northern margin of the Karakum–Tajik continent (indeed, he does not mention the existence of an Alai continent), whilst Biske (1996) would suggest that both the Alai and Karakum–Tajik continents existed (separated by the Vashan unit in the area of the Zeravshan River). In contrast, Brookfield (2000) clearly suggests that the Zeravshan and Nuratau areas form a contiguous region, whilst Burtman (2008) suggests that the entire area belongs to the Alai region (he suggests that the Alai region comprises "the East Alai (and) Zeravshan ranges, and part of the Alai, Turkestan and Gissar ranges", p. 11, Burtman, 2008). The confusion in the literature is largely due to the problems in precisely defining a block/microcontinent, as well as the processes which led to their formation (e.g. Collier et al., 2004; Müller et al., 2001). In this study, we consider the Alai microcontinent to have acted alone (or in close conjunction) with other continental fragments – very similar, in fact, to present-day Indonesia (e.g. Hall, 2011; see also discussion in Yakubchuk, 2008).

The broadly N–S-oriented (e.g. Buslov et al., 2004; Heubeck, 2001; Kheraskova et al., 2010 although Biske and Seltmann, 2010 have proposed an E–W orientation) Turkestan Ocean separated the Alai and Kazakh–Kyrgyz continents and final closure commenced at c. 320 Ma, continuing into the Early Permian (c. 295–290 Ma) (Biske and Seltmann, 2010). Closure and the subsequent collisional and suturing events are recorded in the North Nuratau region although reconstructing the precise palaeogeographic and geodynamic history of such a complex boundary is difficult.

4.1. Tectono-sedimentary history

The sediments of the North Nuratau region were deposited along the margins of the Alai continent whose NE margin (in present day coordinates) faced the Turkestan Ocean. The precise geography of the Alai continent is, however, poorly understood. Konopelko et al. (2007) suggested that it was subdivided into a western Alai segment and an eastern Kyzylkum segment. However, the palaeogeographic relationship between these two fragments is unclear, although they were probably closely related, sharing similar subduction/accretion histories. As noted above, Brookfield (2000) has subdivided the area into a number of units which strike parallel to one another, and are separated by major faults. In his scheme, the Nuratau area forms part of the Turkestan-Alai Unit.

Following the establishment of the Turkestan Ocean, a carbonate-dominated, continental shelf system was established along the northern margin (in present-day coordinates) of the Alai continent (Figs. 13, 14). The interbedded carbonates and (increasingly) cherts were deposited in a relatively low-energy setting, with varying climate (wet/dry) and/or fluvial input controlling the flux of siliciclastic material onto the shelf. The shelf area was a subsiding one, with oceanwards progradation. By Mid-Late Ordovician times, the depositional system had changed somewhat with clastic flux becoming more important, to the point where these sediments dominated the shelf succession, although in more distal areas (e.g. Kitab region), carbonate systems continued to predominate. These variations, with the increase in terrigeneous material in one area, whilst carbonates continued to predominate in others, may have been related to tectonic activity within the Alai microcontinent itself (of which little is known). More likely, however, is the significant eustatic sea-level fall which occurred at the end of the Ordovician and which resulted in the progradation of siliciclastic-rich depositional systems across the newly-exposed shelf. As noted, in deeper, offshore shelfal areas carbonate deposition continued, and this depositional system with proximal siliciclastics and distal carbonates continued into the Early Silurian changing only with the onset of the sea-level rise during the Llandovery. Graptolite-bearing mudstones have also been recorded from the Llandovery (Burtman, 2008) suggesting deeper water conditions at this time.

The reestablishment of carbonate deposition in the ?Wenlock (Silurian) revealed some significant changes distinguishing the depositional systems from those of the Ordovician. Whereas the latter tended to be mixed carbonate-siliciclastic systems (with periods of either clastic or carbonate dominance), the Silurian depositional environments were generally deposited in shelf settings far removed from any terrigenous input, although in some areas graptolite-rich mudstones deposited under deeper-marine conditions have been noted (Burtman, 2008). In general, however, the rise in sea level across the region resulted in the establishment of conditions favourable for carbonate deposition and over time a broad carbonate mosaic was established across the region, including reef-like structures in the Kitab region. The tectonic stability of the region was particularly marked at this time (and possibly reflected by the rare basalts which have been reported (see Burtman, 2008)), although the transition to the Devonian indicates a clear break in depositional and/or tectonic conditions. At this time, a series of conglomerates were deposited. These debrites were derived from both clastic and carbonate sources (as indicated by the clast compositions), and indicate a period of change (uplift/erosion, see also Burtman, 2008) coincident with a sea-level fall at the Silurian–Devonian boundary. Interestingly, thick units of Early Devonian volcanics are present in the region – particularly along the eastern margin of the Kazakh–

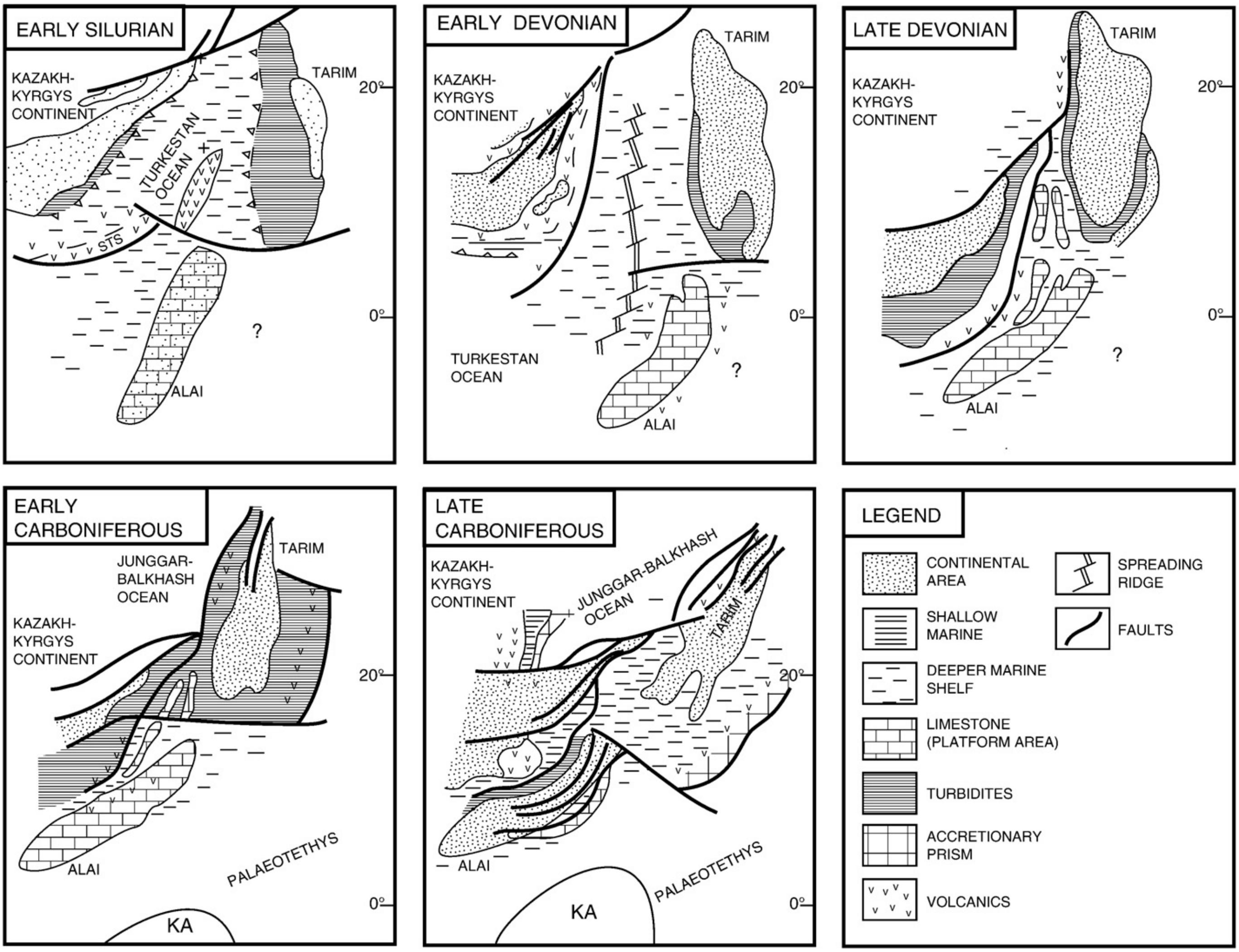

Fig. 13. Schematic palaeotectonic/palaeogeographic maps of the region illustrating the history of the Turkestan Ocean from Silurian–Permian times (modified after this study, Biske, 2000; Bykadorov et al., 2003; Filippova et al., 2001; Heubeck, 2001).

Kyrgyz continent (Filippova et al., 2001), and related to subduction (Jenchuraeva, 2001). Additionally, Early Devonian volcanics have also been reported from the Kurama range in the Middle Tien Shan (i.e. to the W of the Talas-Ferghana Fault) – possibly related to northward subduction beneath the southern margin of the Kazakh–Kyrgyz continent (Shayakubov and Dalimov, 1998). This volcanic pulse, which probably began in the Late Silurian occurred ca. 10 Ma after the termination of the Early Silurian phase of post-collisional magmatism (related to Caledonian events) (Seltmann et al., 2011).

Following this significant period of disturbance, carbonate deposition was rapidly resumed across the region. Indeed, the settings were broadly comparable to those established in the Silurian, and considerable thicknesses of shelf sediments were deposited. That conditions were not altogether stable, however, is indicated by the presence of the interbedded carbonate debrites and tempestites. These storm and/or seismic events periodically triggered mass flows of limestone clasts (cf. Hood and Nelson, 2012). Debris flows can also be related to large-scale slope (e.g. Einsele, 2000; Tisljar et al., 2002) or reef (e.g. Giddings et al., 2009) collapse. Episodic instability and mass wasting can be triggered by various factors, including structural steepening (e.g. forebulge uplift) accompanied by high-magnitude earthquakes. The former results in platform emergence, increased load stresses and excess pore-water pressure in the carbonate ramp (e.g. Payros et al., 1999). The fact that magmatic activity has been recorded for the region from the middle Devonian through to the ?Early Carboniferous (Jenchuraeva, 1997) would support the idea of possible tectonic control on slope and shelf instability at times during the Devonian. Additionally, a number of stratigraphic gaps have been noted, including the absence of the Late Devonian (Burtman, 2008), although – as noted above – some of these may be related to the many eustatic variations which occurred over this period. Indeed, it is possible that sea-level falls may also have triggered debrite formation.

The pattern of occasional phases of tectonic instability, coupled with eustatic variations, which commenced in the middle Devonian continued into the Carboniferous, with a number of stratigraphic gaps also being noted, particularly the absence of the Early Tournaisian and Serpukhovian (Burtman, 2008). The Early and Middle Carboniferous sediments are mainly carbonates and mixed carbonate-siliciclastic units. Siliciclastic input was most likely related to the tectonic instability of the region (Fig. 14). More significant changes occurring in the Mid-Carboniferous where the succession includes volcanic rocks deposited in a submarine setting. This magmatic activity was associated with back arc basin activity (Jenchuraeva, 1997) and marked significant tectonic and palaeogeographic changes in the region heralding the closure of the Turkestan Ocean.

The uppermost Carboniferous units are generally deeper marine, with occasional olistostromes (Burtman, 2008) and their deposition may be related to the development of a foreland basin at that time, as

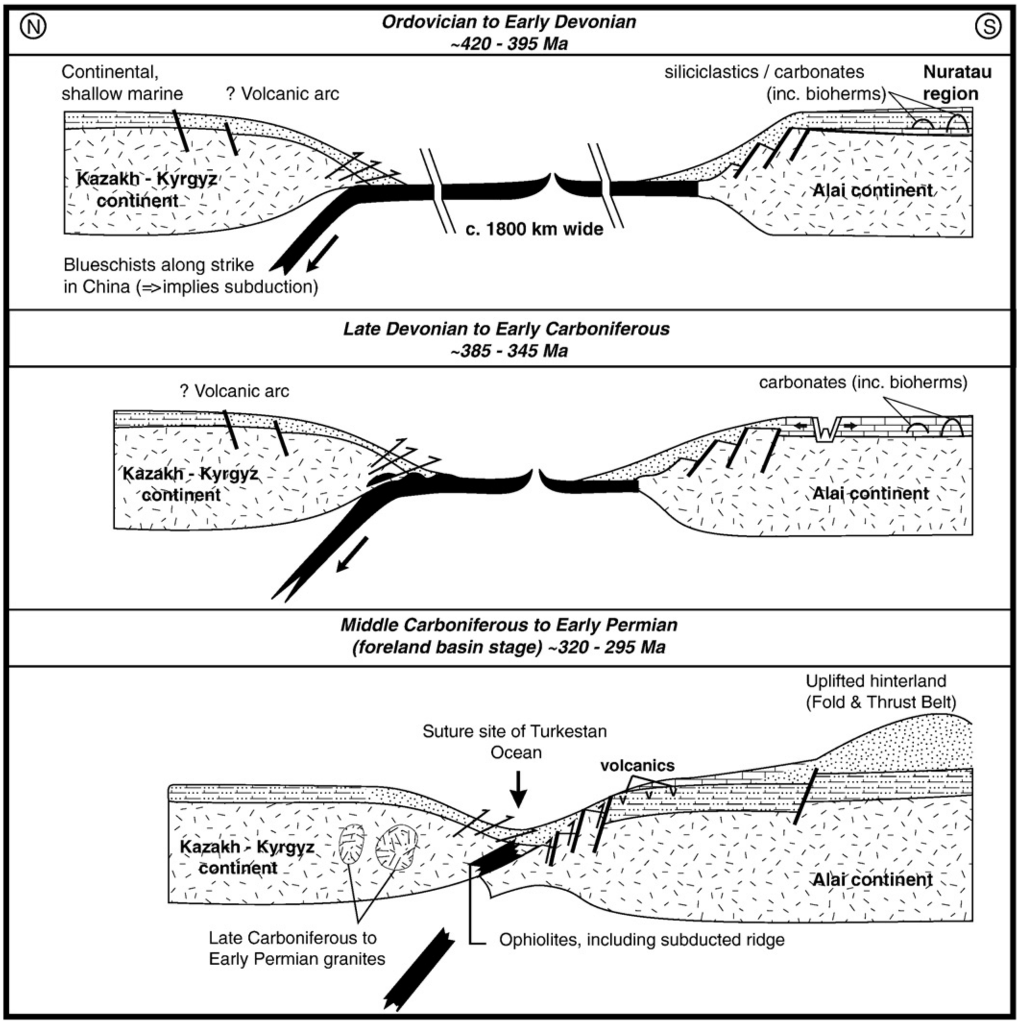

Fig. 14. Schematic reconstruction to indicate the Palaeozoic plate-tectonic setting and evolution of the Kazakh–Kyrgyz continent, the Alai microcontinent and the intervening Turkestan Ocean, Southern Tien Shan. Palaeozoic geographical coordinates are used (this paper and after Pickering et al., 2008).

a result of the migration of thrust sheets from the Kazakh–Kyrgyz continent over the Alai continent. Major crustal structures observed in the Nuratau region show clear evidence of folding and S-oriented thrusting (e.g. Nurtaev et al., 2013) and the formation of these structures, as a result of significant crustal compression and shortening, commenced at this time. Indeed, the fact that these features can be traced laterally as far as Xinjiang in eastern China (e.g. Burtman, 1975; Windley et al., 2007) would suggest that the collisional zone was of great lateral extent. The age of thrusting in eastern China, however, is mainly middle Carboniferous, suggesting a degree of diachroneity eastwards (Windley et al., 2007). In the Nuratau/Kitab region there is little evidence for obduction (i.e. no ophiolitic remnants, not even as eroded fragments within the sediments). However, the presence of ophiolitic successions elsewhere (e.g., Solomovich, 2007) would suggest that a degree of obduction did occur. However, it is likely that suturing and collision varied considerably along strike. These variations were probably related to the presence/absence of continental fragments, as well as changes, for example, in the rates of subduction and/or collision. Given our current knowledge of the events in Variscan Europe (e.g. Kroner et al., 2008; McCann et al., 2008b), the degree of complexity involved in subduction/collision is clear. It is, therefore, probable that the sequence of events in Central Asia were as complex as the Central European Variscan amalgamation. The collisional history probably involved multi-phase subduction/accretion of various microcontinents, ancient island arcs and fragments of oceanic islands (e.g. similar, as noted above, to modern-day Indonesia). During, and subsequent to, the accretions and collisions, numerous intramontane basins would have formed in a variety of tectonic settings. The final tectonic collage would thus comprise a complex tectonic mosaic of subduction-related complexes, island arcs, ophiolitic assemblages and slivers or terranes of crystalline basement, along the strike of the collision.

The final closure of the Turkestan Ocean involved a major change in terms of tectonic activity in the region from compressional to strike–slip movement. The fault zone of the North Nuratau region is part of the extensive Bukantau-South-Ferghana Fault Zone, a deep structure which extends for c. 1000 km (see also Nurtaev et al., 2013). As noted above, there is an almost total absence of normal stratigraphic relationships between the various lithological bodies (lenses) in the Nuratau area. Similar complexity can be observed in the case of Variscan Europe where compression/transpression and indentor tectonics resulted in the formation of a complex suture zone (see Abrajevitch et al., 2008; Kroner et al., 2008; McCann et al., 2008b, for details). In Uzbekistan, the situation was probably similar with suturing and collision varying considerably along strike, and related to the presence/absence of continental fragments and/or changes in the rate of subduction/collision (Nurtaev et al., 2013)The net result of this heterogeneous deformation, with a significant strike–slip component, would have resulted in the development of a series of lenses/blocks of crustal material moving along tectonic strike within a broad zone of transpressive activity, and resulting in a geographical distribution similar to that observed in the present-day North Nuratau region. Additionally, the regional trans-crustal shear zones controlled post-collisional granite emplacement, with areas of crustal weakness facilitating magma ascent (Seltmann et al., 2011), as well as resulting in the reactivation of older faults/lineaments (Nurtaev et al., 2013).

The Early Palaeozoic history of the western Alai continent is comparable, in part, to that of areas further east. Pickering et al. (2008) examined a range of outcrops which are lateral equivalents to the succession examined in the Nuratau region. In this region, the Early–Mid Ordovician Bulaksaj and Early Silurian Chakush formations comprise mainly carbonates and related siliceous shales and are broadly related to the Early Ordovician of the Nuratau region. However, there are clear differences between the two areas, most notably in the fact that the carbonate-shale units are confined to the earliest Ordovician in the Nuratau region, with later units being mainly carbonates or siliciclastics (see above). Additionally, the rocks of the Chakush Formation are markedly coarser, in part, than anything seen in the Nuratau area. The Late Silurian–Mid-Carboniferous of the eastern Alai region is dominated by shallow-marine limestones with associated coral and algal biostromes (Pickering et al., 2008). This is broadly similar to the western part, in the Nuratau region.

Pickering et al. (2008) have suggested that the Silurian sediments of the eastern Alai region were deposited on a slope setting, facing the Turkestan Ocean. In contrast, the sedimentary succession of the western Alai region is more typical of shelf settings. By late Silurian times, shelf sedimentation was dominant across the region. Of particular interest is the absence of subduction-related igneous activity in the eastern parts of the Alai region, which contrast markedly with the thick basalts present in the Nuratau region. Oceanic closure was marked by the onset of subduction-related (Andean type) magmatism on the southern margin of the Kazakh–Kyrgyz continent in Serpukhovian times ending, as a result of collision in the Late Carboniferous (Ges and Seliverstov, 1995). Closure was complete by Carboniferous–Early Permian times, as evidenced by the final emplacement of ophiolitic sequences, collision-related nappe tectonics, igneous intrusions (e.g. Solomovich, 2007) and continental sedimentation (Fig. 14). Permian-age postcollisional magmatic rocks are widespread in the Turkestan-Alai segment of the Southern Tien Shan fold-and-thrust belt and comprise mainly calc-alkaline granitoids (Dalimov and Divaev, 2010; Seltmann et al., 2011; Solomovich and Trifonov, 2002).

Biske (1996) has suggested that small, isolated deep-marine basins existed close to the suture until Early Permian times (possibly similar to the situation of the Silurian-age Pul'gon Fm of Pickering et al., 2008). The postcollisional phase (Permian) witnessed the change from active thrusting through to transform activity corresponding to the transition from collision to strike-slip tectonics, related to the oblique collision between the Tarim, Alai and Kazakh–Kyrgyz continents (Chen et al., 1999). Additionally, two types of K-rich post-collisional Permian-age granites have been recorded — 1) metaluminous granites cropping out along the SE boundary of the Southern Tien Shan Belt with the Tarim Block, and 2) peraluminous granites cropping out along the NW boundary with the Kazakh–Kyrgyz continent (Solomovich and Trifonov, 2002).

In summary, the geological evolution of the North Nuratau region is a microcosm of the broader tectonic events which were associated with the closure of the Turkestan Ocean. The evolution of the region, from a passive margin in Ordovician–Devonian times to more active magmatism and deformation in the Carboniferous and post-collisional sedimentation in the Permian reflects the pattern seen elsewhere in the region (e.g. Tarim continent; Filippova et al., 2001).

Acknowledgements

We would like to thank our two reviewers – both anonymous – for their excellent suggestions on improving the manuscript. Sophia Rütters (Bonn) is thanked for all of the diagrams. This study was supported by a grant from the DARIUS Programme, and we would like to thank Marie-Francoise Brunet and Eric Barrier (both Université Pierre-et-Marie Curie, Paris) for their help and interest.

Appendix A. List of outcrops in the Nuratau and Kitab areas

Ordovician outcrops

1. N40° 19.224′ E 067° 27.768′.
2. N40° 19.268′ E067° 27.678′.
3. N40° 19.283′ E067° 27.583′.
4. N40° 23.566′ E067° 12.735.
5. N40° 22.310′ E067° 22.034′.
6. N40° 22.246′ E067° 22.008.
7. N40° 22.236′ E067° 21.930.

Silurian outcrops

1. N39° 11.039′ E067° 17.638.
2. N40° 22.086′E067° 21.877.

Devonian outcrops

1. N40° 20.888′ E067° 29.924.
2. N40° 08.555′ E067° 44.297′.
3. N40° 08.505′ E067° 44.181′.
4. N40° 08.448′E067° 44.558.
5. N39° 10.804′ E067° 17.476′.

Carboniferous outcrops

1. N40° 20.721′ E067° 17.059 (and surrounding area).

References

Abduazimova, Z.M. (Ed.), 2001. Stratigraphic Dictionary of Uzbekistan (Tashkent, 580 pp. (in Russian)).
Abduazimova, Z.M., Alexandrov, N.V., Tabatchenko, L.M., Shaykurov, N.B., Rakhimov, A.D., 2007. Pecularities of facial-genetic types of cross-sections of Precambrian and Lower Paleozoic deposits of Nuratau Mountains. Geology and Mineral Resources 5, 51–55 (in Russian).
Abrajevitch, A., Van der Voo, R., Bazhenov, M.L., Levashova, N.M., McCausland, P.J.A., 2008. The role of the Kazakhstan orocline in the late Paleozoic amalgamation of Eurasia. Tectonophysics 455, 61–76.
Alekseev, D.V., Degtyarev, E.V., Kotov, A.B., Sal'nikova, E.B., Tret'yakov, A.A., Yakovleva, S.Z., Anisimova, I.V., Shatagin, K.N., 2009. Late Paleozoic subductional and collisional igneous complexes in the Naryn segment of the Middle Tien Shan (Kyrgyzstan). Doklady Earth Sciences 42, 760–764.
Allen, M.B., Zhuoli, L., Hong, Q., Yueze, W., Huawei, Z., Weishi, H., 1991. Field study of a highly active fault zone: the Xanshuihe fault of southwestern China. Geological Society of America Bulletin 103, 1178–1199.
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.
Alsharhan, A.S., Nairn, A.E.M., 1997. Sedimentary Basins and Petroleum Geology of the Middle East. Elsevier, Den Haag (942 pp.).
Bai, Y., Chen, G., Sun, Q., Sun, Y., Li, Y., Dong, Y., Sun, D., 1987. Late Paleozoic polar wander path for the Tarim platform and its tectonic significance. Tectonophysics 139, 145–153.
Bakirov, A.B., Burtman, V.S., 1984. Tectonics of the Tien-Shan Variscides. 27th International Geological Congress: Guidebook Excursion, 032, p. 75 (Moscow).
Bazhenov, M.L., Burtman, V.S., Dvorova, A.V., 1999. Permian paleomagnetism of the Tien Shan fold belt, Central Asia: post-collisional rotations and deformation. Tectonophysics 312, 303–329.
Bazhenov, M.L., Collins, A.Q., Degtyarev, K.E., Lavashova, N.M., Mikolaichuk, A.V., Pavlov, V.E., Van der Voo, R., 2003. Paleozoic northward drift of the North Tien Shan (Central Asia) as revealed by Ordovician and Carboniferous paleomagnetism. Tectonophysics 366, 113–141.
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, Y.S., 1995. Late Paleozoic collision of the Tarimskiy and Kirghiz–Kazakh paleocontinents. Geotectonics 29, 26–34.
Biske, Y.S., 1996. Paleozoic Structure and History of the Southern Tien Shan. Leningrad University, Leningrad (187 pp. (in Russian)).
Biske, Y.S., 2000. Paleogeodynamics of Turkestan Ocean region. 1. Reconstruction for Devonian. Vestnik Sankt-Petersburgkogo Universiteta, Seria 72, 3–13 (in Russian).
Biske, Y.S., Seltmann, R., 2010. Paleozoic Tian-Shan as a transitional region between the Rheic and Urals–Turkestan oceans. Gondwana Research 17, 602–613.

Biske, Y.S., Usmanov, R.R., 1981. Tectonic cover in "sedimentary basins" of northern Nuratau (western Uzbekistan). Vestnik Leningradskogo Universiteta, Seria 24, 5–11 (in Russian).

Biske, Y.S., Komissarov, R.A., Talashmanov, Y.A., 1993. On Paleozoic horizontal movements on the northern margin of the Tarimsky continent from paleomagnetic data. Vestnik SpbU 7, 71–77 (in Russian).

Blakey, R.C., 2008. Gondwana paleogeography from assembly to breakup — a 500 m.y. odyssey. Geological Society of America Special Paper 441, 1–28.

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.

Brooks, G.R., Doyle, L.J., Suthard, B.C., Locker, S.D., Hine, A.C., 2003. Facies architecture of the mixed carbonate/siliciclastic inner continental shelf of west-central Florida: implications for Holocene barrier development. Marine Geology 200, 325–349.

Bukharin, A.K., Breznev, V.D., Maslennikova, I.A., Pyatkov, A.K., Burkov, Y.K., Vasil'ev, I.A., Lirillova, G.B., Morgunova, S.G., 1989. Tectonics of the West Tien-Shan. Nauka, Moscow (151 pp. (in Russian)).

Burtman, V.S., 1975. Structural geology of the Variscan Tien- Shan, USSR. American Journal of Science 275-A, 175–186.

Burtman, V.S., 1980. Faults of Middle Asia. American Journal of Science 280, 725–744.

Burtman, V.S., 1984. Structural evolution of the Tien Shan Variscides. In: Bakirov, A.B., Burtman, V.S. (Eds.), Tectonics of the Tien Shan Variscides: 27th Int. Geol. Congr. Moscow, Guidebook for Excursion 032 in the Kyrgyz Republic, Frunze, Kyrgyzstan, pp. 36–43.

Burtman, V.S., 2008. Nappes of the Southern Tien Shan. Russian Journal of Earth Sciences 10, 1–35.

Burtman, V.S., Gurariy, G.S., Belen'kiy, A.V., Ignatyev, A.V., Audiber, M., 1998. Turkestan ocean in Middle Paleozoic: reconstruction on the base of paleomagnetic data from Tien Shan. Geotektonika 1, 15–26.

Buslov, M.M., Saphonova, I.Y., Watanabe, T., Obut, O.T., Fujiwara, Y., Iwata, K., Semakov, N.N., Sugai, Y., Smirnova, L.V., Kazansky, A.Y., 2001. Evolution of the Paleo-Asian Ocean (Altai-Sayan Region, Central Asia) and collision of possible Gondwana-derived terranes with the southern marginal part of the Siberian continent. Geoscience Journal 5, 203–224.

Buslov, M.M., Fujiwara, Y., Iwata, K., Semakov, N.N., 2004. Late Paleozoic–Early Mesozoic geodynamics of Central Asia. Gondwana Research 7, 791–808.

Bykadorov, V.A., Bush, V.A., Fedorenko, O.A., Filippova, I.B., Miletenko, N.V., Puchkov, V.N., Smirnov, A.V., Uzhkenov, B.S., Volozh, Y.A., 2003. Ordovician–Permian palaeogeography of Central Eurasia: development of Palaeozoic petroleum-bearing basins. Journal of Petroleum Geology 26, 325–350.

Chen, C., Lu, F., Jia, D., Cai, D., Wu, S., 1999. Closing history of the southern Tianshan oceanic basin. Western China: an oblique collisional orogeny. Tectonophysics 302, 23–40.

Collier, J.S., Minshull, T.A., Kendall, J.-M., Whitmarsh, R.B., Rümpker, G., Joseph, Pl, Samson, P., Lane, C.I., Sansom, V., Vermeesch, P.M., Hammond, J., Wookey, J., Teanby, N., Ryberg, T.M., Dean, S.M., 2004. Rapid continental breakup and microcontinent formation in the Western Indian Ocean. Eos 85 (46), 481–484.

Cronier, C., Tsmeyrek, H.S., 2011. First record of the Devonian Phacopid Trilobite "Plagiolaria" from Uzbekistan. Mem. Assoc. Australasian Palaeontologists 39, 43–50.

Dalimov, T.N., 2011. Inter-regional correlation and basic problems of Paleozoic magmatism of Western Tien Shan. Geology and Mining Research 1, 3–17.

Dalimov, T.N., Divaev, F.K., 2010. Main types of upper paleozoic granites formation in Western Tien Shan. Geology and Mining Research 1, 3–19.

Didenko, A.N., Mossakovskii, A.A., Pecherskiy, D.M., Ruzhentsev, S.V., Samygin, S.G., Kheraskova, T.N., 1994. Geodynamics of the Central-Asian Paleozoic oceans. Russian Geology and Geophysics 35, 48–61 (in Russian).

Dobretsov, N.L., Berzin, N.A., Buslov, M.M., 1995. Opening and tectonic evolution of the Paleo-Asian Ocean. International Geology Review 35, 335–360.

Einsele, G., 2000. Sedimentary Basins: Evolution, Facies and Sediment Budget. Elsevier.

Elrick, M., Hinnov, L.A., 2007. Millennial-scale paleoclimate cycles recorded in widespread Palaeozoic deeper water rhythmites of North America. Palaeogeography, Palaeoclimatology, Palaeoecology 243, 348–372.

Filippova, I.B., Bush, V.A., Didenko, A.N., 2001. Middle Paleozoic subduction belts: the leading factor in the formation of the Central asian fold and thrust belt. Russian Journal of Earth Sciences 6, 245–307.

Gao, J., Klemd, R., 2003. Primary fluids entrapped at blueschist to eclogite transition: evidence from the Tianshan meta-subduction complex in northwestern China. Contributions to Mineralogy and Petrology 142, 1–14.

Gao, J., Li, M.S., Xiao, X.C., Tang, Y.Q., He, G.Q., 1998. Paleozoic tectonic evolution of the Tienshan orogen, northwestern China. Tectonophysics 287, 213–231.

Gao, J., Long, L., Klemd, R., Qian, Q., Liu, D., Xiong, X., Su, W., Liu, W., Wang, Y., Yang, F., 2009. Tectonic evolution of the South Tianshan orogen and adjacent regions, NW China: geochemical and age constraints of granitoid rocks. International Journal of Earth Sciences 98, 1221–1238.

Ges, M., Seliverstov, K., 1995. Geodynamic and metallogenic zoning of the Peleothetis boundary in the Chatkal region of Tien Shan. Geology of Ore Deposits 37, 132–142 (in Russian).

Ghes, M.D., 2008. Terrain structure and geodynamic evolution of Caledonian Tien Shan. National Academy of Science of Kyrgyzstan, Bishkek (159 pp. (in Russian)).

Giddings, J.A., Wallace, M.W., Woon, E.M.S., 2009. Interglacial carbonates of the Cryogenian Umberatana Group, northern Flinders Ranges, South Australia. Australian Journal of Earth Sciences 56, 907–925.

Golonka, J., 2007. Phanerozoic paleoenvironment and paleolithofacies maps. Late Paleozoic. Geologia 33, 145–209.

Golonka, J., 2009. Phanerozoic paleoenvironment and paleolithofacies maps. Early Paleozoic. Geologia 35, 589–654.

Grélaud, C., Razin, P., Homewood, P., 2010. Channelized systems in an inner carbonate platform setting: differentiation between incisions and tidal channels (Natih Formation, Late Cretaceous, Oman). In: Van Buchem, F.S.P., Gerdes, K.D., Esteban, M. (Eds.), Mesozoic and Cenozoic Carbonate Systems of the Mediterranean and the Middle East: Stratigraphic and Diagenetic Reference ModelsGeological Society, London, Special Publications 329, 163–186.

Hall, R., 2011. Australia-SE Asia collision: plate tectonics and crustal flow. In: Hall, R., Cottam, M.A., Wilson, M.E.J. (Eds.), The SE Asian Gateway: History and Tectonics of the Australia–Asia CollisionGeological Society, London, Special Publications 355, 75–109.

Hampton, B.A., Ridgway, K.D., O'Neill, J.M., Gehrels, G.E., Schmidt, J., Blodgett, R.B., 2007. Pre-, syn- and post-collisional stratigraphic framework and provenance of Upper Triassic-Upper Cretaceous strat in the northwestern Talkeetna Mountains, Alaska. In: Ridgway, K.D., Trop, J.M., Glen, J.M.G., O'Neill, J.M. (Eds.), Tectonic Growth of a Collisional Continental Margin: Crustal Evolution of Southern AlaskaGeological Society of America Special Paper 431, 401–438.

Haq, B.U., Schutter, S.R., 2008. A chronology of Paleozoic sea-level change. Science 322, 64–68.

Heubeck, C., 2001. Assembly of Central Asia during the middle and late Paleozoic. In: Hendrix, M.S., Davis, G.A. (Eds.), Paleozoic and Mesozoic Tectonic Evolution of Central and Eastern AsiaGeological Society of America, Memoirs 194, 1–22.

Hickey-Vargas, R., 1992. A refractory HIMU component in the sources of island-arc magma. Nature 360, 57–59.

Hood, S.D., Nelson, C.S., 2012. Temperate carbonate debrites and short-lived earliest Miocene yo-yo tectonics, eastern Taranaki Basin margin, New Zealand. Sedimentary Geology 247–248, 58–70.

Jenchuraeva, R.J., 1997. Tectonic setting of porphyry-type mineralization and hydrothermal alteration in Paleozoic arcs and active continental margins, Kyrgyz Range. Mineral Deposits 32, 434–440.

Jenchuraeva, R.J., 2001. Paleozoic geodynamics, magmatism, and metallogeny of the Tien Shan. In: Seltmann, R., Jenchuraeva, R. (Eds.), Paleozoic Geodynamics and Gold Deposits in the Kyrgyz Tien Shan: IGCP-373 Excursion Guide Book, Bishkek (2001), pp. 29–70.

Khain, V.E., 1985. Geology of the USSR. Gebrüder Borntraeger, Berlin (272 pp.).

Kheraskova, T.N., Didenko, A.N., Bush, V.A., Volozh, Y.A., 2003. The Vendian–Early Paleozoic history of the continental margin of Eastern Paleo-Gondwana, Paleo-Asian Ocean, and Central Asian Foldbelt. Russian Journal of Earth Sciences 5, 165–184.

Kheraskova, T.N., Bush, V.A., Didenko, A.N., Samygin, S.G., 2010. Breakup of Rodinia and early stages of evolution of the Paleoasian Ocean. Geotectonics 44, 3–24.

Kim, A.I., Erina, M.V., Yolkin, E.A., 1982. Biostratigraphy of the Lower and Middle Devonian of Central Asia. Proceedings of Field Session of the International Subcommission on the Devonian Stratigraphy, Samarkand, 1978. Nauka, Leningrad, pp. 85–92 (in Russian).

Kim, A.I., Erina, M.V., Apekina, L.S., Lessovaya, A.I., 1984. Biostratigraphy of the Devonian of the Zarafshan–Gissar Mountainous area. FAN Press, Tashkent (95 pp. (in Russian)).

Kim, A.I., Kim, I.A., Popov, L.E., Salimova, F.A., Meshchankina, N.A., Erina, M.V., Ivanova, O.B. (Eds.), 2007. Atlas of Phanerozoic Faunas and Floras of Uzbekistan. Palaeozoic (Cambrian, Ordovician, Silurian, Devonian, Carboniferous, Permian), vol. 1. State Committee on geology and Mineral Resources, Uzbekistan, Tashkent (613 pp. (in Russian)).

Klishevich, V.L., Khramov, A.N., 1993. Reconstructions of Turkestan Paleoocean (Southern Tien Shan) for the Early Devonian. Geotectonics 27, 326–335.

Klishevich, V.L., Rzhevskiy, Y.S., Rodionov, V.P., Khramov, A.N., 1992. Early Permian reconstruction of the Tien Shan region of Paleo-Tethis from paleomagnetic data. Soviet Geology 12, 43–50.

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. Lithos 97, 140–160.

Krawczyk, C.M., McCann, T., Cocks, L.R.M., England, R.W., McBride, J.H., Wybraniec, S., 2008. The Geology of Central Europe. In: McCann, T. (Ed.), Precambrian and Palaeozoic, vol. 1. Geol. Soc., Lond., pp. 303–381.

Kroner, U., Mansy, J.-L., Mazur, S., Aleksandrowski, P., Hann, H.P., Huckriede, H., Lacquement, F., Lamarche, J., Ledru, P., Pharaoh, T.C., Zedler, H., Zeh, A., Zulauf, G., 2008. Variscan tectonics. In: McCann, T. (Ed.), The Geology of Central Europe. Precambrian and Palaeozoic, vol. 1. Geol. Soc., Lond., pp. 559–664.

Kurenkov, S.A., Aristov, V.A., 1995. On the time of formation of the Turkestan paleo-ocean crust. Geotectonics 29, 469–477 (English translation, 1996).

Levashova, N.M., Van der Voo, R., Abrajevitch, A.V., Bazhenov, M.L., 2009. Paleomagnetism of mid-Paleozoic subduction-related volcanics from the Chingiz Range in NE Kazakhstan: the evolving paleogeography of the amalgamating Eurasian composite continent. Geological Society of America Bulletin 121, 555–573.

Loydell, D., 1998. Early Silurian sea-level changes. Geological Magazine 135, 447–471.

Lupton, J.E., Arculus, R.J., Evans, L.J., Graham, D.W., 2012a. Mantle hotspot neon in basalts from the Northwest Lau Back-arc Basin. Geophysical Research Letters 39.

Lupton, J.E., Arculus, R.J., Resing, J., Massoth, G.J., Greene, R.R., Evans, L.J., Buck, N., 2012b. Hydrothermal activity in the Northwest Lau Backarc Basin: evidence from water column measurements. Geochemistry, Geophysics, Geosystems 13, 1–19.

McCann, T., Kiersnowski, H., Krainer, K., Vozárova, A., Peryt, T.M., Oplustil, S., Stollhofen, H., Schneider, J., Wetzel, A., Boulvain, F., Dusar, M., Török, A., Haas, J., Tait, J., Körner, F., 2008a. Permian. In: McCann, T. (Ed.), The Geology of Central Europe. Precambrian and Palaeozoic, vol. 1. Geol. Soc., Lond., pp. 531–597.

McCann, T., Skompski, S., Poty, E., Dusar, M., Vozárova, A., Schneider, J., Wetzel, A., Krainer, K., Kornpihl, K., Schäfer, A., Krings, M., Oplustil, S., Tait, J., 2008b. Carboniferous. In: McCann, T. (Ed.), The Geology of Central Europe. Precambrian and Palaeozoic, vol. 1. Geol. Soc., Lond.

Molnar, P., Tapponnier, P., 1975. Tectonics of Asia: consequences and implications of a continental collision. Science 189, 419–426.

Mossakovsky, A.A., Ruzhentsev, S.V., Samygin, S.G., Kheraskova, T.N., 1993. Central Asian fold belt: geodynamic evolution and formation. Geotectonics 27, 3–32.

Mount, J.F., 1984. Mixing of siliciclastic and carbonate sediments in shallow shelf environments. Geology 12, 432–435.
Mukhin, P., 1997. Uzbekistan. In: Moores, E.M., Fairbridge, R.W. (Eds.), Encyclopedia of European and Asian Regional Geology. Springer, pp. 766–772.
Müller, R.D., Gaina, C., Roest, W.R., Hansen, D.L., 2001. A recipe for microcontinent formation. Geology 29, 203–206.
Mutti, M., Bernoulli, D., Eberli, G.P., Vecsei, A., 1996. Depositional geometries and facies associations in an Upper Cretaceous prograding carbonate platform margin (Orfento Supersequence, Maiella, Italy). Journal of Sedimentary Research 66, 749–765.
Nurtaev, B., Kharin, V., McCann, T., Valdivia-Manchego, M., 2013. The North Nuratau Fault Zone, Uzbekistan - structure and evolution of a Palaeozoic suture zone. Journal of Geodynamics 64, 1–14.
Owens, R.M., Ivanova, O., Kim, I., Popov, L.E., Feist, R., 2011. Lower and Middle Devonian trilobites from Southern Uzbekistan. Memoirs. Association of Australasian Paleontologists 39, 211–244.
Payros, A., Pujalte, V., Orue-Etxebarria, X., 1999. The South Pyrenean Eocene carbonate megabreccias revisited: new interpretation based on evidence from the Pamplona Basin. Sedimentary Geology 125, 165–194.
Pickering, K.T., Koren, T.N., Lytochkin, V.N., Siveter, D.J., 2008. Silurian–Devonian active-margin deep-marine systems and palaeogeography, Alai range, Southern Tien Shan, Central Asia. Journal of the Geological Society of London 165, 189–210.
Ruzhentsev, S.V., Mossakovskiy, A.A., 1996. Geodynamics and tectonic evolution of the Central Asian Paleozoic structures as the result of the interaction between the Pacific and Indo-Atlantic segments of the Earth. Geotectonics 29, 294–311.
Samygin, S.G., Burtman, V.S., 2009. Tectonics of the Ural Paleozoides in comparison with the Tien Shan. Geotectonics 43, 133–151.
Sandberg, C.A., Morrow, J.R., Ziegler, W., 2002. Late Devonian sea-level changes, catastrophic events and mass extinctions. In: Koeberl, C., MacLeod, K.G. (Eds.), Catastrophic Events and Mass Extinctions: Impacts and BeyondGeological Society of America Special Paper 356, 473–487.
Seltmann, R., Konopelko, D., Biske, G., Divaev, F., Sergeev, S., 2011. Hercynian postcollisional magmatism in the context of Paleozoic magmatic evolution of the Tien Shan orogenic belt. Journal of Asian Earth Sciences 42, 821–838.
Shayakubov, T.S., Dalimov, T.N. (Eds.), 1998. Geology and Minerals of the Republic of Uzbekistan ("Universitet" Tashkent, 722 pp. (in Russian)).
Solomovich, L., 2007. Postcollisional magmatism in the South Tien Shan Variscan orogenic belt, Kyrgyzstan: evidence for high-temperature and high-pressure collision. Journal of Asian Earth Sciences 30, 142–153.
Solomovich, L., Trifonov, B., 2002. Post-collisional granites in the South Tien Shan Variscan collisional belt, Kyrgystan. Journal of Asian Earth Sciences 21, 7–21.
Stern, C.R., Frey, F.A., Futa, K., Zartman, R.E., Peng, Z., Kyser, T.K., 1990. Trace-element and Sr, Nd, Pb, and O isotopic composition of Pliocene and Quaternary alkali basalts of the Patagonian Plateau lavas of southernmost South America. Contributions to Mineralogy and Petrology 104, 294–308.
Talling, P.J., Wynn, R.B., Masson, D.G., Frenz, M., Cronin, B.T., Schiebel, R., Akhmetzhanov, A.M., Dalmeier-Tiessen, S., Benetti, S., Weaver, P.P.E., Georgiopoulou, A., Zühlsdorff, C., Amy, 2007. Onset of submarine debris flow deposition far from original giant landslide. Nature 450, 541–544.
Tisljar, J., Vlahovic, I., Velic, I., Sokac, B., 2002. Carbonate platform megafacies of the Jurassic and Cretaceous deposits of the Karst Dinarides. Geologia Croatica 55, 139–170.
Trua, T., Serri, G., Marani, M.P., 2007. Geochemical features and geodynamic significance of the southern Tyrrhenian backarc basin. GSA Special Papers 418, 221–233.
Trua, T., Marani, M.P., Gamberi, F., 2011. Magmatic evidence for African mantle propagation into the southern Tyrrhenian backarc region. GSA Special Papers 478, 307–331.
Webster, G.D., Rakhmonov, U.J., 2009. Devonian (Eifelian) disparid crinoids from the Zeravashan range, southern Tien Shan, Uzbeklstan. Palaeoworld 18, 235–240.
Windley, B.F., Allen, M.B., Zhang, C., Zhao, Z.-Y., Wang, G.-R., 1990. Paleozoic accretion and Cenozoic redeformation of the Chinese Tien Shan Range, central Asia. Geology 18, 128–131.
Windley, B.F., Alexeiev, D., Xiao, W., Kröner, A., Badarch, G., 2007. Tectonic models for accretion of the Central Asian Orogenic Belt. Journal of the Geological Society of London 164, 31–47.
Xiao, W., Huang, B., Han, Ch., Sun, S., Li, J., 2010. A review of the western part of the Altaids: a key to understanding the architecture of accretionary orogens. Gondwana Research 18, 253–273.
Xu, B., Jian, Pl, Zheng, H.F., Zou, H.B., Zhang, L.F., Liu, D.Y., 2005. U-Pb zircon geochronology and geochemistry of Neoproterozoic volcanic rocks in the Tarim Block of northwest China: implications for the breakup of Rodinia supercontinent and Neoproterozoic glaciations. Precambrian Research 136, 107–123.
Yakubchuk, A., 2008. Re-deciphering the tectonic jigsaw puzzle of northern Eurasia. Journal of Asian Earth Sciences 32, 82–101.
Yolkin, E.A., Kim, A.I., Weddige, K., Talent, J.A., House, M.R., 2000. The basal Emsian GSSP in Zinzil'ban Gorge, Uzbekistan. In: Bultynck, P. (Ed.), Subcommission on Devonian Stratigraphy. Recognition of Devonian Series and Stage Boundaries in Geological AreasCourier Forschungsinstitut Senckenberg 225, 17–25.
Yolkin, E.A., Kim, A.I., Talent, J.A., 2008. Devonian sequences of the Kitab Reserve Area. Field Excursion Guidebook Kitab State Geological Reserve, UzbekistanNovosibirsk Publishing House (SB RAS, 97 pp.).
Zhang, S., Barnes, C.R., 2002. Late Ordovician–Early Silurian (Ashgillian-Llandovery) sea level curve derived from conodont community analysis, Anticosti Island, Québec. Palaeogeography, Palaeoclimatology, Palaeoecology 180, 5–32.
Zhou, D., Graham, S.A., Chang, E.Z., Wang, B., Hacker, B., 2001. Paleozoic tectonic amalgamation of the Chinese Tian Shan: evidence from a transect along the Dunshanzi-Kuqa Highway. In: Hendrix, M.S., Davis, G.A. (Eds.), Paleozoic and Mesozoic Tectonic Evolution of Central and Eastern Asia: From Continental Assembly to Intracontinental DeformationGeological Society of America, Memoirs 194, 71–99.
Zonenshain, L.P., Kuzmin, M., Natapov, L.M., 1990. Geology of USSR: A Plate Tectonic Synthesis. Geodyn. Ser., 21. AGU, Washington DC (242 pp.).